PANTHERA LATITUDINAL RANGES INCREASE OVER TIME

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ABSTRACT: The explanations for the latitudinal diversity gradient (LDG), the increase of species from the equator to the poles, have long been debated by scientists for over a century. How this has affected different genera is still not highly researched. To inspect this concept further, the correlation between the big cat genus Panthera's fossil age and the latitudinal range was examined to see if the hypothesis that the older a fossil is, the longer its latitudinal range will be due to the "out of the tropics" theory that species disperse from the tropics over time and several other hypotheses. A linear regression test was performed to determine the correlation coefficient and the significance level between data points. The results of the linear regression test were found to be significant, meaning that as Panthera fossils' age increases, so do their latitudinal ranges. These tests further support the "out of the tropics" theory, meaning the LDG does indeed exist.

Keywords: Panthera, Latitudinal Diversity Gradient, Latitudinal Ranges, Linear Regression, Out of the tropics

Introduction

Diversity amongst species across the planet is not equal across the latitude (Hillebrand, 2004; Mittelbach et al., 2007; Rolland, Condamine, Beeravolu, Jiguet, & Morlon, 2015). The latitudinal diversity gradient is a process of species diversification and abundance around the equator and decreases as the latitude expands north or south (Mittelbach et al., 2007). Although this latitudinal diversity gradient has been a known fact for decades, no definitive research as to why it exists has been determined (Hillebrand, 2004; Mittelbach et al., 2007; Rolland et al., 2015).

Several hypotheses have come forward to explain this gradient across the Earth. One of the most popular hypotheses includes the "out of the tropics" theory, elucidating how the tropics are a biodiversity engine (Jablonski, Roy, & Valentine., 2006). The meaning of this hypothesis is that as time carries on, the likelihood of a species dispersing from the tropics increases. From the research that Jablonski and their team did on this model, they stated this hypothesis was supported by two other hypotheses: the tropics are also a museum, meaning low extinction rates exist as older species reside in the tropics, and a cradle, meaning high diversification rates exist as more and more species are born in the tropics (Jablonski et al., 2006). This research is highly debated amongst scientists with other theories being climate change, altitude changes, or simply one of the three hypotheses stated above without the other two to tag with it (Lewin, 1989).

There have been many studies on the "out of the tropics" hypothesis, studying large groups of animals such as Carnivora, the mammalian class of carnivorous animals, in order to study how they exist in the latitudinal diversity gradient (Hillebrand, 2004; Rolland, Condamine, Jiguet, & Morlon, 2014). However, making large assumptions about research can be detrimental and may lead to missing important outliers in the data that could exist (Jablonski et al., 2006). Large groups of animals cannot be an indicator of all genera or species in how they exist in the latitudinal diversity gradient.

While there are many studies as mentioned before on the latitudinal diversity of large groups of animals such as Carnivora, there

are none on small clades such as *Panthera* (Hillebrand, 2004; Rolland et al., 2015). *Panthera* consists of the big cats that we know today such as the lion, the tiger, and the jaguar (Davis, Li, & Murphy, 2010). Their origination occurred less than 11 million years ago, during the Miocene, an epoch of the geological time scale (Davis et al., 2010). By focusing on this smaller clade, *Panthera*, more evidence may come forward for the "out of the tropics" theory to further support this hypothesis. This will help us scientists understand the reasoning behind why the latitudinal diversity gradient exists. Additionally, by focusing on a carnivorous genus, we may be able to attach this study to the gradient of the animals *Panthera* may see as prey (Davis et al., 2010; Rolland et al., 2015).

In this paper, the hypothesis that will be tested is whether *Panthera* latitudinal ranges increase over time. It is predicted that the older a Panthera fossil is, the larger its latitudinal range will be, due to the "out of the tropics" theory.

Materials and Methods

The data of all mammals was downloaded from the Paleobiology Database on September 23, 2022 (https://paleobiodb.org) into an Excel file. Then, I extracted the genus *Panthera* from this file. The geographic information kept was the minimum and maximum latitudes. From this, the midpoint of the latitudinal ranges was calculated for use in this study. The age of the following fossils of the species within the genus *Panthera* were also averaged: *Panthera blytheae, Panthera gombaszoegensis, Panthera leo, Panthera onca, Panthera pardus, Panthera tigris, and Panthera uncia.* Their ages range from the Miocene to the current epoch, the Holocene.

One species, *Panthera uncia*, was missing latitudinal data, and another species, *Panthera blytheae*, stood as an outlier in the data by severely skewing the trendline due to its age range that was not representative of the population, so they were both omitted from this linear regression test. This left just the *Panthera* species from the Paleocene to the Holocene. As for the outliers within the graph itself, their data did not stand out severely by having an unreliable age as Panthera blytheae did.

A linear regression was performed in Excel, comparing the latitudinal range and age of fossils against each other. A significance level of 0.05 was chosen because this is not a high-risk test. In other words, this significance level will tell us whether the data occurred by random chance. For the linear regression graph, the independent variable is denoted as the age, and the dependent variable is denoted as the latitudinal range. The null hypothesis is that there will be no correlation found between the age of a *Panthera* fossil and its latitudinal range.

Results

The linear regression supports the research hypothesis that the age of *Panthera* species fossils is directly correlated with their latitudinal ranges. The linear regression performed gave a p-value of 0.0005, suggesting that the correlation of these data points is statistically significant. The null hypothesis can be rejected. Figure 1 displays the linear regression performed between the *Panthera* species fossils and their latitudinal ranges. As for the R2 value of 0.275, this gives the meaning that about 27.5% of one variable point is explained by its correlating variable point. The low R2 value still carries significance to the study because real-world models with organisms are harder to predict than controlled physical processes thus explaining the lower R2 value.

The average age generally increased alongside the latitudinal ranges. The oldest species, *P. gombaszoegensis*, at an average age of 2.67235 million years had a latitudinal range of 57.32˚ latitude. The second oldest species, *P. leo* and *P. pardus*, at an average age of 2.6665 million years had latitudinal ranges of 89.05˚ latitude and 86.81˚ latitude, respectively. The third oldest species, *P. onca*, at an average age of

2.45 million years had a latitudinal range of 99.38˚ latitude. The youngest species, *P. tigris*, at an average age of 1.294 million years had a latitudinal range of 56.23˚ latitude.

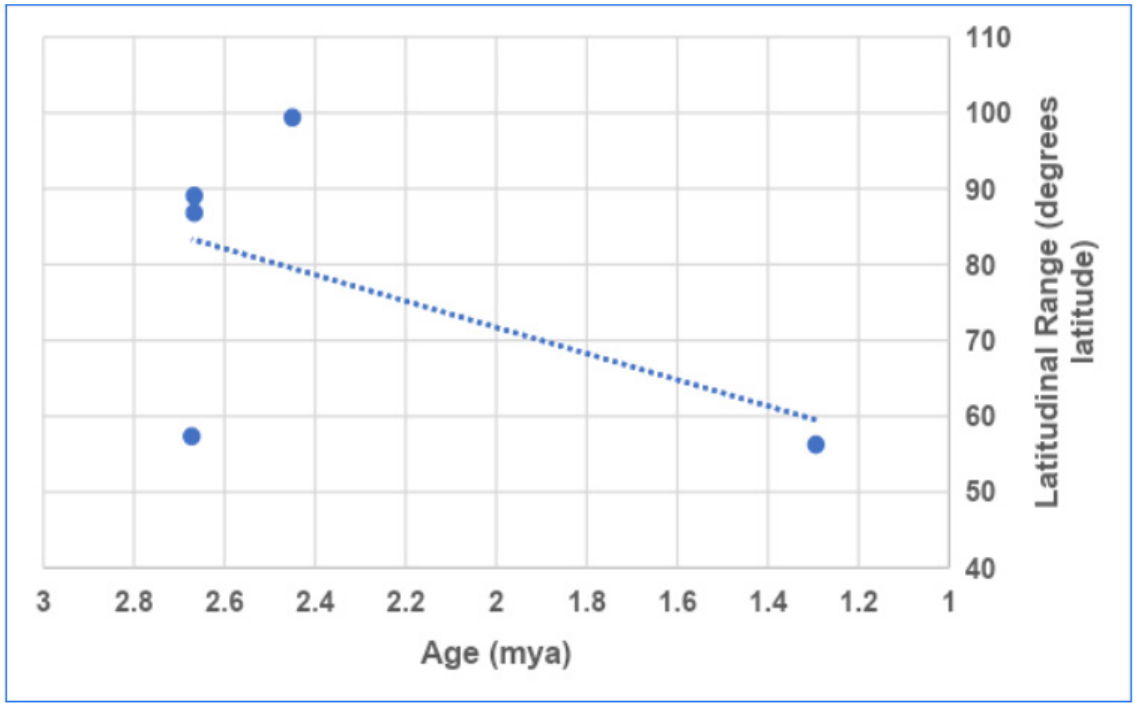

Figure 1. The correlation between the age of Panthera species and their latitudinal ranges. After completing a linear regression, the results indicate a high correlation between the age of Panthera species fossils and their latitudinal ranges. The p-value of 0.0005 indicates that there is a statistically significant correlation between the ages of Panthera species fossils and their latitudinal ranges. The older a Panthera species fossil is, the further its latitudinal range will be. As for the R2 value of 0.275, this gives the meaning that about 27.5% of one variable point is explained by its correlating variable point.

Discussion

Based on the results of the linear regression test, the research hypothesis is accepted. There is a statistically significant correlation between the age of *Panthera* fossils and their latitudinal ranges, meaning that the older a *Panthera* fossil is, the larger its latitudinal range will be. As shown in figure 1, the correlation between the age of the fossils and their latitudinal ranges is visible. This is likely due to the dispersal of species from the tropics over time per the "out of the tropics" theory.

Out of the Tropics

One of the most popular and well-cited explanations for the latitudinal diversity gradient, as mentioned previously, is the "out of the tropics" hypothesis (Jablonski et al., 2006; Jansson, Rodríguez-Castañeda, & Harding, 2013; Mittelbach et al., 2007; Rolland et al., 2015; Rolland et al., 2014). As time goes on, species will disperse from the tropics. The "out of the tropics" theory is supported by the two other theories as Jablonski and their team have stated.

The rate of diversification and the rate of extinction in the tropics contributes strongly to the "out of the tropics" theory (Jablonski et al., 2006). Jablonski is stating how the tropics

maintain this cradle and museum, which drives species to disperse from the tropics over time (Jablonski et al., 2006). However, Jablonski and their team acknowledge the potential of other hypotheses such as climatic change (Jablonski et al., 2006).

Pliocene and Pleistocene

The fossils examined during this study were from the Pliocene and the Pleistocene, two important markers in time due to major climate events such as the warming period during the Pliocene (Jablonski et al., 2013). Jablonski states that because of the warming period during the Pliocene, animals, such as the *Panthera* in this study, were able to disperse from the tropics to higher latitudes (Jablonski et al., 2013). This is due to the surrounding areas of the tropics, such as what we know as temperate zones in the present day, being more adaptable for the animals dispersing from the tropics such as the genus studied in this paper, *Panthera* (Jablonski et al., 2013).

As for the Pleistocene, this was the time of the ice ages (Jablonski et al., 2013; Mittelbach et al., 2007). This ice age has been known to contribute significantly to the movement, diversification, and extinction of a multitude of species (Mittelbach et al., 2007). This could be another climatic change that could factor into the dispersal of species from the tropics.

Other Theories

One idea that emerged in the 80s was that the latitudinal diversity gradient was simply due to the climate changes mentioned previously (Lewin, 1989). Animals were better able to adapt to the warming climates around them, so they dispersed (Lewin, 1989). Scientists argued it had nothing to do with the idea that the tropics are a museum or a cradle or both (Jablonski et al., 2006; Lewin, 1989). However, this statement has little scientific backing (Jablonski et al., 2006). It is shown by several studies that the latitudinal diversity gradient is due to a multitude of factors, not just a single one (Jablonski et al., 2013; Jablonski et al., 2006; Jansson et al., 2013; Mittelbach et al., 2007; Pyron, 2014; Rolland et al., 2015; Rolland et al., 2014).

A combination of several hypotheses such as high speciation rates, low extinction rates, high dispersal rates, climatic conditions, and more all lead to the latitudinal diversity gradient (Jablonski et al., 2013; Jablonski et al., 2006; Jansson et al., 2013; Mittelbach et al., 2007; Pyron, 2014; Rolland et al., 2015; Rolland et al., 2014). This statement is highly supported by all the evidence gathered by scientists over the decades, showing how there are multiple reasons behind why the latitudinal diversity gradient exists (Jablonski et al., 2006).

Additionally, since this study focused on one specific genus rather than a multitude of them, the "out of the tropics" theory is further supported by the data that was collected in this analysis. By focusing on just *Panthera*, we have more research points that can be used when studying the diversification, extinction, climatic changes, predation, and other factors that affect the latitudinal diversity gradient.

Limitations and Future Work

In spite of the fact that all known fossils for the genus *Panthera* from the Paleobiology Database were used in this study, there is still the possibility that bias has occurred. By restricting the data down to a genus, a small sample size was used to assess the hypothesis. If more fossil samples were available in the Paleobiology Database, then a more accurate and precise result may have been generated for this project from the data.

Missing data in the *Panthera* genus also affected this study, resulting in fewer samples to use and less accurate results. Outliers in the data were also excluded from this study due to how they severely skewed the data. If the outliers could be separately studied or somehow

accounted for in the data, then more results for this hypothesis would be potentially available.

While this study examined the possible effects that climate events may have had on the data, this study didn't account for climate changes at certain points in history (Lewin, 1989). By separating fossils individually from their ages due to the points in the geologic time scale that they existed in, more accurate results with further explanations would have been found for this research.

Diversification rates as well as extinction rates were not examined in this study either. Rather than using general data from articles that discuss the high diversification rates and low extinction rates in the tropics that support the dispersal of species from the tropics, a direct study of this data would have been beneficial. By having this data, more evidence to support this museum and cradle hypothesis of the tropics would have been present (Jablonski et al., 2006). From the data in this study, more evidence to support the idea that the tropics are a biodiversity engine found that as time goes on species will disperse from the tropics.

Future studies should examine the diversification rates and the extinction rates of the *Panthera* genus in order to examine their relation to the "out of the tropics" hypothesis supported by this research paper. More *Panthera* fossil samples should be included in the data as well to gather a more accurate result that can further prove the hypothesis that the older a *Panthera* fossil is, their latitudinal ranges will be larger.

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