Data Analysis in Fisheries Science: Relationship Between Predator and Prey Lengths

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March 15, 2021

Abstract

In this project I will investigate the relationship between marine predators and their prey and try to find trends, specifically between their lengths. Using a large data set produced by Barnes et al. [2008], I will use R to identify these relationships using various techniques and plots. Looking at the relationship between predator and prey lengths has important applications in the fishing industry. The research in this paper could give reasons for a minimum length of fish that fisherman are allowed to catch, as the smaller fish could be part of the diet of more predators, and therefore a lack of fish under that minimum length could cause more fish to starve, reducing biodiversity.

Contents

1 Introduction

1.1 The Barnes Data Set

Throughout this project I will be using a data set produced by Barnes et al. [2008] called "Predator and Prey Body Sizes in Marine Food Webs". This data set has 34929 observations of 62 variables, but I will be focussing on just six of these; predator scientific name, predator length, predator length unit, prey scientific name, prey length and prey length unit.

1.2 What other studies have found and how they have influenced my project

1.2.1 Costa's Research

Costa found that mean, minimum, maximum and variance of prey size were all positively associated with body size. This suggests that larger predators consume a variety of different sized prey types, increasing both the maximum and minimum size they eat. A similar result can be found in previous studies looking at terrestrial predators conducted by Vézina [1985] and Costa et al. [2008], who found that larger predators tend to consume a wider range of prey sizes. In a similar study which looks at predacious lizards, Costa actually found a negative relationship, concluding that larger predators were actually consuming a narrow diversity of prey categories.
In my project I will investigate this relationship further, looking at the length of each species rather than their mass to see if this follows the same patterns that Costa and Vézina found. Taking inspiration from Costa's calculations and figures, I will calculate the trophic-niche breadth of predators and plot this against their lengths in millimetres.

1.2.2 Scharf's Research

Scharf et al. [2000] used regression analysis to look at ratio-based trophic niche breadths and found that they generally did not expand with predator ontogeny [1] and tended to narrow for the largest predators. They also found that "the range of prey sizes eaten expanded with increasing predator body size for each of the marine predators examined, leading to asymmetric predator size - prey size distributions".
In my project I will investigate whether these results can be replicated using the Barnes data set (Barnes et al. [2008]). I feel this will be important as the Scharf study uses a relatively narrow data set of only 18 species, all off the northeast US coast, so it will be interesting to see whether these results can be found across the 27 locations, 93 predator types and 174 prey types that were observed by Barnes et al. Taking inspiration from figure 4 in the Scharf paper, I will produce a plot showing the ratio of prey length/predator length, the relative frequencies and the cumulative frequencies.

[1] "The entire sequence of events involved in the development of an individual organism" - Collins English Dictionary

1.3 Explanation of Mathematics Required

1.3.1 Ratio-Based Trophic-Niche Breadth

Trophic niche breadth B can be calculated using the following formula by Levins [1968]

$$B = \frac{1}{\sum p_i^2}$$

where p_i is the relative frequency of occurrence of the ith prey species; and standardised across prey species:

$$B_A = \frac{B-1}{N-1}$$

ranging from 0 to 1, N is the total number of the resource taxa (Lanszki et al. [2019]).

Scharf et al. [2000] examined trophic-niche breadth on a ratio scale by determining changes in the range of relative prey sizes with increasing predator size. The prey size data can be converted to a ratio scale by dividing each prey size by its corresponding predator size, these can then be plotted against the predator size. The trophic-niche breadth at any given predator size can then be represented by the difference between predicted values of upper and lower bound regressions. By comparing the gradients of the upper and lower bound regression lines, we can see whether there is an increase or a decrease in ratio-based trophic niche breadth as predator size increases. If there is a significant difference in the gradients of the lines, we can conclude that there is a correlation between the ratio and predator size, whether this is positive or negative. Furthermore, divergent slopes indicate an increase and convergent slopes indicate a decrease in ratio-based niche breadth as predator size increases.

1.3.2 Regression Techniques

2 Preparing the Data

In order to use this data, I first had to ensure it was usable and suitable for my area of research. On initial inspection of the data set, by plotting the log of the predator lengths against the log of the prey lengths, I could see anomalies where the smaller predators were consuming much larger prey.

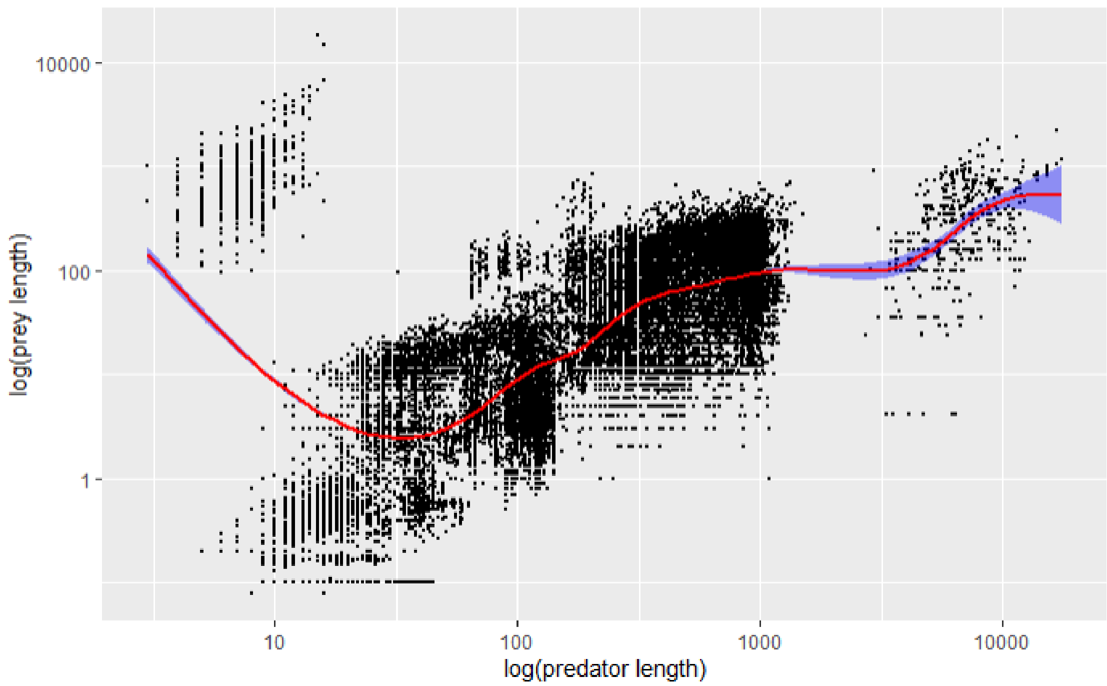

Figure 1: Graph showing the relationship between the log of predator length and the log of the length of their prey

Upon further inspection of the data set itself, I found that there were three different measurement units used for the lengths of the marine animals; these were micrometres (Âμm), millimetres (mm) and centimetres (cm). With a view to create accurate plots from this data set, I converted all length data into millimetres by multiplying the centimetre data by ten, and dividing the micrometre data by a thousand. The length data was then ready to be presented. As can be seen below, the anomalies are no longer present and a positive correlation between predator and prey lengths can be seen.

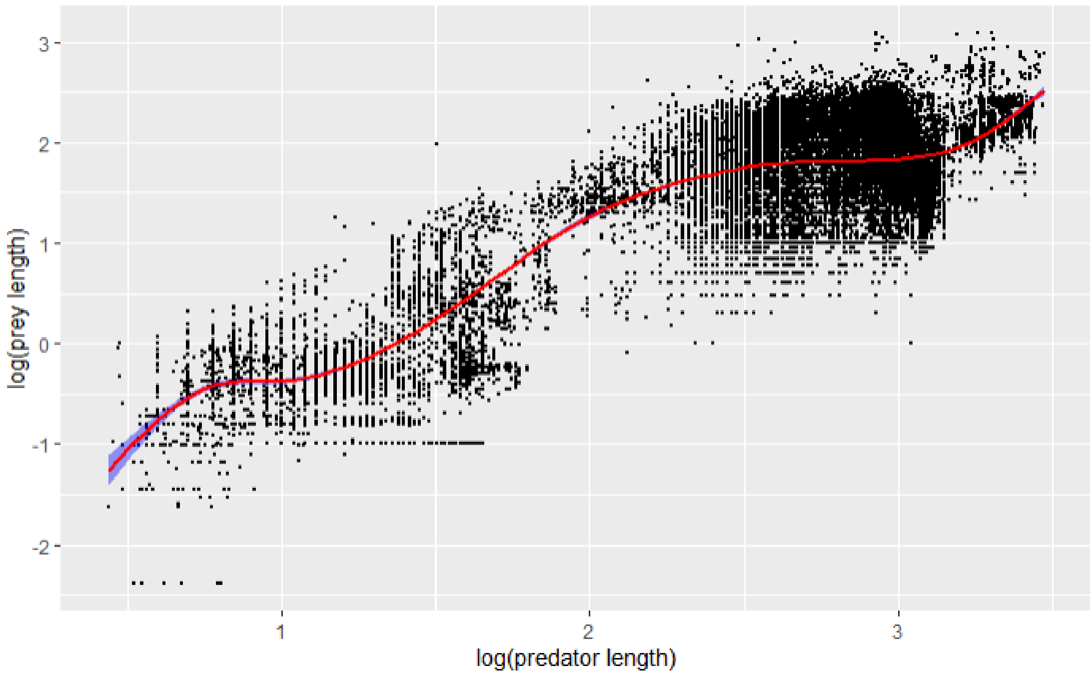

Figure 2: Corrected graph showing the relationship between the log of predator length and the log of the length of their prey

3 Results

3.1 Predator Length - Prey Length Patterns

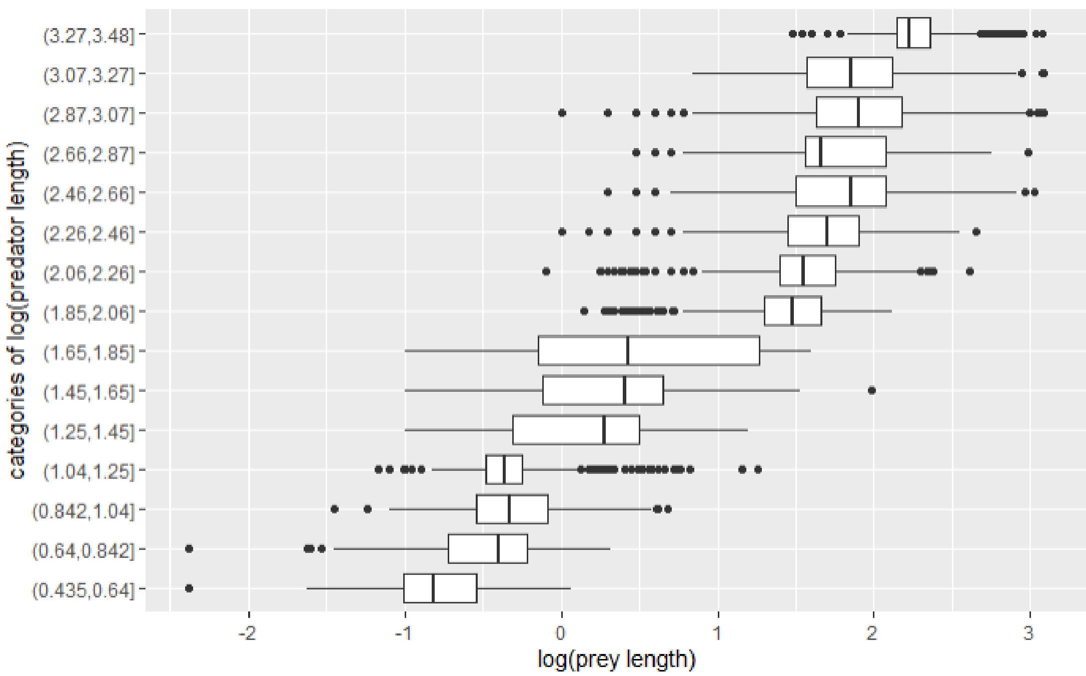

Figure 3: Box plot, using a log scale, showing the range of prey lengths eaten by different categories of predator lengths

3.2 Ratio-Based Trophic-Niche Breadth

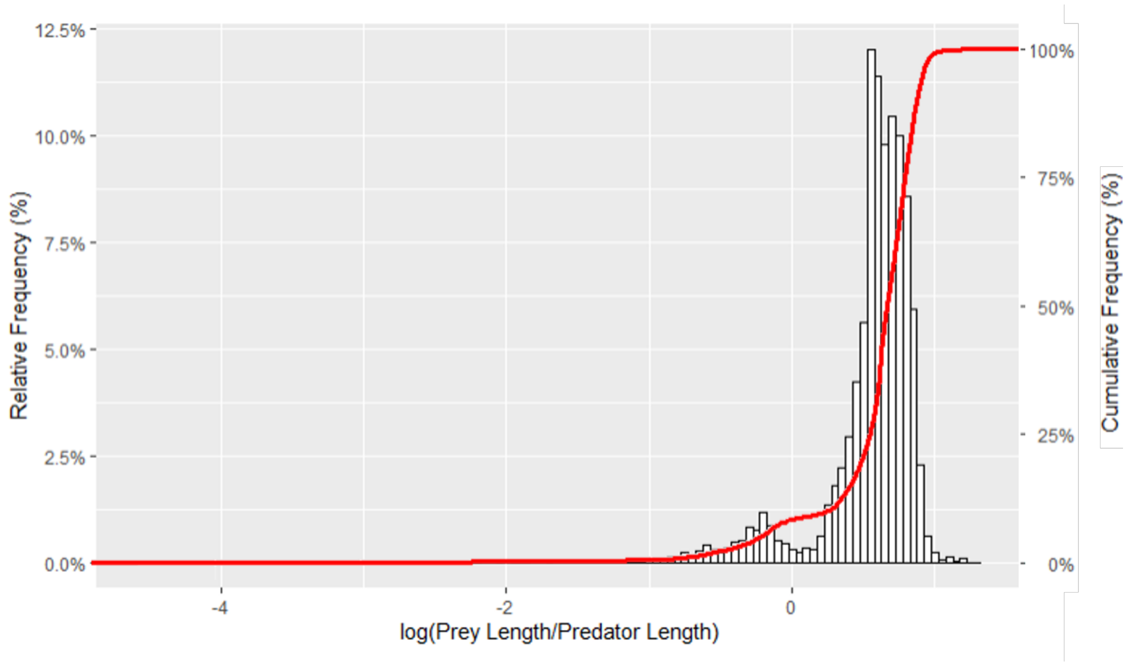

Figure 4: Histogram showing relative frequency distributions of prey size/predator size ratios consumed by marine fish predators and empirical cumulative distribution function shown in red

This shows that predators generally prefer to consume prey that are around 28% of their own size, with around 12.5% of their diets consisting of this prey size, and around 80% of their diets consisting of prey between 7% and 70% of their own size.

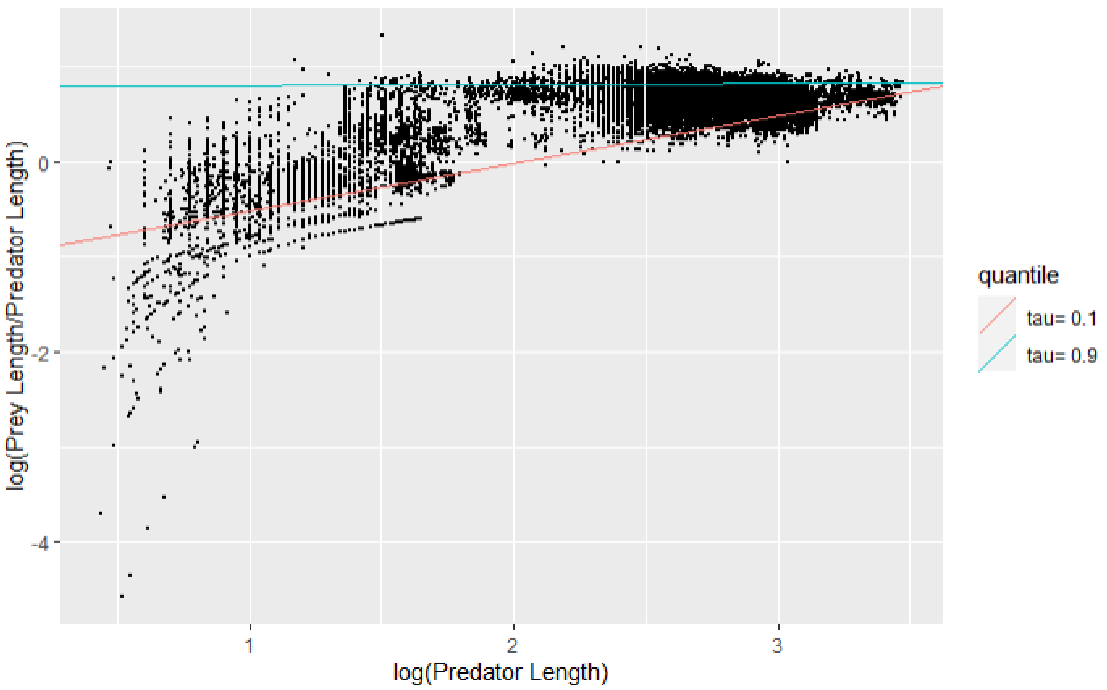

Figure 5: Scatter Diagram showing prey size/predator size ratios as a function of predator size and regression slopes for the 90th (in blue) and 10th (in red) quantiles.

The slopes of the regression lines in figure 5 converge to the same point, so, by the mathematics explained in section 1.3.1, the convergent slopes indicate a decrease in ratio-based niche breadth as predator size increases. Several previous studies have not found a change in ratio-based trophic niche breadth with predator size in general, and only found a "general trend to indicate a decrease in the breadth of relative prey sizes eaten with ontogeny" Scharf et al. [2000]. Due to these findings, I would like to look into species specific ratio-based trophic niche breadth, focussing on just 6 of the species in the data set of varying sizes. In order to choose predators of various sizes, I will look at a summary of the standard predator lengths, and choose those predators that have sizes corresponding to the minimum, 1st quantile, median, 3rd quantile and maximum.

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Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
 0.0    18.5    92.0   275.5   287.4 17490.0       1
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Figure 6: Summary of Standard Predator Lengths from R

I will therefore choose to focus on Paralichthys oblongus (450 entries), Pleuragramma antarcticum (856 entries), Thunnus obesus (1898 entries), Merluccius bilinearis (1389 entries) and Benthosema glaciale (75 entries).

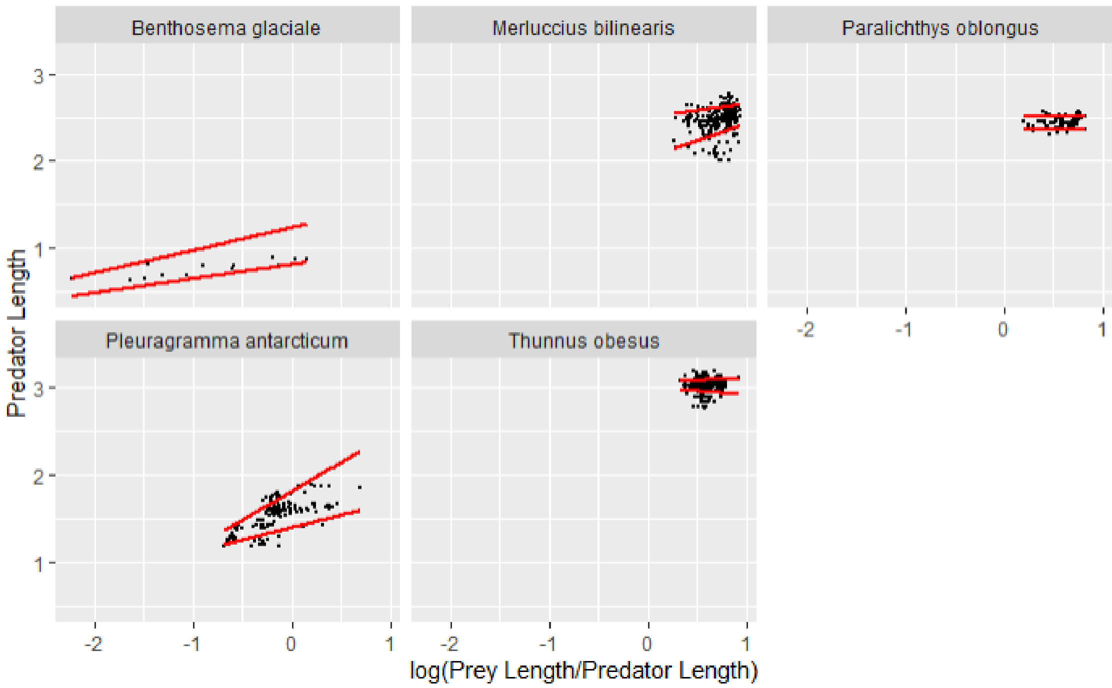

Figure 7: Scatter Diagram showing prey size/predator size ratios of 6 different predators as a function of predator size and regression slopes for the 90th and 10th quantiles.

For the smallest predator I looked at, Paralichthys oblongus, the regression lines corresponding to the 10th and 90th quantiles appear to be parallel, and therefore do not meet, meaning that, for the smallest predators, there is not correlation between ratio of prey size over predator size and predator size. The next predators I looked at were Pleuragramma antarcticum and Thunnus obesus, the regression lines in figure 7 for these predators appear to diverge, suggesting an increase in ratio-based trophic niche breadth as predator size increases. Penultimately, I looked at Merluccis bilinearis and found that, due to the regression lines converging, the ratio-based trophic niche breadth decreases as predator size increases; this follows the relationship found previously within the entire data set. The final, and largest predator I looked at was Benthosema glaciale, the regression lines for which appear to diverge, suggesting a positive correlation between ratio-based trophic niche breadth and predator size, however this is not what was expected. According to the results of Scharf et al. [2000] "the general trend was for smaller average-sized predators to show no significant change, while the largest predators tended to show a decrease in ratio-based trophic-niche breadth with increasing body size", which goes against my findings for Benthosema glaciale. The reason for this discrepancy could be the small sample size for the species, having only 75 entries in the Barnes et al. [2008] data set, meaning overfitting is likely to occur, reducing the accuracy of the results.

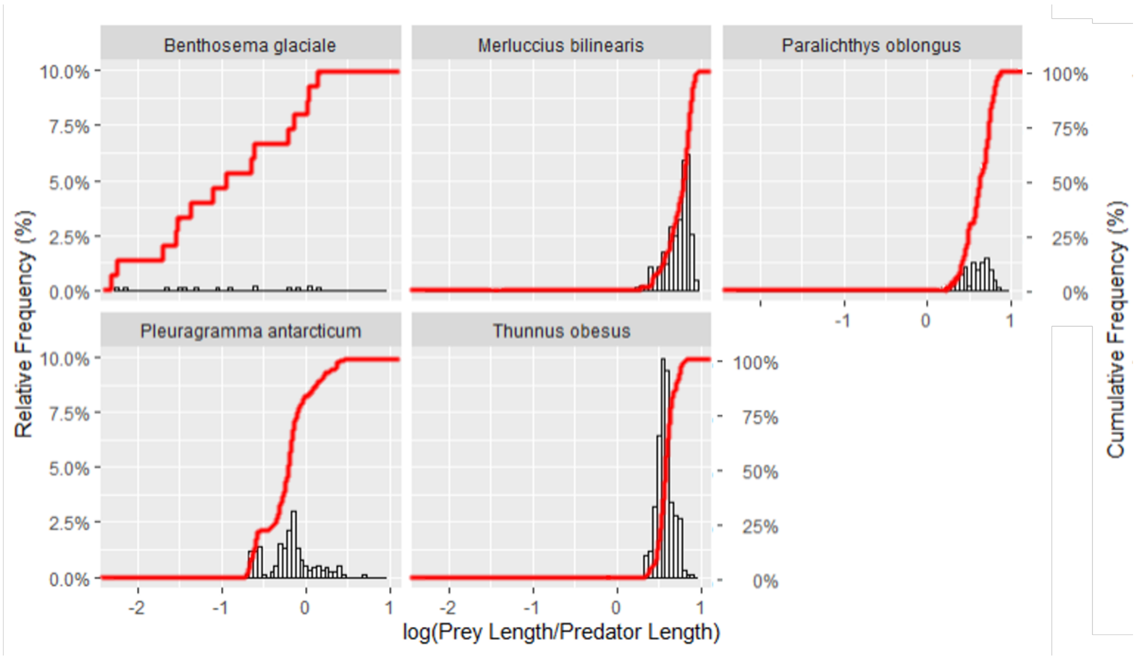

Figure 8: Histogram showing relative frequency distributions of prey size/predator size ratios consumed by 6 chosen predators and empirical cumulative distribution function shown in red

There appears to be some variation between the different predators in the relative frequency distributions of prey size/predator size ratios. For three of the predators I looked at (Paralichthys oblongus, Merluccius billnearis and Thunnus obesus), 100% of their diets consist of prey where $log(predatorlength/preylength)$ is between 0 and 1, meaning the actual ratio is between 1 (the marine animals are of the same size) and 10 (the predators are consuming prey $\frac{1}{10}$th of their size). However, from figure 4 it appears that Benthosema glaciale and Pleuragramma antarcticum actually consume prey larger than them; in particular the Benthosema glaciale eat prey up to 316 times larger, and the Pleuragramma eat prey up to 5.6 times larger than them. It is not clear how this can be possible and it may be by cause of problems within the data set.

4 Conclusions

List of Figures

References

Carolyn Barnes, DM Bethea, RD Brodeur, J Spitz, V Ridoux, C Pusineri, BC Chase, ME Hunsicker, F Juanes, A Kellermann, et al. Predator and prey body sizes in marine food webs: Ecological archives e089-051. *Ecology*, 89 (3):881–881, 2008.

Alain F Vézina. Empirical relationships between predator and prey size among terrestrial vertebrate predators. *Oecologia*, 67(4):555–565, 1985.

Gabriel C Costa, Laurie J Vitt, Eric R Pianka, Daniel O Mesquita, and Guarino R Colli. Optimal foraging constrains macroecological patterns: body size and dietary niche breadth in lizards. *Global Ecology and Biogeography*, 17(5):670–677, 2008.

Frederick S Scharf, Francis Juanes, and Rodney A Rountree. Predator size-prey size relationships of marine fish predators: interspecific variation and effects of ontogeny and body size on trophic-niche breadth. *Marine Ecology Progress Series*, 208:229–248, 2000.

Collins English Dictionary. Ontogeny definition and meaning: Collins english dictionary. URL https://www.collinsdictionary.com/dictionary/english/ontogeny.

Richard Levins. *Evolution in changing environments: some theoretical explorations*. Princeton University Press, 1968.

József Lanszki, Miklós Heltai, György Kövér, and Andrzej Zalewski. Non-linear relationship between body size of terrestrial carnivores and their trophic niche breadth and overlap. *Basic and Applied Ecology*, 38:36–46, 2019. ISSN 1439-1791. doi: https://doi.org/10.1016/j.baae.2019.06.004. URL https://www.sciencedirect.com/science/article/pii/S1439179118302354.