Impact of Global Change on Pollinators and Pollination Services

Peters, V.E., Eastern Kentucky University

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Dear Volunteers of Pollinator Conservation in Costa Rica,

First and foremost I'd like to start off by saying THANK YOU to all of you for your excellent and very hard work in collecting so many cool bees and butterflies of Costa Rica! Owing to everyone's hard work in the field, the data is beginning to reveal some very interesting patterns and we now have enough data to be able to publish some of the early findings which I will detail in the report below. With the support and dedication of Earthwatch volunteers over the past three 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, and in 2018 we collected a total of 3,395 bees! These numbers will greatly improve our estimates of population trajectories for many of the native bee species of Costa Rica! After bringing these thousands of bees back to the EKU lab, we have pinned and identified to species or morphospecies all the bees from 2016 and 2017, and have pinned and identified to tribe all the bees collected in 2018. The numbers described above include only the bees collected in San Luis de Monteverde. Many additional butterflies were collected but these numbers have not yet been tallied. In addition, many bees and butterflies were collected from the Osa during observations of flowering plants in 2017 and 2018. A total of 2,962 bees and butterflies were collected across the two years, with 1092 individuals comprising 89 species collected in all of 2017 and 1870 individuals comprising 111 species collected during the summer of 2018.

This subset of bees and butterflies collected from the Osa across the two years have now been fully analyzed to determine each plant species importance value and role in the plant-pollinator network to understand which plant species performed better in terms of supporting pollinators. We sampled from a total of 20 different plant species during the study. From this data we were able to construct species accumulation curves and the plant-pollinator network to determine which plant species would be best to recommend to conservation and restoration practitioners for pollinators.

In conclusion, we have lots more work to do in the lab on bee identification, 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 which we hope to be working on finalizing during the first half of this year! Thank you all again so much!

Sincerely,

Dr. Valerie E. Peters

SUMMARY

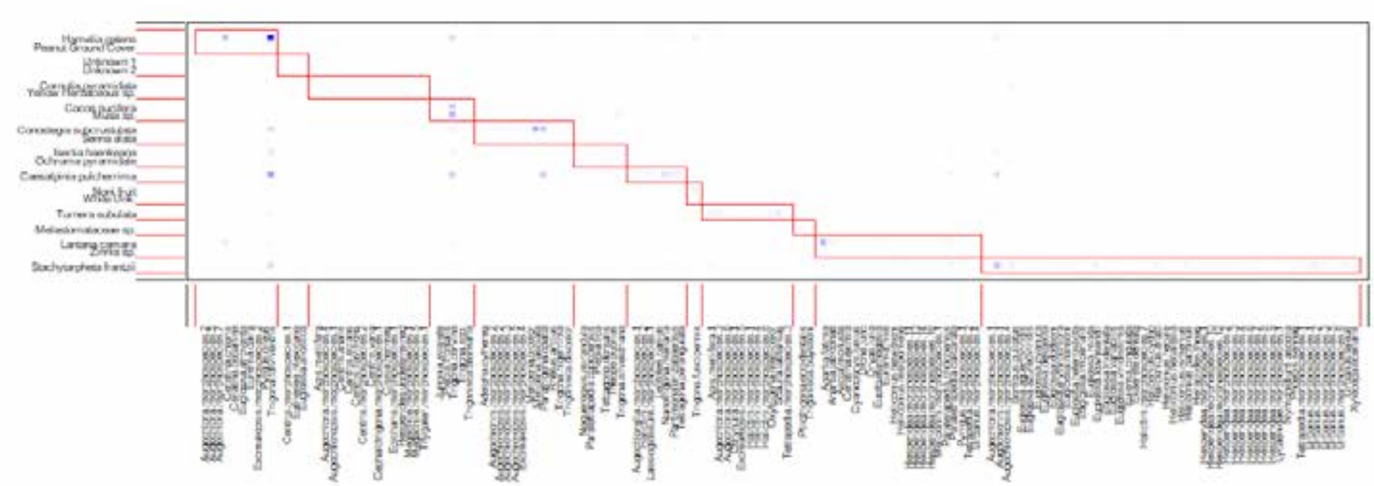
Across both our field sites, we have collected thousands of bees, with 2018 being by far the most productive year thus far. This is very exciting, as we need several years of population data and high numbers of pollinators to determine trends in insect populations since these organisms tend to have very 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). Twelve modules were identified and only one plant species, *Hamelia patens*, was 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.

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. Red boxes indicate a module or compartment.



A total of 2,962 plant-pollinator interactions were observed in the network. In 2017, 1,092 interactions were recorded and in 2018, 1,870 interactions were recorded. A total of 90 bee species and 51 Lepidoptera species were recorded from 380 timed observations, or a total of 190 hours of observations at flowering plants. Table 1 lists the total number of interactions, the total number of species and the total number of 30-minute timed samples that were recorded for each of the 20 plant species. 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 (Figures 2 and 3).

Table 1. Total number of interactions, species and samples for each of the 20 flowering plant species observed in 2017 and 2018.

Plant species	**Interaction abundance**	**Species richness**	**# of samples**
Caesalpinia pulcherrima	496	28	42
Cocos nucifera	79	7	5
Conostegia subcrustulata	416	39	67
Cornutia pyramidata	75	19	11
Hamelia patens	676	39	64
Isertia haenkeana	85	22	17
Lantana camara	240	43	39
Melastomataceae sp.	21	7	1
Musa spp.	130	11	25
Morinda citrifolia	21	1	1
Ochroma pyramidale	30	8	2
Arachis glabrata	11	4	6
Senna alata	8	5	3
Stachytarpheta frantzii	492	76	81
Turnera subulata	139	18	8
Unknown sp1	6	4	1
Unknown sp2	4	2	1
Unknown sp3	3	3	1
Unknown sp4	24	12	4
Zinnia sp.	13	6	1

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.

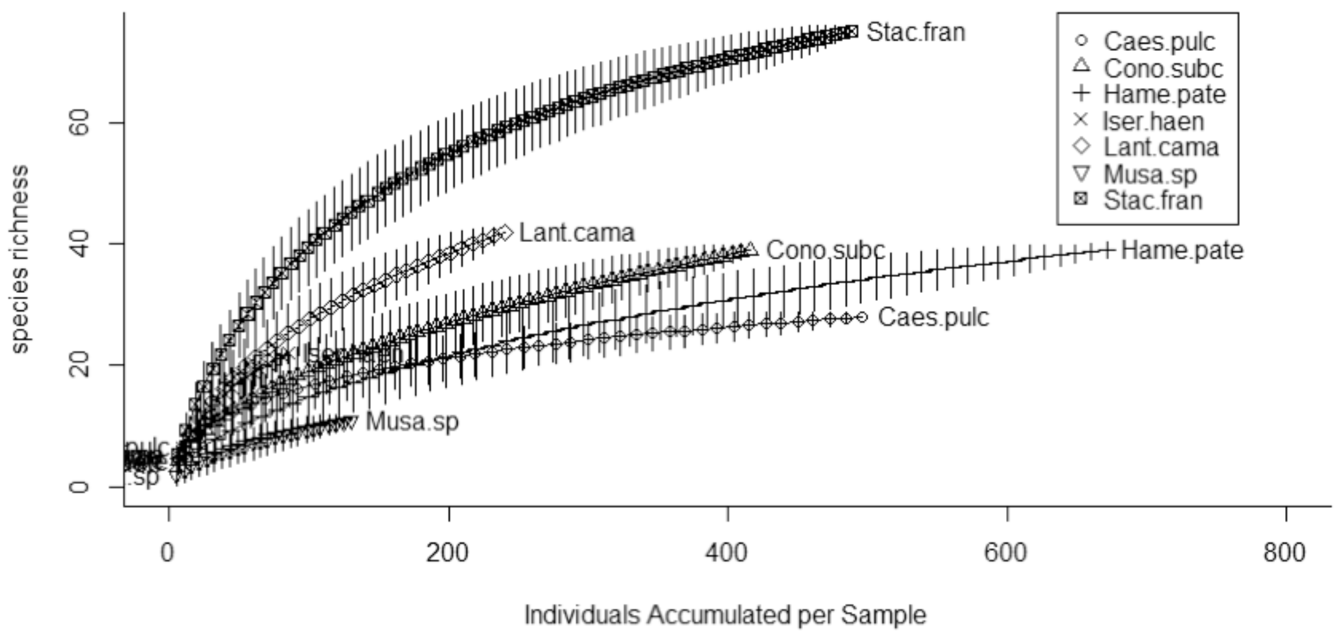
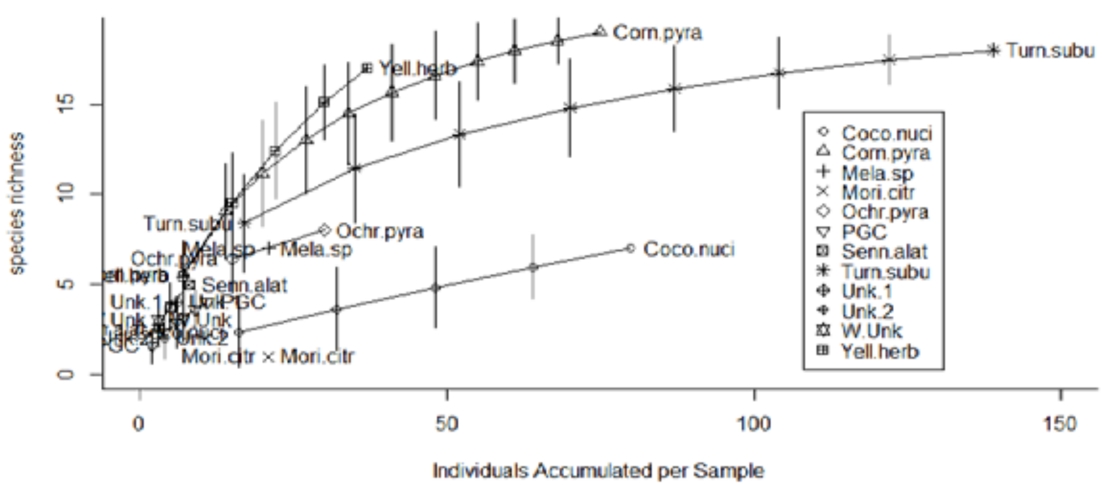
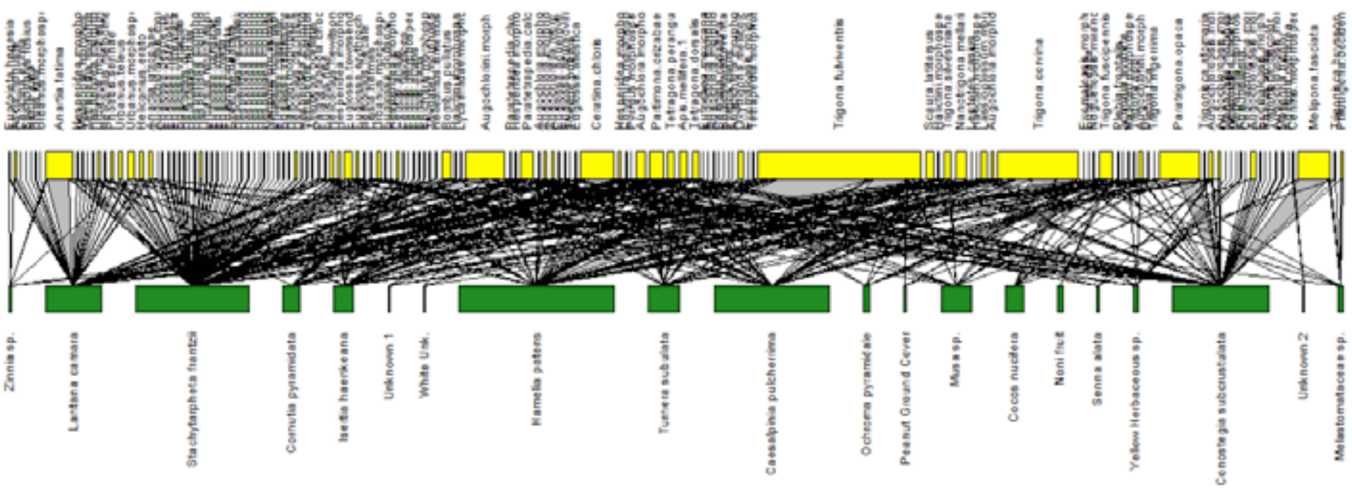


Figure 3. Species accumulation curves for 12 sampled flowering shrub species occurring in the Osa Peninsula of Costa Rica. Curves have been rarified to account for the differences in the abundance of bees that were collected from the plant species. Curves are also rescaled to the number of individuals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



A total of 2,550 bees representing 90 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.

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*).

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 elevational 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, has joined the lab and now that we have enough Meliponini individuals across multiple years, she will begin to statistically analyze the peak abundance numbers for this tribe and the Ceratinini tribe (the two tribes for which we now have the highest number of individuals)

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

	Bee Abundance											
	Total			Bee bowls			Hand collected			Vane Traps		
Tribe/Family	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. Last week we sent some Centridini species to Gordon Frankie's lab at UCLA and at least two species in the collection had not been collected before by their lab. We will soon send these species to another specialist for identification. As we continue to identify species we expect that the number of species in the collection will increase.

In addition, other key groups we have added in hundreds more specimens via the hand collection method; for example, within the Family Megachilidae, this family, like the tribe Meliponini, is particularly underrepresented in bee bowl collections (Megachilidae captures from bee bowls in the three years totaled 7 individuals). Hand collection of Megachilids from the three years added an additional 40 individuals, many of which are unique species. This additional data will allow us to better estimate Megachilid species richness in the area. However, owing to the low rates of capture for Megachilid species (likely because they tend to be rare in the area or have low population densities), evaluating trends in population trajectories will not be feasible for Megachilid species.

Bee bowls tend to capture very high numbers of small bees that don't have strong flight muscles. These bees tend to be found in the family Halictidae and in the tribe Ceratinini in the Apidae family. We have found some interesting patterns using collections of individuals from the bee Tribe Ceratinini which we have been able to identify all species, owing to our collaboration with Dr. Sandra Rehan at the University of New Hampshire, who is the world's leading expert on Ceratinini bees.

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 12 samples collected thus far (Figure 5).

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 6b. During the onset of rainy season in 2016, over 460 mm of rain fell and this was over a period of 36 days. 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 2018, 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. 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 m.a.s.l. to 1100 m.a.s.l.

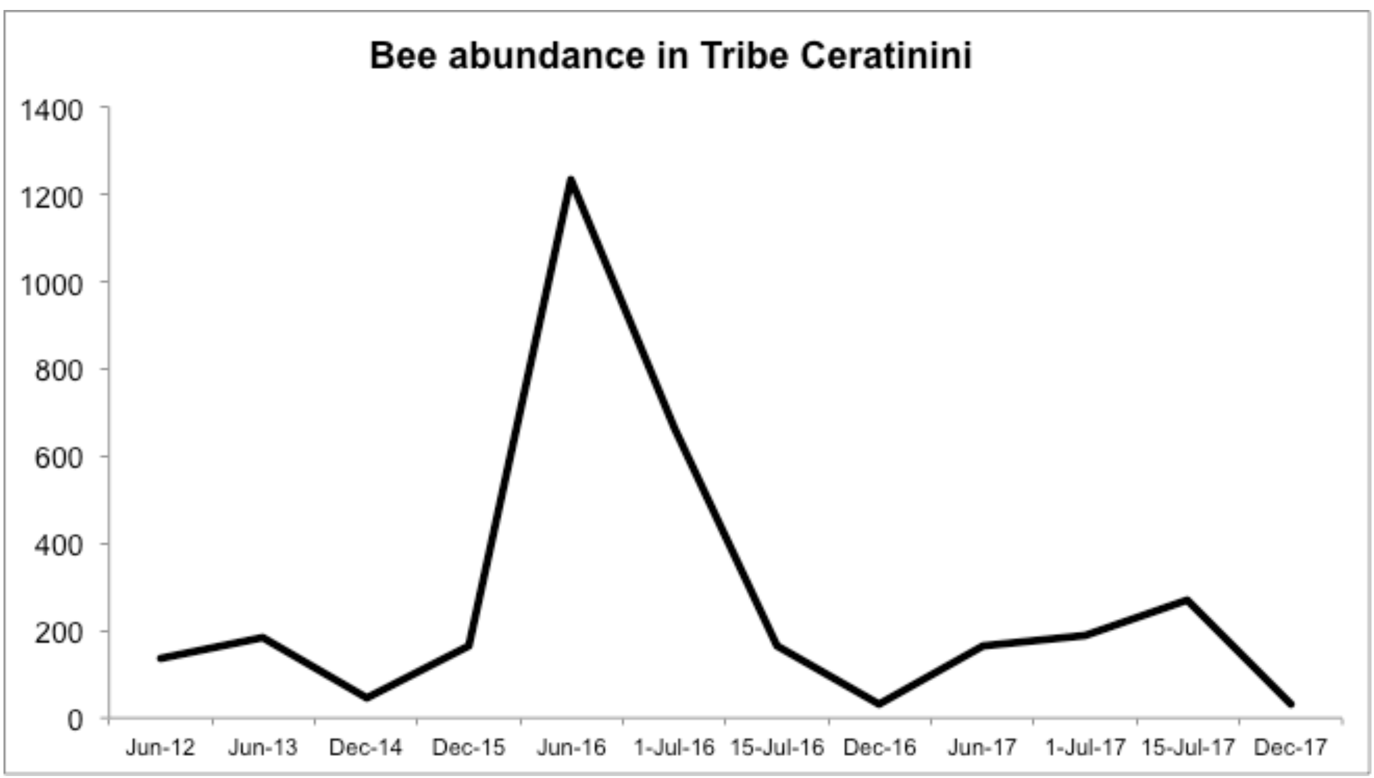
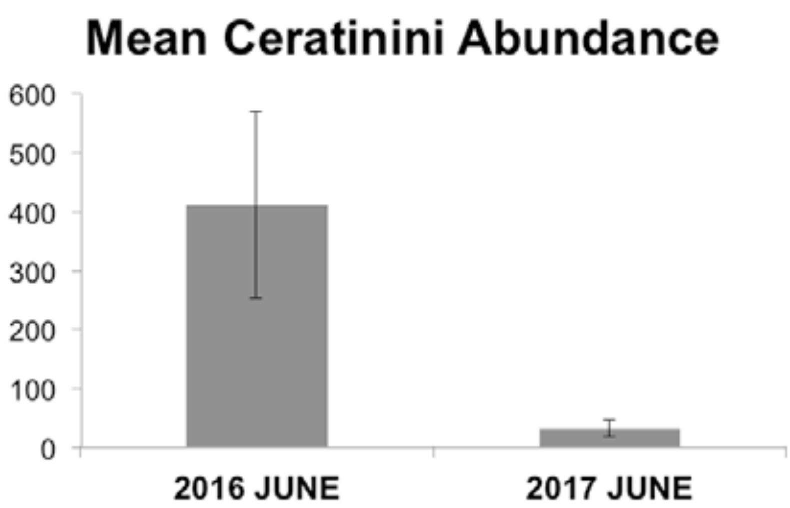
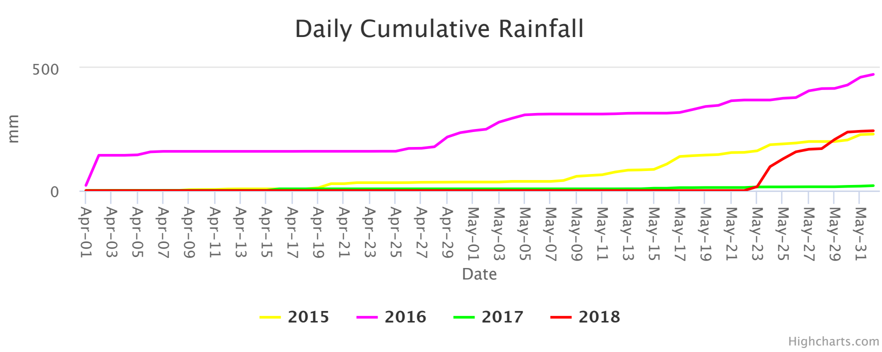


Figure 6a-b. Average Ceratinini abundance from bee bowls collected at all three elevation transects and variation in rainfall abundance, number of rainfall days (2015-2018) at the San Luis weather station

a.



b.



From April-1	To June-1	Precipitation[mm]	Number of Rainy Days
2018	2018	243.805	10
2017	2017	20.065	15
2016	2016	463.825	36
2015	2015	230.12	37

Project Impacts

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

1. Increasing Scientific Knowledge

a) 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 7 volunteer teams during the 2018 field season, the total number of citizen science research hours for June and July 2018 ranges between 245 hours and 308 hours, not including the time of each groups initial travel to and departure from each of our field sites, Monteverde or the Osa Peninsula. In December 2018, using the same estimates, a total of 70-80 citizen science research hours were worked.

b) Peer-reviewed publications

c) Non-peer reviewed publications:

Technical reports, white papers, articles, sponsored or personal blogs

d) Books and book chapters

e) Presentations:

Podcast, recorded December 2018:

http://blogs.oregonstate.edu/pollinationpodcast/2019/01/07/dr-valerie-peters/

bit.ly/PolliNation-ApplePodcasts
bit.ly/PolliNation-iTunes

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

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

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2. Mentoring

a) Graduate students

List graduate students doing thesis work on the project and include student CVs and their research proposal on file with the university as an attachment when you submit your annual report

Student Name	Graduate Degree	Project Title	Anticipated Year of Completion
Chelsea Hinton	M.S.		2019
Kristin Conrad	M.S.		2020

b) Community outreach

Provide details on how you have supported the development of environmental leaders in the community in which you work.

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

3. Partnerships

List your current active professional partnerships that contribute to your project and indicate the type of support these partners provide

Partner	Support Type(s)[1]	Years of Association (e.g. 2006-present)
University of Georgia	Logistics, Permits, Academic support	2005 to present
Osa Conservation	Logistics	2016 to 2018
Finca Kobo	Collaboration	2014 to 2018

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

4. Contributions to management plans or policies

List the management plans/policies to which your project contributed this year

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

2. Type options: agenda, convention, development plan, management plan, policy, or other (define)
3. Level of impact options: local, regional, national, international
4. Primary goal options: cultural conservation, land conservation, species conservation, natural resource conservation, other
5. Stage of plan/policy options: proposed, in progress, adopted, other (define)

5. 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

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[6]

6. 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[7]	Description of contribution	Resulting effect[8]

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

8. 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

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[9]	Description of contribution	Resulting effect

9. 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

ACKNOWLEDGEMENTS

We thank the many Earthwatch volunteers who braved rainstorms and extreme heat to help us gather this data. We also thank the many farmers and private landowners who have supported our projects, especially Oldemar Salazar, Eliza Mata, and Alex Retana.