



## Impact of Global Change on Pollinators and Pollination Services

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Annual Field Report 2019



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Dear Volunteers of Pollinator Conservation in Costa Rica,

This year was an amazing year thanks to all your dedication, passion and hard work! We had a record high number of groups and volunteers in the field, which translated in to very high numbers of bees and butterflies collected. We collected so many that we haven't been able to process all the samples just quite yet, but we are busy working in the field to pin and identify everything. We are enormously grateful for all of you who have helped us with our research, and would like to share with you some cool results that we have begun putting together. Currently, the first paper that Chelsea Hinton and I have finalized is in review, and we are almost finished with the second paper and will hopefully be submitting that paper for peer review by the end of the month!

With the support and dedication of Earthwatch volunteers over the past four years we have successfully increased the yearly average of collected bees sampled from the three elevational gradients in San Luis de Monteverde, CR. For example, from 2012 to 2015, working alone I was only able to collect on average 300 individuals per year, while in 2016 with the help of volunteers conducting surveys we collected a total of 2,945 bees, in 2017 we collected a total of 1,759, in 2018 we collected a total of 3,395 bees and in 2019 so far we have counted 4,532 bees with another approximately 2,000 awaiting pinning! Combining flower visitation data across the elevation gradient for the most abundant bee tribes, the small carpenter bees (Tribe Ceratinini), and the social, stingless bees (Tribe Meliponini), we are beginning to see some clear trends in thermal zone specialization for these economically important bee groups.

We ended up gathering one more year of flower visitation data in 2019 for our Osa lowland plant-pollinator network to ensure that we had sufficient data to describe the interactions and assign roles to the plant species. We are finalizing those analyses in the coming weeks so that we will have the final plant species recommendations for priority plant species for restoration and conservation of pollinators in the Neotropical lowlands.

In conclusion, we have lots more work to do in the lab, but we are very excited to have the data that you have helped us collect and are looking forward to bringing you more updates on our data, as well as some of our first publications from the data! Thank you all again so much!

Sincerely,

A handwritten signature in black ink, appearing to read 'V. Peters'.

Dr. Valerie E. Peters

## SUMMARY

Across both our field sites, we have collected thousands of bees, with 2019 surpassing previous years in terms of productivity owing to the high number of volunteers who supported our project. This is very exciting, as we need several years of population data and high numbers of pollinators to determine trends in insect populations as well as reveal thermal zone specialization since these organisms tend to have very high annual fluctuations in population numbers. In the lab we have now completed the pinning of all specimens collected since June 2016 through December 2018. In addition, all bees collected up until summer of 2018 have been identified to species or morphospecies and all 2018 bees have been identified to Family or Tribe. In 2018, we collected an amazing number of butterflies and bees (i.e., 3395 from Monteverde and 1666 from Osa= 5061 Total Bees), with many species having not been previously collected in the previous years, 2016 and 2017, especially from the Monteverde area. This was due to some unique rainfall patterns that delayed the flowering of some key species, such as *Citrus* spp. (Family Rutaceae) and *Acnistus arborensens* (Family Solanaceae). Variation in rainfall patterns, a key prediction of climate change, may be responsible for the unusual patterns of flowering and pollinator abundances in Monteverde across the years.

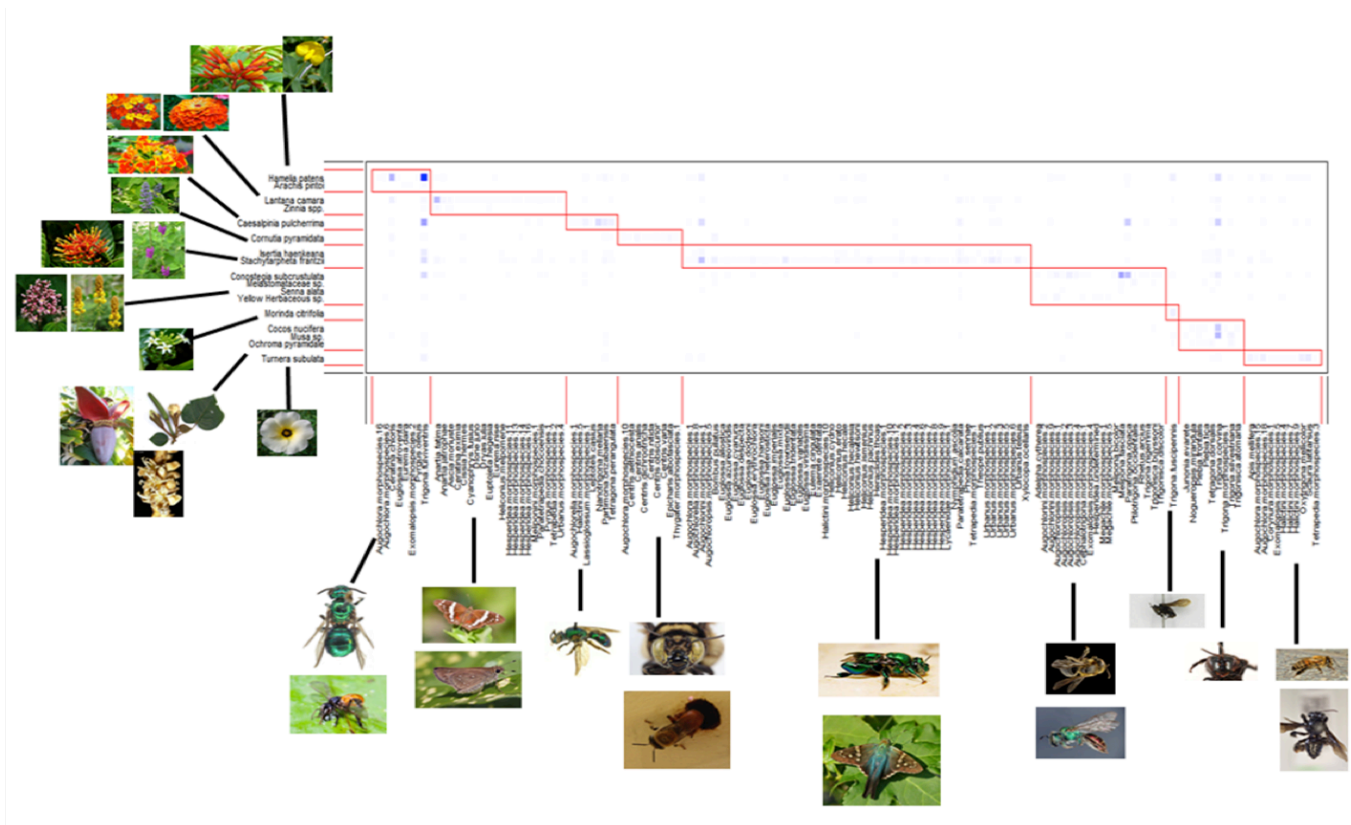
## GOALS, OBJECTIVES, AND RESULTS

### OSA PENINSULA FIELD SITE

Graduate student Chelsea Hinton has now done a great deal of analysis on the bipartite Plant-Pollinator mutualistic network constructed from the timed observations conducted on flowering plants on the Osa Peninsula. Some highlights of her statistical analyses include that across the 20 different plant species observed, the plant species share few pollinators. This result implies that co-planting several species together may improve the restoration success of pollination services compared to the planting of any single shrub species regardless of the duration of the flowering season, including those species that flower continuously during all months of the year. When butterfly and bee visitors were included in the same network, there was a high degree of compartmentalization or modularity in the network (Figure 1). Highly modular networks show that the study area is either relatively intact or that the loss of specialized interactions has not yet occurred. Twelve modules were identified and only two plant species, *Cesalpinia pulcherrima* and *Hamelia patens*, were identified through modularity analysis to have the role of a connector species in the network. Our study aimed to identify network hubs, and based on the idea that plant species with a longer duration of reproductive phenology would accumulate more partners over time, we hypothesized that shrub species with a continuous flowering phenology would all share the same role in the network, as well as be the most important, i.e. network hubs. As we collected more interactions for each plant species, their importance in the network decreased, and all species except *H. patens* held the role of a peripheral species. Thus, in the network, *H. patens*, as a connector species, held the most important role, but we found no network hubs or module hubs in the study. Re-analysis of this network after we add in the 2019 data may change the roles for the plants, or strengthen the results that we currently have by increasing our sample size. Our findings highlight that much more research in the tropics is needed to understand plant-pollinator interactions as research from temperate areas has established that plant species with longer flowering seasons will support more pollinator species, but our work shows that this isn't always the case with longer flowering plant species in the tropics. Instead, communities where many plant species flower continuously throughout the year may allow for more specialized interactions.



Figure 1. Bee and butterfly plant-pollinator mutualistic network. Plant species (20 species) are on the left hand side of the figure, and bee and butterfly species are along the bottom. Representative photographs of plants and pollinators included in a module are shown, with red boxes outlining the observed plant and pollinator species included in each module or compartment.



A total of 2,949 plant-pollinator interactions were observed in our lowland plant-pollinating insect network. A total of 87 bee species and 51 Lepidoptera species were recorded from 377 timed observations, or a total of 190 hours of observations at flowering plants. Rarefaction curves, which estimate true species richness supported by each plant species after removing the confounding effect of abundance, reveal that the plant species *Stachytarpheta frantzii* supported the highest number of bee and butterfly species (Figure 2). Species accumulation curves of bees collected from the 20 flowering plant species show adequate sampling for most plant species, however, some flowering periods were short lived and few observations were conducted (Figure 3).

Figure 2. Species accumulation curves for the seven most heavily sampled flowering shrub species occurring in the Osa Peninsula of Costa Rica. Curves have been rarified to account for the differences in the abundance of bees that were collected from the plant species. Curves are also rescaled to the number of individuals on the x-axis. Vertical lines represent 95% CIs for the species estimates.

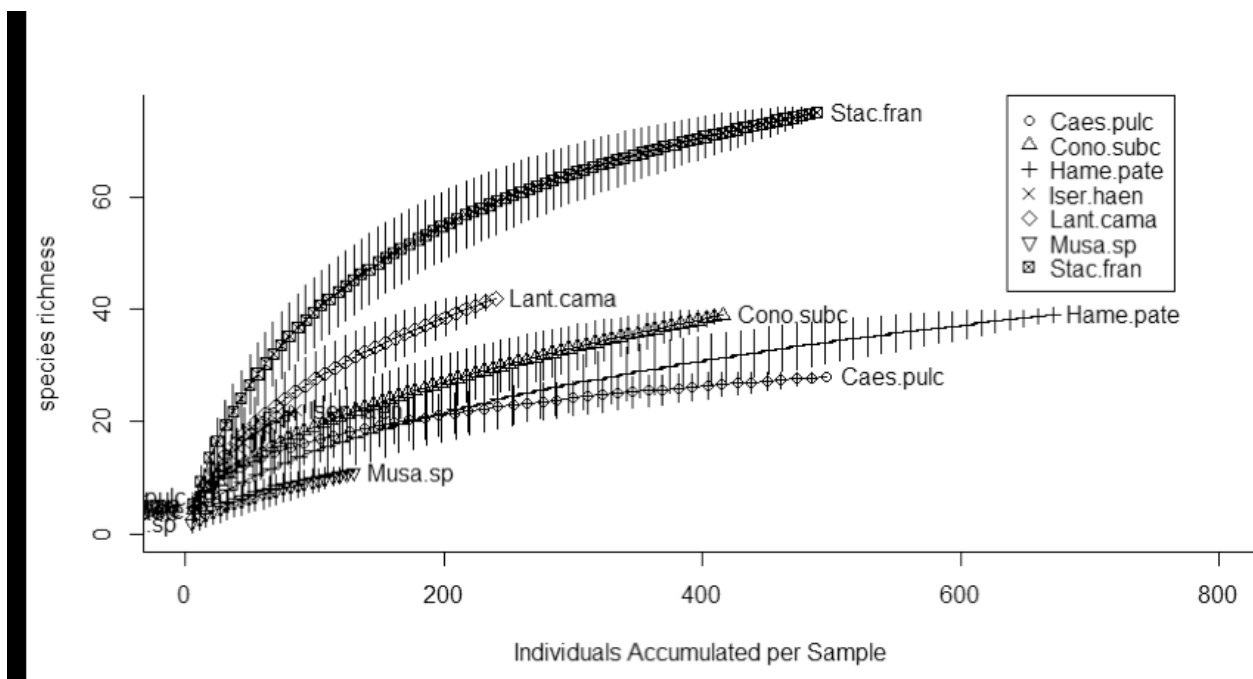
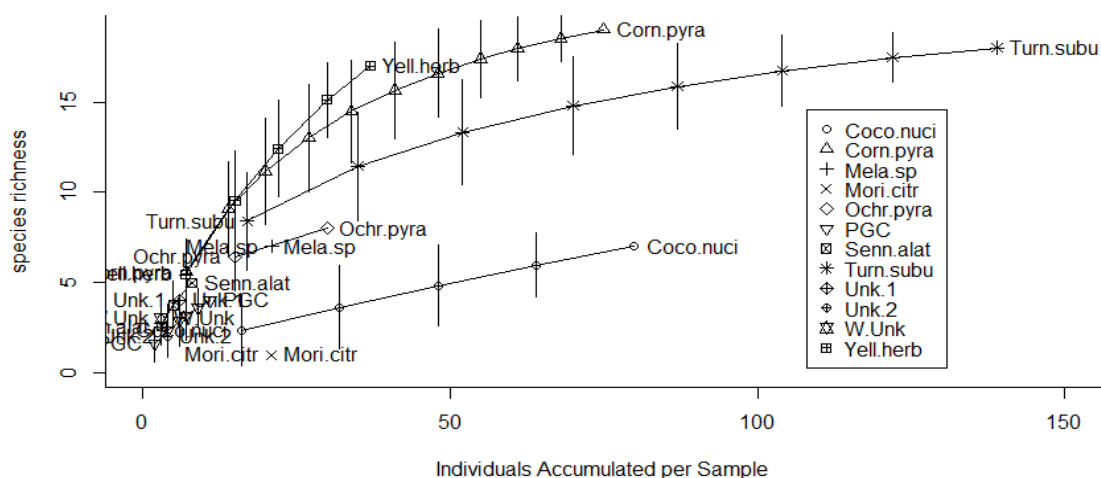
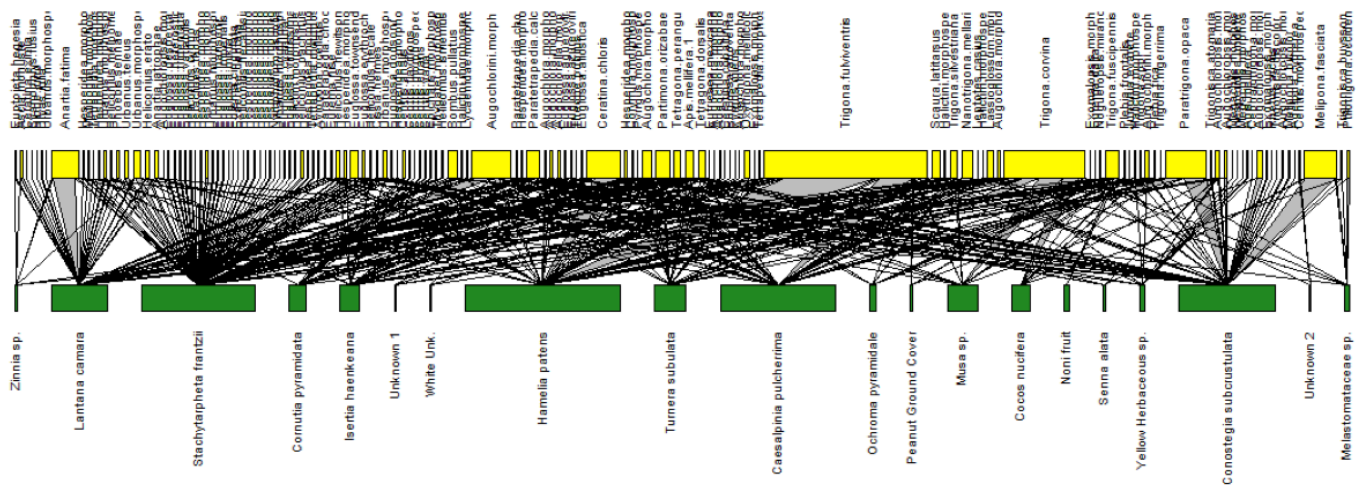


Figure 3. Species accumulation curves for 12 sampled flowering shrub species occurring in the Osa Peninsula of Costa Rica. Curves have been rarified to account for the differences in the abundance of bees that were collected from the plant species. Curves are also rescaled to the number of individuals on the x-axis. Vertical lines represent 95% CIs for the species estimates.



A total of 2,550 bees representing 87 species were collected from the flowering shrubs during the two years, 2017-2018. In addition, a total of 412 butterflies representing 51 species were collected from the flowering shrubs during the two year period. After adding in the bees and butterflies collected in 2018, we re-analyzed the mutualistic network and found that although many bee and butterfly pollinators were shared by the plant species, the overall network was highly compartmentalized (Figure 4). *Hamelia patens* had the highest number of interactions (676 interactions) and the plant species with the highest number of partner species was *Stachytarpheta frantzii* (76 species, Table 1). The bee species with the highest number of interactions was *Trigona fulviventris*, which was not only very abundant but was also collected from all six of the flowering shrub species. This bee species would be considered a super-generalist in terms of the network. The remaining data from 2019 will be added in over the next several weeks.

Figure 4. Plant-pollinator network for 20 flowering plant species occurring in the Osa Peninsula of Costa Rica. Species names on upper level show the names of all bee species collected from the flowering plants. The width of the yellow bars below bee species names indicate the abundance of the bee in the observed network. Black connecting lines indicate that an interaction between a particular bee species and a particular plant species was observed, and the width of the line indicates the frequency that the interaction was observed. The green bars at the base of the interactions each represent one of the flowering plant species observed. The width of the bars represents the number of interactions observed for that plant species.



After adding in the 2018 network interactions, including butterfly visits to flowers, and all 20 observed flowering plant species, the network structure changed from having no modules to being highly modular. This finding further supports the idea that the co-planting of several of the plant species together in restoration and conservation applications would provide the greatest benefit to the pollinator community.

Taking all of these observations together, thus far, our recommendations for restoration and conservation practitioners will be to plant a core of shrubs with an extended flowering duration, in combinations, for example, to plant *C. pulcherrima*, *S. frantzii*, and *C. subcrustulata* together, or *H. patens*, *S. frantzii* and *C. subcrustulata* together, and then to intermix with shrubs of short-term flowering duration. However, if space is limited for planting a variety of species, and only one plant species can be planted then we will recommend planting the shrub species with either the highest rank in the network, the connector, *H. patens*, or the highest diversity of flower visitors (*S. frantzii*).

The next steps for this project after finalizing the flower visitation network will be to submit the paper for peer review to the journal *Ecology*, and we will begin an experimental test of pollinator restoration based on our findings in Las Cruces field station during the summer of 2020.

## SAN LUIS DE MONTEVERDE FIELD SITE

In San Luis de Monteverde, across the three replicate elevational gradients, we collected a total of 2,945 bees in 2016, in 2017 we collected a total of 1,759 bees, and in 2018 we collected a total of 3,395 bees. These totals include all sampling seasons per year including June-July and December of each of the three years.

Table 2 shows the distribution of the abundance of bees within selected bee tribes that were collected from the various sampling methods, comparing the three years, 2016, 2017 and 2018.

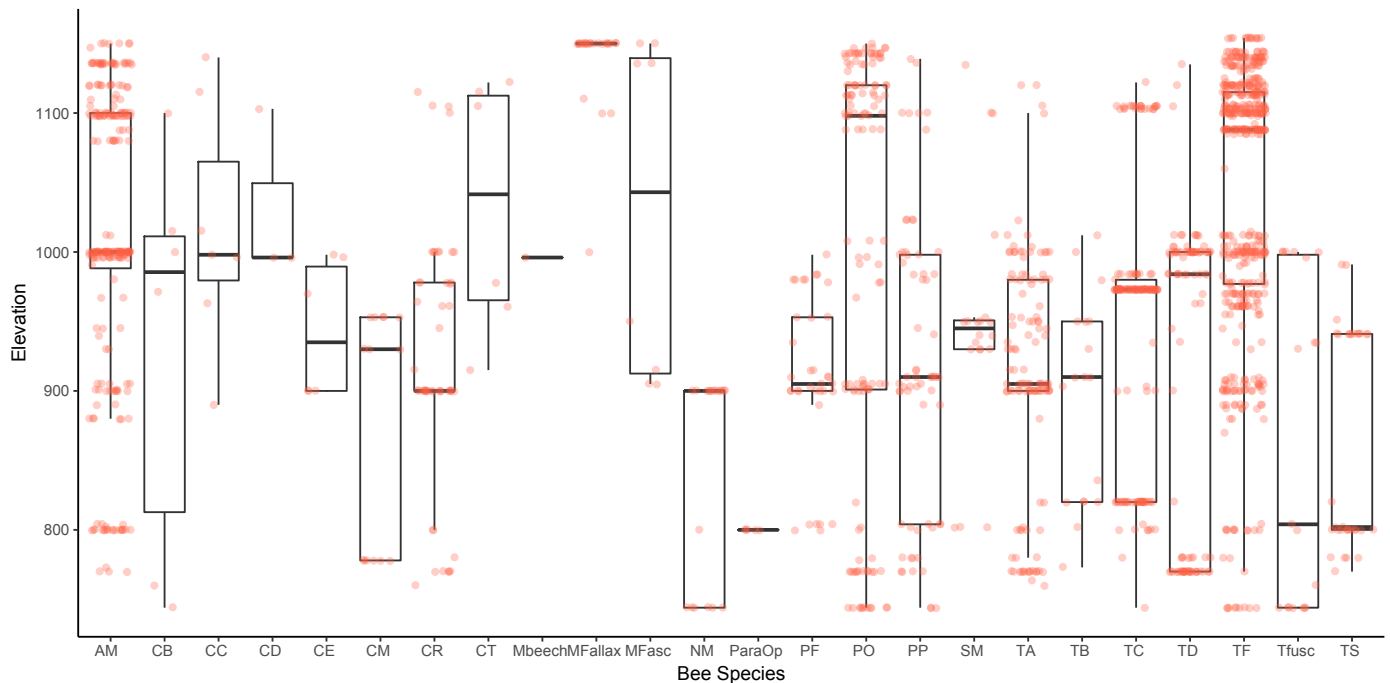
Some interesting trends can be noticed from the table. First, after improving upon our methodology for hand collecting stingless bees with a honey solution between 2016 and the subsequent two years 2017 and 2018, there was a dramatic increase in the number of stingless bees (tribe Meliponini) that were hand collected from the honey solution in 2016 (77 individuals) compared to 2017 (447 individuals) and 2018 (725 individuals). This large increase shows that we were able to effectively increase our sample size of this very important Neotropical pollinator group, with the help of Earthwatch volunteers present at the various elevations to monitor these stations. The increase in sample size (higher abundance) of Meliponini, specifically, will greatly improve our ability to accurately evaluate population trends in stingless bees over time, and to better understand thermal range specialization in stingless bee species as well as how stingless bee populations may be affected by a changing climate. A new graduate student, Kristin Conrad, joined the lab last year, and preliminary analysis of Meliponini and Ceratinini bee species (the two tribes for which we collected the most abundant number of individuals from flowering plants across the elevational gradient) show thermal range specialization for almost all species (Figure 5).

Table 2. Total abundance of bees from selected tribes collected across elevational gradient in San Luis de Monteverde

Tribe/Family	Bee Abundance											
	Total			Bee bowls			Hand collected			Vane Traps		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
Apini	22	78	221	2	3	2	20	74	218	0	1	2
Bombini	1	0	0	1	0	0	1	0	0	0	0	0
Centridini	4	3	2	0	0	0	2	3	1	2	0	1
Ceratinini	2096	606	1318	2053	549	1228	35	51	89	8	6	4
Eucerini	4	10	23	2	8	7	0	1	13	2	1	2
Euglossini	62	55	33	34	16	19	7	10	1	21	2	15
Halictidae	603	423	812	581	338	648	21	78	157	1	7	7
Megachilidae	7	34	12	1	7	1	6	23	11	0	4	0
Meliponini	83	473	745	5	8	8	77	447	725	1	18	12
Xylocopini	2	0	2	0	0	0	1	0	2	1	0	0

In addition to increasing the abundance of collected bees, the presence of Earthwatch volunteers at the various elevations has also increased our ability to detect more species in the area. We now have identified over 300 different species. As we continue to identify species we expect that the number of species in the collection will increase.

**Figure 5. Individuals collected from flowering plant species across an elevation gradient of 750 to 1150 meters above sea level. All bee species included are from the tribes Apini, Ceratinini and Meliponini. Each red dot represents one individual from that species collected at that elevation.**



Our data on bees in the Tribe Ceratinini indicate that long-term data collection will be needed to quantify population trends in some groups of bees, owing to their naturally fluctuating population numbers. For example, bee populations within the Tribe Ceratinini (small carpenter bees) show high fluctuation in abundance over the 10 sampling periods collected thus far (Figure 6). Since we have replicated sites across our elevation gradient we can also see from the figure that the error bars on some sampling periods do not overlap indicating that there is a significant difference in the abundances of Ceratinini collected between those sampling periods that do not have overlapping error bars (Figure 6).

In addition, there may be a relationship between rainfall and the abundance of Ceratinini. It would be expected that rainfall amounts in the early dry season (April-May) would impact bee populations as insect emergence is expected to coincide with the onset of the rainy season in the seasonally dry tropics. In addition, peak flowering occurs at this time, so bee populations could be especially sensitive to rainfall. With changing climate, rainfall has become more erratic in the tropics. Weather data from the San Luis research station supports this idea. A snapshot of weather data is shown in Figure 7. During the onset of rainy season in 2016, over 460 mm of rain fell and this was over a period of 36 days. Both years 2017 and 2018 were unusually dry during the onset of the rainy season, and this could explain the very low numbers of Ceratinini captured from bee bowls in 2017. In 2018, although there were higher amounts of rainfall compared to 2017, the rains were delayed, and the number of individual Ceratinini bees captured in 2018 was more intermediate between 2016 and 2017, approx. 200 individuals per bee bowl sample. This past year, 2019, rainfall was again higher and more representative of a normal May in the study area, and our numbers, once tallied, should help to see if there is a pattern between rainfall and Ceratinini abundance. A new weather station was established during the summer of 2018 at 950 meters above sea level. It is our hope that using the weather station data from both the new weather station and the San Luis weather station, in conjunction with the flowering phenology data and the Ceratinini abundance data, that our data can provide empirical support for how changing patterns of precipitation will affect bees in the seasonally dry Neotropics,



Figure 5. Population fluctuations in populations of some species in the bee Tribe Ceratinini, as observed from capture rates in bee bowls across three replicate transects spanning an elevational gradient of 800 to 1100 meters above sea level.

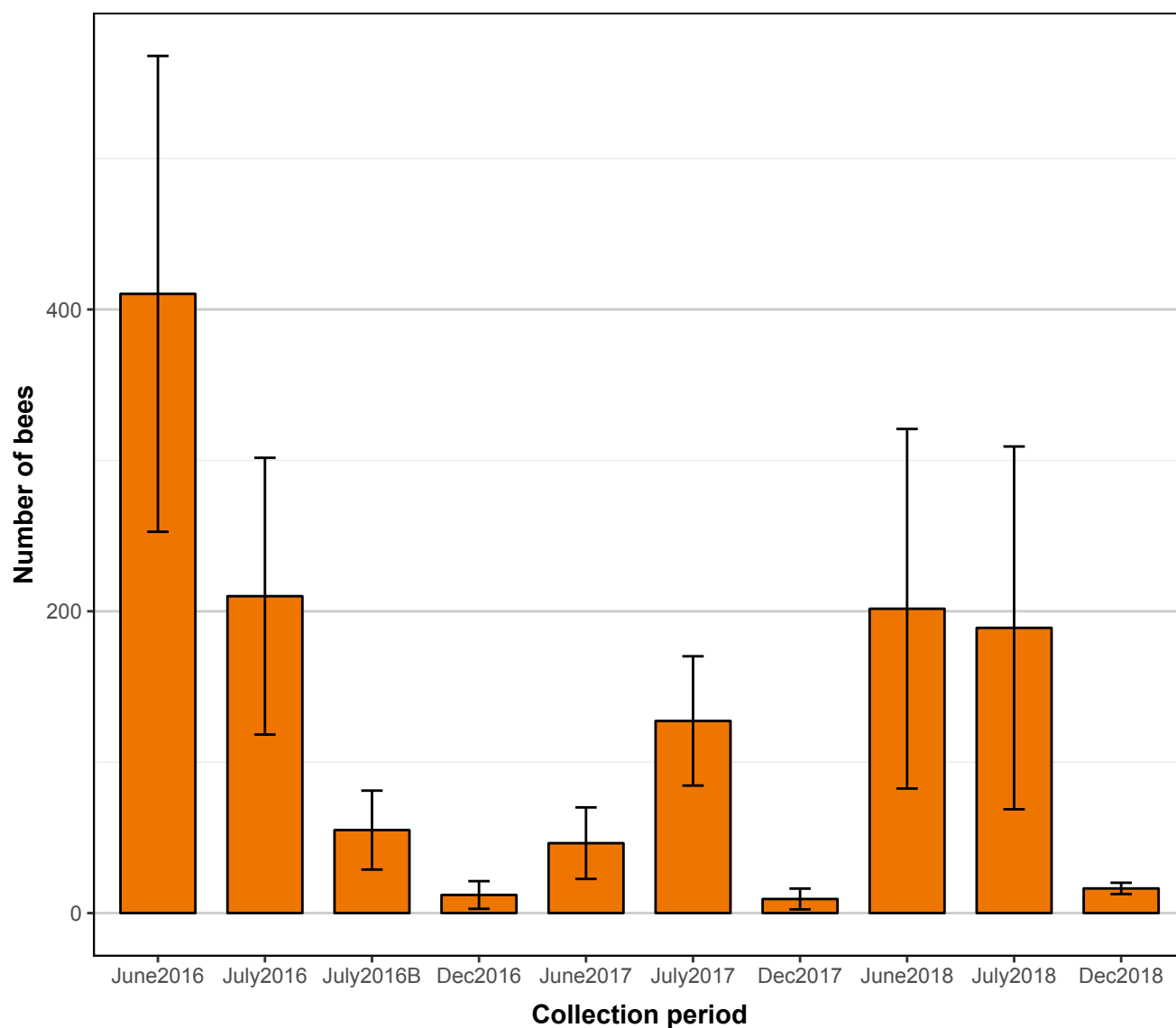
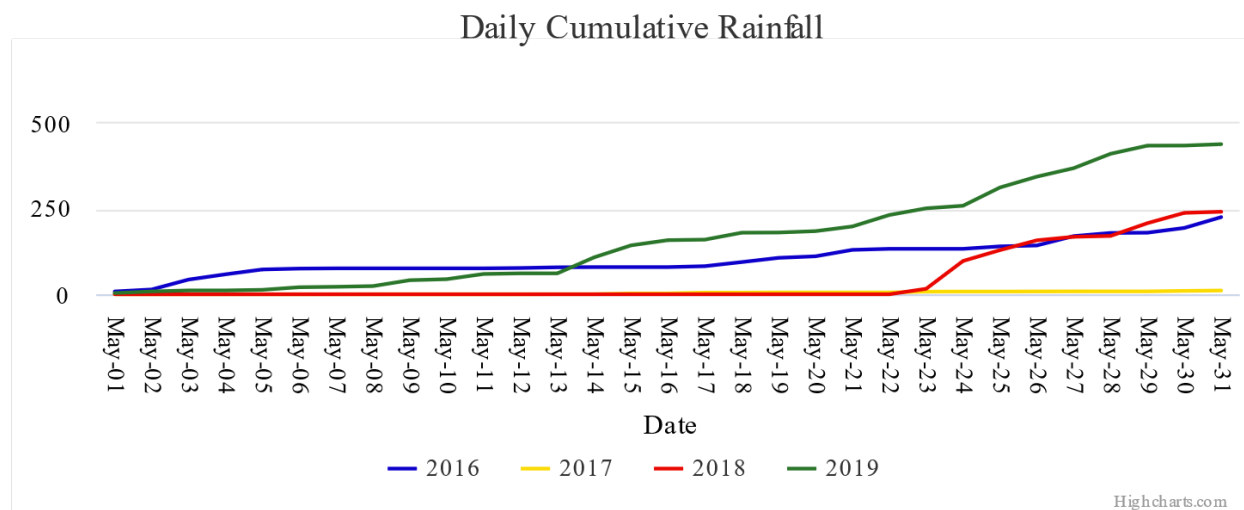


Figure 7. Daily cumulative rainfall and the number of rainfall days (2015-2019) during the onset of the rainy season. Data was obtained from a weather station operated by the University of Georgia at San Luis, 1100 meters above sea level.



Year	Precipitation[mm]	Number of Rainy Days
2019	494.29	39
2018	241.77	9
2017	18.03	14
2016	462.05	35

Finally, our analyses of the community of bees and butterflies supported by the two continuous flowering plant species, *Hamelia patens* and *Stachytarpheta frantzii* has been completed and this work has been submitted for peer review. Our data revealed that each plant species alone, across the elevations can support >50% of bee and butterfly species that we have collected across 9- and 3-years, respectively, of sampling. This result indicates that both plant species could be used widely to support pollinator conservation and restoration in montane tropical landscapes. We also quantified turnover in pollinator community composition temporally for the two plant species to compare bee and butterfly assemblages during times of floral resource scarcity and times of floral resource abundance. Additionally we compared bee and butterfly assemblages to two brief, episodic flowering plant species that flower during the onset of the rainy season. *Hamelia patens* had high overlap with the brief, episodic flowering plant species and low turnover temporally, while *S. frantzii* had low overlap with the brief, episodic flowering plant species and high turnover temporally. This result indicates that *H. patens* may help to mitigate the impacts of climate change while *S. frantzii* may not be as effective.

## PROJECT IMPACTS

Report contributions in the categories below for the past fielding year.

## INCREASING SCIENTIFIC KNOWLEDGE

### TOTAL CITIZEN SCIENCE RESEARCH HOURS

We estimate that on average, volunteers worked daily from 8am to 3pm or a total of 7 hours per day. Some days included nightly lectures to bring that total to approximately 8 hours per day. With each volunteer team spending a total of 5 or 5.5 days in the field and a total of 9 volunteer teams during the 2019 field season, including June-July and December 2019, the total number of citizen science research hours for 315 hours and 396 hours, not including the time of each groups initial travel to and departure from each of our field sites, Monteverde or the Osa Peninsula.

### PEER-REVIEWED PUBLICATIONS

Since our project is still relatively new, we have no peer-reviewed publications to report at this time. However, my graduate student Chelsea Hinton and I have submitted one paper for review and are finalizing another draft to be submitted likely this month. Data is also currently being analyzed for two peer-reviewed papers that will be written by another graduate student Kristin Conrad.

### NON-PEER REVIEWED PUBLICATIONS:

At this time we have no non-peer reviewed publications to report.

### BOOKS AND BOOK CHAPTERS

We have no books or chapters to report.

### PRESENTATIONS:

One of the graduate students who acted as field team leader for this project, Chelsea Hinton, has given a public thesis defense based on this work in May 2019. Kristin Conrad, the other graduate student who served as a field team leader will give her public thesis defense in May 2020. Both students also presented their work as noted below during the annual meetings of the Association for Southern Biologists in Memphis, TN and the Ecological Society of America annual meeting in Louisville, KY in August 2019.

The following project related presentations were given in 2018 and 2019:

1. Podcast, recorded December 2018; <http://blogs.oregonstate.edu/pollinationpodcast/2019/01/07/dr-valerie-peters/>
2. [bit.ly/PolliNation-ApplePodcasts](https://bit.ly/PolliNation-ApplePodcasts)
3. [bit.ly/PolliNation-iTunes](https://bit.ly/PolliNation-iTunes)
4. Peters, V.E. 2018. Invited Seminar Speaker, Wild bees & pollination networks: involving citizen scientists to understand threats and potential recovery strategies, Department of Biology, University of Louisville, April 2018
5. Hinton, C., and V.E. Peters. 2018. Flowering Duration as a Selection Trait for Hub Species in a Plant-Pollinator Network. Association of Southern Biologists Annual Meeting, Myrtle Beach, SC. March 2018
6. Hinton, C.\*, V.E. Peters. 2019. The role of continuous flowering phenology in a Neotropical plant-pollinator network. Ecological Society of America Annual Meeting, Louisville, KY.

7. Conrad, K.\*, V.E. Peters. 2019. Thermal range specialization in tropical bees; implications for climate change. Ecological Society of America Annual Meeting, Louisville, KY.
8. Conrad, K.\*, V.E. Peters. 2019. Thermal range specialization in tropical bees; implications for climate change. Association of Southern Biologists Annual Meeting, Memphis, TN.

## MENTORING

### a) Graduate students

Student Name	Graduate Degree	Project Title	Anticipated Year of Completion
Chelsea Hinton	M.S.	The role of continuous flowering phenology in supporting Neotropical pollinating insects	May 2019
Kristin Conrad	M.S.	Quantifying thermal range specialization in Bee tribes Meliponini and Ceratinini	May 2020

### b) Community outreach

Name of school, organization, or group	Education level	Participants local or non-local	Details on contributions/ activities

## Partnerships

Partner	Support Type(s) <sup>1</sup>	Years of Association (e.g. 2006-present)
University of Georgia/CIEE	Logistics, Permits, Academic support	2005-2019/2019 to present
Eastern Kentucky University	Partial tuition and academic year salary for graduate students	2016 to present
Eastern Kentucky University Summer research fellowship	Summer salary for the PI	2018

<sup>1</sup>. **Support type options: funding, data, logistics, permits, technical support, collaboration, academic support, cultural support, other (define)**

## Contributions to management plans or policies

Plan/Policy Name	Type <sup>2</sup>	Level of Impact <sup>3</sup>	New or Existing?	Primary goal of plan/policy <sup>4</sup>	Stage of plan/policy <sup>5</sup>	Description of Contribution

<sup>2</sup>. **Type options: agenda, convention, development plan, management plan, policy, or other (define)**

<sup>3</sup>. **Level of impact options: local, regional, national, international**

<sup>4</sup>. **Primary goal options: cultural conservation, land conservation, species conservation, natural resource conservation, other**

<sup>5</sup>. **Stage of plan/policy options: proposed, in progress, adopted, other (define)**



## Conserving natural and sociocultural capital

### a) Conservation of taxa

- i. List any focal study species that you did not list in your most recent proposal

Species we work with are insects and IUCN status is unknown, however many pollinator species are economically important and our project will help generate information relevant to the conservation and restoration of pollinating insects in the Neotropics where 98% of flowering plant species rely on animal pollinators.

Species	Common name	IUCN Red List category	Local/regional conservation status	Local/regional conservation status source

- ii. In the past year, has your project helped conserve or restore populations of species of conservation significance? If so, please describe below.

Species	IUCN Red List category	Local/regional conservation status	Local/regional conservation status source	Description of contribution	Resulting effect <sup>6</sup>

<sup>6</sup>. Resulting effect options: decreased competition, improved habitat for species, range increased, population increase, improved population structure, increased breeding success, maintained/enhanced genetic diversity, other

### b) Conservation of ecosystems

In the past year, has your project helped conserve or restore habitats? If so, please describe below.

Habitat type	Habitat significance <sup>7</sup>	Description of contribution	Resulting effect <sup>8</sup>

<sup>7</sup>. Habitat significance options: nursery, breeding ground, feeding site, corridor, migration path, refuge, winter range, summer range, spring range, fall range or other (define)

<sup>8</sup>. Resulting effect options: extent maintained, condition achieved, restored, expanded, improved connectivity or resilience

### c) Ecosystem services

Indicate which ecosystem service categories you are **directly studying** in your Earthwatch research and provide further details in the box below.

☒ Food and water

☐ Flood and disease control

☐ Spiritual, recreational, and cultural benefits

☐ Nutrient cycling

Details:

We are studying the ecosystem service of pollination and the invertebrate animals that provide those services, specifically bees and butterflies.

### d) Conservation of cultural heritage

Provide details on intangible or tangible cultural heritage components that your project has conserved or restored in the past year.

Cultural heritage component <sup>9</sup>	Description of contribution	Resulting effect

<sup>9</sup> Cultural heritage component options: traditional agriculture, artifacts, building(s), hunting ground or kill site, traditional ecological knowledge and practices, monument(s), oral traditions and history, spiritual site, traditional subsistence living

## RESEARCH PLAN UPDATES

Report any changes in your research since your last proposal/annual report. For any 'yes' answers, provide details on the change in the 'Details' box. This section will not be published online.

- 1) Have you added a new research site or has your research site location changed? ☒ Yes ☐ No
- 2) Has the protected area status of your research site changed? ☐ Yes ☒ No
- 3) Has the conservation status of a species you study changed? ☐ Yes ☒ No
- 4) Have there been any changes in project scientists or field crew? ☒ Yes ☐ No

Details – provide more information for any 'yes' answers

We are changing our field site in the CR lowlands from the Osa where only observational work was possible to the Organization for Tropical field studies Las Cruces Station where experimental work will be more possible. Our project scientists will remain the same, but each year, a new graduate student will join us in the field as the field team leaders.

- 5) Provide details on any changes to your objectives, volunteer tasks, or methods, include reason for the change.



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## ACKNOWLEDGEMENTS

We thank the many Earthwatch volunteers who braved rainstorms and extreme heat to help us gather this data, without your help, support and enthusiasm this project would not be possible and not nearly as enjoyable!

We also thank the many farmers and private landowners who have supported our projects, especially Oldemar Salazar, Eliza Mata, and Alex Retana.

We are also especially grateful to Alex, our driver, who not only provides a great deal of enthusiasm, but helps us reach landowners, avoid threatening dogs and find flowering avocado trees among lots of other things!