

Comparing the Latitudinal Ranges of Genera of Mollusca and Arthropoda Before and After the End-Permian Extinction

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Abstract

The end-Permian mass extinction event resulted in the loss of approximately 80% to 90% of marine animal species due to drastic changes in climate. Because warming was a major factor in the extinction, it has been theorized the organisms that did survive were able to do so because they moved to higher latitudes and this hypothesis is consistent with tetrapod data. We hypothesized that this relationship holds true for marine mollusks and arthropods as well. Using Changhsingian (Late Permian) and Induan (Early Triassic) data from the Paleobiology Database, we extracted occurrences of classes Bivalvia, Cephalopoda, Gastropoda, and Ostracoda, which had 2433, 395, 379, and 1717 genus occurrences, respectively. Then, we used the paleolatitude data for each genus occurrence to characterize the latitude distribution of each class before and after the Permian/Triassic transition. We compared the paleolatitude medians before and after the mass extinction for each class to quantify the latitude shift for each class: 23.18° for Bivalvia, 37.45° for Cephalopoda, 29.82° for Gastropoda, and 6.29° for Ostracoda. This finding indicates that each individual class had a different latitudinal shift, with all classes exhibiting a poleward shift north. We also conducted Welch t-tests to compare the differences in latitudinal ranges and found that they were significant (Bivalvia: $p < 2.2e-16$, Cephalopoda: $p = 3.83e-6$, Gastropoda: $p < 2.2e-16$, Ostracoda: $p = 0.0030$). In addition, we ran multiple randomized models to compare them with our original results and found a significant difference between them via the Kolmogorov-Smirnov test, which means that the northward migration could be a biological response. Moreover, the results of our study show that the overall latitudinal range of most classes contracted after the extinction event, with the exception of the Cephalopoda class.

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Introduction

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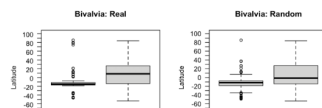
Materials and Data

The Mollusca and Arthropoda phyla were represented through the most data-abundant classes: Bivalvia, Cephalopoda, and Gastropoda classes represented the Mollusca phylum while the Ostracoda class represented the Arthropoda phylum. Each class consists of 2433, 395, 379, and 1717 genus occurrences respectively. We downloaded genus occurrences of these classes covering the Changhsingian (Late Permian) and Induan (Early Triassic) periods via the Paleobiology Database. The geologic ages of the downloaded occurrences were cross-referenced with a dataset of genus stratigraphic ranges that are housed at Stanford.

Results

Overall, each class displayed an overall poleward shift north, with 23.18° for Bivalvia, 37.45° for Cephalopoda, 29.82° for Gastropoda, and 6.29° for Ostracoda. The figures below illustrate the relationship between latitudinal ranges and geologic periods (before and after the end-Permian extinction). Our results were found to be statistically significant via the Welch t-test, with $p < 2.2e-16$ for Bivalvia, $p = 3.83e-6$ for Cephalopoda, $p < 2.2e-16$ for Gastropoda, and $p = 0.0030$ for Ostracoda.

The top left graphs plot this relationship for our real dataset while the top right graphs plot this relationship for the randomized dataset. The bottom left graphs compare the real dataset and the random dataset during the Changhsingian period while the bottom right graphs compare them during the Induan period. After running the Kolmogorov-Smirnov test, we determined that there was a significant difference between the real and randomized datasets (p -values in the table below).



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Methods

We first subsetted our data by sorting through the surviving genera; marine organisms that survived the end-Permian extinction had occurrences within both the Changhsingian and Induan periods. Then, we compared each organism's median paleolatitude during the Changhsingian period with their median paleolatitude during the Induan period to identify any latitudinal shifts. We then plotted the shifts in latitudinal ranges for each

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Discussion

paleolatitude data. Since Cephalopoda and Gastropoda are underrepresented in our data, more data gathered for these classes would provide a more accurate understanding of the Mollusca phylum. Our study can also be expanded to other phyla as well to determine if this northward migration holds true across all phyla. Future studies could also explore potential factors that caused this latitudinal shift during the end-Permian mass extinction, such as temperature and oxygen levels. Currently, it is still not understood why these organisms stayed near the equator despite shifting northward, and additional studies

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SCIENCE LEADS THE FUTURE



Introduction

The end-Permian mass extinction was a result of rapid changes in climate, including the increased temperature and the declining availability of atmospheric oxygen stemming from flood basalt volcanism. Since the majority of marine organisms went extinct after this extinction event, it has been hypothesized that the surviving organisms moved to cooler, more oxygenated areas. A relevant study by Bernardi et al. in 2018 showed that tetrapods had a 10° to 15° northward latitudinal shift after the end-Permian extinction. Our study re-examined the shifts in paleolatitude before and after the end-Permian mass extinction. We also expanded to include the Mollusca and Arthropoda phyla to test whether there is a poleward shift in fossil occurrences that would be consistent with organisms migrating to cooler environments.

Materials and Data

The Mollusca and Arthropoda phyla were represented through the most data-abundant classes: Bivalvia, Cephalopoda, and Gastropoda classes represented the Mollusca phylum while the Ostracoda class represented the Arthropoda phylum. Each class consists of 2433, 395, 379, and 1717 genus occurrences respectively. We downloaded genus occurrences of these classes covering the Changhsingian (Late Permian) and Induan (Early Triassic) periods via the Paleobiology Database. The geologic ages of the downloaded occurrences were cross-referenced with a dataset of genus stratigraphic ranges that are housed at Stanford.

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Results

Overall, each class displayed an overall poleward shift north, with 23.18° for Bivalvia, 37.45° for Cephalopoda, 29.82° for Gastropoda, and 6.29° for Ostracoda. The figures below illustrate the relationship between latitudinal ranges and geologic periods (before and after the end-Permian

extinction). Our results were found to be statistically significant via the Welch t-test, with $p < 2.2\text{e-}16$ for Bivalvia, $p = 3.83\text{e-}6$ for Cephalopoda, $p < 2.2\text{e-}16$ for Gastropoda, and $p = 0.0030$ for Ostracoda.

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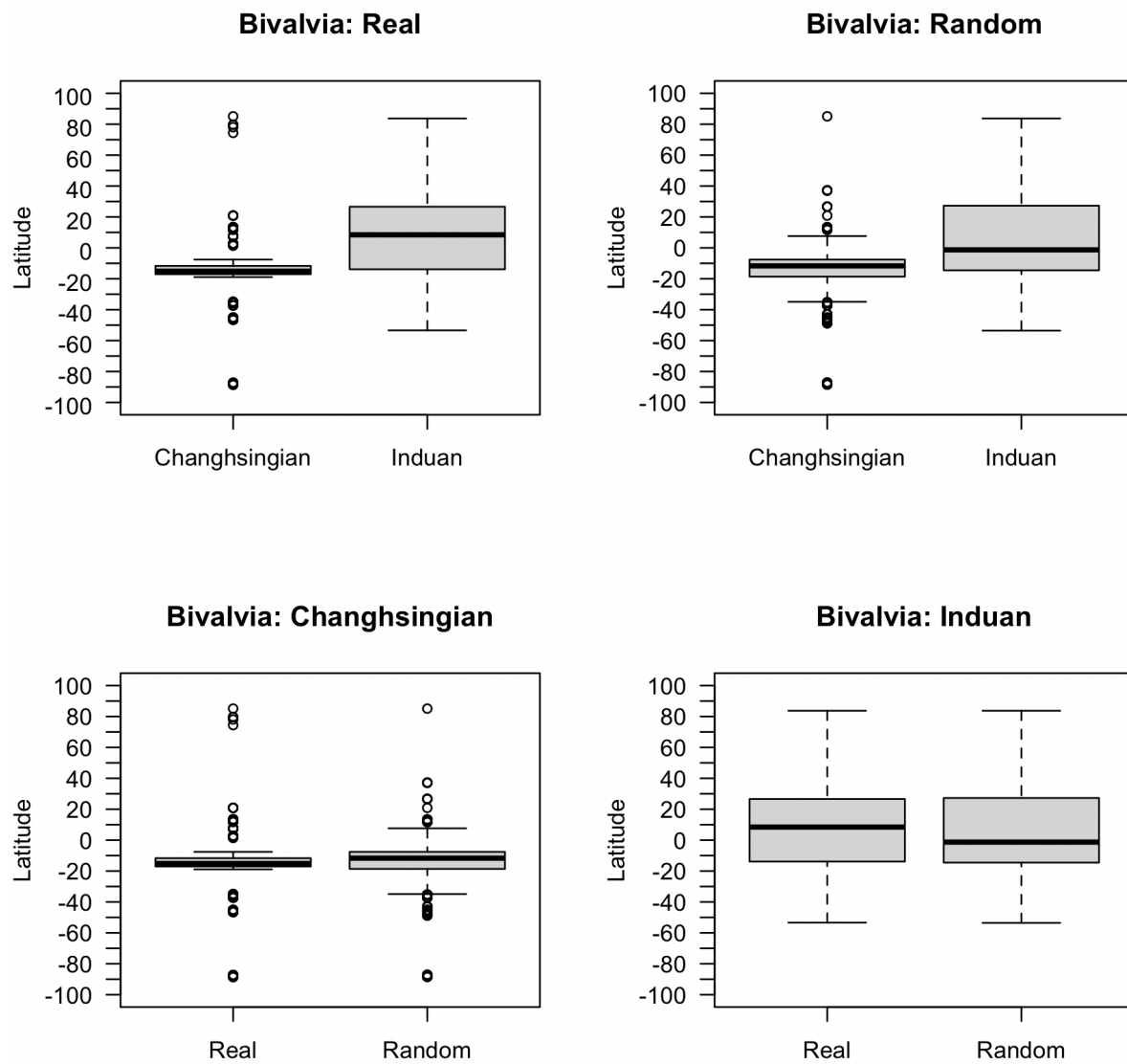


Figure 1. Bivalvia

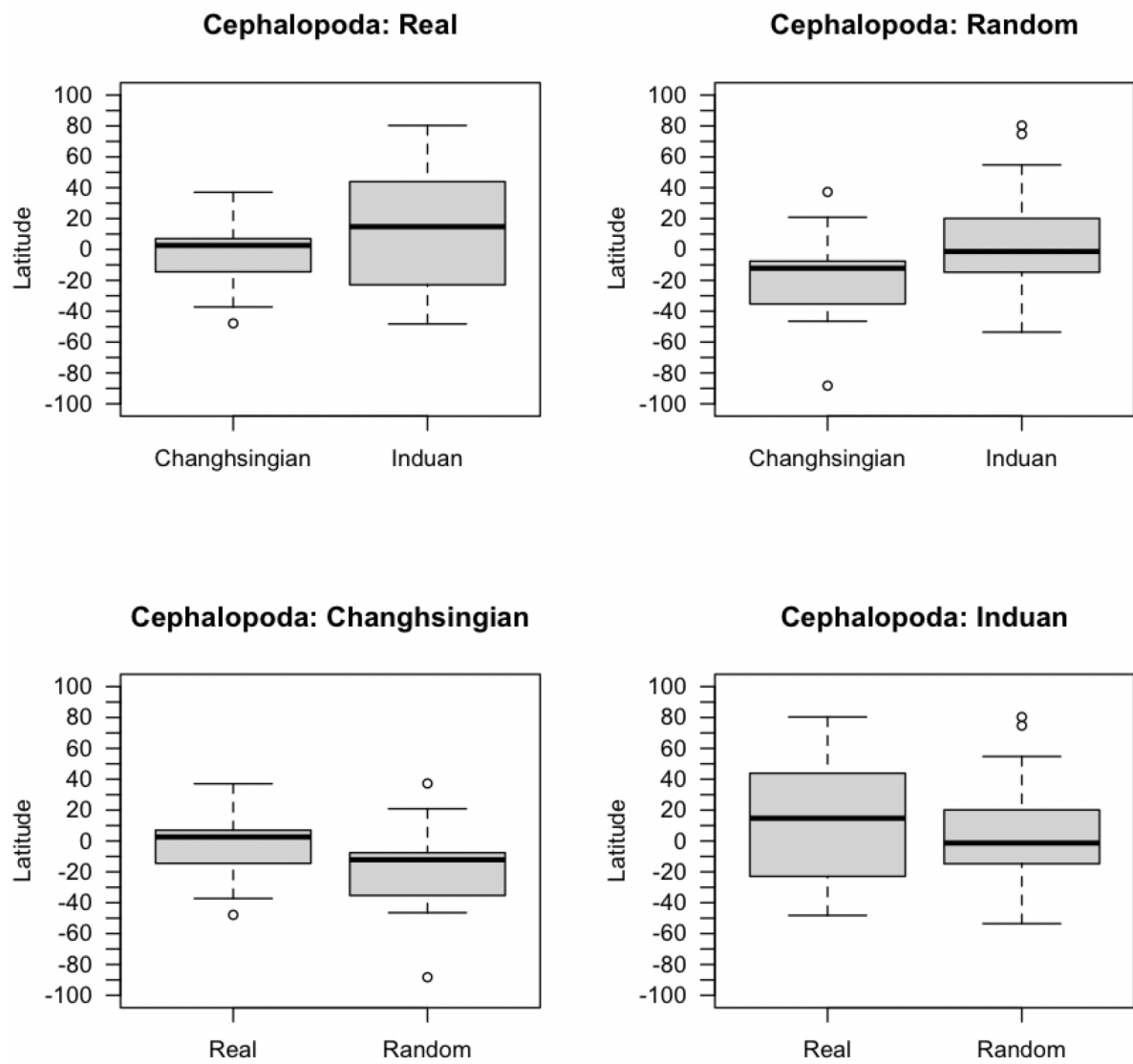


Figure 2. Cephalopoda

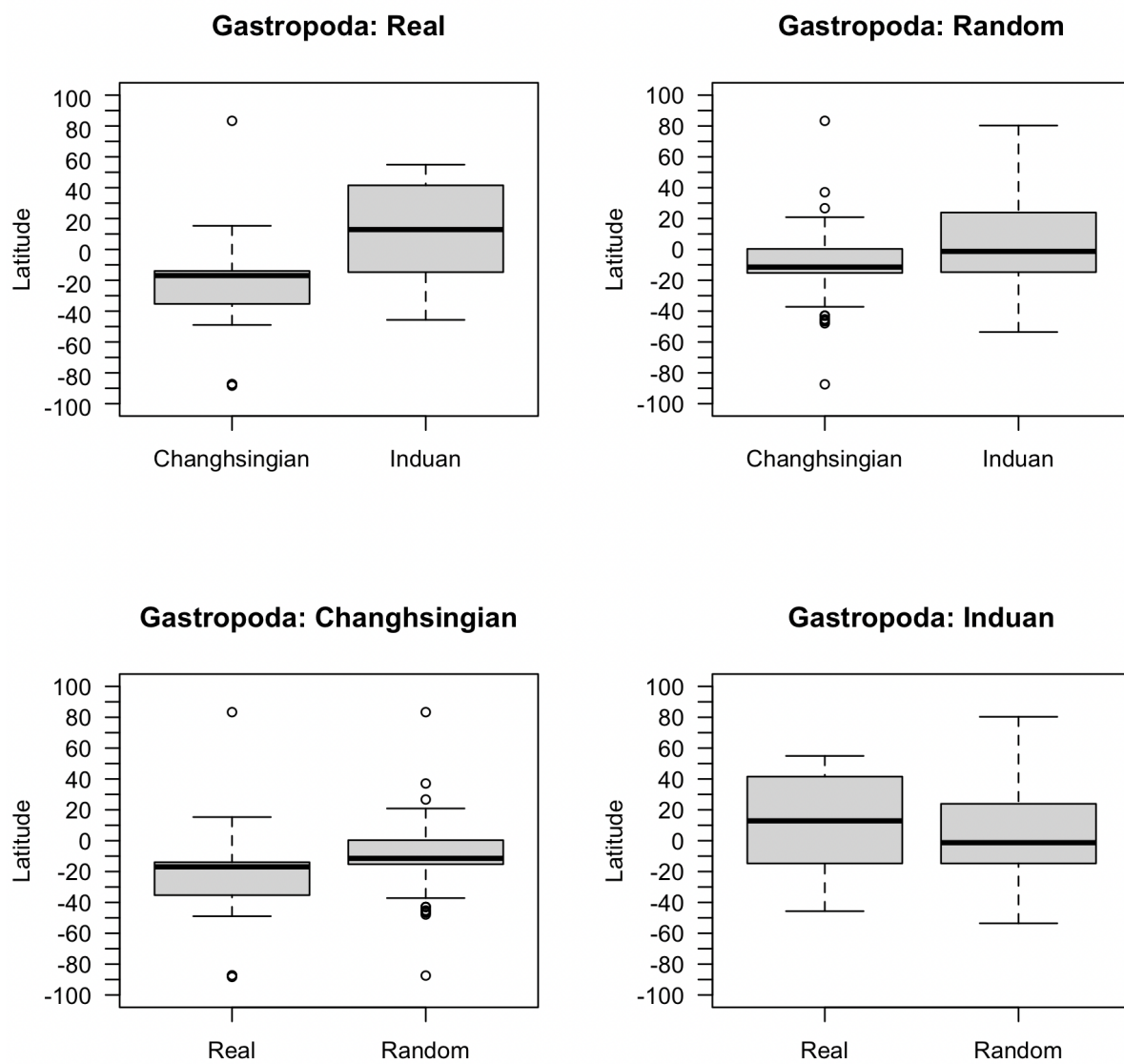


Figure 3. Gastropoda

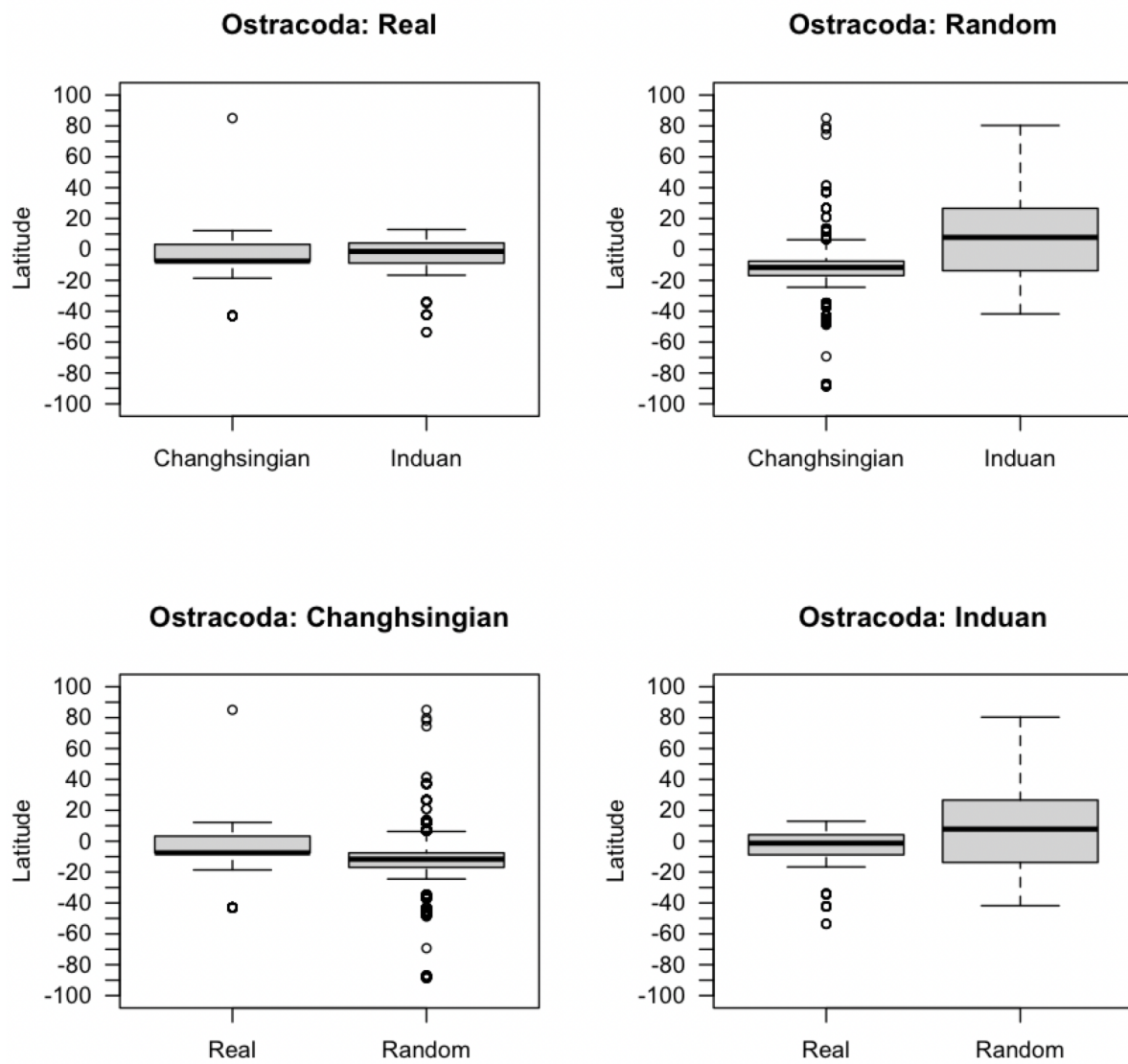


Figure 4. Ostracoda

Class	Paleolatitude during Changhsingian	Paleolatitude during Induan	Average difference in Paleolatitude
Bivalvia	-14.73°	8.45°	23.18°
Cephalopoda	4.12°	41.57°	37.45°
Gastropoda	-16.95°	12.87°	29.82°
Ostracoda	-7.58°	-1.29°	6.29°

Table 1. Average paleolatitude differences for each class

Class	<i>p</i> -value (Changhsingian)	<i>p</i> -value (Induan)
Bivalvia	$p = 3.623\text{e-}13$	$p = 2.816\text{e-}07$
Cephalopoda	$p = 2.554\text{e-}05$	$p = 4.174\text{e-}14$
Gastropoda	$p = 4.996\text{e-}15$	$p = 0.002661$
Ostracoda	$p < 2.2\text{e-}16$	$p < 2.2\text{e-}16$

Table 2. *p*-values for the Kolmogorov-Smirnov tests

Discussion

All of our classes displayed a clear northward shift in latitude (Table 1). Since the real plots vary a significant amount from the randomized plots, our results are likely to be a biological response since they were not replicated even with a random set of data (Table 2). While the overall latitudinal ranges of most of the classes contracted after the end-Permian extinction (Figure 1, Figure 3, Figure 4), the Cephalopoda class is an exception to this trend (Figure 2) since its latitudinal range expanded instead. Cephalopods also notably have the least northward shift in comparison with the other classes. Despite most of the data demonstrating a northward shift in latitudinal occurrences, most genera still occurred around the equator, which was not expected.

This study could be improved in the future with additional paleolatitude data. Since Cephalopoda and Gastropoda are underrepresented in our data, more data gathered for these classes would provide a more accurate understanding of the Mollusca phylum. Our study can also be expanded to other phyla as well to determine if this northward migration holds true across all phyla. Future

studies could also explore potential factors that caused this latitudinal shift during the end-Permian mass extinction, such as temperature and oxygen levels. Currently, it is still not understood why these organisms stayed near the equator despite shifting northward, and additional studies regarding other environmental factors could help answer this.

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Author Information

This research project was conducted by Kelly Tung, McKenna Anderson, and Sakeena Saber as part of their Stanford Earth Young Investigators Biodiversity Internship in 2022. For questions regarding the coding and data analyses aspect of this project, please contact Kelly Tung for more detailed information.

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The end-Permian mass extinction event resulted in the loss of approximately 80% to 90% of marine animal species due to drastic changes in climate. Because warming was a major factor in the extinction, it has been theorized the organisms that did survive were able to do so because they moved to higher latitudes and this hypothesis is consistent with tetrapod data. We hypothesized that this relationship holds true for marine mollusks and arthropods as well. Using Changhsingian (Late Permian) and Induan (Early Triassic) data from the Paleobiology Database,

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