

Investigating the Relationship between Metabolic Rate and Extinction Probability for Arthropoda, Brachiopoda, Echinodermata, and Mollusca Phyla during the Cenozoic Era

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Abstract

From extracting nutrients to releasing energy, biological metabolism plays an integral role in determining evolutionary patterns of organisms through geologic time. A previous study depicted a positive relationship between metabolic rate and extinction probability for Mollusca within the Neogene period. We hypothesized that this relationship extends to other metazoan phyla during the Cenozoic Era. Using specific respiration rates measured from living organisms and body size data for fossil taxa, we estimated metabolic rates of animals across different phyla: Arthropoda, Brachiopoda, Echinodermata, and Mollusca. This analysis was performed at the class level by using the classes with the most data available to represent each phylum: Malacostraca, Ostracoda, Cirripedia, Rhynchonellata, Echinoidea, Bivalvia, Cephalopoda, and Gastropoda. We then used logistic regression to estimate the relationship between the calculated metabolic rates and extinction probability during each epoch of the Cenozoic Era. Results indicate that while each individual phylum has a different extinction probability across each epoch, the regression coefficients for the combination of all studied phyla illustrate no relationship since there is not enough evidence to reject the null hypothesis of no relationship between metabolic rate and extinction probability. Although this means that there is no significant correlation for most of the phyla, there are some exceptions where metabolism does affect extinction probability. During the Oligocene epoch, animals within the Mollusca phylum portray a clear negative correlation between metabolic rate and extinction probability. A negative relationship is also observed for Echinoderms during the Eocene epoch. Despite the crucial role that metabolism plays in species survival, our results indicate that more information is needed regarding specific environmental conditions in order to accurately predict the factors that ultimately affect species survival across marine animals within the Cenozoic Era.

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Introduction
 Metabolism, an essential part of an organism's ability to function, plays a crucial role in determining evolutionary patterns through geologic time. An individual's metabolic rate mainly depends on its body size and temperature, as well as other factors such as respiration rate. Rubner's Surface Law and Kleiber's Laws make observations about how metabolism is dependent on an

Results
 These figures illustrate the relationships (regression coefficients) between extinction probability and metabolic rate of organisms in the Cenozoic Era. Positive coefficients correspond to higher metabolic rates associated with increased extinction probability while negative coefficients correspond to lower metabolic rates associated with increased extinction probability.

Methods
 We found correlations between metabolic rate and extinction probability by running logistic regression analysis in the platform, RStudio. We first assigned each phyla's respiration rate from their's respiration data. We then calculated each organism's body mass by using Stanford's body size database and ash-free dry mass conversions. The values, including Payne's constants, were entered into the metabolic rate equation and the resulting metabolic rates were assigned to each organism.

Materials and Data
 We used the $R_{max} = 0.9e^{-E_a/RT} M^{3/4}$ formula and referenced a previous study, "Metabolic dominance of bioturbation promotes bioturbation diversity decline by more than 150 million years", by Payne, et al to calculate the metabolic rate of each specimen in our study. Payne's paper included the formula's activation energy constant (E) and Boltzmann's constant (k). We completed the formula using data from Stanford's Body Size Database and their's respiration dataset. We used their's respiration calculator to calculate the respiration rate (R) as well as several other sources to convert wet and dry mass numbers (M). Each phyla was represented through the most data abundant classes from our dataset.

Discussion
 Based on our respect to logistical analysis for each phylum, there was insufficient evidence to reject the null hypothesis (no relationship between metabolic rate and extinction probability). Many of the confidence intervals for the regression coefficients crossed 0, which indicates that no conclusion can be made. However, there were some exceptions to this. Both the statistical tests for mollusks within the Eocene epoch (Figure 4) and mollusca within the Oligocene epoch (Figure 5) yielded a negative regression coefficient with confidence intervals

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INTRODUCTION

Metabolism, an essential part of an organism's ability to function, plays a crucial role in determining evolutionary patterns through geologic time. An individual's metabolism mainly depends on its body size and temperature, as well as other factors such as respiration rate. Rubner's Surface Law and Kleiber's Laws make observations about how metabolism is dependent on an organism's surface area and mass, respectively. An interesting and relevant case study by Strotz et al. in 2018 was done on molluscs in the Neogene period which, among other results, identified basal metabolic rate as an extinction predictor. Our study re-examined the relationship between metabolic rate and extinction probability and was expanded to include all metazoan phyla within the Cenozoic Era.

MATERIALS AND DATA

We used the $B_{ind} = b_0 e^{-E/kT} M^{3/4}$ formula and referenced a previous study, “Metabolic dominance of bivalves predates brachiopod diversity decline by more than 150 million years”, by Payne. et al to calculate the metabolic rate of each specimen in our study. Payne’s paper included the formula’s activation energy constant (E) and Boltzmann’s constant (k). We completed the formula using data from Stanford’s Body Size Database and Heim’s respiration dataset. We used Brey’s respiration calculator to calculate the respiration rates (b_0) as well as several other sources to convert wet and dry mass numbers (M). Each phyla was represented through the most data abundant classes from our datasets: Malacostraca, Ostracoda, Cirripedia, Bivalvia, Rhynchonellata, Echinoidea, Cephalopoda, and Gastropoda. We aligned our data according to each epoch in the Cenozoic timescale to observe correlation over time.

RESULTS

These figures illustrate the relationships (regression coefficients) between extinction probability and metabolic rate of organisms in the Cenozoic Era. Positive coefficients correspond to higher metabolic rates associated with increased extinction probability while negative coefficients correspond to lower metabolic rates associated with increased extinction probability.

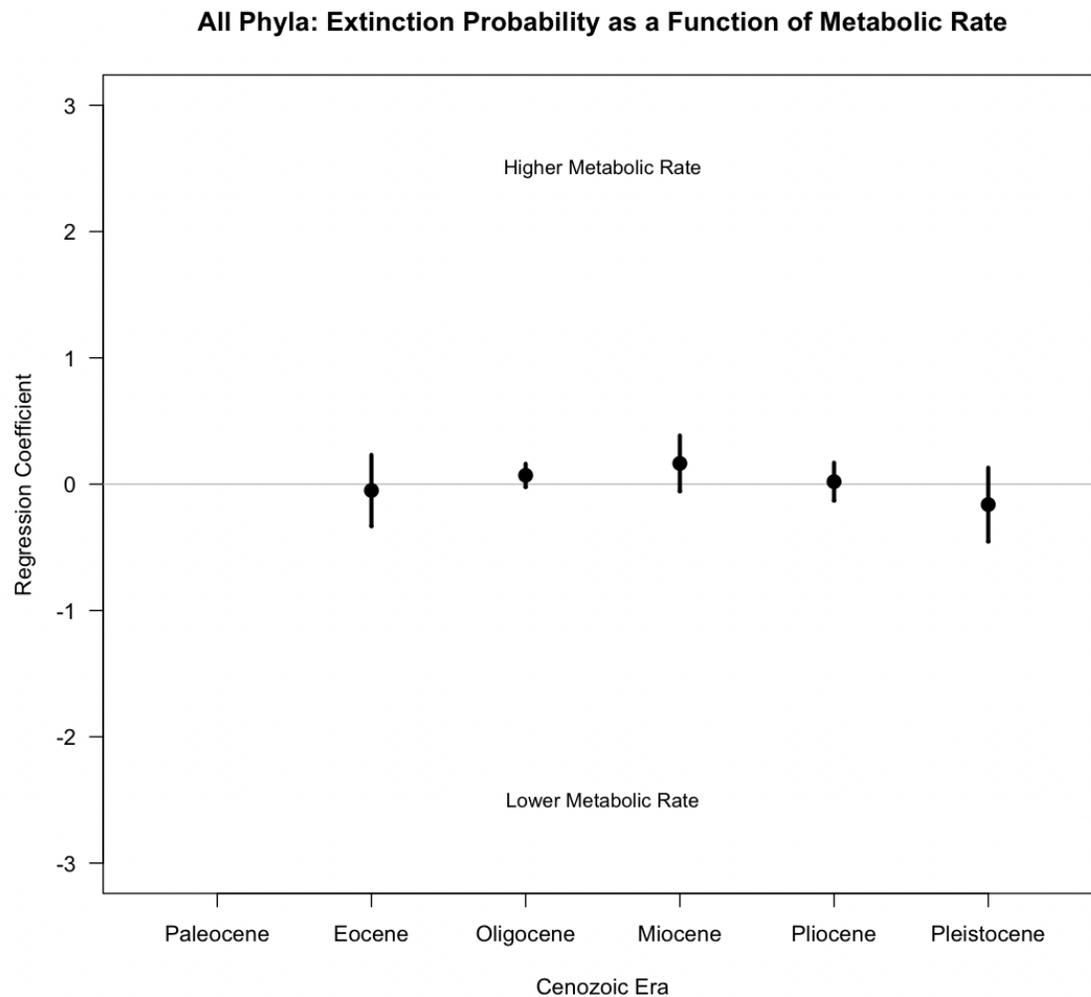


Figure 1

Arthropoda: Extinction Probability as a Function of Metabolic Rate

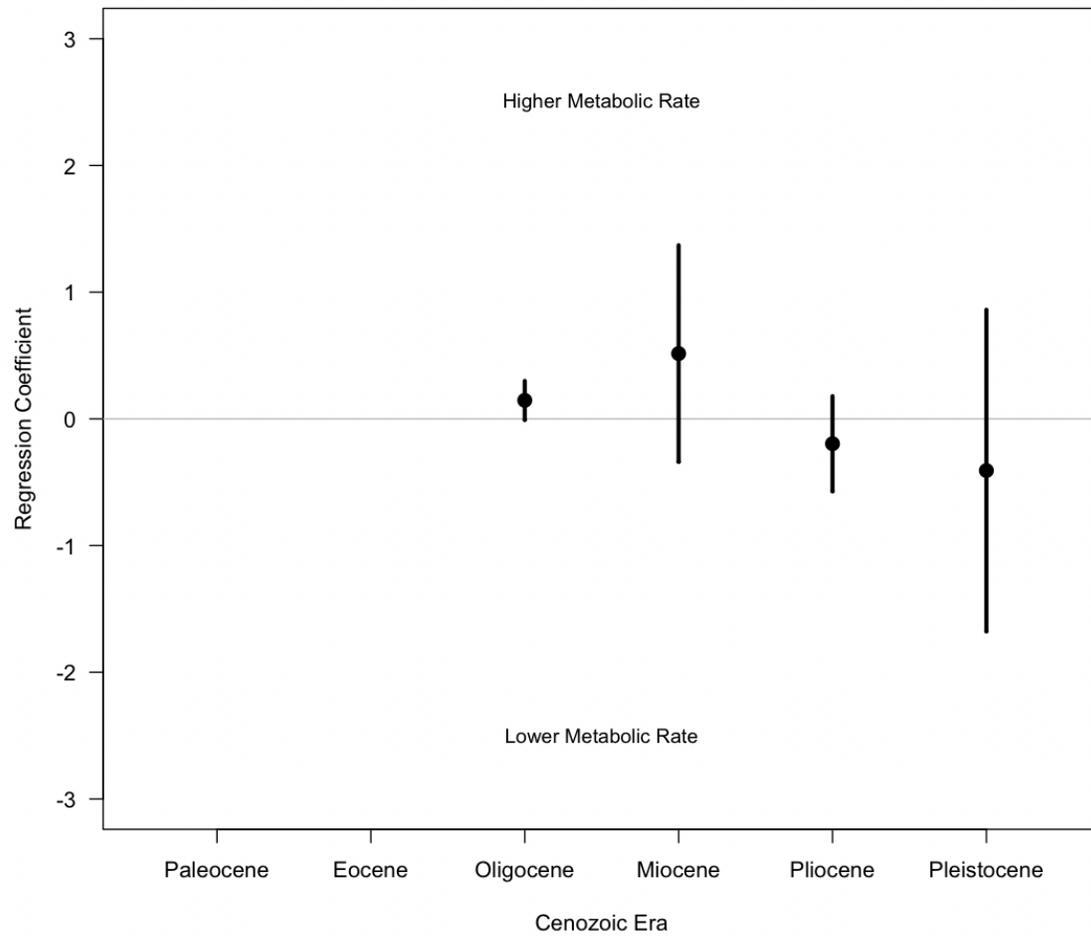


Figure 2

Brachiopods: Extinction Probability as a Function of Metabolic Rate

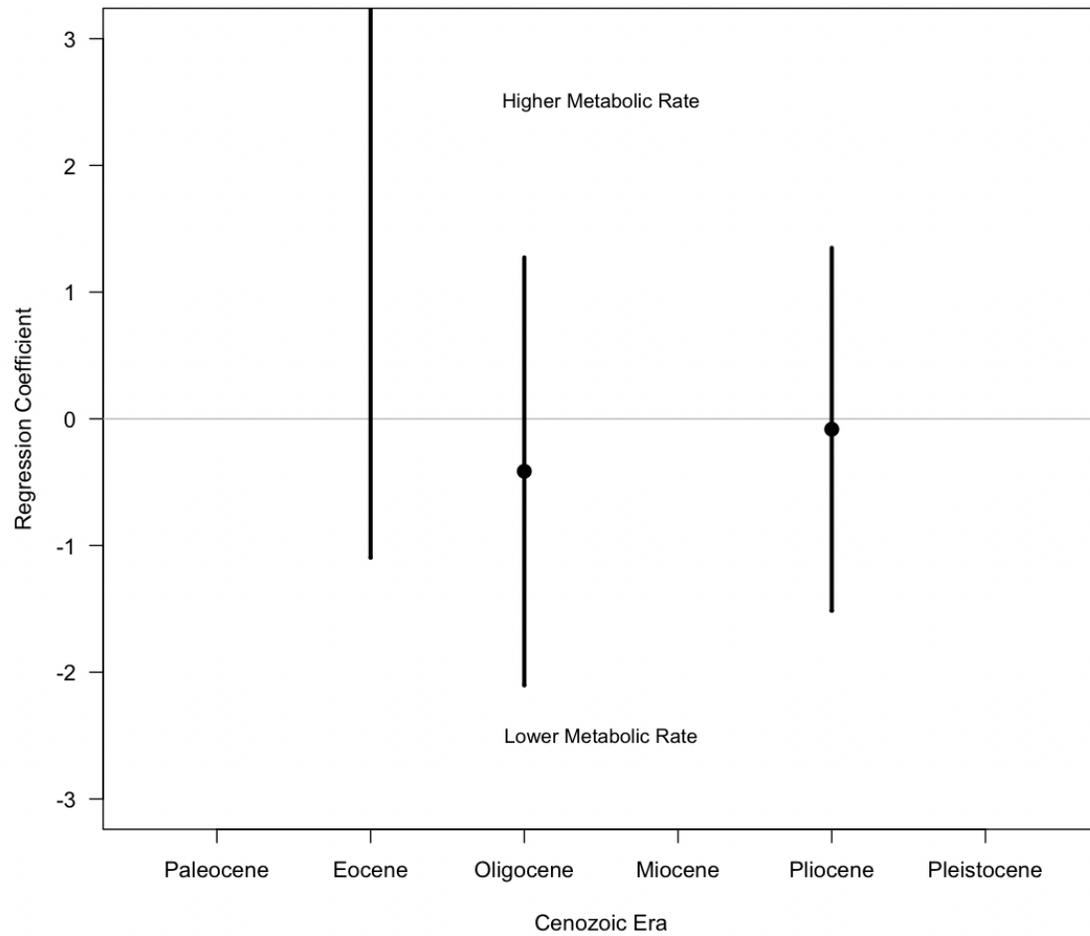


Figure 3

Echinodermata: Extinction Probability as a Function of Metabolic Rate

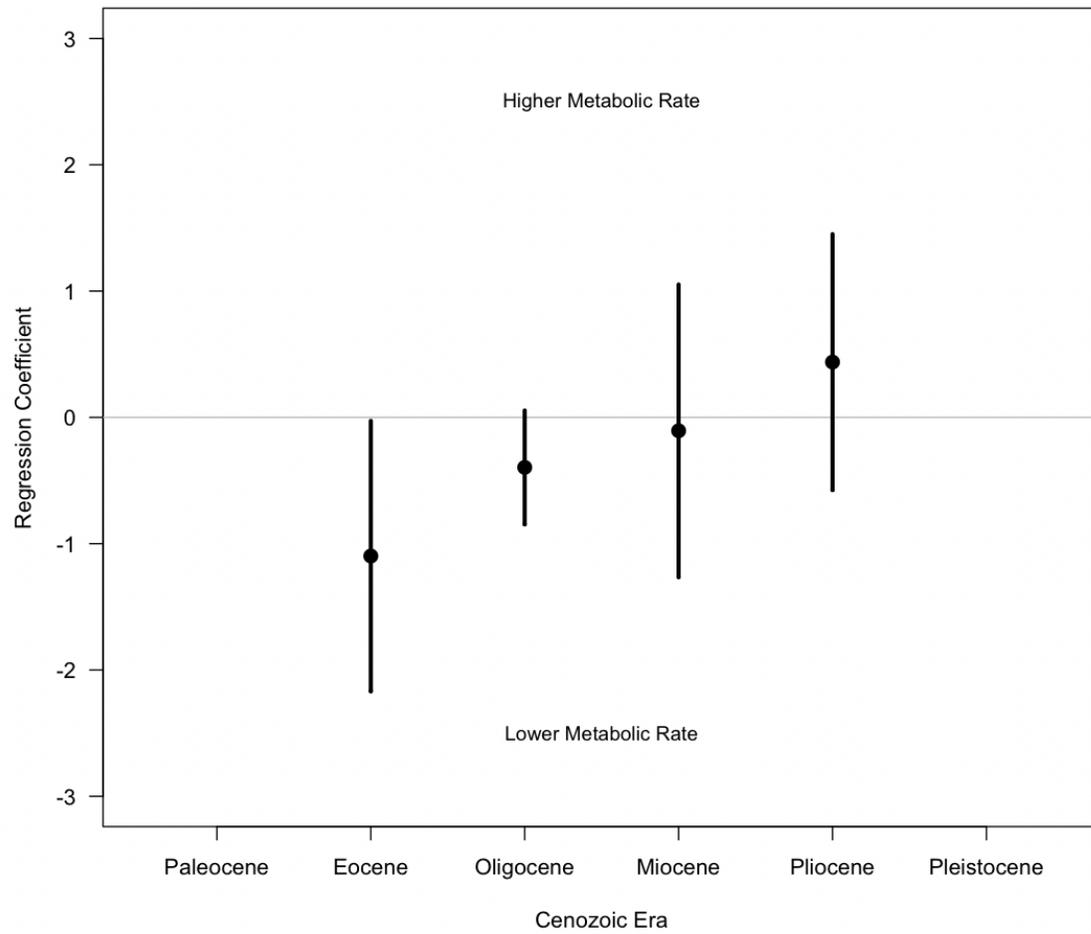


Figure 4

Molluscs: Extinction Probability as a Function of Metabolic Rate

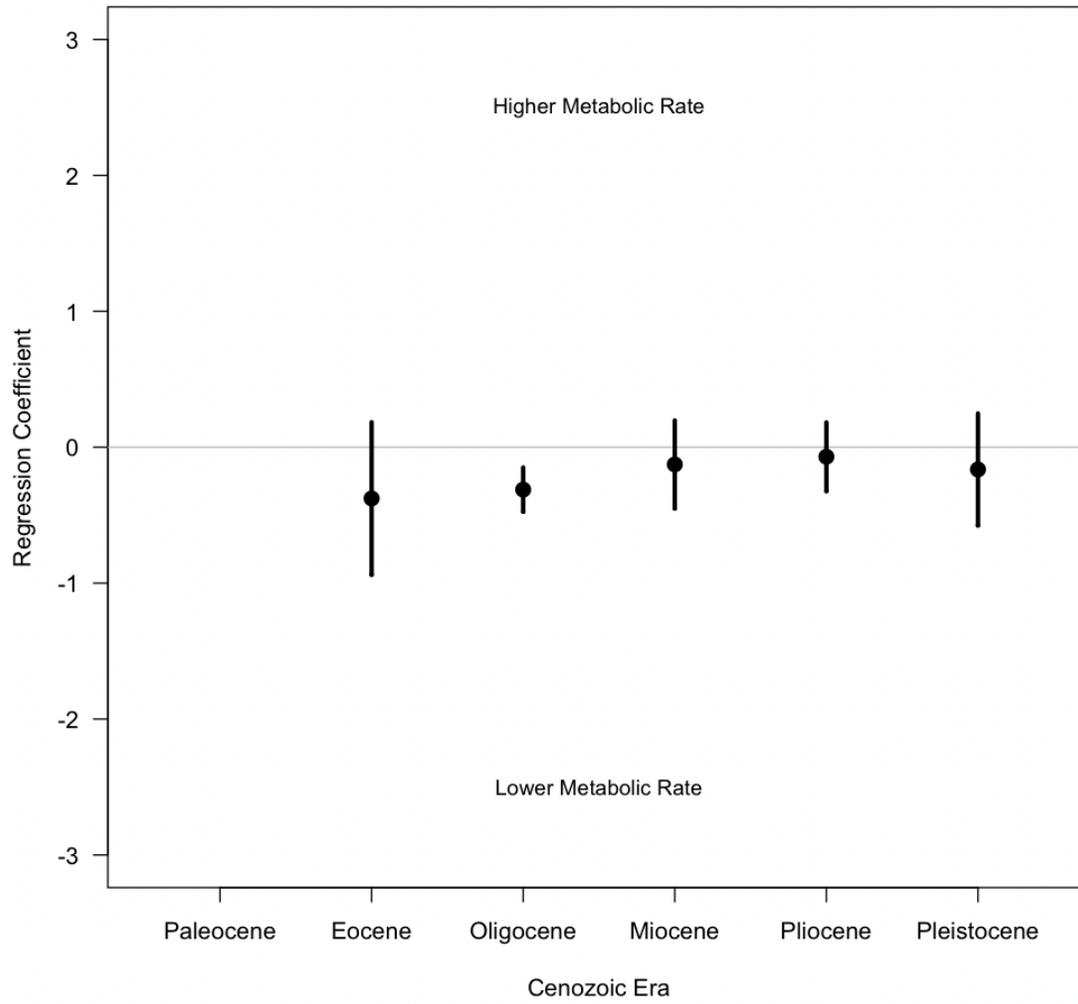


Figure 5

METHODS

We found correlations between metabolic rate and extinction probability by running logistic regression analyses in the platform RStudio. We first assigned each phyla's respiration rate from Heim's respiration data. We then calculated each organism's body mass by using Stanford's body size database and ash-free dry mass conversions. The values, including Payne's constants, were entered into the metabolism equation and the resulting metabolic rates were assigned to each organism that lived during the Cenozoic era. We calculated extinction probability by checking the individual's survival during each epoch and ran multiple logistic regression analyses comparing the metabolic rate and binomial survival probability data. The resulting regression coefficients from the analyses were plotted for comparison.

DISCUSSION

Based on our respective logistical analysis for each phylum, there was insufficient evidence to reject the null hypothesis (no relationship between metabolic rate and extinction probability). Many of the confidence intervals for the regression coefficients crossed 0, which indicates that no conclusion can be made. However, there were some exceptions to this. Both the statistical tests for echinoderms within the Eocene epoch (Figure 4) and mollusca within the Oligocene epoch (Figure 5) yielded a negative regression coefficient with confidence intervals not crossing 0. These negative coefficients correspond with lower metabolic rates associated with higher extinction selectivity.

Our study of metabolism's impact on survival explores an area that has not been researched in-depth within the scientific realm and could yield a deeper understanding to the factors that contribute to an ecologically advantageous organism.

This study could be improved in the future with additional body size and extinction data as that would decrease the confidence intervals where correlation exists. Since our data overrepresented molluscs, more data gathered for the other phylum would provide a more accurate understanding of all phyla in the Cenozoic Era (Figure 1). Future studies could also explore smaller taxonomic groups or other factors related to metabolic rate and extinction, such as Earth's temperature.

ABSTRACT

From extracting nutrients to releasing energy, biological metabolism plays an integral role in determining evolutionary patterns of organisms through geologic time. A previous study depicted a positive relationship between metabolic rate and extinction probability for Mollusca within the Neogene period. We hypothesized that this relationship extends to other metazoan phyla during the Cenozoic Era. Using specific respiration rates measured from living organisms and body size data for fossil taxa, we estimated metabolic rates of animals across different phyla: Arthropoda, Brachiopoda, Echinodermata, and Mollusca. This analysis was performed at the class level by using the classes with the most data available to represent each phylum: Malacostraca, Ostracoda, Cirripedia, Rhynchonellata, Echinoidea, Bivalvia, Cephalopoda, and Gastropoda. We then used logistic regression to estimate the relationship between the calculated metabolic rates and extinction probability during each epoch of the Cenozoic Era. Results indicate that while each individual phylum has a different extinction probability across each epoch, the regression coefficients for the combination of all studied phyla illustrate no relationship since there is not enough evidence to reject the null hypothesis of no relationship between metabolic rate and extinction probability. Although this means that there is no significant correlation for most of the phyla, there are some exceptions where metabolism does affect extinction probability. During the Oligocene epoch, animals within the Mollusca phylum portray a clear negative correlation between metabolic rate and extinction probability. A negative relationship is also observed for Echinoderms during the Eocene epoch. Despite the crucial role that metabolism plays in species survival, our results indicate that more information is needed regarding specific environmental conditions in order to accurately predict the factors that ultimately affect species survival across marine animals within the Cenozoic Era.

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