Climate Change and Caterpillars

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Overview

In most forests, caterpillars eat more leaves than all other herbivores combined. This may come as no surprise to gardeners, who will also understand that their ferocious appetite can significantly influence natural and human-managed ecosystems. The struggle to control these potentially damaging herbivores also poses interesting scientific questions for entomologists. A suite of factors affect interactions between caterpillars, their natural enemies and the plants they feed on—and this is an important area of research, especially relevant for the agricultural community.

One research question is whether caterpillar populations are controlled by “bottom-up” or “top-down” interactions. For example, is it the toxicity or availability of plants that controls caterpillar populations? Or is it natural enemies? And how are these interactions modified by climatic factors? For example, extreme weather events can wipe out insect predators, boosting herbivore population growth. What makes these questions extremely tough to answer is the fact that the relationships between the key “players” vary depending on the species involved. Plants, insects, and their natural enemies—including parasitoids—interact in many different ways.

The Earthwatch project *Climate Change and Caterpillars* fields in five locations across the Americas in order to quantify these interactions across a variety of different gradients. Volunteers work in the Costa Rican rainforest; the cloud forest of the Ecuadorian Eastern Andes; the hardwood and cypress-tupelo forests of Louisiana; the riparian and pine forests and deserts of Arizona; and across to the California/Nevada border, covering mixed

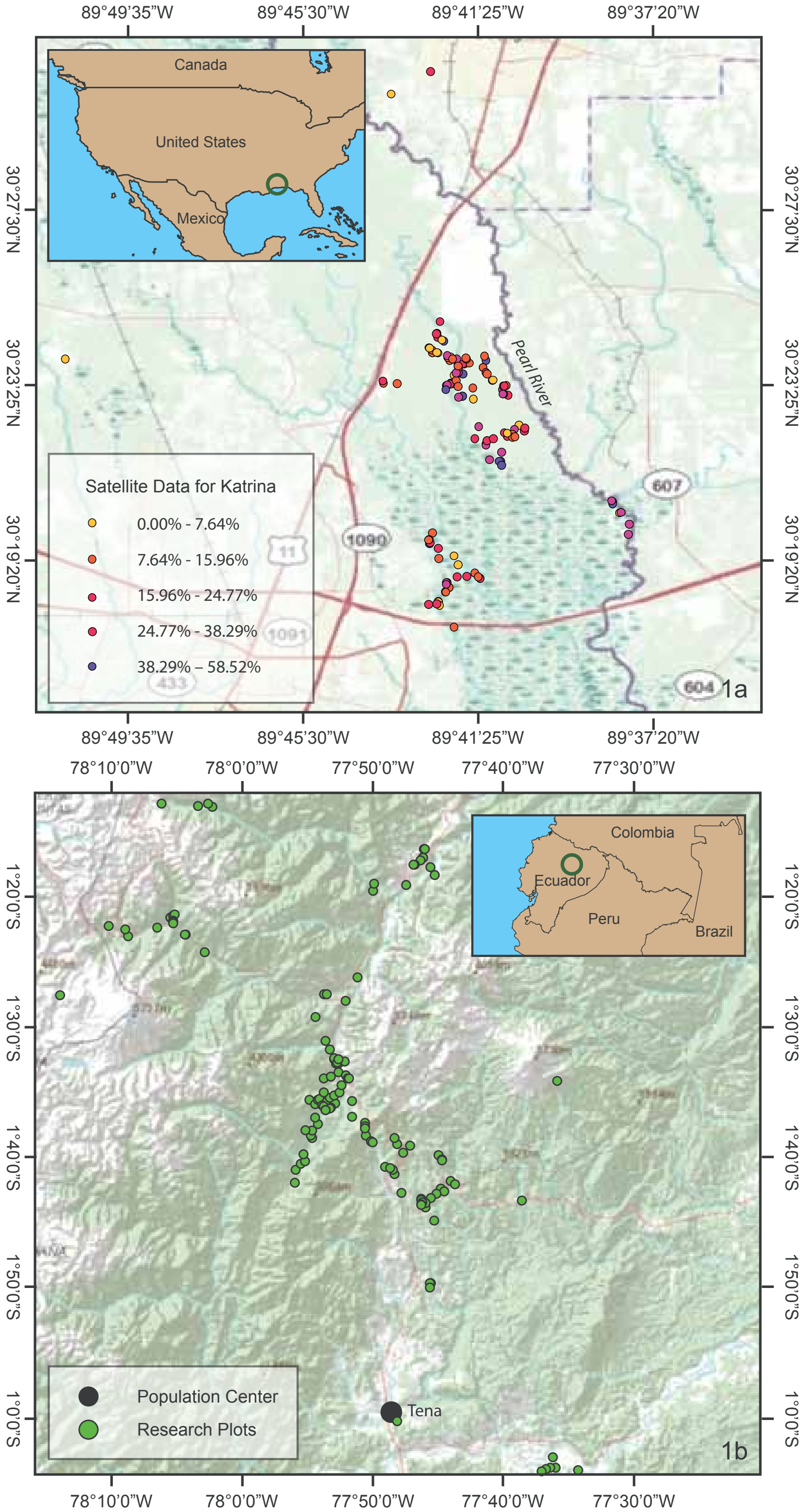

Figure 1: Locations in Ecuador and Louisiana of recent Earthwatch plots where interaction diversity was quantified. Plots are located across gradients of hurricane disturbance (Louisiana), precipitation and disturbance (both sites) to examine how diversity is affected by these variables. Hurricane damage was quantified using satellite data—colors in 1a illustrate percentage of the plot damaged by hurricane Katrina.

Figure 2: In 2010, six Earthwatch teams continued to find new caterpillar and parasitoid species across all of the project's research sites.

conifer forests in the mountains, Great Basin desert, and juniper and pinyon-pine forests in between.

Dr. Lee Dyer's cutting-edge research examines parasitoids, the caterpillars they attack, and the caterpillars' host plants. The caterpillars include 40 families within the Order *Lepidoptera*. Their parasitoid enemies that live and feed on or in their host, eventually killing it, are the parasitic *Hymenoptera* and *Diptera*. The host plants include hundreds of species in all major plant families.

Dyer's premise—unique amongst many prominent theories of ecological diversity—is that if you want to understand the ecology of tri-trophic plant-insect-parasitoid systems, you need to know more than just the species involved; you have to understand how they interact. Dyer has developed a unique method for quantifying what he and other ecologists have termed "interaction diversity," a measurement of the many ways in which different species interact.

Dyer's first goal is to provide extensive data-sets that can help scientists examine how the interaction diversity varies across major climatic and biotic gradients. His second goal is to establish the relationships between interaction diversity and variables such as "ecosystem service" provision and ecosystem stability. This will allow scientists to better predict the responses of ecological communities to climatic changes. For example, climate change and extreme weather events—such as Hurricane Katrina—can disrupt interaction diversity, leading to herbivore outbreaks. As such, they cause unstable ecosystems and diminish ecosystem services.

In addition, parasitoids provide an ecosystem service to farmers because they control certain populations of caterpillars, which can wreak havoc on crops. However, if an extreme weather event caused by climate change wipes out the parasitoids, then it also disrupts that particular ecosystem service.

Research objectives are:

- To determine how hurricanes and climatic variation affect insect diversity
- To determine how hurricanes and climatic variation influence levels of parasitism (and subsequently affect caterpillar densities)
- To address the question of whether tropical caterpillars are more specialized in their niche than temperate caterpillars

Outcomes

Six Earthwatch teams fielded in 2010; they gathered caterpillars and food plants, conducted experiments in the forest and in the laboratory, and raised caterpillars to identify which species were present and which parasitoids they hosted. Every year, the teams find new caterpillar and parasitoid species at all project sites, and they update the species images and data on the project website (www.caterpillars.org).

As discussed earlier, while scientists routinely study measures of species diversity—such as species richness—they have not had a quantitative tool to measure the various ways in which species interact with each other (interaction diversity). Dyer and his team have been working with Earthwatch volunteers to develop a method for quantifying interaction diversity that can be used to test hypotheses about how diversity responds to gradients or disturbances. The metric has been tested and is ready for wider application, so the team is now encouraging other ecologists to use it.

Using the tri-trophic chain of "plant-herbivore-enemy" as an example, the simple metric of diversity includes all of the two-link chains present (herbivore-plant and enemy-herbivore), and the three-link chain (enemy-herbivore-plant). Using this diversity metric, the team has demonstrated that it can provide novel climate change predictions and insight into correlations between diversity, stability, productivity, and ecosystem services.

They have tested the method at all of the Earthwatch project locations, and also

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conducted individual studies specific to each geographic area.

USA – Louisiana, California, Nevada, Arizona: Parasitoids keep caterpillar populations down, so they are important in both forests and agricultural settings as a natural alternative to costly pesticides. To the detriment of these ecosystems, outbreaks of caterpillars can increase in the wake of hurricanes, as it happened after Hurricane Katrina in 2005. Understanding why this happens is vital for the agricultural industry. At the Louisiana study areas, which include multiple hurricane-damaged sites and undamaged sites (for comparisons), up to eight caterpillar species reached outbreak proportions across the hurricane-damaged sites.

Significantly, the team has also developed new models that suggest that *interaction* diversity is more sensitive to climate change than species diversity. That means that before climate change "claims" one species over another and therefore impacts species diversity, it will first impact the way in which these species interact, and possibly affect a large number of species depending on those interactions. This result underscores the need for Dyer's team to continue collecting this crucial dataset. Clear pictures of how even the simplest communities respond to global climate change will only emerge through the kinds of interaction studies that Dyer's team is pioneering.

Laboratory experiments conducted over the past six years have examined the effects of climate change on interaction diversity by creating communities of alfalfa and the cutworm caterpillars and parasitoid wasps associated with them. In 2010 these data, which focused on the impacts of increased CO_2 and temperature on interaction diversity, were combined with Earthwatch field data on extreme weather events and trophic interactions. The most notable experimental results showed that higher temperatures caused increased caterpillar development rates, which caused complete parasitoid mortality. The rates at which the caterpillars developed into moths prevented the parasitoids from being able to develop. This so-called "phenological asynchrony" resulted in significant increases in caterpillar biomass and survival.

These experimental results are important because across project sites the Earthwatch teams continue to find that the occurrence of extreme weather events linked to climate change also cause phenological asynchrony and significantly lower levels of parasitism, allowing populations of caterpillars to increase and causing declines in interaction diversity. These combined results—showing declining levels of parasitism in response to warming, and associated increases in extreme weather events—are a cause for concern amongst scientists and farmers because the biological control in natural and managed systems will decline sharply. This means it is likely that caterpillar outbreaks will also increase as the diverse interactions that have traditionally stabilized natural and managed plant communities are lost.

The interactions between global change and biodiversity are complex, but the clear and strong finding from this project is that the natural control of herbivores by parasitoids is broken down by climate change, and leads to stronger outbreaks of herbivores but lower diversity of species. Understanding these relationships is very important for guiding future management and conservation decisions in light of global change.

La Selva and Tirimbina, Costa Rica: Effects of plant-caterpillar-parasitoid interactions on biodiversity can be substantial in complex ecosystems like rainforests. Since 2006, the teams have been conducting plant diversity experiments with common understory piper shrubs at La Selva, to identify and quantify some of these responses.

Results to date have demonstrated that increases in numbers of caterpillars and other herbivores on these shrubs caused widespread seedling death within the entire understory as a result of the herbivores moving from the piper shrubs to seedlings of many different plants. The researchers hypothesized from this that the caterpillars likely keep the plant diversity of these understory patches in check. They expected that plant seedling diversity would be greater in patches of piper that had normal densities of "generalist" caterpillars—those that can survive in a wide variety of environments and on multiple resources—than in plots from which generalist caterpillars were manually removed.

Sure enough, after 15 months, the plots where the caterpillars were removed had fewer plant species overall than those with caterpillars still present. Removing the caterpillars had enabled some plant species to dominate and outcompete other species for resources like light, nutrients, and water. Generalist caterpillars have therefore been identified as one of many ways that these systems maintain a very high diversity in the rainforest understory. They control competition between plant species and prevent any one plant species from dominating the system.

Recent Publications

Dyer, L.A., Letourneau, D.K., Vega Chavarria, G. and Salazar Amoretti, D. (2010). Herbivores on a dominant understory shrub increase local plant diversity in rain forest communities. *Ecology* **91:**3707-3718

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Rodriguez-Castaneda, G., Forkner, R. E., Tepe, E.J., Gentry, G. L., and Dyer, L. A. (*in press*). Weighing defensive and nutritive roles of ant mutualists across a tropical altitudinal gradient. *Biotropica*

Rodriguez-Castaneda, G., Dyer, L.A., Brehm, G., Connahs, H., Forkner, R.E., and Walla, T.R. (2010). Tropical forests are not flat: how mountains affect herbivore diversity. *Ecology Letters* **13:**1348-1357