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Threshold Moderation Effects: How Body Length Modifies the Effect of Temperature on Parasite Abundance

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INTRODUCTION & AIM

Moderation effects are widely used to model the data in parasitology by including a multiplicative interaction component in the statistical model. The standard practice in empirical research is to examine the statistical significance of the interaction term in regression analysis, with a significant result typically interpreted as confirming an interaction effect. However, in some cases a statistically significant interaction term may correspond to significant effects only at specific moderator values, rather than across its entire range. Similarly, a lack of statistical significance in the interaction term does not preclude the possibility that the effect of the main explanatory variable varies significantly across levels of the moderator.

This study emphasizes a critical insight is that exclusive reliance on the statistical significance of the interaction term in regression models can lead to either an understatement or overstatement of interaction effects. To illustrate, we analysed one dataset of the population of *Planiliza haematocheila* based on analysis of the abundance of gill parasite, *Ligophorus llewellyni*, across localities in the Sea of Azov.

Through statistical models with interaction, our study suggests that host body size (host age) affects the dynamic in parasite abundance seasonally, depending from the temperature of the water.

MATERIALS & METHODS

Data collection. The database covered **535** individuals of pacific so-iuy mullet, *P. haematocheila*, sampled from localities in the Sea of Azov during 1998–2014. The size range for the body length of fish was **11.6–71.5** cm, median **37.9** cm. The **5444** specimens of *L. llewellyni* were collected.

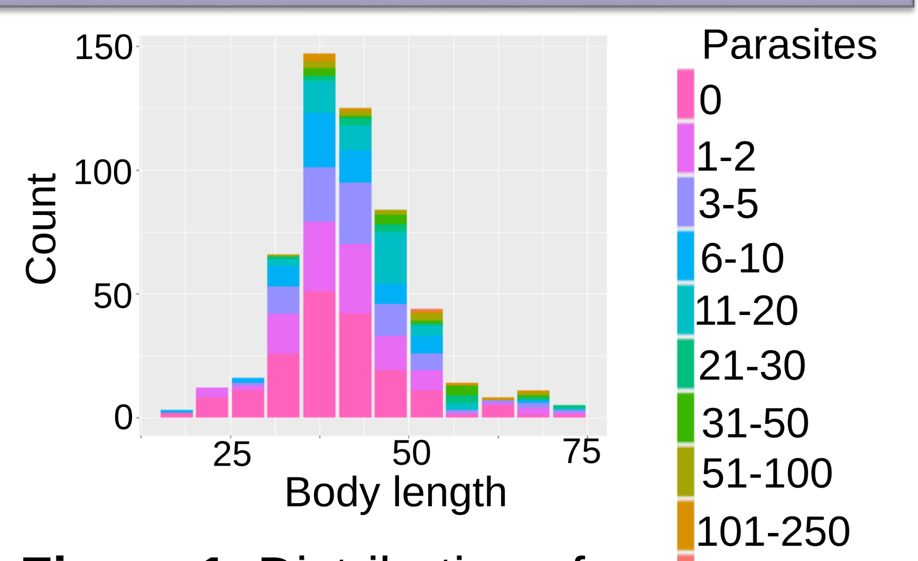

Figure 1. Distribution of *L. llewellyni* in the host.

Statistical analysis. Prior to statistical modelling, a data exploration was performed. For correct model processing, the parasite abundance data was tested to fit the negative binomial distribution (NBD) using Pearson's chi-square statistic. This test was done by applying Quantitative Parasitology 3.0 software. Since the original count data did not fit the NBD (p<0.001) it was square root transformed and rounded to the nearest integer. The newly obtained data showed a good fit to the NBD (p=0.0609) and was used for further analysis.

The host body size was included as a moderator variable because it is one of the most important trait driving parasite infections.

For modelling, the subsets of the data were used to generate a set of generalized linear models with NBD, using MASS::**glm.nb**:

$$(Abundance)^{1/2} \sim Temperature*Body\ length + Month*Body\ length$$

The model 1 included all data, models 2-4 based on subsets of the data. Statistical simulations were applied to depict some hypothetical outcome of results corresponding to different scenarios as it relates to whether parameter estimates suggest a significant main effect or moderating effect, namely, (**A**) no statistically significant main effect or moderating effect, (**B**) a statistically significant moderating effect but no significant main effect, (**C**) a statistically significant main effect and moderating effect, and (**D**) a statistically significant main effect but no significant moderating effect. The marginal effects approach was applied to each scenario. At the same time, the underrepresentation of individuals in the smallest and largest size categories impacted the performance of models.

RESULTS & DISCUSSION

Table. Summary of regression analysis. Grey cells indicate when the effect of predictors were significant (p<0.05); "+/-" the sign of the estimate in the model.

Model	1	2	3	4
Intercept	-	-	-	-
Temperature	+	+	+	-
Month	+	+	+	+
Body length (BL)	+	+	+	+
Temperature : BL	-	-	-	+
Month : BL	-	-	-	-
AIC	1951	1694	1549	1529

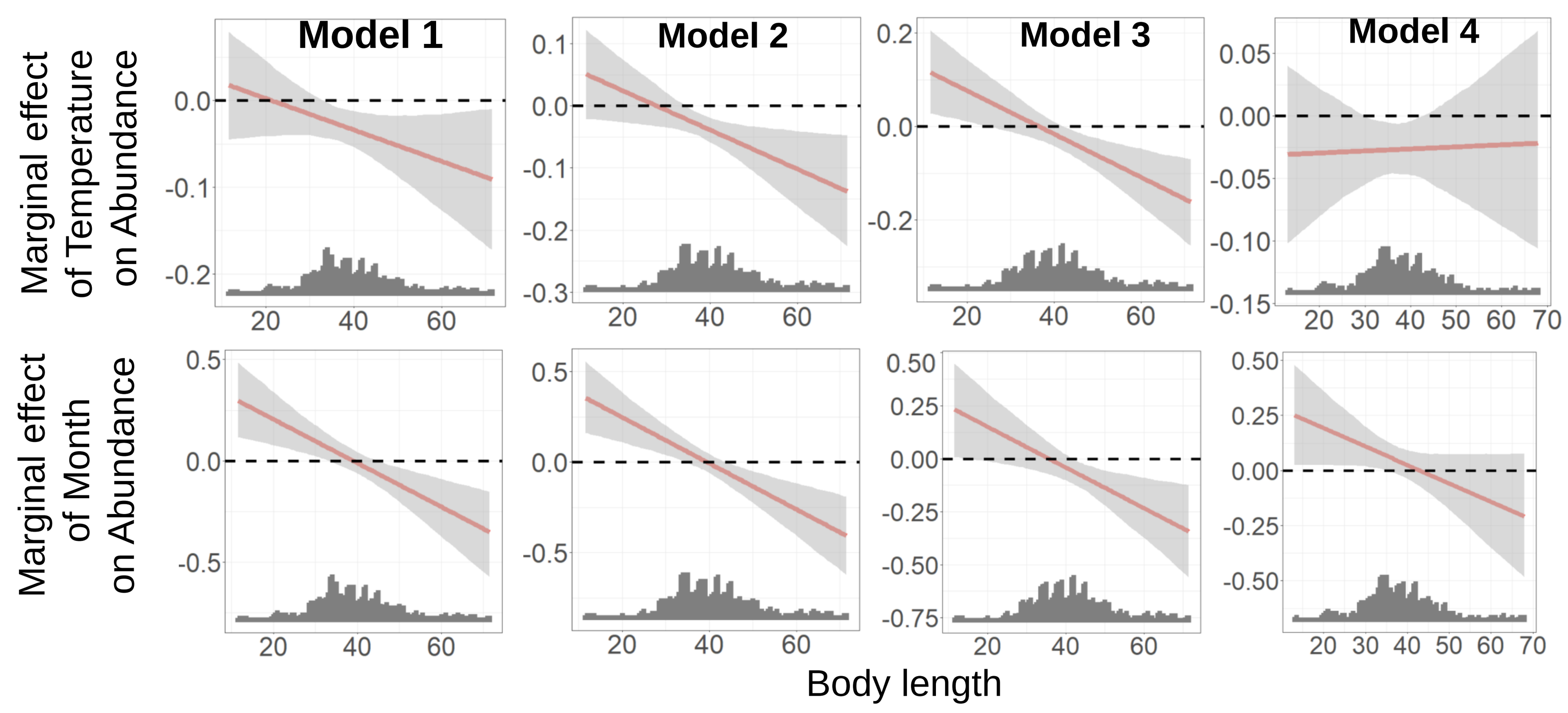

Figure 2. Marginal effect plots. Shown are 95% confidence bands and histograms of host body length.

Scenario A. For model 1, one may suggest that the body length does not influence the interaction between the abundance and temperature. However, the marginal effect plot showed the effect for values of body length in the range 34-71.5 cm, and this effect becomes stronger with increasing body length. Approximately 74% of the observations have values of body > 34 cm. Model 4 was based on subset that less the initial data on 18% and showed hypothetical result that the relationship between abundance and temperature does not change over host body size. **Scenario B**. Model 2 was based on subset that less the initial data on 15% and showed the results similar to model 1. **Scenario C**. For model 3, which was based on subset that less the initial data on 21%, one can pay attention to fish individuals that are especially small or notably large. Models 1-3 demonstrated that parasite abundance changes seasonally, especially for smaller and longer fish. **Scenario D**. For model 4, a potential hypothetical outcome allows to make inferences about hypothesized relationships for host size < 35 cm. From a host's perspective, individuals of different sizes vary in gill surface area available for attachment and in gill-ventilation hydrodynamics. For instance, older hosts generate a stronger gill-ventilation current than younger ones. This could negatively affect parasite abundance during warm periods; conversely, when temperatures decrease, parasite abundance may increase as host motility drops during the cold period. For smaller fish, however, this pattern is absent due to their more rapid somatic growth compared to older specimens during the warm period. This growth expands the surface area available for parasite attachment, thereby driving an increase in abundance.

CONCLUSION

For interaction models, the marginal effect plots provide valuable insights into how the interaction changes across different ranges of the moderator. In our example, warmer water temperatures drive different patterns in the relationship between parasite abundance and fish length.

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