Cephalopod Evolution and the Increase in Size Across the Mesozoic Periods

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ABSTRACT: By looking at a species' change in morphology, which is their shape and size, throughout time, it is possible to learn about the environmental conditions they lived in and what effect they had on them. Specific elements that can play a role in the change of size are extinction events, environmental responses, divergent/speciation occurrences, and adaptions to an ecosystem. In this research paper, cephalopod widths have been examined to see if they have undergone a noticeable change in size throughout the three Mesozoic periods, Jurassic, Triassic, and Cretaceous. The result of this research is that the cephalopods have gone through significant changes in size between every period in the Mesozoic. It is suggested that this increase in size was a response to elements in the environment such as the Marine Mesozoic Revolution, the C/T extinction event, and other evolutionary factors.

Keywords

Size, Cephalopod, Mesozoic, Evolution, Environment, Pressure

Introduction

Many factors place an evolutionary influence on size. Ecological events such as the introduction of new species or a change in an environment can play a role in the cephalopod's evolutionary development. Cephalopods, mollusks that are part of the class Cephalopoda such as cuttlefishes, ammonites, or squids, were chosen for this research since there is a huge diversity of cephalopods in various shape and sizes. This paper focused on cephalopod samples from Europe; having numerous coasts close to the ocean, this would mean Europe is likely to carry an abundance of data. The span of time examined in this research will be throughout the Mesozoic when Cephalopods are recorded to have the most diversity in size within their fossil record.

What jump-started this evolutionary change in size was the Mesozoic Marine Revolution (Tanner et al., 2017). Happening early in the Mesozoic, this revolution was a series of events where cephalopods contested with marine vertebrates (mostly predators). Throughout the revolution, many shelled cephalopods ended up being preyed upon. Cephalopods that survived the challenges presented during the Revolution would adapt, survive, and diversify into modern cephalopods. After the Revolution, diversions among Cephalopod and differing environmental pressures led to the formation of several orders (Strugnell et al., 2006) and diversification of Cephalopod Morphology. (Lindgren et al 2012). The Cenomanian/ Turonian Extinction Event (also known as the C/T event or the C/T Interval) that occurred towards the end the Mesozoic would have also drastically altered the earth's environment and climate, forcing cephalopods to undergo another intense stage of change, forcing them to adapt to the new conditions in their current environment at the time, or migrate to a new one if they could not adapt (Yacobucci, 2017). These would likely result in cephalopods adapting to different conditions, which in turn would cause them to change in size, as an evolutionary response.

This paper tests the hypothesis that over the course of the Mesozoic Era the species in the class Cephalopoda would have gone through a significant change in size from the beginning of the Triassic to the end of the Cretaceous. The importance of this data is that it will help clarify how marine life evolves, as size is a trait that changes with environmental factors or diversification.

Materials and Methods

This data was collected from the fossil works database on October 28, 2017, through restricting the region to Europe, restricting class that was studied as a cephalopod, restricting the time interval to the entire Mesozoic, and setting the measurements as the width (provided in millimeters). Data from periods outside of the Mesozoic were excluded. The data was reorganized into displaying the periods of the Mesozoic (Jurassic, Triassic, and Cretaceous) and the mean width. The statistical test used was ANOVA since the data used three categorical variables – the periods of the Mesozoic - with one categorical variable - width in millimeters. The program used to narrow down, collect the data analysis, and make calculations was 2016 Microsoft Excel. I used an ANOVA test, with a P-Value of zero, a level of significance of 0.05. A statistical significance 0.05 since this was a low-risk study and greater level of significance would be unnecessary.

Results

My hypothesis was that over the course of the Mesozoic Era, the species in the class Cephalopoda would have gone through a significant change in size from the beginning of the Triassic to the end of the Cretaceous. Thus, the research hypothesis is accepted because there are significant differences in size between all three periods according to Figure 1. Table 1 indicates that average cephalopod widths for the Triassic, Jurassic, and Cretaceous were 15.09193 mm, 20.98029 mm, and 31.83559 mm. The standard deviations were 12.1891, 20.65792, 32.55768 for the Triassic, Jurassic, and Cretaceous respectively, represented by the error bars. Figure 3 indicates via one-tailed T-tests that relationships between all three periods, 5.3E-61 for Triassic-Jurassic, 8.52E-145 for Triassic-Cretaceous, 5.4E-56 for Jurassic-Cretaceous are all showing signs of being significantly different. As the P-value is zero and thus is significantly less than all the T-test results, the null hypothesis of there being no significant differences from the Triassic to the Cretaceous is rejected.

Discussion

The hypothesis is accepted because it is shown that between every period of the Mesozoic, cephalopods were showing to go through an increase in sizes between every period according to Figure 1 and the t-tests in Table 2. Table 1 illustrates that cephalopods increased to roughly 5 mm between the Triassic and Jurassic and by roughly 11 mm between the Jurassic and Cretaceous. Because these results indicate significant changes in sizes happened between every period, it's presumed some environmental factors played a role in the

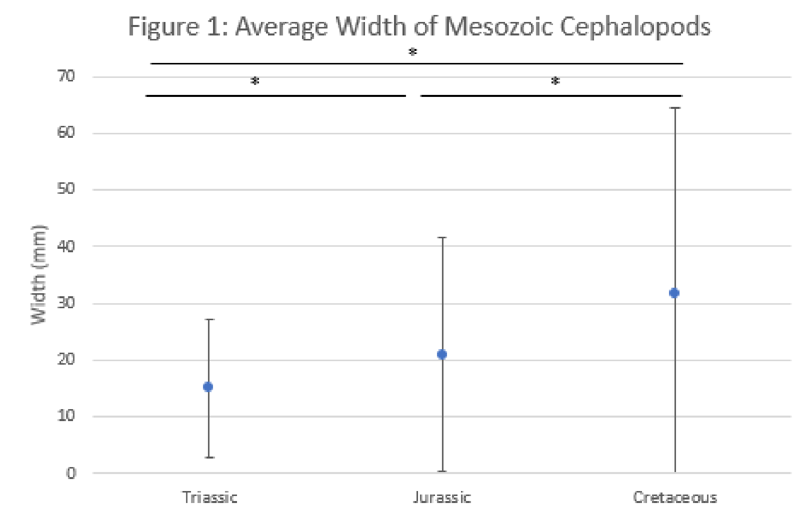

Figure 1: Mean width of recorded Cephalopods throughout the Mesozoic era. ANVOA reveals Width differences between the ages are significant. ($P<<0.001$) Significant differences between periods, post hoc T-test values (for Triassic-Crestaceous, Jurassic-Crestaceous, and Triassic-Jurassic comparisons are $<<0.001$) A statistical significance 0.05 was used since this was a low-risk study.

Table 1: Width Data for Mesozoic Periods

Period	Mean Width of Cephalopods (mm)	Standard Deviation	Number of Cephalopods Examined
Triassic	15.09193 mm	12.1891	6089
Jurassic	20.98029 mm	20.65792	4217
Cretaceous	31.83559 mm	32.55768	2923

Table 2: T-Tests for Significant Differences

Periods	T-test
Triassic - Jurassic	5.36609E-61
Triassic - Cretaceous	8.5208E-145
Jurassic - Cretaceous	5.39984E-56

evolution of cephalopod size during the Mesozoic Era.

Environmental factors will often push cephalopods to evolve in a certain way. Due to having gone through "selective pressures," cephalopods during the Mesozoic would have gone through a convergent evolution and correlated evolution, the former being one where cephalopods develop similar organisms not related to them, with the latter being where they develop traits based on environmental responses. Thus, there would be significant changes in their morphology (Lindgren et al., 2012). These changes would include but are not limited to having harder shells or stronger muscles. The Marine Mesozoic Revolution would have also played a large part in advancing this where predatory vertebrates were easily preying on them. It was heavily described as the rivalry between predators and prey to see which could out-evolve the other (Tanner et al., 2017). Thus, Cephalopods would continue to evolve into having defenses like a stronger, bigger, more protective body. This can be illustrated with a gradual increase in size throughout the Mesozoic.

The Cenomanian/Turonian extinction event, life-changing for all life on earth event that occurred around the mid-Cretaceous, would have further pushed this change. With the rising sea level, global greenhouse effects occurring, and the extinction of species, environments and ecosystems would have through a major reorganization. The C/T interval brought so much change that cephalopod diversity significantly increased in areas coastal areas but are said to, during the Turonian, decrease speciation in open-ocean (Yacobucci 2017). Considering that different environmental pressures have changed cephalopod morphology in various ways, Cephalopods may have increased in size (likely through speciation) to fit the conditions of a post-C/T Interval world.

Research in Xaiver et al., (2015) suggests that cephalopods are subjugated to similar conditions as they were back in the Mesozoic era – global warming and rising sea level - and many more human-made challenges like overfishing and ocean acidification through dumping chemicals and waste into the ocean. These challenges would bring long-term pressures to entire ecosystems (especially at the coastal ecosystems) that cephalopods live in. The research also noted that studying cephalopod shape and size would be a valuable addition in helping modern-day research since it helps scientists understand the environmental conditions they lived in back in the Mesozoic and the conditions they live in now. While granting that cephalopods sizes increased throughout the Mesozoic, man-made pressures are showing to increase the pressure for cephalopods to adapt (Xavier et al., 2015). Thus, it could be inferred that size is affected as a part of evolutionary responses and species diversification in response to environmental pressures.

Alternate explications for the data could be that genetic mutation, where new genes are introduced to a species, or evolutionary divergences, how a species' evolutions branch off into different paths like a family tree, could have given larger-sized Mesozoic cephalopods a competitive advantage over smaller-sized ones. In an instance where a group of larger sized cephalopods and common smaller sized cephalopods contest for food, the larger ones would be able to catch more and reproduce more than the smaller ones. During Paleozoic Era, there has been evidence of Cephalopoda taxa within dividing into several orders, with some continuing to diverging into the late Mesozoic/early Cenozoic as evidenced by their fossils, while others remain incomplete and unclear. (Strugnell et al., 2006). The cephalopods that successfully diverged throughout the Mesozoic may have been bigger cephalopods, while smaller ones would go extinct.

Another alternative explanation is that it was noted that towards the end of the Cretaceous period there was an increase in speciation in coastal areas in a post C/T world (Yacobucci, 2017). With Europe also having many coastal areas the continent could be considered a haven for Cephalopods, or certain types of large cephalopods, to thrive and evolve. However, this does not speak for Cephalopods in areas outside of Europe that may have evolved differently (i.e. decreased in size).

The stakes of this data suggest that long-term changes to the environment will affect how a species developed and survives, as well as what kind of species they will evolve into. Living in a world affected by global warming and going through a change like Mesozoic Marine Revolution and the C/T extinction event, it is necessary to look out for what kind of world the future holds for creatures on earth who will be caught once again and be forced to evolve in new conditions or die.

Limitations and Future Work

Certain biases that may have happened over the course of this research are that the only cephalopods examined were in Europe; cephalopods sizes in other parts of the word may be very different. The fossil record, while an extremely useful resource, cannot catalog every known cephalopod. Further experimentation in this area could focus on cephalopod occurrences throughout the Mesozoic, analyzing species sizes between Mesozoic ages rather than periods, research on convergent and correlated evolutionary traits in niche ecosystems, and analyzing the C-T interval and the Mesozoic Marine Revolution.

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References

Lindgren, A.R., Pankey, M.S., Hochberg, F.G., Oakley, T.H. (2012) "A Multi-Gene Phylogeny of Cephalopoda Supports Convergent Morphological Evolution in Association with Multiple Habitat Shifts in the Marine Environment." *BMC Evolutionary Biology*. [Internet] [cited Nov 18 2017] 12: 129. Available from: https://search-proquest-com. offcampus.lib.washington.edu/docview/1080764217?rfr_id=info%3Axri%2Fsid%3Aprimo

Strugnell, J., Jackson, J., Drummond, A.J., Cooper, A. (2006) "Divergence Time Estimates for Major Cephalopod Groups: Evidence." Multiple Genes from Lebanon. *Cladistics the International Journal of the Willi Hennig Society* [Internet]. [cited Oct 20 2017] 90 (22): 89–96. Available from: http://onlinelibrary.wiley.com.offcampus.lib.washington.edu/doi/10.1111/j.1096-0031.2006.00086.x/full

Tanner, A.R., Duchs,,F., Winklemann, I.E., Gilbert, T., Pankey, M.S., Riberio, A.M., Kocot, K.M., Halanych, K.M., Oakely, T.H., da Fonseca, R.R., Pisani, D., Vinther, J. (2017) "Molecular Clocks Indicate Turnover and Diversification of Modern Coleoid Cephalopods during the Mesozoic Marine Revolution." P*roceeding of the Royal Society* [Internet]. [cited Oct 20 2017] 294(1850): 89–96. Available from: http://rspb.royalsocietypublishing.org.offcampus.lib.washington.edu/content/284/1850/20162818

Xavier, J.C., Allcock, A.L., Cherel, Y., Lipinski, M.R., Pierce, G.J. et al. (2015). "Future challenges in cephalopod research." Marine Biological Association of the United Kingdom. *Journal of the Marine Biological Association of the United Kingdom*, [Internet] [cited Oct 21 2017] 95 (5): 999-1015. Available from: https://search-proquest-com.offcampus.lib.washington.edu/docview/1692855155?rfr_id=info%3Axri%2Fsid%3Aprimo

Yacobucci, M. (2017) "Marine Life in a Greenhouse World: Cephalopod Biodiversity and Biogeography during the Early Late Cretaceous." *Paleobiology*. [Internet] [cited Nov 18 2017] vol. 43 (4): 587–619. Available from: https://search-proquest-com.offcampus.lib.washington.edu/docview/1947583678?rfr_id=info%3Axri%2Fsid%3Aprimo

Appendix

The supplemental raw data for this research can be accessed via the UWB CROW website at: https://thecrowuwb.wordpress.com/