10 years - ANNIVERSARY EDITION *TRAKIA JOURNAL OF SCIENCES*
Trakia Journal of Sciences, Vol. 10, No 3, pp 1-14, 2012

ISSN 1313-7050 (print)
ISSN 1313-3551 (online)

Original Contribution

ALLOMETRIC SCALING OF TOTAL METABOLIC ENERGY PER LIFESPAN IN LIVING ORGANISMS

A. Atanasov*

Department of Physics and Biophysics, Medical Faculty, Trakia University, Stara Zagora, Bulgaria

ABSTRACT

The purpose of the study is to establish and calculate the relationship between the total metabolic energy per lifespan and the body mass of Ectotherms, Mammals and Aves (n=278 living organisms) with 21 orders of magnitude variation between their body mass- from Bacteria to *Elephas maximum and Struthio camelus*.

The study shows the existence of a linear relationship between the total metabolic energy per lifespan P_{ls} (kJ), and the body mass M (kg) of all species from type: $P_{ls}=A_{ls}M^{1.0787\pm0.11}$ with R^2=0.980, coefficient A_{ls}=15.18×10^5kJ/kg, standard error of the exponent SE=±0.11 and 95% confidence interval of the exponent (0.968 - 1.188). The same relationship for Ectotherms, Mammals and Aves without Protozoa (n=260) is of type: $P_{ls}=A_{ls}M^{1.0089\pm0.042}$ with R^2=0.897, A_{ls} =14.16×10^5 kJ/kg, SE= ±0.042, and 95% confidence interval of exponent (0.967-1.051). In all combinations between Ectotherms, Mammals and Aves the exponent is near to 1.0. The linear coefficient A_{ls} is the total metabolic energy, exhausted during the lifespan per 1kg body mass of given organism and appears to be relatively constant parameter, because of rising 10 times only from Ectotherms to Mammals and Aves, despite of 21 orders of magnitude difference between body mass of organisms.

Key words: scaling, metabolic energy, lifespan, ectotherms, mammals, aves

INTRODUCTION

The patterns existing between the fundamental characters of living organisms and their body mass are generally described as a power function. The bioenergetic studies of Kleiber [1], Brody et al. [2], Zeuthen [3], Hemmingsen [4], Kleiber [5], Schmidt-Nielsen [6], McNab [7], Heusner [8], Niklas [9], Nagy [10] and da Silva and Barbosa [11] on Ectotherms, Mammals and Aves have shown that the basal metabolic rate (P, kJ/d) in animals is related to the body mass (M, kg) by the equation:

$$P=aM^{k} \qquad (1)$$

where a is the normalization constant, and k is the allometric scaling exponent. One of the most important points of controversy in the scientific discussion about the power function is focused on the value of the scaling exponent. Some researchers consider the power function (1) with exponent k=0.75 as a universal scaling law, generalized to all living organisms and forms of life (Hemmingsen [4], Kleiber [5], Feldman and McMahon [12], West et al. [13-14], Banavar et al. [15], Savage et al. [16]). On the other hand, several recent studies provided evidences, supporting certain variability in the exponent of the allometric scaling law (Riisgård [17], Dodds et al. [18], Bokma [19], Agutter and Wheatley [20], Glazier [21], Reich et al. [22], White and Seymour [23], White *et al.* [24]).

The values of the scaling exponent k have been studied in other experimental conditions for all animal groups.

Zeuthen[3] and Hemmingsen [4] show that the exponent k is equal to 0.75 in unicellular Eukaryotes. As a hole, unicellular organisms (Eukaryotes and Prokaryotes) showed isometric scaling with exponent k =1.0 [25].

Accordingly to Galvão [26], Ultsch [27], Prosser [28], Schmidt-Nielsen [6], Tudge [29]

***Correspondence to**: *Atanas Todorov Atanasov, Department of Physics and Biophysics, Medical Faculty, Trakia University, 6000 Stara Zagora, 11 Armeiska Str., Bulgaria, E-mail:atanastod@abv.bg* and Makarieva *et al.* [30] the exponent k varied in the interval 0.6-1.0 in Ectotherms.

The data of Kleiber [1, 5], McNab [7], Heusner [8], Agutter and Wheatley [20], White and Seymour [23], White *et al.* [24] shown that in Mammals the exponent k varied in the interval 0.602-0.87.

The data of Lasiewski and Dawson [31-32], Aschoff and Pohl [33], Bennet and Harvey [34], Nagy et al. [35], Rezende [36], Nagy [10] and Rottenberg [37] shown that in Aves the exponent k varied in the interval 0.67-0.734.

Thus, the scaling exponent in Ectotherms, Mammals and Aves varied in the interval 0.6-1.0.

The allometric relationship between the lifespan of living organisms (T_{ls}, years) and the body mass (M, kg) in other evolutionary groups have been expressed also as a power relationship:

$$T_{ls}=bM^{n} \qquad (2)$$

where b is the normalization constant, and n is the allometric scaling exponent. Some researchers, including Fenchel [38], Ernest [39], Brown et al. [40], Damuth [41], Ginsburg and Damuth [42] consider the power law (2) with scaling exponent n=0.25, as a universal scaling law for all living organisms and forms of life. The values of the exponent n have been studied for all animals groups. For Ectotherms the exponent n falls in the interval 0.16-0.30, according to Bonner [43], Günther [44], Prosser [28], Schmidt-Nielsen [6] and Smith-Sonneborn [45]. For Mammals, the exponent n falls in the interval 0.15-0.3, according to Sacher [46], Mallouk [47], Cutler [498] and Speakman et al. [49]. For Aves the exponent n falls in the interval 0.19-0.216, according to Lindstedt and Calder [50-51], Nagy [10], Rottenberg [37], Møller [52] and Bonduriansky [53]. Thus, the scaling exponent n in Ectotherms, Mammals and Aves varied in the interval 0.15-0.3.

Different approaches are available to study the relationship between the total metabolic energy per lifespan and the body mass of animals. The first approach is based on the hypothesis of Rübner [54], that the mass-specific expenditure of the energy per lifespan is relatively constant (C) in different animals, i. e.:

$$(P/M)T_{ls}=C \qquad (3)$$

The hypothesis of Rübner continues being studied for about 100 years, since it was formulated in 1908, because of its fundamentality. Many researchers like Boddington [55] and Speakman [56] discussed this idea theoretically or presented data supporting it or against it. The invariability of the ratio:

$$(P/M)T_{ls}=CM^{\alpha} \qquad (4)$$

where C is the normalization constant and α is the allometric scaling exponent, has been studied from Speakman [56-57] and Nagy [58]. From mathematical point of view, the exponent α = 0 results in independence from the mass M, because M^{α} =1 and the equation (4) would still result in a constant value. A tentative evaluation of Speakman [56] for Mammals and Aves showed that α varied in interval from -0.08 to 0.08. Regarding the combination between the basal metabolic rate and the maximum lifespan, Speakman calculated for Mammals α= -0.0734 (R^2 =0.07) and for Aves α= -0.109 (R^2=0.126).

The 'rate of living' theory of Pearl [59] postulated also that the mass-specific expenditure of energy per lifespan is relatively constant (C) between animals i.e. the product $(P/M)T_{ls}$ $=C$. Because the quotient for invariability in the lifetime expenditure of energy per unit body mass of tissue is not based on statistics, Speakman [56] combined the data about daily energy expenditure in free-living animals, measured by doubly-labelled water method of Nagy [58] and Speakman [57], with the data for maximum lifespan of Carey and Judge [60]. This combination allowed test statistically the 'rate of living' theory. In this case Speakman [56] calculated for Mammals α= -0.208 (R^2 =0.377), for Aves α= -0.0696 (R^2=0.056) and received a significant negative association between residual lifespan and residual daily energy expenditure. Namely, the Mammals that had high rates of expenditure for their body mass died sooner. The results of other authors for birds, like Rottenberg [37], revealed some evidences in support of ‘rate of living’ theory for Mammals and Aves.

A recent approach to study the relationship between the total metabolic energy per lifespan and the body mass of animals [61-65] concerned the study of the direct statistical relationship between the total metabolic energy per lifespan ($P_{ls} = PT_{ls}$) and the body mass (M) of animals i.e. the calculation of the function:

$$PT_{ls}=A_{ls}M^{r} \qquad (5)$$

where A_{ls} is a coefficient and r is a exponent.

In recent publications Atanasov [61-62] showed that for Ectotherms the coefficient A_{ls} varied in interval of (2.34-3.7)×10^5kJ/kg, the exponent r varied in interval of 0.97-1.084 and R^2 falls in interval of 0.97-0.98. For Mammals [63] the coefficient A_{ls} varied in interval of (7.15-11.4) ×10^5kJ/kg, the exponent r varied in interval of 0.97-1.05 and R^2 varied in interval of 0.98-0.983. For Aves [64-65] the coefficient A_{ls} varied in interval of (26.8-37.2)×10^5kJ/kg, the exponent r varied in interval of 0.88-0.939 and R^2 varied in interval of 0.97-0.98. In all cases the exponent r varied around 1.0 in the interval of 0.88-1.084.

The aim of this study is to establish and calculate the coefficient A_{ls} and exponent r in relationship (5) between the total metabolic energy per lifespan and the body mass in a wide range of animals - 278 Ectotherms, Mammals and Aves (all together) with about a 21 order of magnitude variation between the body mass.

DATA AND METHODS

All data for the 278 studied individuals are shown in **Table 1.**

The data for the Ectothermic individuals – the body mass (M, kg), the basal metabolic rate (P, kJ/day), the temperature (t°C), the lifespan (T_{ls} in years and day) and the total metabolic energy per lifespan (P_{ls}, kJ) were taken by paper of Atanasov [61-62] and Fujiwara [66]. Included are the data for 18 unicellular and 38 multicellular ectotherms from the orders of Protozoa, Nematoda, Mollusca, Asteroidae, Arthropoda (Arachnoidae, Insecta), Isopoda (Crustacea), Osteichthytes, Amphibia and Reptilia.

The data for the Mammals were taken by Atanasov [63] and Carey and Judge [60] and involves 95 species, including 3 monotremes (Subclass Prototheria), 16 marsupialis (Subclass Theria, Infraclass Metatheria) and 76 “placentals” (Subclass Theria, Infraclass Eutheria) from orders: Monotremata, Didelphoidea, Dasyurida, Syndactyla, Xenarthra, Pholidota Soricomorpha, Rodentia, Lagomorpha, Artiodactyla, Carnivora, Pinnipedia, Chiroptera and Primates.

The data for Nonpasseriformes Aves were taken by Atanasov [64] and Gregory [67], involving 95 Nonpasseriformes species from the orders of Struthioniformes, Rheiformes, Casuariiformes, Apterygiformes, Sphenisciformes, Procellariiformes, Pelecaniformes, Ciconiiformes, Anseriformes, Charadriiformes, Columbiformes, Falconiformes, Galliformes, Gruiformes, Psittaciformes, Cuculiformes, Strigiformes, Caprimulgiformes, Apodiformes, Coliiformes, Trogoniformes, Coraciiformes, Piciformes.

The data for the 32 Passeriformes were taken by Atanasov [65].

For each organism or animal the total metabolic energy per lifespan P_{ls} is calculated as a product between the basal metabolic rate P(kJ/day) and the lifespan T_{ls}(day):

$$P_{ls}(kJ)=PT_{ls} \qquad (6)$$

For each organism the total metabolic energy per lifespan, per 1kg body mass is calculated as a ratio between P_{ls} (kJ) and the body mass M(kg):

$$A_{ls}(kJ/kg)=P_{ls}/M \qquad (7)$$

Least-square regression analyses were performed using STATISTICA (www.statsoft.com). Logarithm of total metabolic energy per lifespan P_{ls} were regressed against logarithm of body mass M, after that the results were presented in P_{ls} – M functional relationship. The linear coefficient A_{ls}, the correlation coefficient R, the exponent r, the standard error of the exponent SE and the 95% confidence interval CI were calculated for Ectotherms, Mammals and Aves (in common and separately).

Analyses of covariance ANCOVA (www.statsoft.com) were used for estimation of P-level of the correlation between the total metabolic energy per lifespan and the body mass for Ectotherms, Mammals and Aves (in common and separately) by Student’s t-test for p=0.00001.

RESULTS

In data set for Ectotherms (from Bacteria to Alligator) the body mass M, the basal metabolic rate P, the lifespan T_{ls} and the total metabolic energy per lifespan P_{ls} in **Table 1** varied in the intervals of (6×10^{-17} - 49)kg, (1.58×10^{-10} - 1830)kJ/day, 20min - 40years and (2.22×10^{-12} - 267×10^{5})kJ.

In the data set for Mammals (from *Antechinomus laniger* to *Elephas maximum*) M, P, T_{ls} and P_{ls} varied in the intervals of (0.0085-3000)kg, (5.166-165×10^{3})kJ/day, (2-54)years and (3.77×10^{3}-32.52×10^{8})kJ.

In data set for Aves (from *Calypte costae* to *Struthio camelus*) M, P, T_{ls} and P_{ls} varied in the intervals of (0.0032-100)kg, (4.476-9823)kJ/day, (4-45)years and (14.45×10^{3}-161×10^{6}) kJ. Thus, the range of variation of the body mass between all 278 individuals was 3×10^{21} times, the variation of the basal metabolic rate is 1×10^{16} times, the variation of the lifespan is 1×10^{6} times and the variation of the total metabolic energy per lifespan was 6×10^{18} times.

Table 1. *Data for body mass (M), basal metabolic rate (P), lifespan (Tls), total metabolic energy per lifespan (PTls) and temperature (t)° for Ectotherms, Mammals and Aves.*

N	**CLASS, ORDER,SPECIES**	**M(kg)**	**P(kJ/day)**	**T(d, y)**	**PTls(kJ)**	**t(^{0}C)**
	ECTOTHERMS					
	Unicellular organisms					
1.	*Hemophilus*	6.1×10^{-17}	1.068×10^{-9}	0.0207d	2.223×10^{-11}	30°
2.	*Diplococcus*	3.8×10^{-16}	4.383×10^{-9}	0.0175d	7.68×10^{-11}	30°
3.	*Escherichia*	3.9×10^{-16}	4.384×10^{-9}	0.0138d	6.08×10^{-11}	25°
4.	*Shigella*	7.1×10^{-16}	6.85×10^{-9}	0.016d	1.1×10^{-10}	25°
5.	*Staphylococcus*	7.8×10^{-16}	7.41×10^{-9}	0.0186d	1.377×10^{-10}	30°
6.	Bacteria	1×10^{-15}	48×10^{-11} (max)	1/48d	1×10^{-11}	25^0
7.	Bacteria	1×10^{-15}	24×10^{-11} (min)	1d	24×10^{-12}	25^0
8.	*Azotobacter chroococcum*	1×10^{-15}	4.8×10^{-10}	1/24d	2×10^{-11}	30^0
9.	*Bacillus*	4.3×10^{-15}	2.635×10^{-8}	0.0244d	6.432×10^{-10}	30°
10.	*Saccharomyces cereviseae*	2×10^{-14}	36.2×10^{-11}	1/24d	1.5×10^{-11}	20^0
11.	Flagellata and Mastogophora	1×10^{-13}	30×10^{-10} (max)	1d	3.0×10^{-9}	20^0
12.	Flagellata and Mastogophora	1×10^{-13}	3×10^{-10} (min)	7d	2.1×10^{-9}	20^0
13.	Euglena	8×10^{-12}	7.4×10^{-6}	0.438d	3.24×10^{-6}	25°
14.	Chlamydomonas	4×10^{-12}	4.4×10^{-6}	0.4d	1.76×10^{-6}	25°
15.	Tetrahymena	2×10^{-11}	2.55×10^{-5}	0.124d	3.162×10^{-6}	25°
16.	Paramecium	4×10^{-10}	2.33×10^{-4}	0.33d	7.7×10^{-5}	25°
17.	Amoeba	2×10^{-8}	5×10^{-2}	2d	1.0×10^{-1}	25^0
18.	Stentor	8×10^{-8}	7.4×10^{-2}	2d	1.48×10^{-1}	25^0
	Nematoda					
19	*Clymenella torquata*	50×10^{-6}	7.1×10^{-3}	6y	15.5	20^0
20	*Clymenella mucoza*	109×10^{-6}	13.9×10^{-3}	6y	30.5	20^0
21	*Clymenella zonalis*	23×10^{-6}	3.6×10^{-3}	6y	7.8	20^0
22	*Ascaris suum*	1×10^{-5}	2.412×10^{-3}	4y	3.524	20^0
	Mollusca					
23	*Ancylus fluviatilis*	2×10^{-5}	1.707×10^{-3}	8y	4.984	16^0
24	*Haliotis rufescens*	3×10^{-3}	0.1733	10y	630	16^0
	Asteroidae					
25	*Asterias rubens* (sea star)	10×10^{-3}	1.93	7y	4.93×10^{3}	11^0
	Arthropoda (Arachnoidae)					
26	Spider (*Phidiphor*)	3.37×10^{-4}	24.12×10^{-3}	6y	52.5	17^0
27	Spider (*Achaeranea*)	0.73×10^{-4}	12.54×10^{-3}	5y	22.85	17^0
28	Aranei spider (*Phidippus audax*)	5.68×10^{-4}	25.48×10^{-3}	10y	93	17^0
	Arthropoda (Insecta)					
29	*Lepisma saccharina*	1.25×10^{-6}	8.5×10^{-3}	24d	0.204	17^0
30	*Drozofila melanogaster*	1.2×10^{-6}	8.4×10^{-3}	24d	0.202	20^0
	Arthropoda, Isopoda (Crustacea)					
31	*Emerita portoricensis*	15×10^{-3}	796×10^{-3}	10y	2.9×10^{3}	20^0
32	*Orcomella*	2.4×10^{-3}	203×10^{-3}	10y	740.65	17^0
33	*Laborchestia*	2.7×10^{-4}	22.92×10^{-3}	10y	83.671	20^0
	Osteichthytes (Pisces)					
34	*Notothenia coriiceps*	0.2	5.4	24y	47.3×10^{3}	0^0

35	*Chaenocephalus aceratus*	0.2	6.07	24y	53.2×10^3	0^0
36	*Mugil cephalus*	0.149	7.19	18y	47.2×10^3	14^0
37	*Girella nigricans*	0.070	4.42	12y	19.7×10^3	20^0
38	*Anguilla anguilla*	0.040	1.698	12y	7.4×10^3	17^0
39	*Bagarius bagarius*	0.147	6.52	25y	59.5×10^3	17^0
40	*Salvelinus alpinus*	0.112	11.075	12y	48.5×10^3	18^0
	Amphibia					
41	Frog (*Rana*)	32×10^{-3}	0.852	36y	11.2×10^3	15^0
42	Frog (*Acris*)	30×10^{-3}	1.447	25y	13.2×10^3	15^0
43	Salamandra (*Salamandra atra*)	13.4×10^{-3}	0.482	20y	3.5×10^3	14^0
	Reptilia					
44	Reptilia (*Amphibolurus*)	373×10^{-3}	25.18	10y	9.2×10^4	28^0
45	Reptilia (*Dipsosaurus*)	64×10^{-3}	0.965	10y	3.5×10^3	20^0
46	Reptilia (*Lasepta*)	6.3×10^{-3}	0.744	10y	2.72×10^3	19^0
47	Tortoise (*Chrysemys*)	0.25	4.48	30y	4.9×10^4	18^0
48	Sauria (*Iguana*)	0.785	58.7	20y	4.3×10^5	20^0
49	Crocodile (*Alligator*)	49	1.83×10^3	40y	267×10^5	28^0
	Reptilia (Snakes)					
50	Boidae	1.0	10	30y	109.5×10^3	18^0
51	Boa	10	100	30y	109.5×10^4	18^0
52	Colubridae	0.080	1	14y	5×10^3	18^0
53	Piton	5	17	30y	1.86×10^5	18^0
54	Eunectes	11.3	114.5	30y	12.53×10^5	20^0
55	Natrix	0.084	2.834	14y	14.5×10^3	16^0
56	Grass-snake	3.27	28.4	30y	3.11×10^5	17^0
	MAMMALS					
	Monotremata					
57	*Tachiglossus aculeatus*	2.5	301.5	14y	15.4×10^5	30-31°
58	*Zaglossus bruijni*	10.3	593.78	20y	43.34×10^5	30-31°
59	*Ornithorhynchus anatinus*	1.3	228.6	9y	7.51×10^5	30-31°
	Didelphoidea					
60	*Lutreolina crassicaudata*	0.812	195.85	5y	3.57×10^5	36°
61	*Didelphis marsupialis*	1.329	298.66	6y	6.54×10^5	36°
62	*Didelphis virginiana*	3.257	518.5	8y	15.14×10^5	36°
	Dasyurida					
63	*Antechinus macdonnellensis*	14.1×10^{-3}	9	2y	6.57×10^3	36°
64	*Antechinus stuartii*	36.5×10^{-3}	17.6	2.5y	16.06×10^3	36°
65	*Antechinomus laniger*	8.5×10^{-3}	5.166	2y	3.77×10^3	36°
66	*Dasyuroides byrnei*	89×10^{-3}	37.35	3y	40.89×10^3	36°
67	*Isodon macroourus*	1	200.9	8y	5.87×10^5	36°
68	*Perameles nasuta*	0.645	152.46	7y	3.9×10^5	36°
69	*Sminthopsis crassicaudata*	15×10^{-3}	9.64	2y	7×10^3	36°
70	*Planigale maculata*	13×10^{-3}	13.65	1.5y	7.47×10^3	36°
71	*Sacrophilus harrisii*	5.05	628.11	10y	22.926×10^5	36°
	Syndactyla					
72	*Trichosurus vulpecula*	1.982	305.5	8y	8.9×10^5	37°
73	*Macropus robustus*	4.69	693.9	11y	25.7×10^5	37°
74	*Macropus rufus*	40	4×10^3	15y	21.9×10^6	37°
75	*Macropus eugenii*	4.796	671	11y	26.94×10^5	37°
	Xenarthra					
76	*Bradypus variegatus*	3.79	331	19y	22.95×10^5	37°
77	*Dasypus novemcinctus*	3.32	384.4	10y	14×10^5	37°
	Pholidota					
78	*Manis tricuspis*	2.73	439.7	8y	12.8×10^5	37°
79	*Manis javanica*	4.22	529.3	11y	21.25×10^5	37°
	Soricomorpha					
80	*Blarina brevicauda*	21×10^{-3}	25.326	1.2y	11.09×10^3	37°
	Insectivora					
81	*Sorex caecutiens*	3.6×10^{-3}	15	0.8y	4.32×10^3	37.9°
82	*Sorex araneus*	5.0×10^{-3}	17.64	0.8y	5.08×10^3	37.9°

	Rodentia					
83	*Cricetus cricetus*	0.362	111.75	4y	16.3×10^4	37.8°
84	*Liomys salvini*	43.8×10^{-3}	22.51	2.5y	20.63×10^3	37.8°
85	*Liomys irroratus*	48.1×10^{-3}	25.99	2.5y	23.72×10^3	37.8°
86	*Microtus minutus*	9.8×10^{-3}	17.97	0.8y	5.175×10^3	37.9°
87	*Microtus mexicanus*	28×10^{-3}	22	1.5y	12×10^3	37.8°
88	*Ochrotomys nuttalli*	19.5×10^{-3}	23.78	1.5y	12.84×10^3	37.8°
89	*Mus musculus*	0.021	20.9	1.5y	1.14×10^4	37.8°
90	*Neotoma cirenea*	0.321	120.78	3.5y	15.43×10^4	37.8°
91	*Neotoma lepida*	0.139	48.24	3.5y	6.16×10^5	37.8°
92	*Neotoma fuscipes*	0.187	71.27	3.5y	9.1×10^4	37.8°
93	*Neotoma albigula*	0.172	61.4	3.5y	7.84×10^4	37.8°
94	*Ondatra zibethicus*	0.842	333	3.5y	42.54×10^4	37.8°
95	*Perognathus longimembris*	11.5×10^{-3}	11.428	1.5y	6.25×10^3	37.8°
96	*Perognahtus hispidus*	39.5×10^{-3}	23.82	2y	17.387×10^3	37.8°
97	*Peromyscus eremicus*	21.5×10^{-3}	15.35	1.5y	8.4×10^3	37.8°
98	*Peromyscus californicus*	45.5×10^{-3}	22.61	2.5y	20.63×10^3	37.8°
99	*Peromyscus leucopus*	22.2×10^{-3}	26.77	1.5y	12.15×10^3	37.8°
100	*Chinchilla laniger*	0.494	111.99	8y	3.27×10^5	37.8°
101	*Lagostomus maximus*	6.784	916.36	13y	43.48×10^5	38°
102	*Kerodon rupestris*	0.750	193	6y	422.97×10^3	37.8°
103	*Cavia porcellus*	0.5	192	6y	4.2×10^5	37.8°
104	*Marmota monax*	2.65	319.6	10y	11.665×10^5	38°
105	*Rattus fuscipes*	0.076	40.68	3y	445.5×10^2	37.8°
106	*Rattus lutreolus*	0.109	30.49	3.5y	3.9×10^4	37.8°
107	*Rattus rattus*	0.132	80.86	3.5y	10.33×10^4	37.8°
108	*Rattus sordidus*	0.187	51.4	4y	75.04×10^3	37.8°
109	*Sigmodon hispidus*	0.161	168.4	3y	1.6×10^5	37.8°
	Lagomorpha					
110	*Lepus europaeus*	2.5	528	8y	15.4×10^5	38°
111	*Lepus americanus*	1.528	686.4	7y	17.54×10^5	38°
112	*Lepus californicus*	2.3	632.3	8y	18.4×10^5	38°
113	*Lepus timidus*	3.004	521.6	9y	17.1×10^5	38°
114	*Lepus alleni*	3.362	729.8	9y	23.97×10^5	38°
115	*Sulvilagus audubonii*	0.702	220.12	7y	5.62×10^5	37.8°
	Artiodactyla					
116	*Antilopa americana*	32	4 322	18y	28.4×10^6	37.9°
117	*Camelus dromedarius*	407	23 630	26y	224.25×10^6	37.8°
118	*Elephas maximum*	3×10^3	165×10^3	54y	32.52×10^8	36°
119	*Capreolus capreolus*	19	3 666	13y	17.4×10^6	37.9°
120	*Cervus elaphus*	58	7.8×10^3	18y	51.2×10^6	37.9°
121	*Equus cabalus*	400	32 000	40y	4.67×10^8	37.8°
122	*Ovis aries*	49	4 200	20y	30.7×10^6	37.9°
123	*Ovis canadensis*	65	10 660	20y	77.8×10^6	37.9°
124	*Bubalus caffer*	420	29 400	35y	37.5×10^7	37.8°
125	*Rupicapra rupicapra*	40	3 140	21y	24.07×10^6	37.9°
126	*Sus scrofa*	140	12×10^3	15y	65.7×10^6	37.8°
127	*Tayassu tajacu*	20.2	2 826	15y	15.47×10^6	37.9°
	Carnivora					
128	*Lutra lutra*	10	2 200	15y	120.4×10^5	37.9°
129	*Gulo gulo*	12.7	2 818	15y	154.29×10^5	37.9°
130	*Meles meles*	11.05	1 439.2	16y	84.05×10^5	37.9°
131	*Enhydra lutris*	40	12.35×10^3	16y	721.2×10^5	37.9°
132	*Vulpes vulpes*	5.01	1 208.4	12y	5.29×10^6	38°
133	*Canis latrans*	10	1 320.5	18y	86.76×10^5	38°
134	*Canis familiaris*	14	1 881	18y	123.6×10^5	37.9°
135	*Panthera onca*	18	2 436	20y	177.8×10^5	37.9°
136	*Felis silvestris*	3	546	11y	21.9×10^5	38°
137	*Mustela vison*	0.66	238.6	8y	6.97×10^5	37.8°
	Pinnipedia					

138	*Phoca vitulina*	26	7 400	13y	35.1×10^6	37.9°
139	*Delphinapterus leucas*	170	22 962	25y	209.5×10^6	37.8°
140	*Hyperoodon ampullatus*	1 000	69.46×10^3	40y	1014×10^6	37.8°
	Chiroptera					
141	*Desmodus rotundus*	0.029	9.65	8y	28.18×10^3	37.8°
142	*Vampyrops lineatus*	0.022	15.6	6y	34.16×10^3	37.8°
143	*Macroderma gigas*	0.148	67.97	19y	2.48×10^5	37.8°
144	*Eumops perotis*	0.057	14.2	10y	51.83×10^3	37.8°
145	*Pteropus policephalus*	0.598	153	13y	7.26×10^5	37.8°
	Primates					
146	*Pan troglodytes*	45	4.62×10^3	40y	67.45×10^6	37.9°
147	*Macaca mulatta*	5	960	25y	86.4×10^5	38°
148	*Pongo pygmaeus*	150	15.54×10^3	45y	251.75×10^6	37.8°
149	*Gorilla gorilla*	250	$21x10^3$	45y	340×10^6	37.8°
150	*Hylobater lar*	8	1 512	25y	136×10^5	38°
151	*Homo sapiens*	65	7.56×10^3	75y	204×10^6	37.9°
	AVES					
	Struthioniformes					
152	*Struthio camelus*	100	9 823	45y	161.3×10^6	40°
153	*Struthio camelus*	100	5 442.36	45y	89.4×10^6	40°
	Rheiformes					
154	*Rhea americana*	21.7	3 344	50y	61×10^6	40°
	Casuariiformes					
155	*Casuarius bennetti*	17.6	2 156.9	50y	39.36×10^6	40°
156	*Dromiceus novaehollandiae*	38.925	3 746.1	45y	61.5×10^6	40°
	Apterygiformes					
157	*Apteryx australis*	2.38	347.77	28y	35.5×10^5	40°
158	*Apteryx owenii*	1.095	178.486	24y	15.65×10^5	40°
159	*Aptreryx haasti*	2.54	360.734	28y	36.86×10^5	40°
	Sphenisciformes					
160	*Pygoscelis papua*	6.29	1 603.45	35y	20.48×10^6	40°
161	*Pygoscelis adeliae*	3.97	1 055.87	32y	12.3×10^6	40°
162	*Eudyptes pachyrhynchus*	2.6	597.32	28y	61×10^5	40°
163	*Eudyptes chrysocome*	2.506	862	28y	88×10^5	40°
164	*Eudyptes crestatus*	2.33	503.7	28y	51.5×10^5	40°
165	*Eudyptula albosignata*	1.15	570.57	24y	50×10^5	40°
	Procellariiformes					
166	*Macronectus giganteus*	3.63	1 492.68	30y	16.3×10^6	40°
167	*Pterodroma hypoleuca*	0.18	89.87	15y	4.92×10^5	40°
168	*Pterodroma mollis*	0.274	150.9	18y	9.9×10^5	40°
169	*Pachyptila salvini*	0.165	133.76	15y	7.32×10^5	40°
170	*Puffinus griseus*	0.740	249.13	18y	16.36×10^5	40°
	Pelecaniformes					
171	*Pelecanus occidentalis*	3.038	894.5	35y	11.4×10^6	40°
172	*Sula dactylatra*	1.289	475.26	29y	50.3×10^5	40°
173	*Sula sula*	1.017	375.78	28y	38.4×10^5	40°
174	*Phalacrocorax auritus*	1.33	474	29y	50.2×10^5	40°
	Ciconiiformes					
175	*Ardea herodias*	1.87	535	31y	60.54×10^5	40°
176	*Hydranassa tricolor*	0.31	147.55	18y	9.5×10^5	40°
177	*Mysteria americana*	2.5	840.18	33y	101.2×10^5	40°
178	*Leptoptilos javanicus*	5.71	1 283.2	39y	182.66×10^5	40°
	Anseriformes					
179	*Cygnus buccinator*	8.88	1 747.24	40y	255×10^5	40°
180	*Branta bernicla*	1.168	390.4	29y	41.3×10^5	40°
181	*Aix sponsa*	0.485	271.7	24y	23.8×10^5	40°
182	*Anas platyrhynchos*	1.1323	434.7	25y	39.6×10^5	40°
183	*Anas crecca*	0.25	143.8	20y	10.5×10^5	40°
184	*Anas querquedula*	0.289	192.7	20y	14×10^5	40°
185	*Aythya fuligula*	0.574	233.2	20y	17×10^5	40°

	Charadriiformes					
186	*Tringa ochropus*	0.09	79.4	10y	2.9×10^{5}	40°
187	*Stercorarius skua*	0.97	409.6	25y	37.4×10^{5}	40°
188	*Larus delawarensis*	0.439	249.13	20y	18.2×10^{5}	40°
189	*Larus occidentalis*	0.761	293	20y	21.3×10^{5}	40°
190	*Gygis alba*	0.0981	70.22	15y	3.84×10^{5}	40°
	Columbiformes					
191	*Columba unicincta*	0.318	148	20y	10.8×10^{5}	40°
192	*Columba livia*	0.315	150	20y	10.95×10^{5}	40°
193	*Columba livia*	0.266	140.87	20y	10.3×10^{5}	40°
194	*Streptopelia decaocto*	0.187	110	20y	8.03×10^{5}	40°
	Falconiformes					
195	*Vultur gryphus*	10.32	1 467.18	40y	21.4×10^{6}	40°
196	*Falco sparverius*	0.117	72.73	15y	4×10^{5}	40°
197	*Accipiter nisus*	0.135	81.93	19y	5.68×10^{5}	40°
198	*Buteo buteo*	1.012	324.37	28y	33.15×10^{5}	40°
199	*Gypaetus berbatus*	5.07	953	30y	104.3×10^{5}	40°
	Galliformes					
200	*Lagopus lagopus*	0.524	268.36	18y	18.81×10^{5}	40°
201	*Lagopus lagopus*	0.509	294.7	18y	19.36×10^{5}	40°
202	*Callipepla gambelii*	0.126	65.21	10y	2.38×10^{5}	40°
203	*Gallus gallus*	2.43	670.47	16y	39.155×10^{5}	40°
	Gruiformes					
204	*Grus canadensis*	3.89	702.2	25y	64×10^{5}	40°
205	*Anthropoides paradisea*	4.03	919.6	25y	83.9×10^{5}	40°
206	*Crex crex*	0.096	68.13	15y	3.75×10^{5}	40°
207	*Fulica atra*	0.412	176	20y	12.85×10^{5}	40°
	Psittaciformes					
208	*Melopsittacus undulatus*	0.0337	41.38	15y	2.265×10^{5}	40°
209	*Myiopsitta monachus*	0.0815	67.72	18y	4.45×10^{5}	40°
210	*Myiopsitta monachus*	0.0831	68.13	18y	4.47×10^{5}	40°
211	*Myiopsitta monachus*	0.0831	59	18y	3.87×10^{5}	40°
212	*Neophema pulchella*	0.04	50.16	15y	2.74×10^{5}	40°
	Cuculiformes					
213	*Cuculus canorus*	0.128	108.26	17y	6.7×10^{5}	40°
214	*Eudyramys scolopacea*	0.188	142.12	17y	8.8×10^{5}	40°
215	*Cacomantis variolosus*	0.0238	16.3	12y	0.71×10^{5}	40°
216	*Cacomantis variolosus*	0.0238	10.45	12y	0.46×10^{5}	40°
217	*Centropus senegalensis*	0.175	130	17y	8.06×10^{5}	40°
	Strigiformes					
218	*Athene cunicularia*	0.1427	58.52	19y	4.06×10^{5}	40°
219	*Glaucidium cuculoides*	0.163	74.82	20y	5.46×10^{5}	40°
220	*Strix aluco*	0.52	179.74	25y	16.4×10^{5}	40°
221	*Aegolius acadicus*	0.124	56.43	19y	3.91×10^{5}	40°
222	*Asio otus*	0.240	110.35	22y	8.86×10^{5}	40°
	Caprimulgiformes					
223	*Podargus ocellatus*	0.145	48.9	15y	2.68×10^{5}	40°
224	*Chordeiles minor*	0.072	38	12y	1.66×10^{5}	40°
225	*Caprimulgus europaeus*	0.0774	55.59	12y	2.43×10^{5}	40°
226	*Phalaenoptilus nuttalli*	0.035	13.376	12y	0.586×10^{5}	40°
227	*Eurostopodus guttatus*	0.088	35.11	13y	1.67×10^{5}	40°
	Apodiformes					
228	*Calypte anna*	0.0054	9.9	4y	14.45×10^{3}	40°
229	*Eugenes fulgens*	0.0066	8.6	4y	12.55×10^{3}	40°
230	*Calypte costae*	0.0032	4.476	4y	6.5×10^{3}	40°
231	*Selasphorus platycercus*	0.003	5.79	4y	8.85×10^{3}	40°
232	*Patagona gigas*	0.0191	24.74	8y	72.24×10^{3}	40°
233	*Archilochus alexandri*	0.0033	6.27	4y	9.15×10^{3}	40°
	Coliiformes					
234	*Colius striatus*	0.0512	46.8	12y	2.0×10^{5}	40°

235	*Colius castanotus*	0.069	89.45	12y	3.9×10^5	40°
236	*Colius castanotus*	0.0577	66	12y	2.9×10^5	40°
237	*Urocolius macrourus*	0.0485	63.5	12y	2.8×10^5	40°
238	*Urocolius indicus*	0.0535	61.86	12y	2.7×10^5	40°
	Trogoniformes					
239	*Alcedo atthis*	0.0343	32.6	10y	1.19×10^5	40°
240	*Trogon rufus*	0.053	37.2	12y	1.6×10^5	40°
	Coraciiformes					
241	*Upupa epops*	0.067	47.65	12y	2.08×10^5	40°
242	*Merops viridis*	0.0338	25.5	10y	0.93×10^5	40°
243	*Merops viridis*	0.0338	33.86	10y	1.2×10^5	40°
	Piciformes					
244	*Jynx torquilla*	0.0318	30.9	10y	1.12×10^5	40°
245	*Dendrocopus major*	0.098	77.3	15y	4.23×10^5	40°
246	*Picoides major*	0.117	89.87	15y	4.92×10^5	40°
	Passeriformes					
247	*Regulus regulus*	0.0055	15.88	10.53y	61×10^3	40°
248	*Psaltriparus minimus*	0.0055	10.45	10.53y	40.16×10^3	40°
249	*Auriparus flaviceps*	0.0068	14.212	10.96y	56.87×10^3	40°
250	*Tiaris canora*	0.0007	13.376	11.02y	53.82×10^3	40°
251	*Parula americana*	0.007	10.45	11.02y	42.05×10^3	40°
252	*Vermivora pinus*	0.0078	12.958	11.36y	53.73×10^3	40°
253	*Loxops parva*	0.0079	12.122	11.37y	50.3×10^3	40°
254	*Troglodytes troglodytes*	0.009	18.39	11.56y	77.6×10^3	40°
255	*Troglodytes aedon*	0.0097	25.08	11.7y	107.1×10^3	40°
256	*Dendroica dominica*	0.0098	13.794	11.75y	59.16×10^3	40°
257	*Delichon irbica*	0.0205	30.51	13.5y	150.34×10^3	40°
258	*Carduelis chloris*	0.0311	46.816	14.635y	250×10^3	40°
259	*Cardinalis cardinalis*	0.0410	50.996	15.424y	287.1×10^3	40°
260	*Pipilo alberti*	0.0466	62.7	15.61y	361.68×10^3	40°
261	*Loxia pytyopsittacus*	0.0537	68.97	16.23y	408.73×10^3	40°
262	*Perisoreus canadensis*	0.0645	83.6	16.81y	512.94×10^3	40°
263	*Sturnus vulgaris*	0.067	75.66	26.93y	467.6×10^3	40°
264	*Sturnus vulgaris*	0.075	71.33	17.3y	488.3×10^3	40°
265	*Cyanocitta cristata*	0.0808	71.9	17.54y	460.48×10^3	40°
266	*Cyanocitta stelleri*	0.0991	86.1	18.24y	573.2×10^3	40°
267	*Acridotheres cristatellus*	0.1094	104.08	18.58y	705.84×10^3	40°
268	*Pica pica*	0.202	148.4	20.88y	1131×10^3	40°
269	*Corvus monedula*	0.215	161.35	21.13y	1244×10^3	40°
270	*Corvus caurinus*	0.306	412.56	22.6y	3403.2×10^3	40°
271	*Corvus frugilegus*	0.390	225.72	23.664y	1950×10^3	40°
272	*Corvus brachyrhynchos*	0.3848	283.4	23.6y	2441×10^3	40°
273	*Corvus corone*	0.518	286.33	24.975y	2610×10^3	40°
274	*Corvus corone*	0.540	330.22	25.17y	3034×10^3	40°
275	*Corvus corax*	0.85	384.56	27.44y	3851×10^3	40°
276	*Corvus corax*	0.866	396.68	27.54y	3988×10^3	40°
277	*Corvus corax*	1.203	475.27	29.31y	5085×10^3	40°
278	*Corvus corax*	1.208	517.48	29.33y	5540×10^3	40°

An allometric analysis has shown that a linear relationship between the total metabolic energy per lifespan ($P_{ls}= PT_{ls}$, kJ) and the body mass (M, kg) of all together - Ectotherms, Mammals and Aves (n=278 individuals) in log-log plot holds:

$$PT_{ls}=A^{all}_{ls}M^{1.0787\pm0.11} \qquad (8)$$

with corresponding coefficient R^2=0.980, coefficient A^{all}_{ls} =15.18×10^5 kJ/kg, standard error of the exponent SE= ±0.11 and confidence interval (CI) of 95% (0.968-1.188). The graphic presentation of relationship (8) for all 278 Ectotherms, Mammals and Aves is shown on **Fig. 1.**

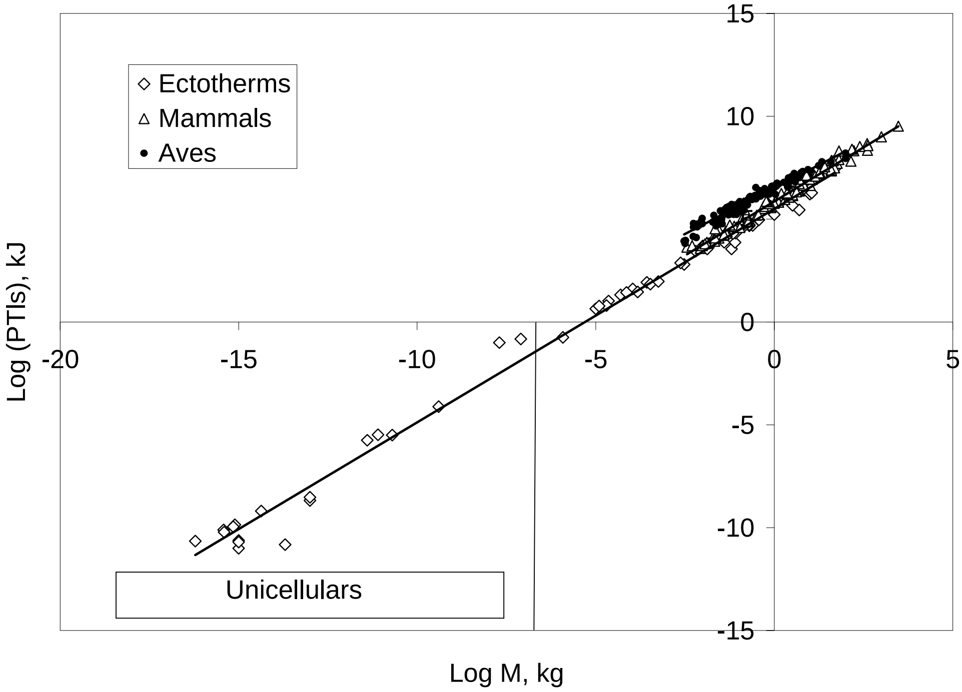

Fig. 1. The relationship between the total metabolic energy per lifespan (Pls=PTls, kJ) and the body mass (M, kg) for 278 Ectotherms, Mammals and Aves. The unicellular organisms are divided from multicellular organisms (animals) by vertical line.

The relationship for Ectotherms, Mammals and Aves (n=260) without Protozoa is linear too:

$$PT_{ls}=A_{ls}M^{1.0089\pm0.042} \qquad (9)$$

with R^2=0.897, coefficient A_{ls}=14.16×10^5 kJ/kg, standard error of the exponent SE= ±0.042 and CI of 95% (0.967-1.051). In (8) and (9), the linear coefficients A_{ls} vary negligible and appears to be the total metabolic energy, exhausted during the lifespan per 1kg body mass of animals.

In (8), for all 278 Ectotherms, Mammals and Aves and in (9) for all animals without Protozoa, the value of the exponent is equal to 1.0 in the confidence interval of 95%. The high correlation coefficients (R^2=0.897-0.980) between the total metabolic energy per lifespan and the body mass of animals means that the correlations are not random.

The relationships between the total metabolic energy per lifespan and the body mass separately for Ectotherms, Mammals and Aves are given in **Table 2**.

It is well known fact that the log-log plot reduces the residual variability, which means that large deviations from predicted, appear as small deviations. In (8) and (9) the down limits of confidence intervals of the exponents are equal (0.967-0.968), but the upper limits are different (r=1.051 without Protozoa and 1.188 with Protozoa), because the total metabolic energy per lifespan for Protozoa scale with body mass as $M^{1.16}$ (R^2=0.95).

In this connection, P-level of the correlation (8) has been estimated by Student's t-test for p=0.00001 and two null hypotheses for exponents and intercepts were tested for Ectothrms, Mammals and Aves using method of analyses of covariance ANCOVA.

Since, the histogram of residual total metabolic energy per lifespan P_{ls} against body mass M for all 278 Ectotherms, Mammals and Aves individuals shows the normal (Gaussian) distribution, this means that the general relationship (8) is statistically significant for p=0.00001.

The first tested hypotheses is that the slopes of exponents of the regression lines for Ectotherms and Mammals are all the same. The 95% confidence interval of the slopes (r=1.038±0.024) for Ectotherms is 1.014-1.062

and for Mammals ($r=1.051\pm0.029$) is 1.022-1.080. Since the confidence intervals of the slopes for Ectotherms and Mammals are overlap the first hypothese for Ectotherms and Mammals is confirme.

The second tested hypotheses is that the intercepts of the regression for Ectotherms and Mammals are all the same. The confidence intervals (95% level) of the intercepts for Ectotherms are 5.31-5.69 and the same for Mammals is 5.81-5.88. Since the two intercepts are different the second hypothesis is rejected. Consequently, the Ectotherms and Mammals appear on general relationship (8) as two groups with equal slope but different intercept.

The same hypotheses applied for Aves against Ectotherms and Mammals show that the 95% confidence interval of the slopes ($r=0.893\pm0.033$) for Aves is 0.86-0.926 and the confidence intervals (95% level) of the intercept for Aves is 6.41-6.73. Therefore, the confidence interval of the slope and intercept for Aves differs considerably from the confidence interval of slopes and intercepts for Ectotherms and Mammals. This shows that three groups (Ectotherms, Mammals and Aves) clearly distinguish on the general relationship (8). In spite of the fact that the group of Aves differ considerably from the groups of Ectotherms and Mammals, because of small range of variation (1×10^5 times) between body mass of Aves in comparison to big range of variation (3×10^{21} times) between body mass of all individuals (Ectotherms, Mammals and Aves) the group of Aves affect negligible the slope of general relationships (8).

DISCUSSION

Some relationships between the total metabolic energy per lifespan and the body mass, separately for class Ectotherms, Mammals and Aves, and in combination of all are summarized in **Table 2.**

Table 2. *The relationships between the total metabolic energy per lifespan (Pls, kJ) and the body mass (M, kg) for class Ectotherms, Mammals and Aves, separately and in combination (n- is the number of individuals).*

Item	Class of animals	$Pls = AlsM^r$	R^2
a)	All(Ectotherms, Mammals and Aves)(n=278)	$Pls=15.18\times10^5M^{1.0787\pm0.11}$	0.980
b)	All without Protozoa (n=260)	$Pls=14.16\times10^5M^{1.0089\pm0.042}$	0.897
c)	Ectotherms (n=56)	$Pls=3.14\times10^5M^{1.038\pm0.024}$	0.992
d)	Mammals (n=95)	$Pls=7.15\times10^5M^{1.051\pm0.029}$	0.981
e)	Ectotherms and Mammals (n=151)	$Pls=5.88\times10^5M^{1.062\pm0.030}$	0.994
f)	Ectotherms without Protozoa (n=38)	$Pls=2.268\times10^5M^{0.958\pm0.035}$	0.988
g)	Aves (n=127)	$Pls=32.2\times10^5M^{0.893\pm0.033}$	0.957
h)	Aves and Mammals(n=222)	$Pls=17.3\times10^5M^{0.896\pm0.036}$	0.886
i)	Aves and Ectotherms (n=183)	$Pls=25.77\times10^5M^{1.106\pm0.12}$	0.984

Table 2 shows that in five equations (a, b, c, d, e) – (a) for all Ectotherms, Mammals and Aves, (b) for all animals without Protozoa, separately for Ectotherms(c) and Mammals(d), and for the combination Ectotherms – Mammals(e), the exponent r falls in the interval of 1.0-1.08. In the three equations (f, g, h) – (f) for Ectotherms without Protozoa, (g) for Aves and (h) for the combination Aves-Mammals, the exponent r is lower than 1.0 and falls in the interval of r=0.893-0.896. In the combination (i) for Aves- Ectotherms, the exponent r exceeds 1.08 (r=1.106). It is observed that exponents for class Aves, combinations between Aves-Mammals and combination between Aves-Ectotherms define the minimum and the maximum limits of the exponent r, from the minimum of 0.893 to the maximum of 1.106. The mean point of this interval (0.893-1.106) is the value 0.999 that is close to 1.0. All animals (Ectotherms, Mammals and Aves), without Protozoa, give the relationship with exponent exactly 1.0 i.e. r =1.0089 with standard error of the slope $SE=\pm0.042$. In the case of all animals (Ectotherms, Mammals and Aves), including Protozoa, the exponent becomes 1.0787 with standard error of the slope $SE=\pm0.11$. This show, that Protozoa enlarges considerably the exponent from 1.0089 to 1.0787 and the standard error of the slope from 0.042 to 0.11. This is possible, because the Ectotherms, including Protozoa, have the biggest range of body mass (1×10^{17} times) in comparison to Mammals (1×10^7 times), and to Aves (1×10^5 times). Without Protozoa, the Ectotherms have

again a higher range of body mass, about $5x10^7$ times, in comparison to Mammals and to Aves (1×10^7 times). The Ectotherms only, including Protozoa, have exponent r =1.038, but without Protozoa the exponent is r=0.958. The mean point (0.996) of this interval (from 0.958 to 1.038) is very close to 1.0. Thus, in other combinations between Ectotherms, Mammals and Aves, the exponent r varied around 1.0 and does not exceed the given minimum and maximum values (from 0.893 to 1.106) with mean point close to 1.0.

From eq. 'c', 'd', 'g' on Table 2 can be observed that the total metabolic energy per lifespan, per 1 kg body mass (A_{ls}) grows from the value of 3.14×10^5 kJ/kg in Ectotherms to 7.15×10^5 kJ/kg in Mammals, and to 32.2×10^5 kJ/kg in Aves. Thus, A_{ls} rises 10 times only from Ectotherms to Aves, despite of the 21 orders of magnitude difference between the body mass of animals. This shows that in evolution the coefficient A_{ls} is a relatively constant parameter. On the contrary, the individual values of A_{ls} between 278 studied organisms change 300-500 times. For example: from Bacteria to *Elephas maximum* it changes about 300 times and from Bacteria to *Covus corax* it changes about 550 times (see Appendices).

The linearity between the total metabolic energy per lifespan and the body mass of animals leads to additive connection between three allometric relationships: 1/ the basal metabolic rate and the body mass ($P = aM^k$), 2/ the lifespan and the body mass ($T_{ls} = bM^n$) and 3/ the total metabolic energy per lifespan and the body mass ($P_{ls}=A_{ls}M^r$). The additive connection can be expressed by the equations (10) and (11):

$$P_{ls}=PT_{ls}=(aM^k)\times(bM^n)=abM^{k+n}=A_{ls}M^r \qquad (10)$$

$$A_{ls}=ab, \qquad r=k+n=1.0 \qquad (11)$$

If we know the 'metabolism-mass' or the 'lifespan-mass' relationship, we can calculate the other additive relationship, using equations (10) and (11).

A several other scientific problems are conected with total metabolic energy per lifespan. Hoever, the finding of the basic scaling laws in biology and others natural sciences will allow us to build 'scientific theory of all'.

REFERENCES

1. Kleiber, M., Body size and metabolism. *Hilgardia*, 26: 315-332, 1932.
2. Brody, S., Procter, R.C. and Ashworth, U.S., Basal metabolism, endogenous nitrogen, creatinine and neutral sulphur excretions as function of body weight. *Univ Miss Agric Sta Res Bull*, *220*:1-40, 1934.
3. Zeuthen, E., Oxygen uptake as related to body size in organisms. *Quart Rev Biol*, 28:1-12, 1953.
4. Hemmingsen, A.M., Energy metabolism as related to body size and respiratory surface and its evolution. *Rep Stemo Hosp Nordisk Ins Lab*, 9: 1-110, 1960.
5. Kleiber, M., The fire of life, John Wiley and Sons, 1961.
6. Schmidt-Nielsen, K., Scaling: Why is Animal Size so Important? Cambridge Univ. Press, UK, 1984.
7. McNab, B.K., Complications inherent in scaling the basal rate of metabolism in animals. *Quart Rev Biol*, 63: 25-54, 1988.
8. Heusner, A.A., Size and power in Mammals. *J Exp Biol*, 160: 25-54, 1991.
9. Niklas K.J., Plant allometry: The scaling of Form and Process, Chicago Univ. Press, USA, 1994.
10. Nagy, K.A., Field metabolic rate and body size. *J Exp Biol*, 208: 1621-1625, 2005.
11. Da Silva, J.K.L. and Barbosa, L.A., Non-universal interspecific allometric scaling of metabolism. *Braz J Phys*, 39:15-25, 2009.
12. Feldman, H.A. and McMahon, T.A., The ¾ mass exponents for energy metabolism are not a statistical artifact. *Resp Physiol*, *52*:149-163, 1983.
13. West, G.B., Brown, J.H. and Enquist, B.J., A general model for the origine of allometric scaling laws in biology. *Science* 276: 122-126, 1997.
14. West, G.B., Brown, J.H. and Enquist, B.J., The fourth dimension of life: fractal geometry and allometric scaling of organisms. *Science* 284:1677-1679, 1999.
15. Banavar, J.R., Damuth, J., Maritan, A.and Rinaldo, A., Suuply-demand balance and metabolic scaling. *Proc Natl Acad Sci USA* 99: 10506-10509, 2002.
16. Savage, V.M., Gillooly, J.F., Woodruff, W.H., West, G.B., Allen, A.P., Enquist, B.J. and Brown, J.H., The predominance of quarter-power scaling in biology. *Func Ecol* 1: 257-282, 2004.

17. Riisgård, H.U., No foundation of a '¾ power scaling law' for respiration in biology. *Ecol Letters* 1: 71-73, 1998.
18. Dodds, P.S., Rothman, D.H. and Weitz, J.S., Re-examination of the '3/4-law' of Metabolism. *J Theoret Biol* 209: 9-27, 2001.
19. Bokma, F., Evidence against universal metabolic allometry. *Func Ecol* 18:184-187, 2004.
20. Agutter, P.S. and Wheatley, D.N., Metabolic scaling: consensus or controversly? *Theoret Biol Med Model* 1:13-48, 2004.
21. Glazier, D.S., Beyong the '3/4 power law': variation in the intra- and interspecific scaling of metabolic rate in animals. *Biol Rev Cambr Phylos Soc* 80**:** 611-662, 2005.
22. Reich, P.B., Tjoelker, M.G., Machado, J.L.; and Oleksyn, J., Universal scaling of respiratory metabolism, soze and nitrogen in plants. *Nature* 439: 457-461, 2006.
23. White, C.R. and Seymour, R.S., Mammalian basal metabolic rate is proportional to the body mass. *Proc Natl Acad Sci USA*100: 4046-4049, 2003.
24. White, C.R., Cassey, P. and Blackburn, T.M., Allometric exponents do not support a universal metabolic allometry. *Ecology* 88: 315-323, 2007.
25. DeLong, J.P., Energetics, shifting constraints, and evolution of eukaryotes: How metabolism scaled unicells. Proceedings of the 94th ESA Annual Meeting, Albuquerque, PS 60-195, 2009.
26. Galvão, P-E., Tarasantchi, J. and Guertzenstein, P., Heat production of tropical snakes in relation to the body weigth and body surface. *Amer J Physiol* 209: 501-506, 1965.
27. Ultsch, G.R., Gas exchange and metabolism in the sireniadae (Amphibia-Caudata). Oxygen consumption of submerged sirenids as a function of body size and respiratory surface area.*Comparat Biochem Physiol* 47A: 485-498, 1974.
28. Prosser, C.L.,Comparative physiology of animals, Mir, Moscow, Russia, 1977.
29. Tudge, C., The variety of life: a survey and a celebration of all the creatures that have every lived, Oxford University Press, UK, 2000.
30. Makarieva, M.M., Gorshkov, V.G. and Li, B-L., Energetics of the smallest: do bacteria breathe at the same rate as whales? *Proc Roy Soc B* 272: 2219-2224, 2005.
31. Lasievski, R.C. and Dawson, W.R., A re-examination of the relation between standart metabolic rate and body weight in birds. *Condor* 69:13-23, 1967.
32. Lasievski, R.C. and Dawson, W.R., Calculation and miscalculation of the equations relating avian standard metabolism to body weigth. *Condor* 71: 335-336, 1969.
33. Aschoff, J. and Pohl, H., Rhytmic variations in energy metabolism. *Fed Proc* 29:1541-1552, 1970.
34. Bennett, P.M. and Harvey, P.H., Active and resting metabolism in birds: allometry, phylogeny and ecology. *J Zool* (Lond.) 213: 327-363, 1987.
35. Nagy, K.A., Girard, I.A.and Brown, T.K., Energetics of fre-ranging mammals, reptiles and birds. *Ann Rev Nutr* 19: 247-277, 1999.
36. Rezende, E.L., Swanson, D.L., Novoa, F.F. and Bozinovic, F., Passerine versus nonpasserine: So far, no statistical differences in the scaling of avian energetics. *J Exp Biol 205*: 101-107, 2002.
37. Rottenberg, H., Exeptional longevity in songbirds is associated with high rate of evolution of cytochrome b, suggesting selection for reduced generatation of free radicals. *J Exp Biol* 210: 2170-2180, 2007.
38. Fenchel, T. Increasing rate of natural increase: the relationship with body size. *Oecologia* (Berlin) 14: 317-326, 1974.
39. Ernest, S.K.M. Life history characteristics of placental nonvolant mammals. *Ecology* 84: 3402-3409, 2003.
40. Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M. and West, G.B. Toward a metabolic theory of ecology. *Ecology* 85:1771-1789, 2004.
41. Damuth, J., A macroevolutionary explanation of energy equivalence in the scaling of body size and population density. *Amer Nat* 169: 621-623, 2007.
42. Ginsburg, L. and Damuth, J., The space lifetime hypothesis: viewing organisms in four dimensions, literally. *Amer Nat* 171: 125-131, 2008.
43. Bonner, J.T., Size and cycle. Princeton University Press. Princeton, NJ, 1965.
44. Günther, B., On theories of biological similarity. Fortschr. expt. theoret. Biophysik, VEBGeorg Thieme Verlag, Leipzig, Band 19, 1975.
45. Smith-Sonneborn, J., Longevity in protozoa. *Basic Life Sciences* 42:101-109, 1987.

46. Sacher, G.A., Relation of lifespan to brain wegth and body weigth in mammals. G.E. Wolstenholme ed., *Ciba Foundation Colloquium on Aging* 1: 115-141, 1959.
47. Mallouk, R.S., Longevity in vertebrates is propotional to relative brain weigth. *Fed Proc* 34: 2102-2103, 1975.
48. Cutler, R.G., Aging and cell function. In Johnson J.E. (ed.), Plenum, New York, 1984.
49. Speakman, J.R., Selman, C., McLaren, J.L. and Harper, E.J., Living fast, dying when? The link between aging and energetics. *J Nutrition* 132: 1583S-1597S, 2002.
50. Lindstedt, S.L. and Calder, W.A., Body size and longevity in birds. *Condor* 78: 91-94, 1976.
51. Lindstedt, S.L. and Calder, W.A., Body size, physiological time, and longevity in homeothermic animal.*Quart Rev Biol* 56: 1-16, 1981.
52. Møller, A.P., Relative longevity and field metabolic rate in birds. *J Evol Biol* 21:1379-1386, 2008.
53. Bonduriansky, R., Sexual selection, sexual conflict and the evolution of ageing and lifespan. *Functional Ecology* 22: 443-453, 2008.
54. Rübner, M., Das Problem det Lebensdaur und seiner beziehunger sum Wachstum und Ernarnhung. Munchen: Oldenberg, 1908.
55. Boddington, M.J., An absolute metabolic scope for activity. *J Theoret Biol* 75: 443-449, 1978.
56. Speakman, J.R., Body size, energy metabolism and lifespan. *J Exp Biol* 208: 1717-1730, 2005.
57. Speakman, J.R., Doubly-labelled Water: Theory and Practice. London: Chapman and Hall, 1997.
58. Nagy, K.A., Field bioenergetics of mammals- what determines field metabolic rate. *Aust J Zool* 42: 43-53, 1994.
59. Pearl, R. The Rate of Living. London: University of London Press, UK, 1928.
60. Carey, J.R. and Judge, D.S., Longevity records: life spans of mammals, birds, reptiles, amphibians and fish. Odense Monographs on Population Aging, ed. B. Jeaune and J.W. Vaupel, Odense: Univ. Press, 2000.
61. Atanasov, A.T., Linear relationship between the total metabolic energy per lifespan and the body mass of poikilothermic animals. *Bulgarian Meicine* 12: 7-9, 2004.
62. Atanasov, A.T., The linear allometric relationship between total metabolic energy per lifespan and the body mass of pokilothermiv animals. *BioSystems* 82: 137-142, 2005.
63. Atanasov, A.T., The linear allometric relationship between total metabolic energy per lifespan and the body mass of mammals. *BioSystems* 90: 224-233, 2007.
64. Atanasov, A.T., The near to linear allometric relationship between total metabolic energy per lifespan and the body mass in Nonpasseriformes birds. *Bulgarian Journal of* Veterinary *Medicine* 10: 13-19, 2007.
65. Atanasov, A.T., The near to linear allometric relationship between the total metabolic energy per lifespan and the body mass of Aves. *Animal and Veterinary Advances* 7: 425-432, 2008.
66. Fujiwara, N., The scaling rule for environmental organizing systems in a gravitational field. *BioSystems* 73: 11-116, 2004.
67. Gregory, T.R., Animal Genome Size Database (http://www.genomesize.com., 2008.