Two Phases in the Evolution of the Body Size of Dinosaurs

Jerzy Trammer
Institute of Geology, Warsaw University, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland
E-mail: jtrammer@uw.edu.pl

Received: July 26, 2011 Accepted: August 18, 2011 Published: March 1, 2012
doi:10.5539/jgg.v4n1p75 URL: http://dx.doi.org/10.5539/jgg.v4n1p75

Abstract

During the Late Triassic – Jurassic phase of the evolution of dinosaurs, their mean and maximum body size increased concurrently with increasing species diversity. On the contrary, in the Cretaceous, although the number of dinosaur species increased, the body size ultimately decreased. This might have been connected with the increase of the number of land masses and the decrease of their areas in the Late Cretaceous caused by global tectonics.

Keywords: Dinosauria, Species diversity, Body size, Evolution, Global tectonics

1. Introduction

The aim of the present contribution was to recognize how the evolutionary changes of body size of dinosaurs were related to the changes of their species diversity. As yet this question was not investigated respecting the Dinosauria.

2. Material and Methods

Dinosaurs appeared in the Late Triassic Carnian Age and disappeared 164.5 million years later at the end of the Cretaceous in the Maastrichtian. I have divided this time span into 14 intervals (Table 1) of similar length. Using data from the most complete compendium of the dinosaur body masses (Paul, 2010), I computed the number of the found dinosaur species, as well as the mean and maximum body mass of those species for each interval. I have taken into consideration all the species from Paul (2010) with a known age of occurrence and estimated mass.

Different methods resulting in disparate estimates are employed to obtain body masses of dinosaur species. There is advantageous, therefore, that all the mass estimates of Paul (2010) are based on the same method: on the measure of a dinosaur volume – then converted into body mass (for the explanation of the method see Paul 1997).

There is no correlation between the number of species and the duration of an interval ($r = -0.033$; p (uncorrelated) = 0.91). Results of the calculations (Table 1) are plotted in the form of time series (Figure 1).

3. Results

Two distinct phases (Figure 1) may be distinguished during the evolutionary history of dinosaurs: the first – from their appearance in the Triassic till the end of the Jurassic Period (intervals 1 to 7), and the second one – in the Cretaceous (intervals 8 to 14).

In the first phase, both the time series of the species number and those for the mean and maximum body mass contain statistically significant upward trends (regression coefficients r of the series values against their observation times amount 0.834, $p = 0.019$; 0.855, $p = 0.014$ and 0.785, $p = 0.036$, respectively). Throughout this phase the mean and maximum body mass are strongly correlated with the species diversity (for first differences $r = 0.97$, $p = 0.0002$ and $r = 0.967$, $p = 0.00035$, respectively). This suggests that increase in body mass was driven by increasing species diversity.

During the second (Cretaceous) phase, after the extinction in the latest Jurassic, the number of species increased again showing an upward trend ($r = 0.827$, $p = 0.021$). The species increase was even almost twice as fast as in the first phase (Figure 1). However, the mean and the maximum body mass provide no statistically significant trends ($r = 0.176$, $p = 0.705$ and $r = 0.68$, $p = 0.09$, respectively), and there is no significant correlation between the mean and the maximum body mass and the specific diversity (first differences $r = -0.72$, $p = 0.104$ and r = -

0.409, p = 0.419, respectively). Contrary to the first phase, in the second phase the dinosaurs were not consistently larger with increasing diversity.

4. Discussion

It is likely that the pattern presented in Figure 1 is at least partly caused by global tectonics. There were four continents in the Late Jurassic but already nine in the Late Cretaceous and the mean area of a continent decreased almost three times at that time in comparison with the Late Jurassic continents (Smith *et al*., 1994; Figure 1). This might have increased the species number of dinosaurs by increasing their provinciality (Kurten, 1969; Schopf, 1979; Dodson, 1990; Rosenzweig, 1995; Hedges *et al.*, 1996) but simultaneously decreased their maximum and mean body mass, as the body size of big animals decreases with decreasing land area (Burness *et al*., 2001).

Many authors argued that in a radiating clade there is a strong correlative relation between the maximum body size and species diversity (Stanley, 1973; Gould, 1988; McShea, 1994; Trammer & Kaim, 1997; Trammer, 2002, 2005; Gillman, 2007; McClain & Boyer, 2009) such that the continuing increase in size parallels diversification. Other researches (Smith *et al*. 2010) did not provide support for such strong correlation. The example of dinosaurs presented herein suggests that under conditions of unconstrained diversification, the maximum body size changes with time in concert with the diversity but the size of a land area may ultimately constrain the increase of body size weakening the correlation between size and diversity.

As it is widely acknowledged, differentiated sampling intensity of various parts of the geological column may bias the results of quantitative studies based on the fossil record (e.g. Smith, 2007). The number of formations may be used as an estimate of sampling intensity related to rock availability, paleontologist interest etc. (Peters & Foote, 2001; Wang & Dodson, 2006). The number of terrestrial formations in each of the Early, Middle and Late Jurassic epochs is significantly smaller than in the Late Triassic Epoch (Peters & Foote 2001, Wang & Dodson 2006), therefore the Late Triassic – Late Jurassic increase in the species number (Figure 1) is likely to be genuine and not an artifact of sampling intensity. The number of terrestrial formations in the Late Cretaceous is greater than in the Early Cretaceous (Peters & Foote 2001, Wang & Dodson 2006)), so the Cretaceous increase in the species number (Figure 1) may be spurious but the study of Wang & Dodson (2006) showed that this increase was rather genuine. The maximum size, sampled from the statistical population of differently sized objects, increases with sample size. On the contrary, the maximum size of dinosaurs decreased with the increasing number of formations and the increasing number of species in the Late Cretaceous, which suggests that this decrease may be reliable.

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Table 1. Species-level diversity and body size of dinosaurs in fourteen intervals of their evolutionary history. Computed using data from Paul (2010)

Number of interval	Included stages	Duration of interval [Ma]	Number of species	Body mass [kg]	
				mean	maximum
14	Maastrichtian	5.5	83	3,392	50,000
13	Turonian, Campanian	15	144	2,104	50,000
12	Cenomanian, Turonian, Coniacian	14	53	6,659	80,000
11	Albian	12	42	5,471	50,000
10	Aptian	13	42	2,624	20,000
9	Hauterivian, Barremian	9	35	3,689	35,000
8	Berrasian, Valanginian	11	10	2,212	17,000
7	Kimmeridgian, Tithonian	11	78	9,567	125,000
6	Callovian, Oxfordian	9	47	5,363	75,000
5	Aalenian, Bajocian, Bathonian	11	27	3,470	14,000
4	Pliensbachian, Taorcian,	14	19	604	3,500
3	Rhaetian, Hetaangian, Sinemurian	14	27	1,202	7,000
2	Norian	13	20	952	7,000
1	Carnian	13	9	83	500

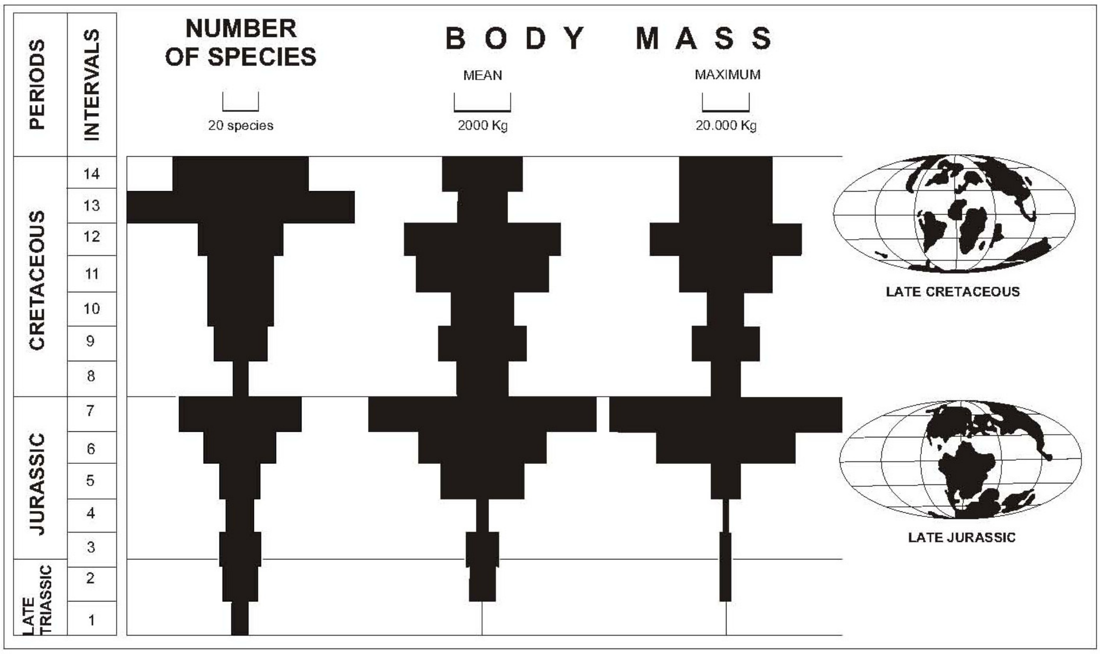

Figure 1. Species-level diversity and body size of dinosaurs over their history. Distribution of land masses on Earth in the Late Jurassic and in the Late Cretaceous after Smith *et al*. (1994) is also presented. For duration and geological age of the intervals consult Table 1. Further explanations and discussion in the text