“Brain to Body Mass Ratio Correlation with Rate of Net Diversification Across Mammals.”

Raza Ahmed

Dr. Jonathan Mitchell

April 9, 2021.

**Brain to Body Mass Ratio Correlation with Rate of Net Diversification Across Mammals**

INTRODUCTION

In evolutionary biology, understanding why certain lineages have diversified more than others remain a crucial topic. Extrinsic factors affecting speciation and/or extinction rates, such as geological changes, climatic cycles, and ecological opportunities, have historically been blamed for variations in the rate at which lineages diversify. Biological traits may help understand why species diversification is so uneven across the mammals. Other environmental variables and unique traits can also play a role (Scholl and Wiens 2016).

The difference in biological traits like brain/body mass ratio can be critical in driving macroevolutionary dynamics. Since phenotypic differentiation can lead to reproductive isolation, which can lead to speciation (Schoenemann 2004). When a trait changes more quickly in certain species than others in response to selective pressures, (high evolvability). This rapid change can allow for more rapid access to new ecological niches or the establishment of reproductive isolation, resulting in a faster rate of speciation. Individuals will be able to avoid harsh environmental environments and competitive encounters by rapid evolution of new phenotypes, lowering extinction rates. The result of these processes can cause an increase in net diversification. The overall effect of these processes on net diversification (net diversification = speciation - extinction) will be determined by which of these rates responds more strongly to phenotypic transition(Adams et al. 2009).

Understanding the association between traits and diversification rates is significant because it has the ability to explain the causes of widespread heterogeneity in species diversity across clades and geographical areas. The rates at which new species evolve (speciation rate) and existing species become extinct (extinction rate) are referred to as diversification rates. Fossils, records on the species diversity of clades and their ages, and phylogenetic trees can all be used to predict diversification rates(Scholl and Wiens 2016). In this study, phylogenetic tree was used to calculate the diversification rates with different models, and it is hypothesized that **l**ineages of mammals with larger brains to body mass ratio have higher diversification rates.

MATERIALS AND METHODS

*Data Collection*

Data of brain mass and body mass of 1105 species of mammals divided into 25 clades was taken from the work of Heldstab, S. A., K. Isler, and C. P. van Schaik published in 2018 (doi.org/10.5061/dryad.753d06g). They obtain their data on brain size and body mass from existing multiple datasets as well as published literature. They used female species when possible, to minimize error created by sexual dimorphism. Body mass was obtained from the same specimens as brain size when it was available. Incase brain and body mass were not collected from the same specimens, the most extensive sample of wild body mass data available was used (Heldstab et al. 2018). The phylogenic tree was obtained by adding the scientific names of all the species on *vertlife.org*.

*Data Analysis*

Bayesian Analysis of Macroevolutionary Mixtures (BAMM) version 2.5.0 was used to estimate the rates of speciation (λ), extinction (μ), and net diversification (r) across the 1105 species tree. In BAMM, *expectedNumberOfShifts* parameter was set to 100, *numberOfGenerations* parameter was set to 10000000, and a*cceptanceResetFreq* parameter was set to 1000.

The relationship between brain/body mass ratio and a macroevolutionary parameter (λ, μ, and r) calculated by BAMM were compared to a null correlation distribution generated using STructured Rate Permutations on Phylogenies (STRAPP). STRAPP is robust to phylogenetic pseudoreplication. The null correlations are created by permuting the evolutionary rates at the phylogenetic tree's tips while keeping the position of rate shift events in the phylogeny constant.

DR (Diversification Rate) is a function of estimating net diversification. When the speciation rate between the species is high, they are shorter branch length, and they result is high level of DR. While the species with longer branches have low diversification and low DR value. DR metric with inverse equal splits was run in *R* with the data set of all the mammals and the code was written by Pascal Title.

RESULTS

Diagram

Description automatically generated

Figure 01: Phylogenetic tree of all the species in the data set with their brain/body mass ratio. Red color indicates the lowest brain/body mass ratio and dark blue indicates the highest brain/body mass ratio.

The Brain/Body mass ratio Phylogeny tree shows the different value of traits across the 1105 species (Figure 01).

Graphical user interface

Description automatically generated with low confidenceDiagram

Description automatically generated**Diagram

Description automatically generated**Diagram, schematic

Description automatically generated

Net Diversification

Extinction

Speciation

Figure 02: Phylogenetic tree with Speciation, Extinction, and Net Diversification using the BAMM Analysis. Dark blue color indicates the lowest value and bright red color indicates the highest value.

Mean speciation, mean extinction, and mean net diversification (mean speciation – mean extinction) was calculated from the BAMM analysis and the phylogeny trees were drawn for each of them (Figure 02). BAMM analysis estimated 8 shifts with the probability of 0.30 and 9 shifts with probability of 0.22.

Chart, scatter chart

Description automatically generated

Figure 03: DR rates calculated by DR analysis plotted against the brain/body mass ratio.

Chart, scatter chart

Description automatically generatedDR rates are most closely related to the diversification. A cor.test was performed on DR rates and Brain/Body mass ratio, using spearman method and rho was estimated as -0.17 (p-value < 0.01) indicating a negative relationship (Figure 03).

Figure 04: Graph between mean diversification calculated using BAMM analysis and trait.

STRAPP values for relationship between trait and speciation is (estimate = -0.09, p-value = 0.8), for extinction is (estimate = 0.08, p-value = 0.68), and for net diversification is (estimate = -0.30, p-value = 0.28) (Figure 04).

DISCUSSIONS

There was no correlation observed between the brain/body mass ratio and the net diversification. Net diversification is dependent on the speciation rate and the extinction rate. If the speciation rate is increasing and the extinction rate is increasing, we will get a large net diversification rate in the population. The BAMM analysis indicated rate of shifts between 8 and 9, Indicating diversification happening across the mammals. The results did not give us evidence towards our hypothesis of this paper. It was hypothesized that **l**ineages of mammals with larger brains to body mass ratio have higher diversification rates. The STRAPP analysis showed a negative relationship between the trait and the net diversification rate, and a positive relationship with extinction. There is a relationship, but we have a high p-value of 0.8,0.68,0.28 for speciation, extinction, and net diversification, respectively. The higher p-values for all macroevolutionary dynamics suggest that our sample data is insufficient to rule out the possibility of random sample error. Because of that, we cannot conclude a negative relationship between brain/body mass ratio and net diversification.

DR rates were also calculated, the relationship DR rates, and brain/body mass ratio was calculated using spearman’s method. The rho value observed was estimated as -0.17 (p-value = 1.055 x 10 -8). Note that R gave an error that the exact p-value cannot be calculated, and the best p-value calculated was estimated. This value does not account for the autoregression that is why these numbers can not enough to conclude that there is a correlation between the diversification rate and higher brain/body mass ration across mammals.

There was no correlation found between the brain/body mass ratio and the diversification rate. There is study done across birds, where they found no correlation between the brain size of birds and the diversification, but they found a positive correlation between the rate of change in brain size and net diversification rates (Sayol et al. 2019). If further calculations are done on the rate of evolution of brain/body mass ratio and diversification, we may find a relationship.

There are also some problems with the data set collected, the brain size and the body mass are only taken from one individual from the whole species, one individual cannot represent the average brain and body size across the species. This can create a huge error in the calculations. This kind of error can be reduced by taking samples of multiple individuals across a single specie and taking the average. One other big problem with the data set was the environmental factors involved. Some of the species were under hibernation. It is found that hibernation does constrains brain size in mammals, which effects the value of brain size, effecting the brain/body mass ratio. If we can reduce these errors, we may be able to get a result make a conclusion between the relationship between the brain/body ratio and the diversification.

Weakness of BAMM, STRAP, DR. ????

As the name indicates the DR statistics is mostly represents the diversification rate but Jetz et. al concluded that DR statistics is a much better representation of speciation and very poorly correlated to the net diversification. BAMM is very computational and detects the rate shifts when have enough calculations. As a result, it would prove to be restrictive in the amount of rate heterogeneity it detects in phylogenies. While DR will still detect heterogeneity in tip rates as a function of stochastic variation in branch lengths, even if true rates do not differ among lineages.

ACKNOWLEDGEMENTS

Special thanks to Dr. Jonathan Mitchell for his thought-provoking feedback and assistance in running BAMM, STRAPP, DR, and creating all the graphs and trees.

LITERATURE CITED

Adams, D. C., C. M. Berns, K. H. Kozak, and J. J. Wiens. 2009. Are rates of species diversification correlated with rates of morphological evolution? Proceedings of the Royal Society B: Biological Sciences 276:2729–2738. Royal Society.

Heldstab, S. A., K. Isler, and C. P. van Schaik. 2018. Hibernation constrains brain size evolution in mammals. J. Evol. Biol. 31:1582–1588.

Sayol, F., O. Lapiedra, S. Ducatez, and D. Sol. 2019. Larger brains spur species diversification in birds. Evolution 73:2085–2093.

Schoenemann, P. T. 2004. Brain Size Scaling and Body Composition in Mammals. Brain Behav Evol 63:47–60.

Scholl, J. P., and J. J. Wiens. 2016. Diversification rates and species richness across the Tree of Life. Proc Biol Sci 283.