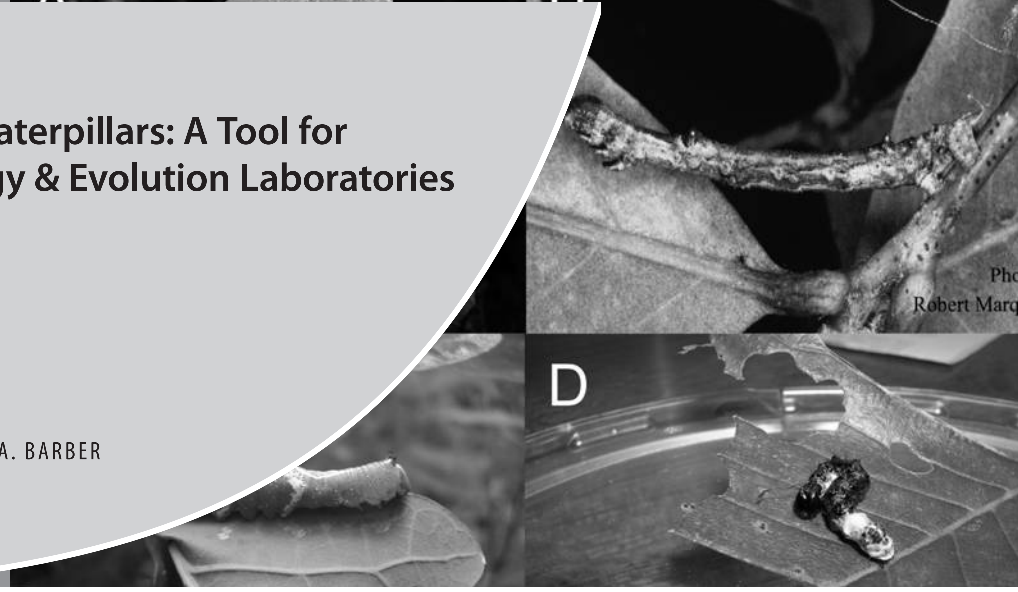
INQUIRY & INVESTIGATION

Clay Caterpillars: A Tool for Ecology & Evolution Laboratories



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Abstract

I present a framework for ecology and evolution laboratory exercises using artificial caterpillars made from modeling clay. Students generate and test hypotheses about predation rates on caterpillars that differ in appearance or "behavior" to understand how natural selection by predators shapes distribution and physical characteristics of organisms.

Key Words: *Behavior; foraging; herbivore; inquiry; predation.*

Ecological and evolutionary processes determine the patterns and organization of communities of organisms around us. Yet these processes can be challenging to explore in a classroom setting because they often take place within large spatial and long temporal scales. Here, I present a framework to explore both ecological and evolutionary patterns using clay models of caterpillars, placed outdoors to experience "predation" from birds.

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A central objective of ecology is to explain the abundance and distribution of organisms through their interactions with the environment and other organisms. One of the most important of these interactions is predation, whereby one organism consumes another. A species is likely to be more abundant in a habitat where it is less likely to be eaten. Predation can also be a strong form of natural selection. For example, habitat selection is often a genetically influenced behavioral trait. Alleles that cause prey to choose high-predation habitats will not last long in a population. But alleles that reduce the likelihood of getting eaten (because the potential prey go where the predators do not) will be passed on by their not-eaten owners. Similarly, physical characteristics that reduce predation rates on a species will also be passed on to progeny.

Caterpillars, the plant-eating larvae of moths and butterflies, must cope with high levels of predation (Bernays, 1997). They are often important food resources for songbirds (Holmes et al., 1979). Caterpillars avoid predation in two ways: physical defenses and camouflage. Many caterpillars are covered with stinging spines or hairs that discourage birds from eating them (Figure 1A; Whelan et al., 1989). Others contain toxic chemicals that make birds sick. These toxic chemicals are usually produced by caterpillars' host plants; caterpillars sequester them so that they become concentrated within the insects' bodies. Monarch butterflies and caterpillars are famous for the cardenolides they sequester from milkweed plants that elicit vomiting in birds. Like poison dart frogs in the tropics, chemically defended caterpillars often have bold, colorful patterns to warn would-be predators to avoid them, known as aposematic coloration.

Camouflaged caterpillars use colors and patterns to blend in with leaves, branches, or other backgrounds to hide from predators. Some brown and gray species rest on branches in plain view of birds, but stretch out to expertly mimic small twigs (Figure 1B). Others are mottled in green or brown and sit along the very edge of the leaf they have been eating. The result is a strong resemblance to a tattered, necrotic leaf edge (Figure 1C). Amazingly, some caterpillars even "hide" in plain view by resembling bird droppings (Figure 1D)!

The low mobility of many caterpillars means that they are limited in their ability to choose a habitat and thus rely on their ovipositing (egg-laying) mothers to place them in a good area to complete their growth and metamorphoses. Students can play the role of these mothers or choose the appearance or "behavior" of caterpillars made out of modeling clay to explore in a guided, inquiry-based fashion how predation affects the distribution, survival, and ultimately the evolution of moth and butterfly caterpillars.

○ Objectives

- Students will gain an understanding of how an organism's appearance or behavior influences its likelihood of being attacked by a predator.

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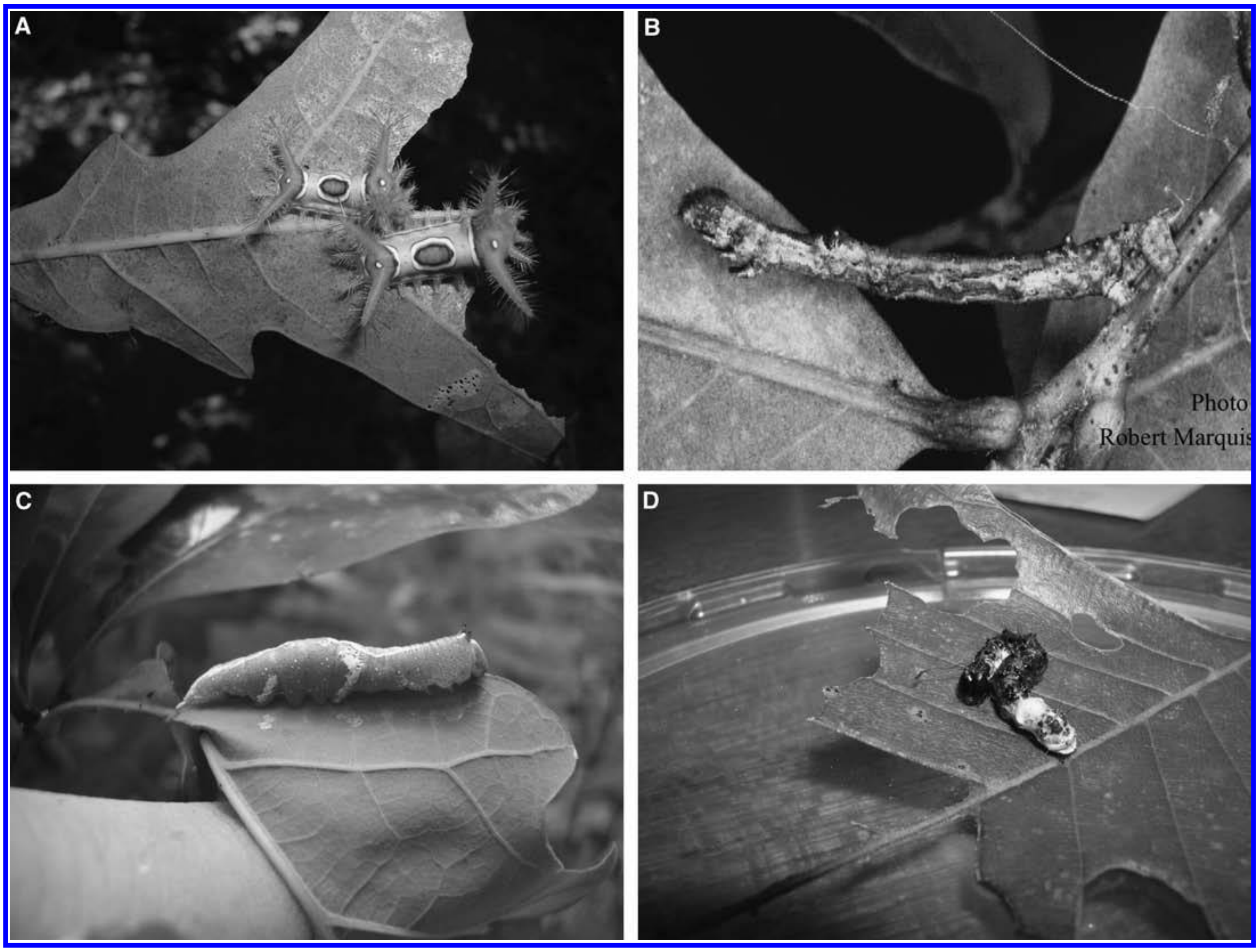

Figure 1. (A) Some caterpillars are well defended with stinging spines. Other caterpillars use camouflage to hide from predators by resembling (B) twigs, (C) necrotic leaf edges, or (D) bird droppings.

- Students will understand how predation and predator behavior can influence the abundance and distribution of prey organisms.
- Students will understand how predation acts as natural selection to influence the appearances or behaviors in a population.
- Students will generate and test specific hypotheses.

○ Procedure

A clay-caterpillar lab activity has four parts: (1) formulating hypotheses, (2) making and placing caterpillar models, (3) collecting "predation" data, and (4) quantifying and interpreting results.

Hypotheses

The key principle for students to understand from this activity is that different predation rates based on physical and behavioral traits result in different patterns of occurrence and natural selection. Thus, it is critical that students formulate hypotheses that emphasize (1) where or how birds will be more likely to attack caterpillars and (2) which kinds of caterpillars will be more likely to be attacked. We present example hypotheses in Table 1. Working in small groups can help students both in brainstorming to formulate hypotheses and in making the caterpillars.

Models & Set-Up

Models of caterpillars should be made of soft modeling clay that will not harden when placed on plants; modeling clay is available at art and craft stores. I have found that working the clay in your hands for a few minutes softens it and makes it easier to form. Students can make models that mimic native species using field guides or web resources (Table 2). Making a large number of caterpillars (20+) will emphasize the importance of replication in scientific experimentation and provide more robust results.

Formulating hypotheses may be aided by taking students out to the study site ahead of time to observe plants and other characteristics of the environment. The study site can be a playground (as long as there are bushes or trees available) or a nearby woodlot or natural area. I have attached clay caterpillars to leaves and branches using pure silicone (available at hardware stores), which will remain secure for at least several days. Mark trees or branches so that caterpillars

Table 1. Example hypotheses and how to test each.

Hypothesis	Method
Appearance hypotheses	
Camouflage caterpillars will have lower predation.	Place green caterpillars on similarly colored leaves and on brown bark where they are more visible.
Birds avoid caterpillars with bright colors because they might be poisonous.	Make half of caterpillars green or brown and half bright red or yellow.
Birds prefer to eat big caterpillars.	Make half of the caterpillars small and half large.
Behavior hypotheses	
Birds forage at different rates on different tree species.	Place caterpillars on different species of trees.
Caterpillars are more likely to get eaten at the edge of a forest.	Place caterpillars at a forest edge and deeper within a forest.
Birds look for food more often in higher branches of a tree.	Place half of the caterpillars on low tree branches and half on higher branches using a ladder.
Caterpillars that spend time in groups are less likely to be eaten than lone caterpillars.	Place 5 caterpillars on some branches and just 1 on others.

Table 2. Resources for images, geographic ranges, and biological information on caterpillars.

Books
Wagner, D.L. (2005). *Caterpillars of Eastern North America: A Guide to Identification and Natural History*. Princeton, NJ: Princeton University Press.
Allen, T.J., Brock, J.P. & Glassberg, J. (2005). *Caterpillars in the Field and Garden: A Field Guide to the Butterfly Caterpillars of North America*. New York, NY: Oxford University Press.
Websites
BugGuide – Lepidoptera. http://bugguide.net/node/view/57
Discover Life – Caterpillars Identification Guide and Checklist. http://pick4.pick.uga.edu/mp/20q?guide=Caterpillars
Caterpillars of Eastern Forests. http://www.npwrc.usgs.gov/resource/insects/cateast/families.htm
Caterpillars of Pacific Northwest Forests and Woodlands. http://www.npwrc.usgs.gov/resource/insects/catnw/index.htm

can be easily relocated. I use surveyor's flagging to mark branches and colored twisty-ties to mark the specific shoots or leaf bunches on which the caterpillars are glued.

Collecting Data

Clay caterpillars need to remain on trees for at least 24 hours, and it may take as long as a week for birds to find a large enough proportion that students can draw meaningful conclusions. Caterpillars that have been "attacked" by birds sometimes have obvious bill marks (Figure 2A), but it may be necessary for students to closely inspect them for more subtle evidence (Figure 2B). The telltale sign of birds is linear indentations that angle toward one another, created by the edges of the mandible. Beware that other leaves or branches bumping into the clay can also make linear marks; students should be careful when handling and gluing models not to accidentally mark them with fingernails. Insect "attacks" may occur and are characterized by small chunks of clay torn off the caterpillar (Figure 2C).

○ Results

Students can calculate results as the proportion of caterpillars depredated by birds. For advanced secondary or college-level classes, this lab can be ideal for introducing chi-square statistical tests. Part of the value of this activity is that there is no "correct" outcome. Results may frequently be opposite students' predictions, or there may be no great difference in predation between one group of caterpillars and another. This gives students the opportunity to ask why their hypotheses may have been falsified and why the observed predation patterns may have taken place. For example, if caterpillars placed near the ground were attacked with the same frequency as caterpillars up on tree branches, it may mean that birds spend equal time foraging at these heights. Or perhaps two different species of birds were attacking the caterpillar, one that feeds on the ground and one in trees.

Example Exercise

This simple example is based on a summer research project by a high school student participating in the Students and Teachers As Research Scientists program at the University of Missouri, St. Louis.

Hypothesis: Birds hunt for food along forest edges more than within the forest interior, so caterpillar models on edge trees should be attacked more than forest trees.

Procedure: 21 white oak (*Quercus alba*) trees growing along forest edges were each paired with another white oak growing within the forest. Only white oak was used, to control for possible variation in bird foraging among tree species. Three caterpillar models were attached to separate leaves on each tree and checked after 72 hours.

Results: The proportion of attacked caterpillars on each tree was averaged for edge and interior trees, and bird predation was found to be higher in the forest interior (Figure 3).

Conclusions: Bird predation is lower along forest edges than within the forest, so forest edges may be a safer habitat for caterpillars. We may predict from these results that ovipositing female moths and butterflies would preferentially lay eggs along forest edges because females that prefer to lay eggs within the forest expose

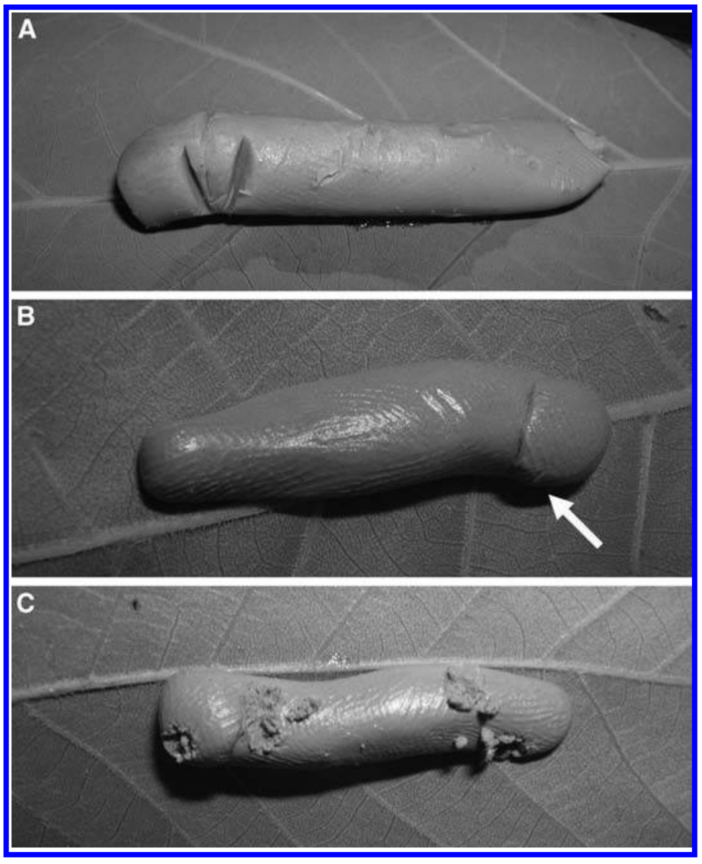

Figure 2. Clay caterpillar models may show (A) distinct, deep marks from bird bills or (B, arrow) small, subtle marks. (C) Insects tend to tear into clay, leaving small chunks and holes.

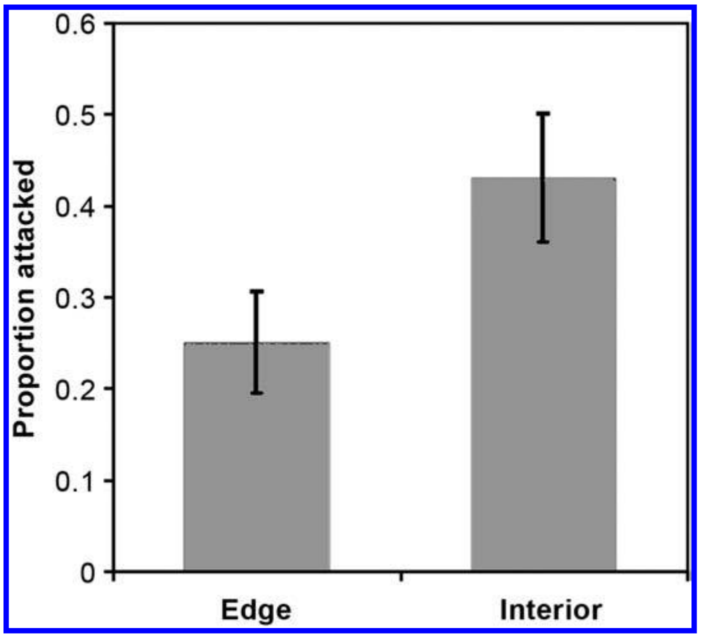

Figure 3. Mean proportion of clay caterpillar models attacked on forest edge and interior trees.

their young to more predation. Over time, as more edge-preferring moths than interior-preferring ones survive and lay eggs on forest edges, most members of a population will prefer trees growing along forest edges.

Advanced Questions

Beyond basic hypotheses such as those in Table 1, clay caterpillars can be used to ask more complex ecological and evolutionary questions. Indeed, ecologists have begun to employ them in contemporary research (e.g., Loiselle & Farji-Brener, 2002; Richards & Coley, 2007; Skoczylas et al., 2007; Fáveri et al., 2008).

One possible lab experiment involves the cues that birds use to locate food. Some birds apparently search for leaves with visible insect damage that indicate prey is nearby (Heinrich & Collins, 1983). Students could place half of the caterpillars on undamaged leaves and half on leaves that have been artificially damaged with a hole-punch that mimics bites by an insect herbivore.

Students can test the effects of chemical defenses by incorporating plant material into clay caterpillars. Dry leaves of plants known to contain defensive chemicals, like milkweed, sumac, and tomato leaves. Grind the leaves into a fine powder with a mortar and pestle or a coffee grinder and roll the clay in the powder as you form the caterpillars. Lettuce makes a suitable control powder because it has few chemical defenses. If natural plant materials are not readily available, spices (e.g., black pepper, red pepper, cinnamon, nutmeg, etc.) can be used. Birds have poor senses of smell and taste, so they are unlikely to respond to the defended caterpillar treatment; but insects may respond strongly to the presence of leaf chemicals. In this case, the identity of the predator as bird or insect can reveal important differences in selection pressure.

More detailed studies of spatial predation patterns are also possible. In the edge–interior example above, the students also measured the distance of forest interior trees from the edge. This data showed that, although predation was greater within the forest, the probability of bird attack was greatest 20–30 m from the edge and declined deeper in the forest.

○ Conclusions

Perhaps the most appealing feature of clay caterpillars as a lab tool is their flexibility, which gives students the opportunity to direct their investigation on the basis of their own interests. The possible hypotheses for students to explore are almost limitless and, with no "wrong" answers, interpreting results can be a valuable critical-thinking exercise. With a little guidance, clay caterpillars can allow students to observe how predation acts as a selective force to shape the ecological and evolutionary patterns we see in the natural world.

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References

Bernays, E.A. (1997). Feeding by lepidopteran larvae is dangerous. *Ecological Entomology*, *22*, 121–123.

Fáveri, S.B., Vasconcelos, H.L. & Dirzo, R. (2008). Effects of Amazonian forest fragmentation on the interaction between plants, insect herbivores, and their natural enemies. *Journal of Tropical Ecology*, *24*, 56–64.

Heinrich, B. & Collins, S.L. (1983). Caterpillar leaf damage, and the game of hide-and-seek with birds. *Ecology*, *64*, 592–602.

Holmes, R.T., Schultz, J.C. & Nothnagle, P. (1979). Bird predation on forest insects: an exclosure experiment. *Science*, *206*, 462–463.

Loiselle, B.A. & Farji-Brener, A.G. (2002). What's up? An experimental comparison of predation levels between canopy and understory in a tropical wet forest. *Biotropica*, *34*, 327–330.

Richards, L.A. & Coley, P.D. (2007). Seasonal and habitat differences affect the impact of food and predation on herbivores: a comparison between gaps and understory of a tropical forest. *Oikos*, *116*, 31–40.

Skoczylas, D.R., Muth, N.Z. & Niesenbaum, R.A. (2007). Contribution of insectivorous avifauna to top down control of *Lindera benzoin* herbivores at forest edge and interior habitats. *Acta Oecologia*, *32*, 337–342.

Whelan, C.J., Holmes, R.T. & Smith, H.R. (1989). Bird predation on gypsy moth (Lepidoptera: Lymantriidae) larvae: an aviary study. *Environmental Entomology*, *18*, 43–45.

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