Far Eastern Entomologist

Number 475: 17-30 ISSN 1026-051X (print edition) ISSN 2713-2196 (online edition) May 2023

https://doi.org/10.25221/fee.475.3
https://elibrary.ru/akpudj
https://zoobank.org/References/E828548A-EBFE-4CFE-8AFA-F699C9931211

ESTIMATION OF BIOMASS OF DUNG BEETLES (COLEOPTERA: SCARABAEOIDEA) FROM THE RUSSIAN FAR EAST

S. A. Shabalin

Federal Scientific Center of the East Asia Terrestrial Biodiversity, Far East Branch of the Russian Academy of Sciences, Vladivostok, 690022, Russia. E-mail: oxecetonia@mail.ru

Summary. Data on dry biomass and body length are given for 47 species of dung beetles from the southern part of the Russian Far East. The length-to-body weight relation in specimens of 47 species of dung-beetles was calculated, to enable biomass to be estimated from information about body length. Shown, the selection of optimal models of length-weight relationship of dung-beetles depends on the types of trophodynamic relationships of beetles and its size classes. When conducting ecological studies using such an indicator as dry biomass, it is necessary to determine the biomass of individual species from regional faunas, and to determine the biomass along the length of the body of beetles, it is necessary to use exclusively models built also for regional faunas.

Key words: Coleoptera, Scarabaeoidae, dung-beetles, biomass, functional groups, length-weight relationship.

С. А. Шабалин. Оценка биомассы жуков-навозников (Coleoptera: Scarabaeoidea) Дальнего Востока России // Дальневосточный энтомолог. 2023. N 475. С. 17-30.

Резюме. Приводятся данные по биомассе сухого вещества и длине тела для 47 видов жуков-навозников с Дальнего востока России. Для 47 видов жуков-навозников были рассчитаны отношения длины тела жуков к биомассе, для того чтобы можно было оценить биомассу по информации о длине тела. Показано, что выбор оптимальных моделей соотношения длины и массы жуков-навозников зависит от типов трофодинамических отношений жуков и их размерных классов. При проведении экологических исследований по такому показателю, как сухая биомасса, необходимо определять биомассу отдельных видов из региональных фаун, а для определения биомассы по длине тела жуков необходимо использовать исключительно модели, построенные также для региональных фаун.

INTRODUCTION

In ecology, biomass is an important characteristic of communities, useful for tool for comparison and evaluation of dynamic processes. Previous studies of the biomass of dung beetles affect mainly the Western part of the Palearctic (Koskela & Hanski, 1977; Lobo, 1993), and the Neotropical (Radtke & Williamson, 2005; Radtke *et al*., 2006). Most of these studies concerned the study of mainly museum specimens (Gilbert, 2011). Direct collection in nature and subsequent processing of the material occurs only in a few works (Koskela & Hanski, 1977; Lobo, 1993). The large geographic disjunctions of these studies with the dung beetle fauna of the Eastern Palearctic do not allow us to use the obtained data on beetle biomass to assess the regional characteristics of dung beetle communities in the Far East Russia.

The objectives of the study included the determination of regional features of the biomass of individual species of beetles, the determination of the dependence of biomass on the body length of beetles in different functional groups.

MATERIAL AND METHODS

All specimens were collected in the southern part of Primorskii krai (Russian Far East) from April to November in 2019–2022.

The determination of biomass was carried out for each species separately. To do this, the beetles were placed in an oven at a temperature of 70°C and kept for 5 days until a constant weight was reached. Each specimen was weighed on an Ohaus Explorer Pro/Adventurer scale. Body length was measured using ocular micrometer. Functional groups were determined by a combination of trophodynamic relationships of beetles and their size classes. Types of trophodynamic relationships are given according to Hanski and Cambifort (1991): dweller beetles that live in the thickness of manure and tunneler beetles moving under a pile of substrate and storing provisions for larvae. The following size classes of beetles are accepted: small (*s*) up to 4.7 mm, medium (*m*) from 4.7 mm to 8.0 mm, and large (*l*) over 8.0 mm (Shabalin, 2020).

The calculations were carried out in the programs Past 4.12, and Excel 2007. Both untransformed data and log-logarithmic transformation data were used to build models. The Akaike Information Criterion (AIC) was used in the selection of model. Lower values for the AIC imply a better fit. Also, for the selection of models, the determination coefficient was used.

RESULTS AND DISCUSSION

A total of 5402 specimens of beetles were weighed and measured. The data on biomass and body length was found for 48 species of dung beetles from 3 families (Table 1). The body length of beetles ranged from 2.77 mm (*Liothorax plagiatus*) to 22.90 mm (*Copris ochus*), and their dry weight from 0.70 mg to 430.50 mg, respectively.

Dry biomass is known for some species from Finland (Koskela & Hanski, 1977) and Mongolia (Jargalsaikhan *et al.*, 2023). This data allows us to compare the specified indicators with our data. For *Otophorus haemorrhoidalis*, *Esymus pusillus*, and *Bodilopsis sordida* the dry biomass values (Table 1) are slightly lower, for *Acrossus rufipes* are slightly higher than for the same species in Finland (Koskela & Hanski, 1977). Our data on the dry biomass of *Onthophagus gibbulus* and *O. bivertex* Heyden is higher, and for *Geotrupes koltzei* lower than that of the beetles collected in Mongolia (Jargalsaikhan *et al*., 2023). However, the data obtained are within the standard deviation. Only for one species, *Agrilinus ater*, the obtained dry biomass values are lower, and these values do not overlap with the standard deviation. This is probably due to the small number (10) of beetles weighed in Finland (Koskela & Hanski, 1977), in our work more than 25 times more were weighed (Table 1).

Table 1. The length (mm, mean and SD) and dry weight of the taxa examined

Taxon	DW, mg	SD of DW	LM, mm	SD of LM	n	FG
Family Trogidae						
Trox cadaverinus komareki Balthasar, 1931	32,70	-	9,80	-	1	D-l
Trox ussuriensis Balthasar, 1931	40,75	1,63	9,90	0,14	2	D-l
Family Geotrupidae						
Geotrupes koltzei Reitter, 1892	234,27	86,00	21,52	2,14	32	T-l
Phelotrupes auratus (Motschulsky, 1858)	178,19	36,10	17,93	1,06	36	T-l
Family Scarabaeidae						
Caccobius brevis Waterhouse, 1875	5,81	1,45	4,73	0,39	250	T-m
Caccobius christophi Harold, 1879	12,20	3,59	6,36	0,52	202	T-m
Caccobius kelleri (Olsoufieff, 1907)	21,80	13,61	7,97	0,57	3	T-m
Caccobius sordidus Harold, 1886	9,13	2,13	5,66	0,37	216	T-m
Copris ochus Motschulsky, 1861	430,50	203,97	22,90	3,27	4	T-l
Liatongus minutus (Motschulsky, 1861)	34,66	6,77	9,60	0,73	80	T-l
Onthophagus uniformis Heyden, 1886	60,45	18,56	10,78	0,70	13	T-l
Onthophagus atripennis Waterhouse, 1875	30,71	7,80	8,70	0,73	246	T-l
Onthophagus bivertex Heyden, 1887	19,01	4,87	7,91	0,59	241	T-m
Onthophagus punctator Reitter, 1892	6,79	2,04	5,07	0,51	61	T-m
Onthophagus gibbulus Pallas, 1781	57,03	17,26	11,31	0,87	68	T-l
Onthophagus olsoufieffi Boucomont, 1924	9,41	2,64	5,92	0,47	16	T-m
Onthophagus fodiens Waterhouse, 1875	30,65	7,81	8,56	0,75	58	T-l
Onthophagus japonicus Harold, 1874	32,56	9,87	9,14	0,76	61	T-l
Sisyphus schaefferi morio Arrow, 1909	60,75	15,06	11,50	0,99	2	R-l
Acanthobodilus languidulus (A. Schmidt, 1916)	5,90	1,08	6,06	0,36	136	D-m
Acrossus binaevulus (Heyden, 1887)	17,25	2,19	9,15	0,21	2	D-l
Acrossus depressus (Kugelann, 1792)	16,00	-	8,50	-	1	D-l
Acrossus rufipes (Linnaeus, 1758)	34,63	7,76	10,48	0,94	13	D-l
Acrossus superatratus (Nomura & Nakane, 1951)	10,68	2,73	7,09	0,61	51	D-m
Aganocrossus urostigma (Harold, 1862)	4,21	0,95	5,43	0,26	221	D-m
Agrilinus ater (De Geer, 1774)	4,23	1,03	5,04	0,35	242	D-m

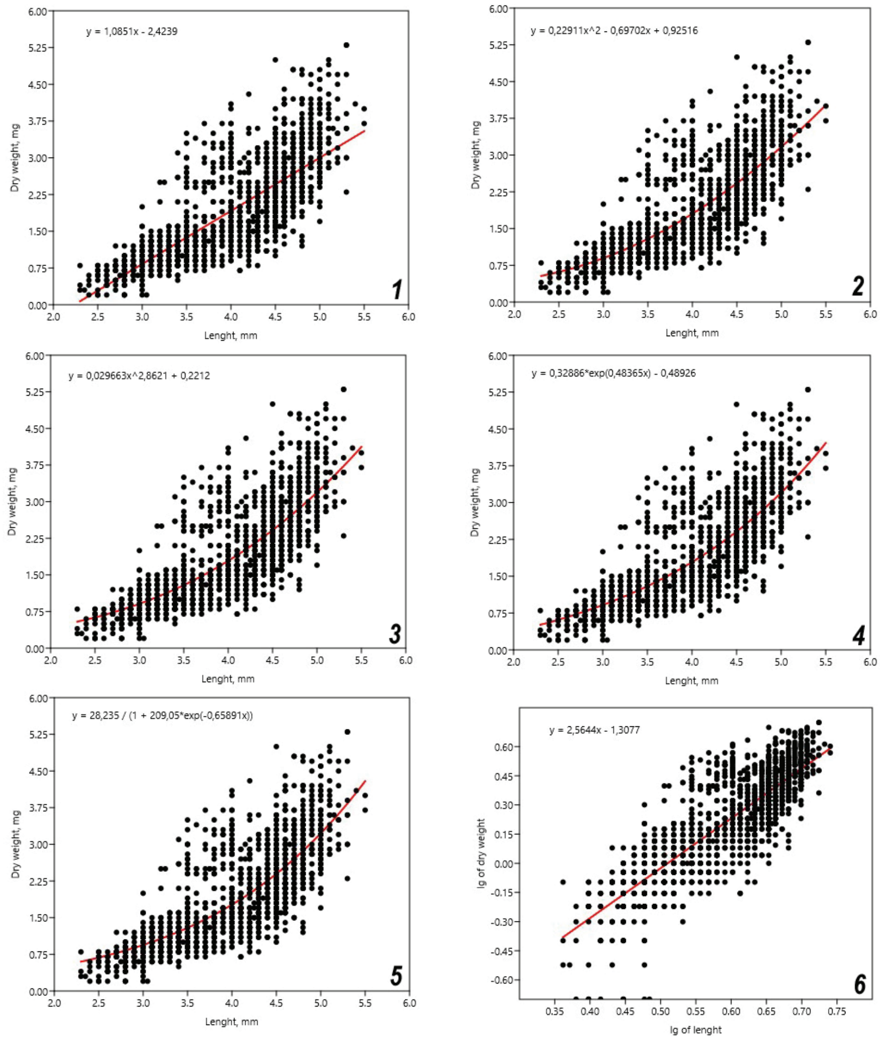
Table 1. Continue

Taxon	DW, mg	SD of DW	LM, mm	SD of LM	n	FG
Aphodaulacus koltzei (Reitter, 1892)	1,85	0,55	4,48	0,26	252	D-s
Aphodaulacus nigrotessellatus (Motschulsky, 1866)	3,12	0,60	5,00	0,28	87	D-m
Aphodaulacus variabilis (Waterhouse, 1875)	3,56	0,84	5,75	0,37	210	D-m
Aphodiellus impunctatus (Waterhouse, 1875)	11,65	4,46	7,13	1,05	4	D-m
Bodilopsis sordida (Fabricius, 1775)	8,26	1,90	6,66	0,51	205	D-m
Colobopterus indagator (Mannerheim, 1849)	18,00	-	9,00	-	1	D-l
Colobopterus notabilipennis (Petrovitz, 1972)	23,91	7,67	9,58	0,59	8	D-l
Colobopterus propraetor (Balthasar, 1932)	22,41	7,07	9,07	0,78	304	D-l
Esymus pusillus (Herbst, 1789)	1,28	0,39	3,67	0,27	212	D-s
Eupleurus subterraneus (Linnaeus, 1758)	9,10	2,34	6,62	0,53	5	D-m
Gilletianus comatus (Schmidt, 1920)	2,53	0,62	4,68	0,23	106	D-s
Labarrus sublimbatus (Motschulsky, 1860)	2,44	0,64	4,51	0,32	238	D-s
Liothorax plagiatus (Linnaeus, 1767)	0,70	0,53	2,77	0,22	123	D-s
Otophorus haemorrhoidalis (Linnaeus, 1758)	3,34	0,80	4,70	0,33	167	D-s
Pharaphodius rugosostriatus (Waterhouse, 1875)	3,95	0,86	5,37	0,34	225	D-m
Phaeaphodius rectus (Motschulsky, 1866)	5,82	1,45	5,91	0,42	271	D-m
Plagiogonus culminarius (Reitter, 1900)	1,02	0,28	3,22	0,21	234	D-s
Planolinus nikolajevi (Berlov, 1989)	2,40	0,42	4,00	0,28	2	D-s
Pseudacrossus nasutus (Reitter, 1887)	3,61	1,14	5,19	0,48	126	D-m
Sinodiapterna songrini (Stebnicka & Galante, 1992)	2,80	0,54	3,82	0,28	108	D-s
Sinodiapterna troitzkyi (Jakobson, 1897)	7,84	1,78	5,39	0,33	29	D-m
Teuchestes brachysomus (Solsky, 1874)	23,56	5,01	8,44	0,55	227	D-l

Abbreviations: DW – average dry weight; LM – length mean; SD – standard deviation; n – number of specimens; FG – functional group (D – dweller; T – tunneler; R – roller; l – large, m – medium, s – small).

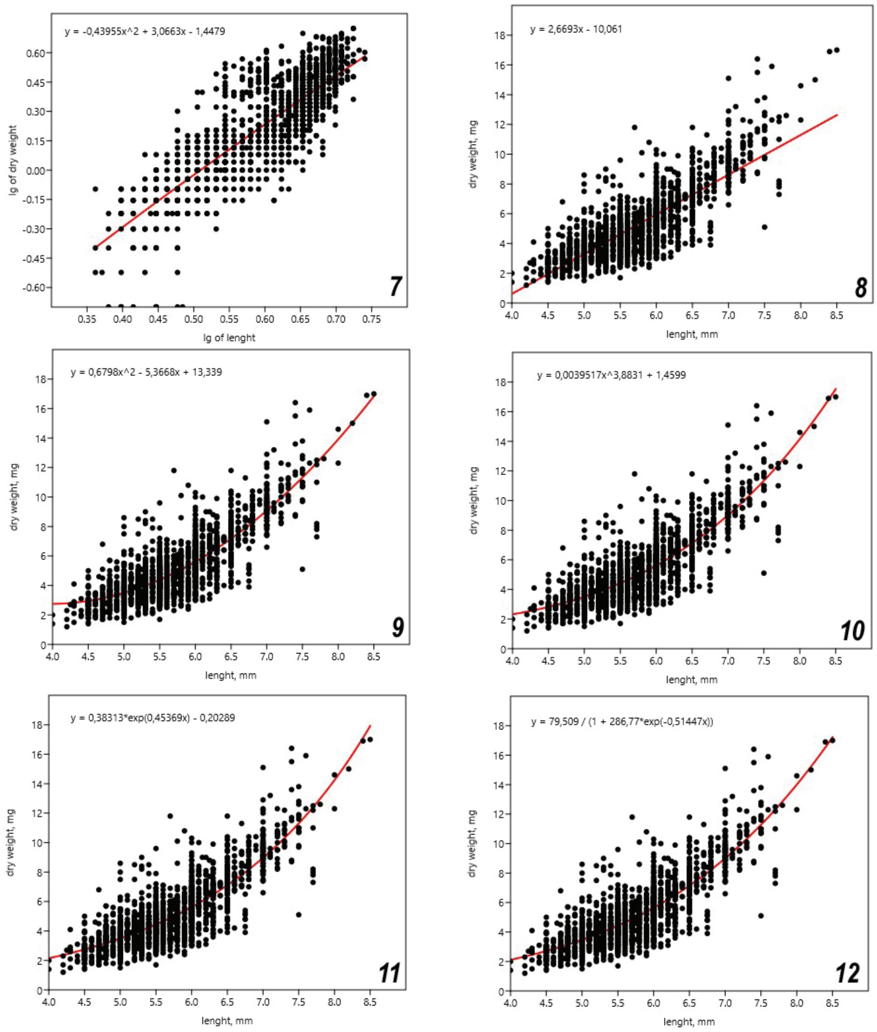
Biomass may be an important biological variable, but it is not necessarily easily measured. For insects, where specimens are mounted or pinned before drying, determinations of biomass may be impossible. Proxies or estimators of biomass, such as linear measurements, have been useful, especially for related taxa that often share similar body design. However, linear measurements have proven less useful across a broad spectrum of taxa because general regression equations are not accurate for all taxa and do not encompass geographic variation (Radtke & Williamson, 2005).

We considered the following distribution models of length-weight relationship: linear function model, quadratic function model, power function model, exponential function model and logistic function model for a small dwellers (Figs 1–7), medium dwellers (Figs 8–17),



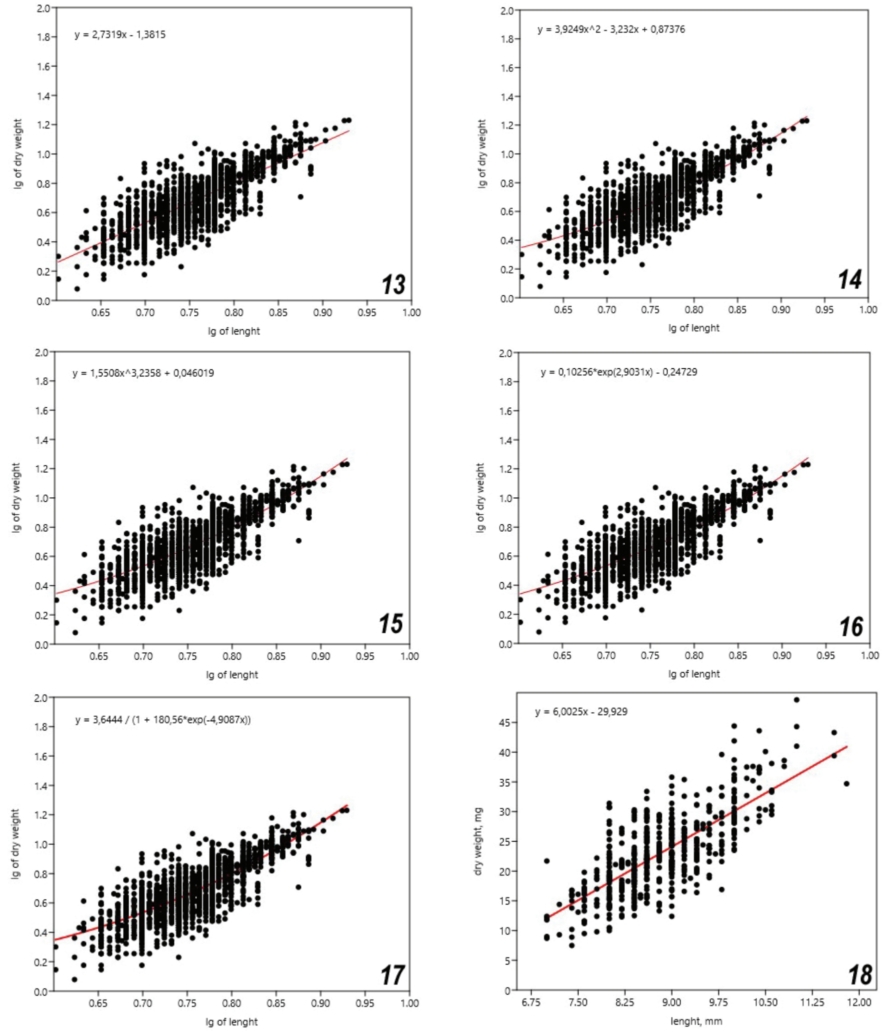
Figs 1–6. Models of length-weight relationship and functions for a small dwellers (n=1441) dung-beetles: 1–5 – untransformed data; 6 – log-logarithmic transformation data; 1 – linear function model (R^2=0.5970, AIC=569.91); 2 – quadratic function model (R^2=0.6094, AIC=554.40); 3 – power function model (R^2=0.6103, AIC=553.25); 4 – exponential function model (R^2=0.6113, AIC=551.78); 5 – logistic function model (R^2=0.6104, AIC=553.01); 6 – linear function model (R^2=0.6817, AIC=32.78).

large dwellers (Figs 18–27), large tunnelers (Figs 28–37), and medium tunnelers (Figs 38–47) dung-beetles. We did not obtain power function, exponential function, and logistic function models for a small dwellers dung-beetles with a log-logarithmic transformation data, because we received some negative values for the length of the beetles or their dry biomass.



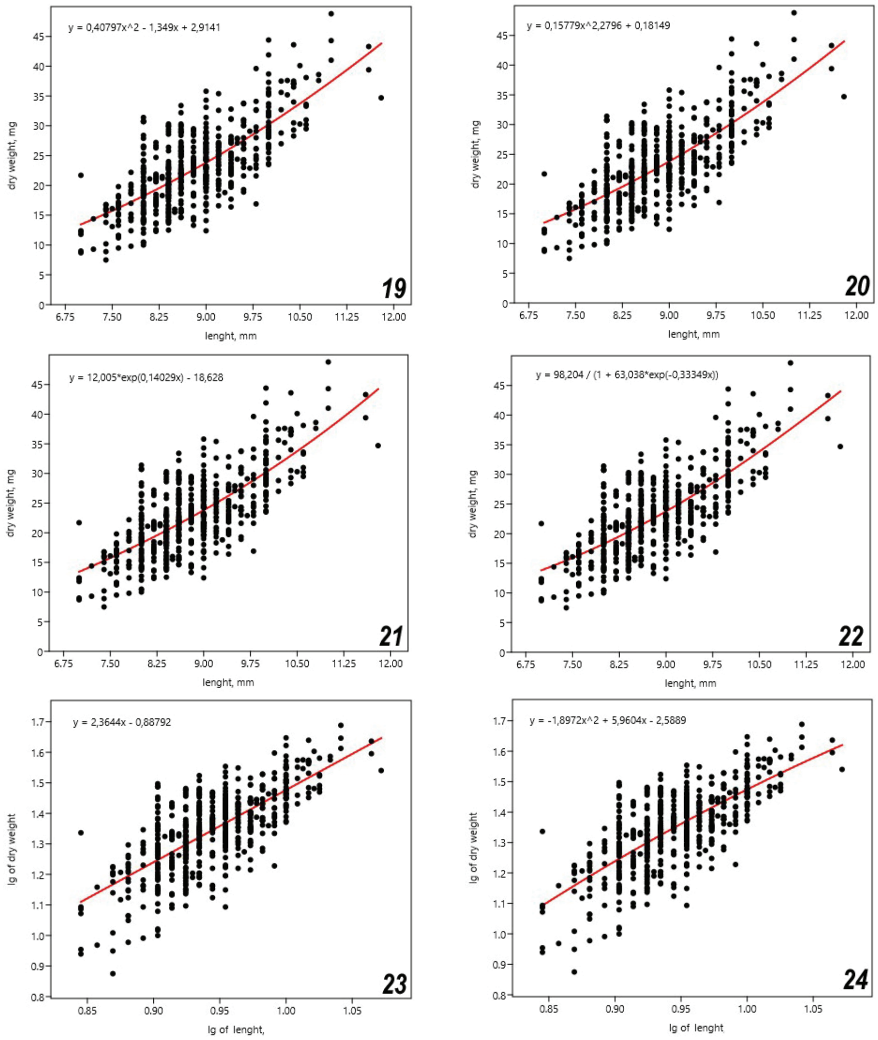
Figs 7–12. Models of length-weight relationship and functions for a small dwellers (fig. 7, n=1441) and medium dwellers dung-beetles (figs 8–12, n=1808): 7 – log-logarithmic transformation data; 8–12 – untransformed data; 7 – quadratic function model (R^2=0.6819, AIC=34.77); 8 – linear function model (R^2=0.6535, AIC=3151.70), 9 – quadratic function model (R^2=0.6937, AIC=2788.40); 10 – power function model (R^2=0.6932, AIC=2793.50); 11 – exponential function model (R^2=0.6922, AIC=2802.20); 12 – logistic function model (R^2=0.6926, AIC=2897.20).

The body length of the small dwellers dung-beetles ranged from 2.77 mm to 4.68 mm, and their dry weight from 0.70 to 2.80 mg (Table 1). For this group of beetles, the best results are shown by the log-logarithmic transformed data (figs 6–7; $0.6817<R^2<0.6819$),



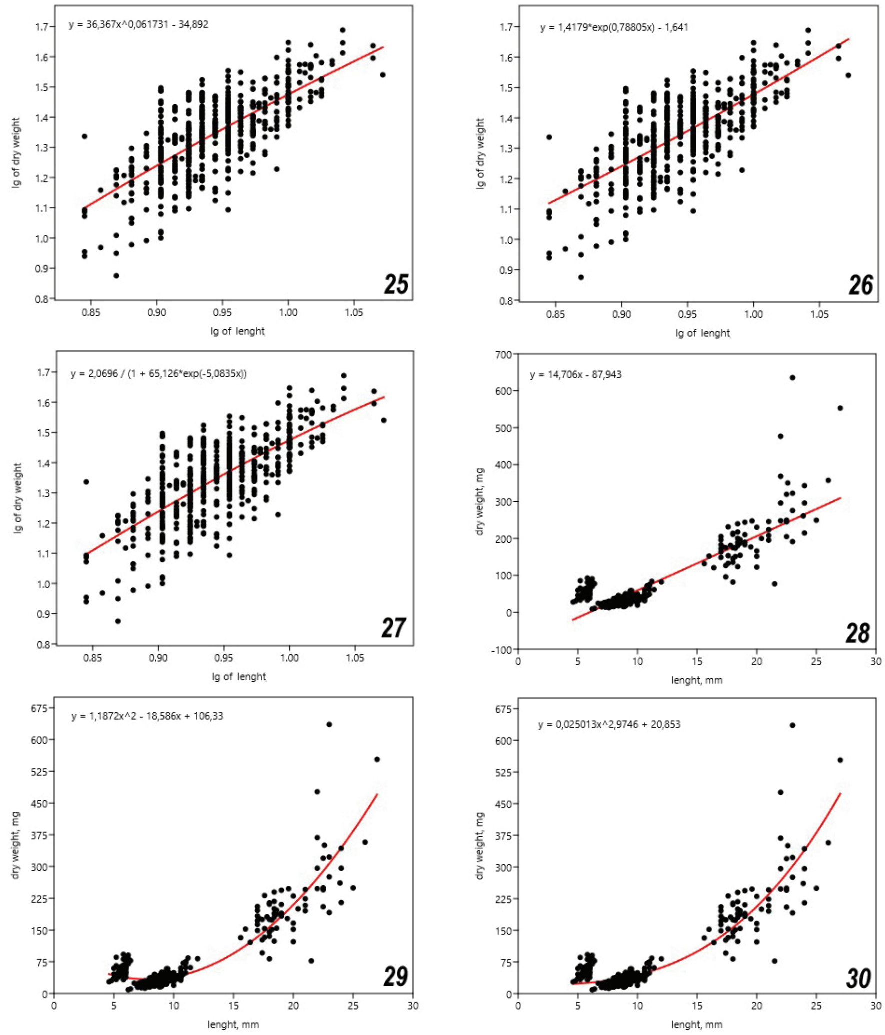
Figs 13–18. Models of length-weight relationship and functions for a medium dwellers (Figs 13–17, n=1808) and large dwellers (Fig. 18, n=599) dung-beetles: 13–17 – log-logarithmic transformation data; 18 – untransformed data; 13 – linear function model (R^2=0.6242, AIC=24.92); 14 – quadratic function model (R^2=0.6307, AIC=26.57); 15 – power function model (R^2=0.6308, AIC=26.56); 16 – exponential function model (R^2=0.6308, AIC=26.56); 17 – logistic function model (R^2=0.6308, AIC=26.56); 18 – linear function model (R^2=0.5320, AIC=11563).

then untransformed data (Figs 1–5; $0.5970<R^2<0.6113$). The linear function model is the most acceptable with a log-logarithmic transformation data (Fig. 6), with a lower value of AIC.



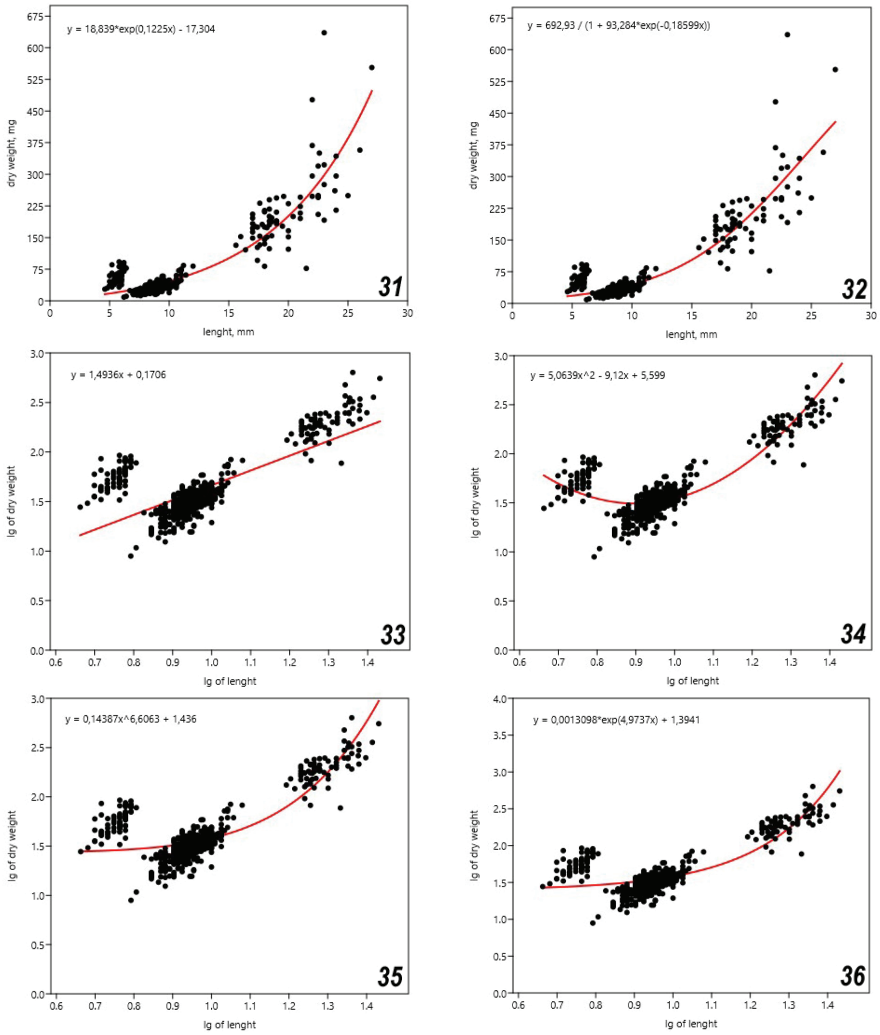
Figs 19–24. Models of length-weight relationship and functions for a large dwellers (n=599) dung-beetles: 19–22 – untransformed data; 23, 24 – log-logarithmic transformation data; 19 – quadratic function model (R^2=0.5353, AIC=11484); 20 – power function model (R^2=0.5353, AIC=11483); 21 – exponential function model (R^2=0.5355, AIC=11479); 22 – logistic function model (R^2=0.5352, AIC=11486); 23 – linear function model (R^2=0.5150, AIC=8.57); 24 – quadratic function model (R^2=0.5160, AIC=10.58).

The body length of the medium dwellers dung-beetles ranged from 5.00 mm to 7.13 mm, and their dry weight from 3.12 to 11.65 mg (Table 1). For this group of beetles, the best results are shown by the untransformed data (Figs 8–12; 0.6535<R2<0.6937), then log-



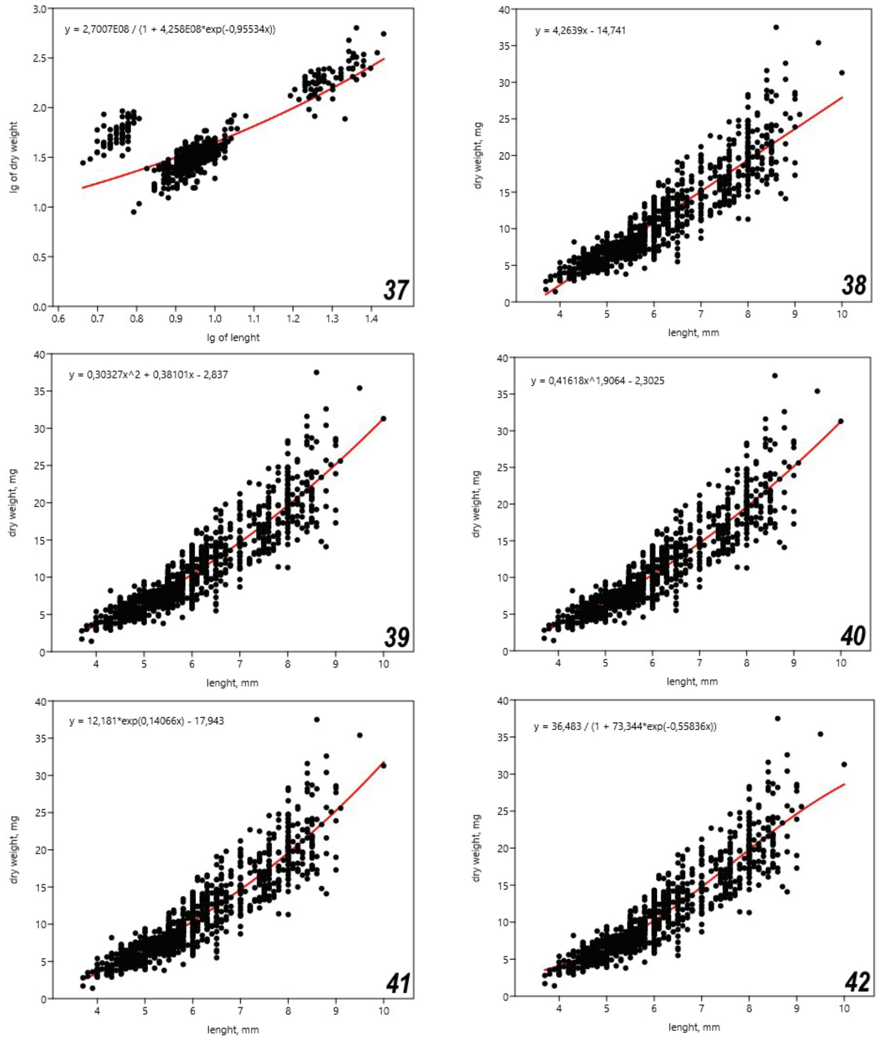
Figs 25–30. Models of length-weight relationship and functions for a large dwellers (figs 25–27, n=599) and large tunnelers (figs 28–30, n=598) dung-beetles: 23–27 – log-logarithmic transformation data; 28–30 – untransformed data; 25 – power function model (R^2=0.5119, AIC=10.58); 26 – exponential function model (R^2=0.5138, AIC=10.60); 27 – logistic function model (R^2=0.5154, AIC=10.59); 28 – linear function model (R^2=0.7259, AIC=7.75E09); 29 – quadratic function model (R^2=0.8459, AIC=4.36E05); 30 – power function model (R^2=0.813, AIC=4.77E05).

logarithmic transformed data (Figs 13–17; $0.6242<R^2<0.6308$). The quadratic function model is the most acceptable without a log-logarithmic transformation data (Fig. 9), with a lower value of AIC in this group of the functional models.



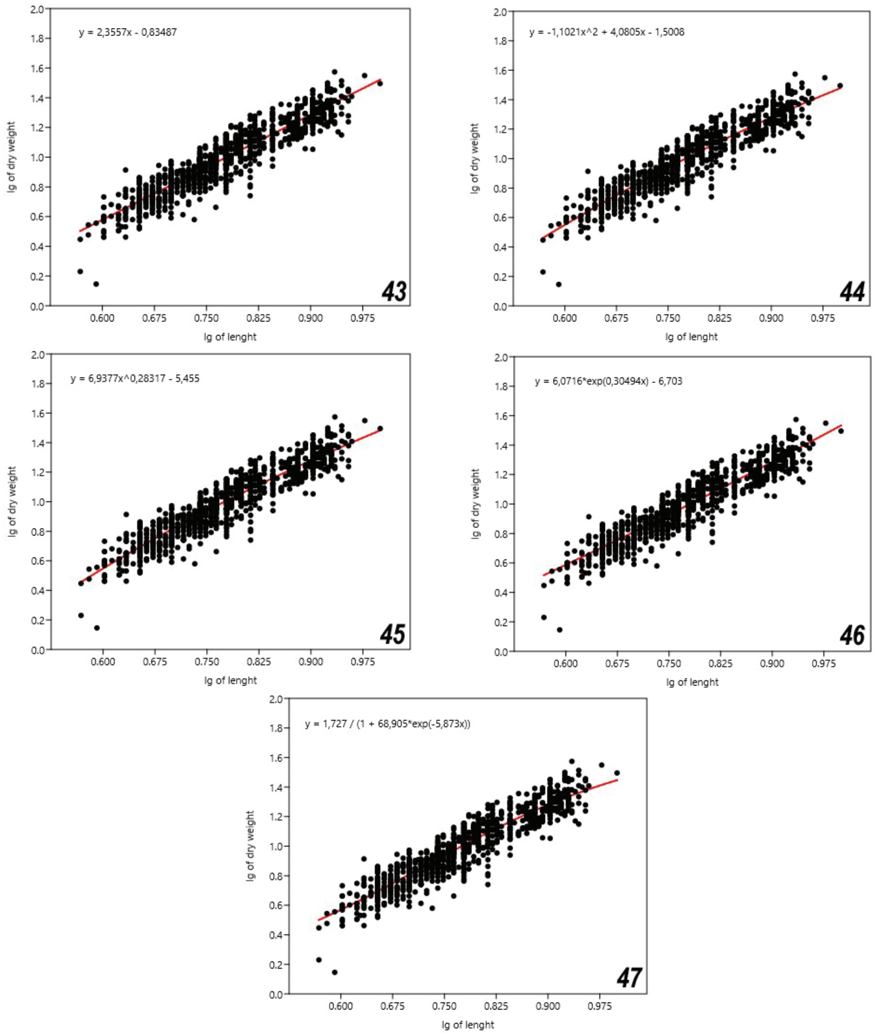
Figs 31–36. Models of length-weight relationship and functions for a large tunnelers (n=598) dung-beetles: 31–32 – untransformed data; 33–36 – log-logarithmic transformation data; 31 – exponential function model (R^2=0.8205, AIC=5.08E05); 32 – logistic function model (R^2=0.8276, AIC=4.88E05); 33 – linear function model (R^2=0.5047, AIC=30.24); 34 – quadratic function model (R^2=0.7814, AIC=17.61); 35 – power function model (R^2=0.7089, AIC=21.44); 36 – exponential function model (R^2=0.6979, AIC=22.03).

The body length of the large dwellers dung-beetles ranged from 8.44 mm to 10.48 mm, and their dry weight from 16.00 to 40.75 mg (Table 1). For this group of beetles, the best results are shown by the untransformed data (Figs 18–22; $0.5320<R^2<0.5355$), then log-



Figs 37–42. Models of length-weight relationship and functions for a large tunnelers (Fig. 37, n=598) and a medium tunnelers (Figs 38–42, n=988) dung-beetles: 37 – log-logarithmic transformation data; 38–42 – untransformed data; 37 – logistic function model (R^2=0.5743, AIC=28.57); 38 – linear function model (R^2=0.8348, AIC=5807.50); 39 – quadratic function model (R^2=0.8419, AIC=5560.30); 40 – power function model (R^2=0.8419, AIC=5560.10); 41 – exponential function model (R^2=0.8418, AIC=5562.10); 42 – logistic function model (R^2=0.8406, AIC=5607).

logarithmic transformed data (Figs 23–27; $0.5119<R^2<0.5160$). The exponential function model is the most acceptable without a log-logarithmic transformation data (Fig. 21), with a lower value of AIC in this group of the functional models.



Figs 43–47. Models of length-weight relationship and functions for a medium tunnelers (n=988) dung-beetles (log-logarithmic transformation data): 43 – linear function model (R^2=0.8622, AIC=11.06); 44 – quadratic function model (R^2=0.8638, AIC=12.99); 45 – power function model (R^2=0.8639, AIC=12.99); 46 – exponential function model (R^2=0.8609, AIC=13.14); 47 – logistic function model (R^2=0.8632, AIC=13.02).

The body length of the large tunnelers dung-beetles ranged from 8.70 mm to 22.90 mm, and their dry weight from 30.65 to 430.50 mg (Table 1). For this group of beetles, the best results are shown by the untransformed data (Figs 28–32; $0.7259<R^2<0.8459$), then log-logarithmic transformed data (Figs 33–37; $0.5047<R^2<0.7814$). The quadratic function model is the most acceptable without a log-logarithmic transformation data (Fig. 29), with a lower value of AIC in this group of the functional models.

The body length of the medium tunnelers dung-beetles ranged from 4.73 mm to 7.97 mm, and their dry weight from 5.81 to 21.80 mg (Table 1). For this group of beetles, the best results are shown by the log-logarithmic transformed data (Figs 43–47; $0.8609<R^2<0.8639$), then untransformed data (Figs 38–42; $0.8348<R^2<0.8419$). The power function model is the most acceptable with a log-logarithmic transformation data (Fig. 45), with a lower value of AIC.

It is known that for small dry insects species the linear relationship may be best, but in the case of heavier species a power function provides better predicted values. In our study, as well as in Spain (Lobo, 1993), for species with small body sizes, the best results are obtained by a linear relationship between body length and dry biomass of beetles, however, in our case, the data needed a log-logarithmic transformation. For large and medium-sized species of dung-beetles in the south of the Russian Far East, as well as in Spain (Lobo, 1993), quadratic, exponential, and power function models are most acceptable, in our most cases without a log-logarithmic transformation of the initial data. The logarithmic transformations used in power functional model diminish the contribution of larger specimens more than that of the smaller ones. If the range of values is small, because the species have a similar morphometric shape, linear regression can produce more accurate biomass predictions. Nevertheless, if the group to be studied varies notably in shape, or if it is comprised of large and heavy species, the power relationship will probably give the best results (Lobo, 1993). Variation within models of length-weight relationship comes from many sources. All beetles in a genus have more or less the same morphology, but there will always be physical differences among species. What is reflected in the various versions of models for different functional groups. Any morphological differences between males and females provide additional variation. Also, beetles that have just emerged may have a thinner exoskeleton than older beetles, such that two beetles of the same length may exhibit different biomasses (Radtke *et al.*, 2006).

Thus, the presented models of length-weight relationship data show that for each functional group of beetles, it is required to use its own models, and for some size classes of beetles, it is preferable to log-logarithmic transform the original data. When conducting ecological studies using such an indicator as dry biomass, it is necessary to determine the biomass of individual species from regional faunas, and to determine the biomass along the length of the body of beetles, it is necessary to use exclusively models built also for regional faunas.

CONCLUSION

The presented data on the dung beetle biomass can be used to assess in a regional dung beetle community in the Russian Far East and the dynamic processes occurring in them. The selection of optimal models of length-weight relationship depends on the types of tropho-dynamic relationships of beetles and its size classes. The constructed models and functions can be used to determine the biomass of beetles along the length of the body without weighing.

ACKNOWLEDGEMENTS

The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (theme No. 121031000151-3).

REFERENCES

Gilbert, J.D.J. 2011. Insect dry weight: shortcut to a difficult quantity using museum specimens. *The Florida Entomologist*, 94(4), 964–970.

Hanski, I., Cambefort, Y. (Ed.). 1991. *Dung beetle ecology*. Princeton, New Jersey: Princeton University press. 481 p.

Jargalsaikhan, P., Altangerel, G., Enkhchimeg, T., Aibek, U., Bayartogtokh, B. 2023. Variation in Dung Removal Rates by Dung Beetles (Coleoptera: Scarabaeoidea) in a Temperate, Dry Steppe Ecosystem. *Diversity*, 15: 91. DOI: 10.3390/d15010091

Koskela, H., & Hanski, I. 1977. Structure and succession in a beetle community inhabiting cow dung. *Annales Zoologici Fennici*, 14(4), 204–223.

Lobo, J.M. 1993. Estimation of dung beetle biomass (Coleoptera: Scarabaeoidea). *European Journal of Entomology*, 90(2): 235–238.

Radtke, M.G., & Williamson, G.B. 2005. Volume and Linear measurements as predictors of dung beetle (Coleoptera: Scarabaeidae) biomass. *Annals of the Entomological Society of America*, 98(4): 548–551. DOI: 10.1603/0013-8746(2005)098[0548:VALMAP]2.0.CO;2

Radtke, M.G., Da Fonseca, C.R.V. & Williamson, G.B. 2006. Volume as a predictor for biomass: equations for Neotropical Scarabaeidae. *Annals of the Entomological Society of America*, 99(5): 831–836. DOI: 10.1603/0013-8746(2006)99[831:VAAPFB]2.0.CO;2

Shabalin, S.A. 2020. Assembly of dung beetles (Coleoptera: Scarabaeidae) – inhabitants of sheep dung in the south of Sikhote-Alin. *A. I. Kurentsov's Annual Memorial Meetings*, 31: 185–198. [In Russian] DOI: 10.25221/kurentzov.31.16