

Red hue in Tadpole tails decreases based on predator presence

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Introduction

Plasticity refers to an organism's ability to display differential phenotypes according to its environment (Xuea and Leibler 2018). Such capability of change and adaptation allows for many organisms to have higher fitness. Many organism's physical environments continuously vary due to climate change, which leads to higher temperatures and elevated sea levels. Furthermore, organisms must also display plasticity in the presence of predators for survival. An organism's change in shape and color is typically linked to predator-induced phenotypic plasticity (Arnett and Kinnison 2017). Predation risk becomes higher if organisms do not adjust to different predatorial signals present in their environment. Adjustment to these signals can be size, as a smaller size could allow an organism to escape quickly or color to decrease predator visibility. Further, predator-induced phenotypic plasticity has been studied in tadpoles, specifically in *Dendropsophus ebaraccatus*. Scientists who collected data from tadpoles in ponds near Gamboa, Panama examined the plasticity of tadpoles from shaded environments containing predators and compared them to their study ponds (Touchon and Warkentin 2008). This allowed them to analyze the predator's likelihood of consuming an egg from a particular environment. Touchon and Warkentin mainly observed the phenotypic differences shown on the tails of the tadpoles, not specific color quantities. Through detailed examination of Touchon and Warkentin's research, we investigated how predators influence the value of red color on the tails of tadpoles, *Dendropsophus ebaraccatus*. Hence, we aimed to determine if the average red value was influenced by predators through image analysis. Based on this information, we hypothesized that if tail color is plastic within the tadpoles, the tadpoles with redder, thus darker, tails will be more prevalent in an environment with predators. Thus, their tails will have an increased average red value. The darker color would allow the tadpoles to decrease their visibility to predators and become less likely to be consumed compared to tadpoles with more transparent, less red tails. Since the red color is similar to foliage and sludge found at the bottom of the ponds, the tadpoles will be able to camouflage themselves and potentially avoid any ambush attacks. To test our hypothesis, we compared the average red color value of those tadpoles in the presence of a dragonfly predator and to a control group

Methods

The goal of Touchon and Warkentin's experiment was to investigate phenotypic plasticity in tadpoles of tree frogs (*Dendropsophus ebraccatus*). Specifically, they were looking at how the tadpoles develop under control conditions, with dragonfly predators, or with fish predators. Their methods consisted of taking seven mating pairs of the tree frogs from the Quarry Pond in Gamboa, Panama. Then, mating pairs were placed in plastic bags with water, and they were left to breed overnight. There were 2100 eggs, and they were returned to the pond the following day. A couple of days later, they collected 20 of each predator from the same pond. Then, the tadpoles were divided into groups containing 20 tadpoles in each container; the container had another section with either a predator or no predator for the control group. They documented the phenotypes of the tadpoles by taking photographs of them, in groups of 5. For conducting our experiment, we measured average redness in tadpole tails in an insect predator environment compared to the control environment. We looked at 40 tadpoles from each environment. To prevent measurer bias, we divided the image analysis evenly to ensure not just one person was measuring the control, for example. Using the software ImageJ, combined with the tadpole images given to us from the experiment above, we were able to analyze average redness. First, we measured the tails. We defined the tail as the distance from the base of the iridescent mouth bubble to the tip of the narrow tail tip (Figure 1). Then, we divided the length in half for a controlled area (Figure 1). By doing this, we determined the area of the tail proportional to body size. We outlined the second half of the tail using the "polygon" tool, and then we used this area to measure the RGB, specifically, the average red value. Lastly, we conducted a one-tailed t-test

comparing mean values of the control group to the insect predator group.

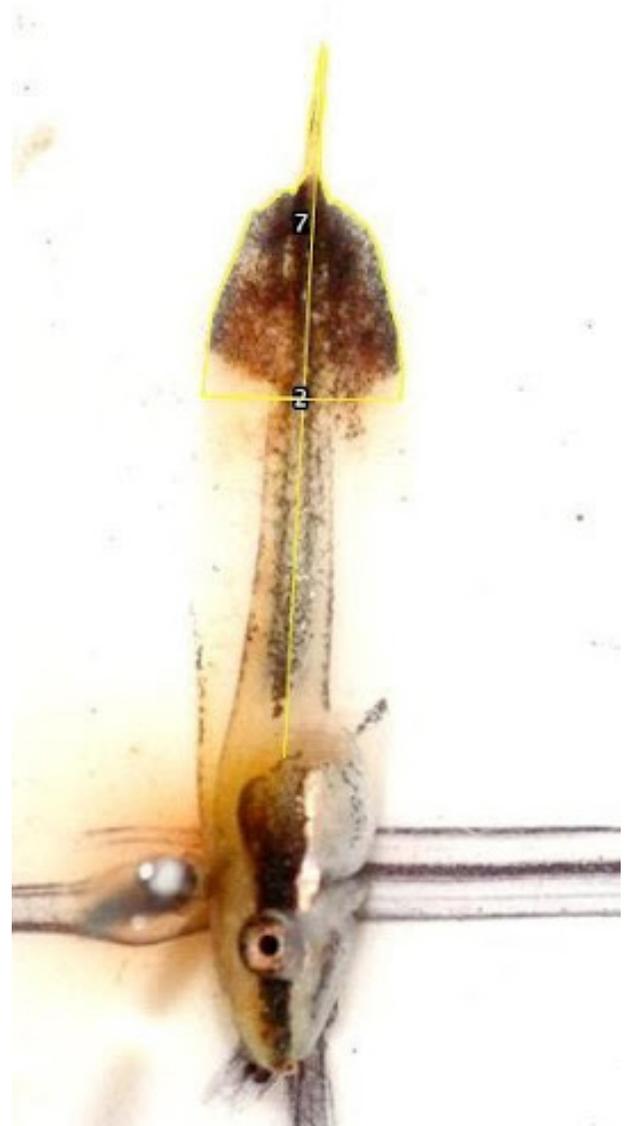


Figure 1:

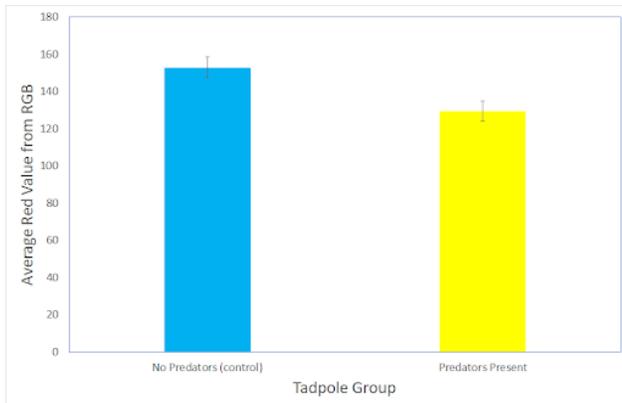
Measurement of the tail. Line 2 represents the length of the tail. The halfway point of the tail is where the 2 is marked, and measurement 7 represents the area that was used to measure the colored part of the tail.

Results

Our data shows that the average red value decreased when the tadpoles were present with insect predators (Graph 1). Average red value was highest when tadpoles were not present with predators (Graph 1). The mean red value for the control group was 152.91, and the mean value for the insect predator group was 129.36. Our t-test determined that there was a significant difference between the control group and the predator group ($T78 = 3.069$, $p < 0.0015$, et al., 2014). These neurodegenerative diseases, along with some other representative examples, are showcased in Figure 3a.

Figure 1:

Average Red Color Present on Tadpole Tails in Environments with Predators and without Predators: The x-axis represents the types of tadpole groups ($n=40$). The blue bar represents the No Predators (control) tadpole group, and the yellow bar represents the Predator tadpole group. The y-axis represents the average red value from RGB measurements,



with 255 being the reddest value and 0 being no red present. The standard error for the blue bar is 5.45, and the standard error for the yellow bar is 5.42.

Discussion

We report a significant difference in red color on tadpole tails in *D. ebraccatus*. Specifically, we observed a higher average red value on the tails of the tadpoles in the control group, and a lower average red value on the tails of the tadpoles in the group containing dragonfly predators. Although significant, these data do not support our hypothesis, as the tadpoles in the predator-laden environment did not have tails with a higher average red value as predicted. However, our data does support the presence of predator-induced phenotypic plasticity in these tadpoles, as the difference in tail color based on predator presence was significant. Our results align with previous studies that have demonstrated that such a shift in phenotype in the presence of a predator is due to plasticity (Arnett and Kinnison 2017).

Discrepancies between our results and our hypothesis may have been due to improper color analysis; average redness may have not been the best measure. The tadpole tails in the predator-laden environment presented a reddish, brownish tail color, whereas the control group tails presented a brighter and lighter red orange color. Because of the color composition of brown, the RGB values may have been skewed, yielding semi-equal quantities of each color, and in turn, decreasing the average red value. Furthermore, the vibrancy of the tail color may have skewed the average red value. The control group tails were much more vibrant and had higher average red values. This indicates that vibrancy may equate to a purer red color. In a study investigating predator-induced color change and camouflage in horned ghost crabs, *Ocypode ceratophthalmus*, researchers observed changes in both color and saturation, a measure of brightness (Stevens et al. 2013). Saturation may be more important in color analysis than previously thought. Thus, in the future, measuring saturation may be a better way to analyze the chromatic differences in the tails of *D. ebraccatus* tadpoles.

Although this plastic trait may be beneficial in predator avoidance, it may have negative implications in energy and resource allocation, as predator-induced phenotypic plasticity has been shown to be quite costly. McCollum and Leimberger (1997) demonstrated how costly this plasticity can be by providing evidence of tadpoles only showing a color change in a predator-laden environment when they were well fed. This evidence demonstrates that plastic traits are so costly that they require a surplus of resources. If *D. ebraccatus* tadpoles were to not require a surplus of resources to induce this plasticity, they may suffer stunted growth if energy is allocated to plasticity instead of development. It is unknown whether *D. ebraccatus* tadpoles allocate their energy and resources in a similar way, and so, this would be a worthwhile avenue for future research.

Moreover, this study has important applications in other areas of research, specifically, amphibian conservation. Plasticity in tail color may have benefits in protection from harmful UV radiation in *D. ebraccatus* tadpoles. UV radiation is known to be detrimental to frogs, as a review documenting amphibian decline cited numerous cases where increased UV radiation has caused stunted growth, malformations, and slowed development (Alton and Franklin 2017). As tadpoles are at the most critical post-embryonic developmental stage, it can be assumed that UV

radiation is most detrimental for them. Having plasticity in tail color can be extremely beneficial in these cases, as a darker tail yields a higher melanin content, equating to increased UV radiation protection. This trait, although currently present for predator avoidance, may be co-opted for UV radiation protection in the future, especially as the ozone layer continues to thin. Future studies should investigate the differences in UV ray protection between tadpoles reared without predators and tadpoles reared with predators to determine if the co-option of this trait for UV ray protection could be a possibility for *D. ebraccatus*.