

## Lessons from La Selva: Caterpillar and Parasitoid Declines in a Lowland Tropical Forest By Danielle Salcido

“Surely, wisdom is given to all things, and the tiniest of creatures are the teachers of kings.”  
-Unknown

Our study observing long-term trends in plant-caterpillar-parasitoid interactions at La Selva Biological Research Station has many great stories behind it. The paper we recently published from this work was titled, *Loss of Dominant Caterpillar Genera in a Lowland Tropical Forest*, and published in *Scientific Reports* in January 2020 (Salcido *et al.* 2020). It was generously awarded the **2019-2020 Organization of Tropical Studies (OTS) Kimberly G. Smith Outstanding Student Paper Award** for which I am very grateful. In addition to the published results, *Loss of Dominant Caterpillar Genera in a Lowland Tropical Forest* represents a story shaped by and shared with many people beyond the author list. Cumulatively, it represents a scientist’s foresight, patience and dedication to cultivating long-term tropical data, along with decades of volunteer work from Earthwatch citizen scientists, collaborations with researchers across multiple disciplines, and the tireless work of local natural historians. Personally, it represents my first publication as first author, which was an academic feat I never imagined accomplishing in my lifetime. The work behind this paper forged new and life-long friendships and the opportunity to share work with a broad audience following its feature in the May 2020 issue of *National Geographic* (which finally made my graduate research accessible to friends and family!). Here is a quick recap on the backstory to a paper that has shaped my graduate career and fostered my most memorable life experiences. I hope the suite of *eCanopy* readers from their various backgrounds and experiences at OTS stations enjoy this story. For me it starts with an email as I sat in my office at the University of Nevada, Reno (UNR), but really it begins at La Selva Biological Research Station in the early 1990s when my advisor first came to experience its entangled bank.



A sample of the many hands involved in this project and relationships forged that make the cumulative experience of a research project all the more memorable. Left to Right (top to bottom): Photo1: Beto Garcia, myself, Angela Smilanich and Lee Dyer hiking La Sleva trails. Photo2: High school team of Earthwatch Citizen Scientists. Photo3: 2017 REU students, Victor Ruiz Hernandez & Said Haji. Photo 4: Honorary Earthwatch Citizen scientists: Ronald Parry & Skip Young. Photo 5: Myself & Bernal Matarrita, one of the many helpful La Selva employees (i.e. Daniel Brenes, Orlando Vargas, Marisol Luna) who our research would be impossible without. Photo 6: Daisy & Krystal Garcia, friends of Puerto Viejo . Photo7: Saw Chanchanok, one of many colleagues with whom I have had the wonderful opportunity to work with in the field.

It was late fall of 2016 and I had just completed my first year of graduate school, when an email landed in my inbox. It was forwarded by my advisor, Lee A. Dyer, and was a request for his

participation in the *Innovative Research on Climate Change Across the USA and Latin America: 5<sup>th</sup> Latin American/Hispanic Symposium* at the 2017 Entomological Society of America Conference. Lee figured it would be a good motivator for me to start some analyses and gain experience presenting at an academic conference. At that point, I was a master's student and we had agreed that my project would incorporate his long-term interaction diversity datasets cataloging plant-caterpillar-parasitoid interactions across the Americas. I immediately considered all the reasons I should not agree to present at a conference: *I have planned to research latitudinal, not climate gradients in network parameters! I don't have analyses completed to write an abstract! I do not have experience with professional presentations! I haven't even attended a conference before! I will stand up there in front of brilliant scientists and fail!* It may seem like a very dramatic reaction to a great opportunity, but stifling cases of imposter syndrome often cast shadows on possibilities. Without encouragement I would have said “no”, which has been a both unsettling and constructive reflection. Eventually I would come to learn that by agreeing to do the presentation, not only would I develop my self-confidence as a researcher, but I also embarked on a research question that serendipitously became a focal topic in research circles from 2017 to present: *insect declines*.

Luckily, as good mentors do, Lee in his characteristically calm and supportive demeanor recognized my hesitance, halted further self-doubt and assured me I'd be fine and had plenty of time. He added that we should meet because he had a few ideas following the symposium's theme. We later met and he mentioned it was his observation that Puerto Viejo was experiencing increased flooding over the years of his collections at La Selva Biological Research Station. If that was the case, then it would be interesting to explore if there were consequences for the insect communities. He thought it may be fruitful or interesting to revisit the hypothesis tested in Stireman *et al.* (2005) for that site. Fifteen years prior, Stireman *et al.* (2005) had explored the hypothesis that parasitism frequency was negatively associated with extreme precipitation events. The paper provided support for this and further showed the relationship is stronger for specialist parasitoids. I left the meeting and it was time to play with the data. Without having acquired climate data yet, I decided a reasonable place to start was to look at parasitism across time. I plotted parasitism frequency across the 22-years of data to see if there was any evidence of a decline. It was the easiest graph I'd make in my graduate career, and sure enough, parasitism was decreasing quite dramatically. *Cool*, I thought, Lee was onto something. I realized I was naïve to the importance of those results, because when I showed Lee, I got the most excited and visceral reaction from him—still unmatched to date. I'll never forget his reaction was one of genuine surprise and excitement which quickly became immediate concern as he realized the implications of such a result. And just like that, we began examining long-term patterns of caterpillar-parasitoid interactions at La Selva Biological Research Station.



Parasitoids through stages of collection. Left to Right: Tachinid eggs on the abdominal segments of *Telemiades* sp. An adult parasitoid reared from a host. Vials for transport to the University of Nevada, Reno. Identified parasitoids returned to us from collaborating taxonomists.

It was about a month before the conference and by that point we had convinced another collaborator, Dr. Matt Forister to work with us. Matt agreed to collaborate with us in part because he had been working with a long-term dataset cataloguing butterfly abundance in the Sierra Nevada Mountains started by his collaborator and former advisor, Art Shapiro. By this time, I had climate data that showed extreme precipitation events at La Selva had increased. In an email correspondence about next steps, Matt mentioned a paper just published that had some relevant results that we should be sure to cite down the line. The study had just been published by Hallman *et al.* (2017) showing dramatic and concerning declines in the abundance of adult flying insects from long-term data out of Germany. Little did we know at the time, but their study would come to capture the attention of scientists and journalists around the globe assessing the state of insect populations. A year later a *New York Times* article titled, *The Insect Apocalypse is Here* would catch the public's attention and revealed the inspirational detail that amateur naturalists and citizen scientists played an important role in realizing what became one of the most highly discussed studies in 2017 and the focus of ecologists and entomologists for years to follow.

The conference presentation came and went and no surprise it was a great experience where I came to learn conferences are wonderful opportunities to get valuable feedback and new ideas. My next steps were to explore the relationship between parasitism and climate and examine patterns of abundance and diversity in caterpillar hosts, but analyses took a hiatus that semester. First, we fielded an Earthwatch team to La Selva that February and I began a crowdfunding campaign through Experiment.com to help support Beto and Wilmer, the project parataxonomists, to help with the parasitoid project. This campaign was successfully funded, but most important to me was how close it brought Beto and I together. For the campaign it was recommended we post field notes for prospective donors and I decided to make video tutorials of Beto and I in the field. Production of these videos proved to be quite amusing and hilarious to the both of us, and I credit that as the start of many field experiences that bonded Beto and I in a life-long friendship. When I returned to UNR, I focused primarily on my qualifying exams since I had decided to switch from a master's to a PhD program. In order to motivate me to make some more progress on the La Selva parasitoid project after my exams, I signed up to do a poster

presentation at the 2018 Entomological Society of America Conference. Interest in the topic of insect declines was becoming more apparent, and Lee kept reminding me that we needed to make progress on it but remained patient while I studied up on statistical approaches like structural equation modeling that could be implemented for analyses.

A month before the conference, a study using long-term tropical data was published by Lister & Garcia (2018) in the *Proceedings of National Academy of Science*. The study provided evidence for substantial declines in arthropod abundance with concomitant increases in various climate variables. This was a big deal – not only had another study provided more evidence for declines, but this was unique for its tropical origin. Then, a month later the aforementioned *New York Times* article was published and just like that, buzz surrounding insect declines grew exponentially! While my poster drew little attention at the conference, Lee had given a talk at a symposium titled *Responses of Trophic Interactions to Stress at Different Spatial and Temporal Scales* and highlighted some of the results coming out of La Selva. This is how the journalist Elizabeth Kolbert, who began preparing for a *National Geographic* article titled, *Where Have All the Insects Gone?*, became aware that Lee's lab was also examining the occurrence of insect declines in the tropics.

What seemed to me at first a small-scale study for a conference symposium, was now clearly a very timely topic. Following statistical suggestions from Matt Forister, we incorporated a Bayesian approach to examine caterpillar host abundances across time. Results from these analyses became one of the most shocking components of the project and hence the title of the paper. We worked very hard through spring of 2019 to complete the manuscript. By this time, I had developed the structural equation models that showed really interesting associations among temperature anomalies in addition to precipitation anomalies which initially guided our study. We submitted our manuscript to the first journal in the summer of 2019 and began fielding with our Earthwatch teams. This time, a unique member joined us that field season – David Liittschwager, a National Geographic photographer whose assignment for the article was to photograph insects. He joined our Earthwatch fielding expeditions to photograph caterpillars and parasitoids collected by the volunteers in Arizona and Costa Rica. Family and friends were very excited by this news, and I was still in disbelief of how fortuitous all this was.

Finally, in January 2020 our research was published in *Scientific Reports*. In our final product we showed that caterpillar and parasitoid diversity in the protected forests of La Selva Biological Research Station was declining over time, along with the diversity of their interactions. Networks in the first five years of collection were much less reticulate than those in the most recent five years of collection. Climate anomalies including precipitation and temperature anomalies contributed to these declines in diversity, but the large direct effect of time in our models indicated that other unmeasured variables such as pesticide or land use outside La Selva are also likely explanations. We also showed that for 64 caterpillar host genera for which we had substantial data, that 26 genera, or 41%, showed evidence of declines in the frequency of encounter. In a few cases, certain genera were increasing and interestingly these included species that have been noted as pest species of tropical agriculture. As one may imagine, these losses had functional consequences – parasitism declined overtime primarily from specialist parasitoids. The models with most support showed that positive precipitation anomalies (*i.e.*, floods) and their one-year time lag was partly responsible for the declines in parasitism. These were quite

discomforting results and provided an example of how lowland tropical forests are affected by climate change and the vulnerability of tropical specialist ectotherms.



Selection of the diversity of caterpillars we have collected along the way.

For visitors to La Selva Biological Research Station, it's hard to imagine that a place that appears to a visitor teeming with life – from the howler monkeys encountered on the Rio Puerto Viejo bridge, to the sloths and iguanas on the branches in the trees adjacent to it, to the sounds of the diverse avifauna and leaf cutter ants crossing the paths – that the caterpillars hiding under leaves and the parasitoids developing within them are disappearing. A walk past the light trap at night is perhaps more convincing of the state of moths at La Selva. Our study is a reminder that ecosystems in protected forests are not immune to climate change and changes in ecosystem diversity and function can happen rapidly – on a scale of a researcher's career. As disheartening as our results may be to the individual who has witnessed La Selva's beauty and intrigue, or the researcher who considers La Selva their natal forest or entangled bank, these remnant forest patches continue to be vital on many levels. They remain libraries of unread books waiting to be read by the naturalist, they are playgrounds of possibility for the ever-curious researcher and most importantly terrain of continued evolution for the insects that inhabit it.

In his 2019 perspective piece in *Biological Conservation*, Dan Janzen wrote in regards to the wave of studies examining insect declines, "...when a house is burning down, I need the fire department to keep it from spreading, not a thermometer to measure the obvious heat and flames." When I first read that piece, I thought, "Darn, my study is another thermometer!" In that piece, he continued that the fire department may manifest itself in many forms: continued conservation and restoration of land, continued development or maintenance of multi-decadal monitoring programs and facilitation of bioliterate tropical societies that favor individual action.

The continual work of OTS and people who support organizations like OTS facilitate all three efforts. I hope our paper, which comes from one of too few long-term tropical datasets, helps support efforts that aim to draw awareness and gain resources to secure funding for institutions like OTS so that they can better serve their mission to sustain tropical ecosystems. If anything, next time you have the pleasure of visiting an OTS research station, zoom in and flip over a leaf or two to encounter and acquaint yourself with the beautiful, yet vulnerable, world of caterpillars.

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