Frequency-Dependent Batesian Mimicry in Northern Water Snakes (*Nerodia sipedon*) and Eastern Copperheads (*Agkistrodon Contortrix*) in Sympatric and Allopatric Regions of the Hudson Valley in New York State

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Abstract

Species that are subjected to become preyed upon have a chance to evolve traits of Batesian mimicry to protect them from predation. The purpose of this study was to test the prediction that predators are more likely to avoid the mimics of perceived toxic species, this study focused on northern water snakes (mimic) and eastern copperheads (model). Throughout this study, Batesian mimicry was investigated using clay polymer plasticine replicas similar to the ones used in the study done by Pfenning (2001). In Batesian mimicry, the mimics level of protection should break down where the model is absent because predators in such areas would not be under selective pressure to avoid the model. Therefore, exposing replicas in sympatric and allopatric regions of New York State would provide reasoning that Batesian mimicry is evolving in sample species. Mean predation rates demonstrate a difference between the two regions however slight, with the results not being statistically significant. These results suggest that Batesian mimicry may be evolving between northern water snakes and eastern copperheads although bigger sample sizes and more studies would need to be conducted to prove these findings.

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Being eaten is inarguably one of the most serious threats that any organism faces during its lifetime. As such, a wide variety of protective adaptations have evolved to help organisms mitigate the chances of being attacked and eaten, one of the most interesting of which involves the art of deception when harmless, palatable species resemble harmful, non-palatable species causing potential consumers to misidentify and avoid them. Henry Walter Bates (1862) first described this mimicry phenomenon when he observed that a palatable species of butterfly appeared to reduce its risk of predation by resembling other non-palatable species in the same area (Bates, 1862; Wickler 1968; Edmunds 1974). Since then, this type of mimicry, which has come to be known as Batesian mimicry, has been described in many organisms including plants, animals, and fungi where harmless, palatable species (i.e., the mimics) increase their fitness and chances of survival by evolving deceptive characteristics that make them resemble other local harmful, unpalatable species (i.e., the models). In these relationships, when both the mimic and the model exist in sympatry, it can be predicted that both are afforded protection from predation, whereas the mimic's level of protection should break down where the model is absent because predators in such areas would not be under selective pressure to avoid the model. Pfennig (2001) tested this prediction in a study investigating whether predators are more likely to avoid the mimics of venomous snakes in areas where both are present by exposing plasticine replicas of nonvenomous scarlet king snakes (*Lampropeltis triangulum elapsoides*), which mimic deadly eastern coral snakes (*Micrurus fulvius*), to natural predators (e.g., black bears, foxes, raccoons, etc.) along lower latitudinal and altitudinal transects in North Carolina where both king snakes

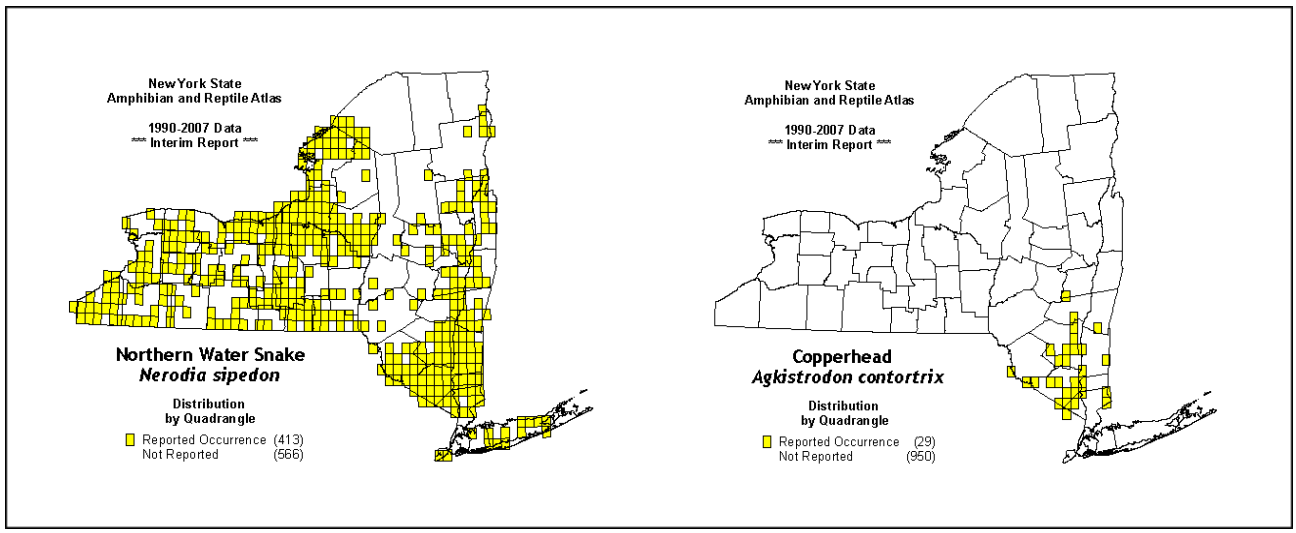
and coral snakes were present (i.e., sympatric areas) and higher latitudinal and elevational transects where coral snakes were absent (i.e., allopatric areas). They found that the frequency of predator attacks on king snake mimic replicas was significantly lower in sympatric regions where coral snakes were present than in allopatric regions where they were absent. Furthermore, they found that the attack frequencies increased with latitude and altitude as coral snake abundance and the degree of mimic camouflage decreased. Thus, their findings clearly support the prediction that the protection benefits afforded to mimics are locally dependent on the presence and abundance of the model (Pfennig, D. W., Harcombe & Pfennig, K. S., 2001).

That said, a very similar relationship that has yet to be studied in detail involves the venomous eastern copperhead (*Agkistrodon contortrix*) and the nonvenomous northern water snake (*Nerodia sipedon*). Both snakes are commonly found throughout the central and eastern United States where they sympatrically inhabit rocky wooded areas adjacent to streams, lakes, and rivers, and both snakes exhibit a similar coloration pattern which is indicative of a Batesian mimicry relationship in which selective pressures have resulted in the harmless northern water snakes becoming mimics of their harmful neighbors to reduce their predatory risks (Mengak, 2012). In addition, as was the case in North Carolina with king snakes and coral snakes, the contiguous geographic distribution of northern water snakes and eastern copperheads in sympatric and allopatric regions of the Hudson Valley in New York State lends itself to replicate the methods of Pfennig (2001) to test the prediction that a mimic's protective benefits are greatest in sympatric areas where their model is present. Thus, because both species are commonly found in the lower Hudson Valley and only northern water snakes are found north of Albany, these regions can be considered sympatric and allopatric respectively (Figure 1) and the procedures of Pfennig (2001) can be replicated to the to shed light on the degree to which

northern water snakes are protected from predation by being mimics of eastern copperheads (Howington, 2004; Mengak, 2012).

Figure 1

Geographic distribution of venomous eastern copperheads (Agkistrodon contortrix) and nonvenomous northern water snakes (*Nerodia sipedon*). *Maps provided by NYS DEC.*



Purpose

The purpose of this study was to test the prediction that predators are more likely to avoid the mimics of venomous snakes in areas where both are present by exposing plasticine replicas of nonvenomous northern water snakes (*Nerodia sipedon*)), a presumed mimic of the eastern copperhead (*Agkistrodon contortrix*), to natural predators along transects in the Hudson Valley region of New York State where copperheads are present (i.e., sympatry) and where they were absent (i.e., allopatry).

Methods and Materials

Study Sites

Kelders Farms (41°47’20’’ N, 74°15’31’’ W) is a family farm located in the Hudson Valley in Kerhonkson, NY bordering the Rondout Creek. Kelders Farms is approximately 1.151 km in width with Rondout Creek being approximately 0.063 km in length. Kelders Farms served as the sympatric research site where both the mimic, northern water snakes, and their model eastern copperheads coexist. Hunter Mountain (42°11’10’’ N, 74°13’49’’ W) is a hiking and ski area in the Hudson Valley in Greene County New York. Hunter Mountain served as the allopatric research site where only the mimic northern water snakes reside in relation to the absence of their model, the eastern copperhead.

Snake Replicas

A total of 320 snake replicas were constructed by molding nontoxic plasticine clay into cylinders measuring approximately 20 cm (*l*) X 4 cm (*d*) to resemble the typical body size of adult water snakes and copperheads that will be threaded onto S-shaped wires to resemble the typical body shapes of snakes. Then, 160 of the replicas were painted with beige crossed lines to resemble a typical northern water snake. 160 were not painted, remaining brown to resemble several abundant nonvenomous species found throughout the regions to serve as controls.

Transects

Snake replicas were arranged in pairs (doublets) containing one northern water snake replica and one brown control snake replica along 1 transect in natural habitats of each of the 16 study sites. Each transect contained ten doublets that would be spaced at 50-meter intervals with two meters between the replicas in each doublet that were then anchored to the ground with 1.5 meters of fishing wire connected to a metal stake to prevent predatory removal.

Data Collection

All replicas were collected four weeks after they were placed in the field and returned to the lab where they were scored for attack by a person who had no knowledge of where the replicas were placed. A replica was only considered to have been attacked if it contained clear evidence of teeth or claw marks from a carnivorous predator. Furthermore, impressions from rodents, insects, or natural inferences such as rainfall were excluded from the analysis because they do not represent threats to living snakes, and missing replicas were noted but not counted as predatory attacks.

Results

Collection Analysis

After four weeks, 231 replicas had been collected. A total of 132 replicas had been labeled as attacked which accounted for approximately 41.25% of all replicas placed (320) and 57.1% of all replicas collected. Attacks in sympatry were less than in allopatry with 51 (31.88%) replicas attacked, 31 (19.38%) being plain brown and 20 (12.5%) being painted. Sympatric attacks spanned across only seven transects with transect eight yielding zero attacks. Attacks in allopatry were more than in sympatry with 81 (50.63%) replicas attacked, 40 (25%) being plain brown and 41 (25.63%) being painted. Allopatric attacks spanned across all 8 transects.

Figure 2

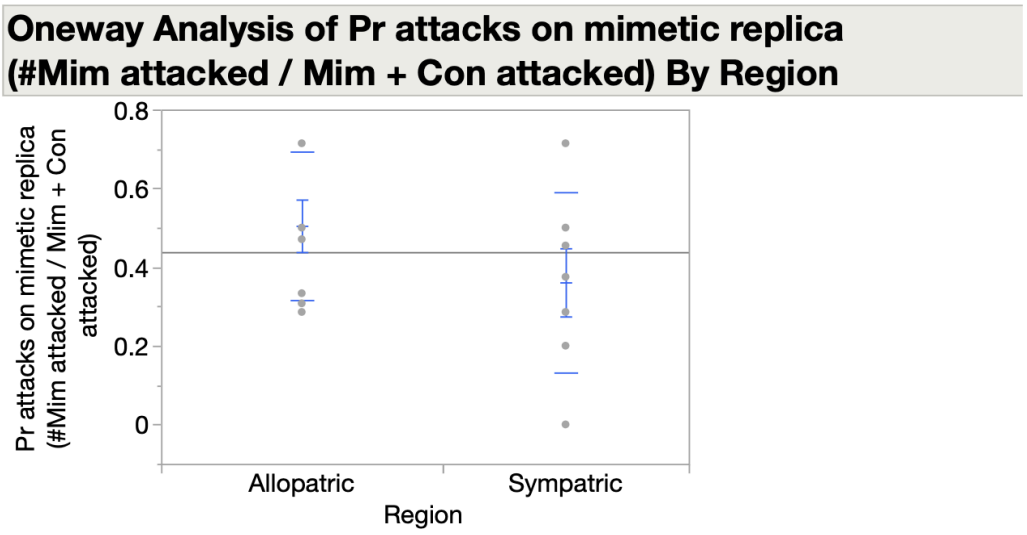


Table 1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%
Allopatric	8	0.5050232	0.1886405	0.0666945	0.3473158
Sympatric	7	0.3613636	0.2291243	0.0866008	0.149459

Figure 3

t Test

Sympatric-Allopatric
Assuming unequal variances

Difference	-0.14366	t Ratio	-1.31428
Std Err Dif	0.10931	DF	11.70012
Upper CL Dif	0.09518	Prob > |t|	0.2139
Lower CL Dif	-0.38250	Prob > t	0.8930
Confidence	0.95	Prob < t	0.1070

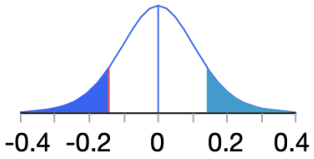


Table 2

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Allopatric	8	74.500	64.000	9.31250	1.170
Sympatric	7	45.500	56.000	6.50000	-1.170

Discussion

Overall, the predation rates of the clay mimic replicas in allopatric and sympatric regions of the Hudson Valley were as expected. Our data indicates that the predation rates on the replicas painted the pattern of the non-toxic northern water snake were higher in allopatry than in sympatry, however slight (figure 2). A study by Bates, H. W. (1862) discovered a specific evolutionary defense mechanism in Amazonian butterflies where a nonvenomous species would evolve through natural selection to resemble the appearance of a similar venomous counterpart which would later be known as Batesian Mimicry. Additionally, a study by Pfennig, D et al. (2001) discovers the existence of Batesian Mimicry in the non-toxic scarlet king snake in relation to its model, the venomous coral snake, using plasticine replicas of the snakes to gather predation information and prove that Batesian Mimicry is influencing predator's decisions to attack the scarlet king snake pattern differently in allopatric and sympatric regions of North Carolina. The results from this study showed a similar reaction to those in Pfennig, D et al. (2001) with the predator's predation of the northern water snake pattern being influenced by residing in an allopatric or sympatric region of the northern water snake and eastern copperhead population zones.

This study was the first investigation of Batesian Mimicry within northern water snakes and eastern copperheads. The proportion of attacks on the mimetic pattern in sympatry, 0.36, was less than that in allopatry, 0.5 (Tabel 1). Although there was a trend for fewer attacks in sympatry then in allopatry, this was not significantly significant with $p > 0.2$ from both tests (figure 4). Replicas being lost and not counted towards the total number of collections may have affected the total number of attacks. Additionally, a storm prior to collection of the sympatric models

washed away parts of paint and clay, potentially covering up/ deteriorating attack marks that may have existed.

Conclusions

Tests on Batesian mimicry within northern water snakes and eastern copperheads residing in sympatric regions of the hudson valley yielded lower attacks compared to its allopatric counterpart. These results show that this difference was not statistically significant, this requires further research to determine if Batesian mimicry is evolving in northern water snakes. Future research should include an increase in sample size of both the mimic and model replicas to provide more data and excuse unneeded environmental impact. Additionally, more spacing between transects in larger sites would add to diversity in predators, with different sites residing in varied elevations similar to Pfennig, D et al. (2001).

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