Moth Wing Shape and Size as a Defense Strategy Against Bats

Neeka Sewnath, Chris A. Hamilton, Geena M. Hill, Akito Y. Kawahara

Department of Biology, Florida Museum of Natural History, University of Florida, Gainesville, FL

Introduction

Moths and bats have been engaged in an aerial warfare for more than 60 million years. It has been hypothesized that moth wings, especially their elaborate shape and large size, may serve as a defense against bats. Preliminary studies in the PI's lab show that wild silk moths with large wings and twisted tails produce a wing-like fluttering when in flight which helps to divert bat attack (Barber et al., 2015). Wild silk moths (family Saturniidae) are an ideal group to test whether shape and size are anti-bat strategies because the family is diverse taxonomically (van Nieukerken et al., 2011)) and morphologically, particularly at the apices of the hindwings (Ylla et al., 2005). Despite the diversity of shape and size, little is known as to why they have evolved such variable forms.

Hypothesis

The project aims to answer two fundamental questions related to the bat-moth arms race within the Saturniidae:

1) Are particular areas of a moth's wing more prone to bat attack?

2) Are such areas, if present, elaborate in some taxa (in the form of ornamentation, tails, lobes, etc.)?

We hypothesize that bat attacks will occur on the hindwings more than the forewings since this is where most shape variation appears to occur.

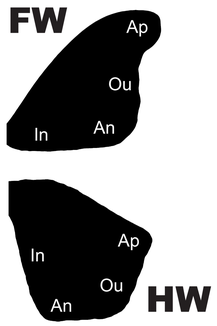
Methods

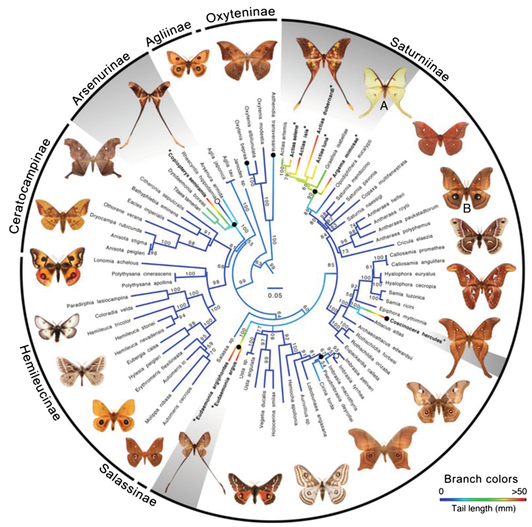
- Used moth specimens found in the FLMNH collection from across the family Saturniidae
- Wing damage was evaluated to determine whether the damage was likely to have occurred due to bat predation
- Damage was assessed based on prior knowledge of bat bite damage seen during behavior trials
- Selected taxa were restricted to the subfamily Saturniinae
    - ≥ 3 damaged specimens per species
    - total of 110 specimens across three tribes, 9 genera, and 15 species
- All females were emitted from the analysis to account for sexual dimorphism within species
- "models" for each species were created to compare how wing shape is affected by bat bites
    - five specimens with no damage
    - represented "best case" undamaged mean wing shape
- Each specimen was photographed using a standard Lepidoptera photography protocol
- Broadly, bat bite location was scored based on occurring on the forewing (FW) or hindwing (HW)
- Specifically, location was broken down into four main wing regions for both FW and HW:
    1) Apex (Ap) 2) Outer Margin (Ou)
    3) Anal Angle (An) 4) Inner Margin (In)
- To determine whether bat bite location was statistically occurring in any area more frequently than another, Generalized Linear Mixed Model analyses (glmm) were applied in SAS University Edition (SAS Institute, Cary NC)
    - used 9 binary response variables
    - FW.In was not used because no bites occurred in any of our specimens

Results

We find that position of the bat bite is significant across our analyses, with the hindwing attracting more bat bites than the forewing (Pr>F; <.0001). Additionally, when bats attack the hindwing, they bite the Outer Margin (HW.Ou) area more frequently than any other area.

position of bat bite	Ap	Ou	An	In
FW	24	19	13	0
HW	15	52	21	3





Conclusions

Large species of Saturniidae tend to possess tails extending from the hindwing. Tails have evolved at least 4 times throughout the evolutionary history of the Saturniidae (Barber et al., 2015). Our data supports our hypothesis that particular areas of a moth's wing are more prone to bat predation. Because of this, we conclude that bat predation has provided a strong selective pressure that has driven moth wing shape evolution (in particular the evolution of tails – known anti-predator mechanisms), providing bats a target and allowing for moths to escape and survive.

References

Barber, J., Leavell, B.C., Keener, A.L., Breinholt, J.W., Chadwell, B.A., McClure, C.J.W., Hill, G.M., Kawahara. A.Y. (2015) Moth tails divert bat attack: Evolution of acoustic deflection. *PNAS*. **112(9)**: 2812-2816.

Bonhomme V, Picq S, Gaucherel C, Claude J. (2014). Momocs: outline analysis using R. *Journal of Statistical Software*. **56(13)**: 1-24.

van Nieukerken, E.J. *et al*. (2011) Order Lepidoptera Linnaeus, 1758. In: Zhang, Z.-Q. (Ed.), Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. *Zootaxa*, **3148**: 212–221.

Ylla, J., Peigler, R.S. & Kawahara, A.Y. (2005) Cladistic analysis of moon moths using morphology, molecules, and behaviour: *Actias* Leach, 1815; *Argema* Wallengren, 1858; *Graellsia* Grote, 1896 (Lepidoptera: Saturniidae). *SHILAP Revista de Lepidopterología*, **33**: 299-317.