FORESTGEO ARTHROPOD INITIATIVE
ANNUAL REPORT 2019

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I. BACKGROUND AND PARTICIPATING FORESTGEO SITES

The 'Arthropod Initiative' of the Center for Tropical Forest Science (CTFS) aims at monitoring key arthropod assemblages over long-term and studying insect-plant interactions over the network of the Forest Global Earth Observatories (ForestGEO, https://forestgeo.si.edu/research-programs/arthropod-initiative). The Initiative integrates with ongoing monitoring of plant dynamics within the ForestGEO network, causes minimum possible impact to the plots and focus on a priority set of assemblages chosen for their ecological relevance, taxonomic tractability and ease of sampling. At each participating ForestGEO site, the first years of the program are usually devoted to a 'baseline' survey. The baseline survey is followed by longer-term programs of field work and analysis, organized into two main sub-programs: monitoring, and key interaction studies. The monitoring sub-program is directed to detecting long-term changes, as reflected in priority assemblages, driven by climatic cycles, climatic change and landscape scale habitat alteration. Monitoring protocols are derived from those used during the baseline survey. The food web approach of interaction studies targets interactions between plants and specific insect assemblages, with different protocols than those used for monitoring.

So far, the Arthropod Initiative involves eight ForestGEO sites: Yasuni in Ecuador, Barro Colorado Island (BCI) in Panama, Rabi in Gabon, Khao Chong (KHC) in Thailand, Tai Po Kau (Hong Kong), Dinghushan and Xishuangbanna (XTBG) in China and Wanang (WAN) in Papua New Guinea. At BCI, four full-time research assistants were in charge of arthropod monitoring protocols in 2019: Filonila Perez, Ricardo Bobadilla, Yacksecari Lopez and Alejandro Ramirez. The program coordinator, YB, doubled as BCI site supervisor. The collections and staff of the ForestGEO Arthropod Initiative in Panama are based at the Tupper complex.

Most of the insect monitoring at KHC in 2019 was under the responsibility of Montarika Panmeng, Manat Reungaew, Kanyakarn Sripila and Sontaya Promchaisri. Supervision at KHC was assured by Sarayudh Bunyavejchewin, Nantachai Pongpattananurak, (Kasetsart University, Bangkok), Watana Sakchoowong (Thai National Parks Wildlife and Plant Conservation Dept) and YB (one visit of three weeks). At WAN, Francesca Dem (Binatang Research Centre), Vojtech Novotny (Czech Academy of Sciences and University of South Bohemia) and YB supervised assistants Roll Liplip, Ruma Umari, Fidelis Kimberg and Ananias Kamam, who were in charge of ForestGEO protocols. At Yasuni David Donoso (Escuela Politécnica Nacional, Quito, Ecuador) and assistants performed Winkler protocols to monitor litter ants, while Maria Fernanda Checa and Sebastian Mena (Museo QCAZ de Invertebrados. Pontificia Universidad Católica del Ecuador) organized butterfly transects. Timothy Bonebrake and Chum-Lim Luk supervised butterfly monitoring at the plots of Tai Po Kau, and Dingshushan. At Xishuangbanna, Aki Nakamura (Xishuangbanna Botanical Gardens) supervised butterfly, ant, fruitfly and termite monitoring.

II. TAXONOMIC STUDIES AND DNA BARCODING

We got results from ten plates of DNA barcoding, which helped to refine our BCI collections for Dynastinae, Passalidae, Isoptera, Reduviidae and Arctiinae, notably. David Donoso (Escuela Politécnica Nacional, Quito, Ecuador) refined ant identifications in our collections as part of our ant projects, which should soon result in a few interesting papers. Alejandro Ramirez is improving the taxonomy of the reduviids of BCI as part of his MSc at the University of Panama. José Palacios-Vargas and his team at the Laboratorio de Ecología y Sistemática de Microartrópodos (UNAM, Mexico) prepared and identified ca 1,700 slides of soil Collembola from BCI, as part of our metabarcoding project (see below). The Collembola fauna of Panama is very poorly known, with a reported 20 species for the whole of the country. Prof. Palacios-Vargas and his team discovered 61 morphospecies (including 43 identified species) in the soils of BCI, and many of these species have now DNA barcodes.

We consolidated our DNA barcoding data (+13,000 sequences available in projects ABCI, AKHC and AWAN) and started different pilot projects related to DNA metabarcoding on BCI. This should help us one day to efficiently monitor most of arthropod species on the island. Results from Malaise trap samples, sequenced at the University of Guelph (Kate Perez; Global Malaise Program) were deposited in BOLD projects GMTPV (BCI: 12,727 sequences), GMTBR (KHC: 16,221 sequences) and GMTPW (WAN: 15,042 sequences). Further, the results of 100 soil and litter soil samples are now deposited on the platform mBrave (http://www.mbrave.net/), as well as 20 samples of light traps (join project with Greg Lamarre, Petr Blažek and Richard Ctvrtecka of the University of South Bohemia). All together these various sample represent > 7 GB of data that we have started analyzing. Anakena Castillo, of INDICASAT in Panama, went to the laboratory of Mehrdad Hajibabaei (University of Guelph) to learn more about bioinformatics. We intend to start analyzing soon these results.

III. MONITORING: BARRO COLORADO ISLAND, KHAO CHONG AND WANANG

Year 2019 represented the eleventh year of insect monitoring at BCI. So far, the BCI database contains data on 594,350 arthropods, including 2,499 focal species (1,816 of which with pictures, 73%) and 69,323 pinned specimens in our collections (250 drawers). Each year we collect at BCI 330 insect samples (80 light trap samples, 50 Winkler samples, 120 butterfly transects, 40 termite transects and 40 bee bait samples) and in 2019 this represented 50,179 arthropods. Field protocols represent routine work and most of our work at BCI is focused on improving our insect collections.

We started an active collaboration with the laboratory of Greg Lamarre (University of South Bohemia) and his colleagues Benita Laird-Hopkins, Petr Blažek and Richard Ctvrtecka. Greg was the PI in Panama and at Fort Royal of a large project funded by ERC looking at hostplant-caterpillar interactions (see publications, Volf et al., 2019). Greg will be helping Yves to take the ForestGEO Arthropod Initiative one step further, in terms of data analyses and new projects. In Panama, Greg's lab is located at the Gamboa complex. Petr and Richard helped to get light trap samples for DNA metabarcoding, while Greg and Benita started a new project on insect thermal tolerance. Benita is a PhD student at the University of South Bohemia, supervised by Greg and Yves, and her thesis will estimate thermal tolerance for a range of taxa on BCI. Chris Dahl (University of South Bohemia) successfully defended his PhD thesis entitled "A cross-continental comparison of fruit-and seed-feeding insects in the rainforests of Panama, Thailand and Papua New Guinea". Congratulation to Chris for a well-deserved PhD! Three interns helped the ForestGEO Arthropod Initiative in Panama during 2019, Maikol Guevara, Pamela Pomanco and Stephany Arizala Cobo, all thanked here for their excellent work. Congrats also to Stephany, who successfully defended her MSc thesis at the University of Campinas (Brazil), entitled "Taxonomia e Sistemática Filogenética do gênero de aranhas Neotropical *Acanthoctenus* Keyserling, 1877 (Acanthocteninae, Ctenidae, Araneae)". Illiana Quníntero also worked with Sofia Gripenberg (University of Reading, U.K.) on damage inflicted by insect herbivores on seedlings. Three volunteers helped us greatly in 2019. Yorlene Serrano improved the picture coverage of our focal species for BCI. Eduardo Navarro developed an interactive key for the orchid bee genus *Euglossa* on BCI, which is available at https://forestgeo.si.edu/research-programs/arthropod-initiative/arthropod-resourcesrecursos. If possible, we are planning to develop more of interactive keys for several of our focal taxa. Rick Buesink helped Greg and Benita with the thermal tolerance project.

World-wide there are concerns about global insect decline, reflected by a flurry of publications on this topic. The ForestGEO Arthropod Initiative also contributed to this debate in 2019. Yves and Greg wrote a summary article for *Science* entitled "Towards a world that values insects" and we reproduce the integrality of the article in Appendix I. Yves and colleagues Ralph Didham and Simon Leather, as senior editors of *Insect Conservation and Diversity*, are preparing a special issue of this journal on insect decline, to be published next year. Yves also co-authored with +75 renowned entomologists the article "A roadmap for insect conservation and recovery", which will be published in January 2020 in *Nature Ecology and Evolution*.

2019 represented our ninth year of monitoring at KHC. We collected 370 insect samples (80 light trap samples, 50 Winkler samples, 120 butterfly transects, 40 termite transects and 80 McPhail samples). So far, our database includes 190,150 specimens (39,000 pinned specimens in collections) and 2,470 focal species. We still need to improve on processing quickly insect samples and including representative insect pictures in our database. At WAN, 2019 represented the seventh year of insect monitoring. The ForestGEO insect database contains data on 56,000 specimens, but apart from butterflies and fruitflies, few of these specimens are yet identified.

IV. INTERACTION STUDIES

We are still in the process of analyzing data resulting from the study of seed predators and herbivore damage on seedlings at the three sites of BCI, KHC and WAN. These studies were funded by the Grant Agency of the Czech Republic and result from a collaboration with Sofia Gripenberg (University of Reading), Owen Lewis (University of Oxford), Richard Ctvrtecka; Philip Butterill, Leonardo Ré Jorge (University of South Bohemia) and Simon Segar (Harper Adams University). Six papers resulting from these projects were published in 2019, including the excellent summary of seed predator interactions on BCI led by Sofia and published in *Ecology Letters*. Yves is leading the effort for contrasting similar data at the three sites. The other project monitored the survivorship of seedlings in control plots and in plots treated with insecticide, to evaluate the action of insect herbivores on seedlings. Richard is helping Yves to database all the results and our seedling damage database includes now + 4 mio records. We expect to start analyzing these impressive data next year. The Grant Agency of the Czech Republic also funded a new project to Yves and collaborators at the University of South Bohemia (Greg, Richard and Daniel Souto), entitled "Integrating genomic and trophic information into long-term monitoring of tropical insects: pollinators on Barro Colorado Island, Panama". This exciting project will start next year and will include a new PhD student, supervised by Yves, Greg and Daniel.

V. FORESTGEO ARTHROPOD DATABASE

Phil Butterill (University of South Bohemia) continued to implement the new ForestGEO Arthropod database. The local version is 100% complete and routinely used by 7 sites. The web version, which will essentially mirror snapshots of data for the sites of BCI, KHC and WAN, is ready and undergoing final security tests in Washington. It should be on-line early next year. The database and related web pages will allow to foster scientific collaboration via a better visibility of the ForestGEO Arthropod Initiative. All Yasuni butterfly data and pictures have been uploaded on the BCI local application, with the help of Sebasian Mena. The saturniid data collected by Andrew Aldercotte in the Panama Canal Zone as part of his MSc thesis at the University of Bangkor were also uploaded in the ForestGEO Arthropod database.

Next year we plan to include in the database the insect seed predator data, which represent over 80,000 insect records with hostplant information. The BCI local application will be moved shortly a server of the Smithsonian's data center in Herndon, Virginia, instead of the current local sever at STRI. The current web pages of the ForestGEO Arthropod Initiative are at https://forestgeo.si.edu/research-programs/arthropod-initiative. The personal web page of the program coordinator is maintained at https://stri.si.edu/scientist/yves-basset.

VI. SCIENTIFIC OUTPUT

In 2019, the ForestGEO Arthropod Initiative trained, at the sites of BCI, KHC and WAN, 17 assistants (7: BCI, 6: KHC, 4: WAN); 2 interns (all at BCI); one MsSc student (BCI) and two PhD students (BCI-WAN). We wrote 8 publications, including one in *Science* and one in *Ecology Letters*. In 2019, we initiated new collaboration with colleagues interested in the ForestGEO Arthropod Initiative and we expect these new collaborations to flourish in 2020 and to lead to an increasing number of exciting publications.

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Other publications of the program coordinator in 2019:

Volf, M., Klimeš, P., Lamarre, G.P.A., Redmond, C.M., Seifert, C.L., Abe, T., Auga, J., Anderson-Teixeira, K., Basset, Y., Beckett, S. Butterill, P.T., Drozd, P., Gonzalez-Akre, E., Kaman, O., Kamata, N., Laird-Hopkins, B., Libra1, M., Manumbor, M., Miller, S.E., Molem, K., Mottl, O., Murakami, M., Nakaji, T., Plowman, N.S., Pyszko, P., Šigut, M., Šipoš, J., Tropek, R., Weiblen, G.D. & Novotny, N. 2019. Quantitative assessment of plant-arthropod interactions in forest canopies: a plot-based approach. *PLoS ONE,* **14**, e0222119.

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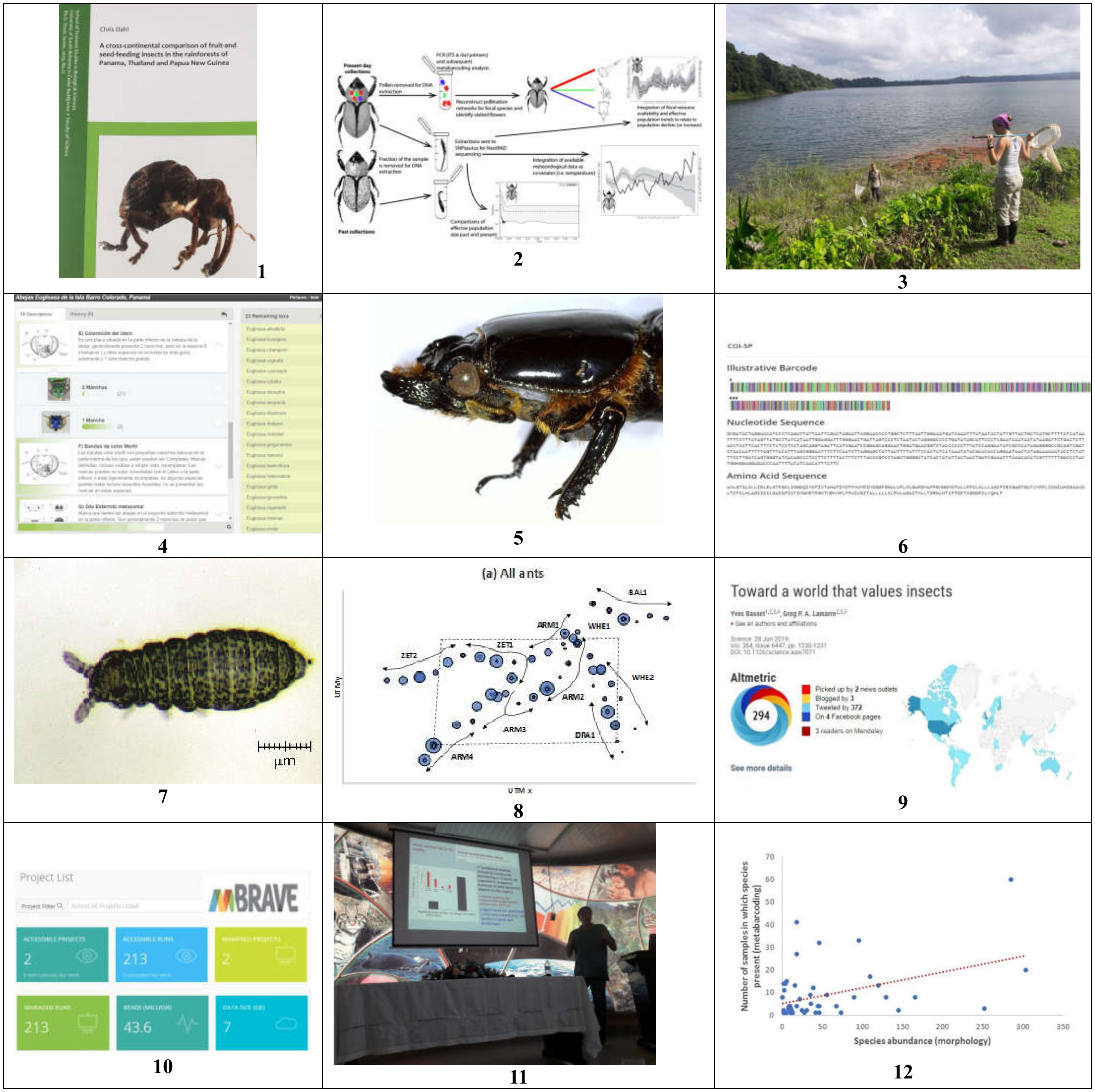
Selected manuscripts in preparation related to the ForestGEO Arthropod Initiative:

Monitoring tropical insects in the 21st century (submitted to *Adv. Ecol. Res*.)
Enemy-free space and the distribution of ants, springtails and termites in the soil of one tropical rainforest (submitted to *Eur. J. Soil Biol*.)
Functional groups of rhinoceros beetles (Coleoptera, Dynastinae) in Panama.
Long-term monitoring of social insects in tropical rainforests.
Calibrating biodiversity for long-term monitoring: detecting changes in assemblage composition from temporarily and spatially variable insect data.
Invasive ants in the Yasuni National Park. Where do they come from?
Host specificity and interaction networks of insects feeding on seeds and fruits in tropical rainforests.
Assemblages of tephritid fruit flies along an elevational gradient in the rainforests of Papua New Guinea.
Ant male flights in a Neotropical seasonal forest are shaped by low relative humidity and not by rainfall or moonlight

Plate I. Representative activities/items for the ForestGEO Arthropod Initiative in 2019. (1) Cover of the PhD thesis of Chris Dahl. (2) Flow diagram for the new project on BCI insect pollinators that will start in 2020. (3) Arizala and Buesink chasing butterflies on BCI for the thermal tolerance project. (4) Screen shot of the interactive bee key. (5) Lateral view of the head of *Passalus* sp. 16 (Passalidae), specimen BCI167268, which was sequenced. (6) Illustrative DNA barcode for specimen BCI167268, as seen in BOLD project BCIPA. (7) *Brachystomella mataraniensis*, one of the Collembola which was sequenced for the soil DNA metabarcoding project. (8) Density of ants along the trails of the BCI plot (soil DNA metabarcoding project). (9) Altmetric data (n = 294) of the article published in *Science*. (10) Current project list on the mBrave platform. (11) Basset invited to talk at the University of Panama (Congreso Cientifico Nacional). (12) Relationships between species abundance and the number of samples in which the species was recovered by metabarcoding (soil DNA metabarcoding project).



APPENDIX I. FULL TEXT OF BASSET & LAMARRE (2019), PUBLISHED IN *SCIENCE* (see next page).

CONSERVATION

Toward a world that values insects

Rapid adoption of conservation measures is key to protecting insect populations

By Yves Basset[1,2,3,4] and Greg P. A. Lamarre[2,3,5]

Insects make up the bulk of terrestrial diversity (*1*). Reports of insect declines, best documented in Europe and North America, suggest that 40% of insect species in temperate countries may face extinction over the next few decades (*2*), although this figure is probably inflated (*3*). Other studies have highlighted falling insect biomass in Germany and Puerto Rico (*4*, *5*), as well as threats to many insect taxa in Europe (*5*) and insect pollinators worldwide (*6*) that support food production (*7*). To protect insects, it is crucial that they are considered as separate species with distinct responses to threats, with particular attention to tropical insects and their habitats. Bees and butterflies may serve as an initial focus, but conservation efforts must go far beyond these iconic species. Halting habitat loss and fragmentation, reducing pesticide use, and limiting climate change are all required if insect populations are to be preserved.

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THE MAIN THREATS

Trends in biodiversity decline are more severe for invertebrates than for vertebrates (*4*), because the former are highly specialized in terms of food resources and microhabitats. About half of insect species are herbivores and have intimate relationships with their host plants; the slightest alteration to plant abundance or phenology may therefore have severe consequences for insect populations. Multiple interacting threats affect insects, often with negative consequences not just for the insect species themselves but also for other species that rely on them and for overall ecosystem functioning. However, little is known about the identity, genomics, or ecological role of most insect species.

Habitat loss and fragmentation are probably the most serious threats to temperate and tropical insects, particularly to rare, endemic, and specialized species, resulting in reduced and homogeneous assemblages of generalist species across space (*8*). Habitat loss is fueled by agricultural expansion and intensification, which involves substantial use of chemical pesticides (insecticides and herbicides). The latter are another substantial threat to insect species; insecticides have been linked to insect decline in temperate countries (*2*, *4*) and to global pollinator decline (*6*). The increasing introduction of large-scale agriculture in the tropics may similarly cause substantial harm to insect populations through the impacts of pesticides beyond agricultural systems (*9*). The use of fertilizers and herbicides may also shift plant composition, altering the population dynamics of host plants and dependent insects (*3*).

Climate change, and especially the frequency of extreme climatic anomalies, may be especially detrimental to tropical insects, which tend to have narrow geographic ranges and low tolerance to changes in temperature and rainfall (*5*, *10*). Invasive species and pathogens may also threaten local populations, as can light pollution (*2*, *3*).

IMPROVING KNOWLEDGE

Insects are the central component of the living world, and their protection is crucial to maintaining functioning ecosystems and ensuring food security (*4*, *7*). However, scientific knowledge is limited because of insufficient funding for entomological science and the resulting scarcity of adequate field studies. Many past studies have relied on overall insect biomass measurements, which are relatively easy to conduct (*2*, *5*). However, insect biomass greatly varies in space and time and provides little information about the population dynamics of specific species. Instead, population trends can be summarized by combining insect species into different functional groups (*10*), which may help to identify which species are coping better or worse with anthropogenic changes (*3*).

Furthermore, many studies are resurveys—that is, snapshots taken at specific time intervals rather than continuous monitoring. The latter is crucial for evaluating how insects respond to individual threats. Comparison of snapshots is further complicated by habitat changes, does not accurately capture which species are present or absent, and may yield misleading trends (*3*).

Assemblages monitored in the long term must be representative of local insect populations and reasonably diverse. Findings of low insect densities and rates of local extinction must be corroborated with independent studies, particularly in the tropics, where many species subsist at low densities (*10*). Further, contrasting insect responses to threats must be acknowledged and scrutinized (*3*, *10*). For example, many native species may be declining in temperate forests, but several pest species are expanding their geographical range in response to climate change (*7*). Efficient monitoring programs can benefit from recently developed technologies involving molecular methods (*11*) or bioacoustics, as well as from citizen participation (*6*).

Conservation efforts cannot succeed without sound ecological knowledge of the role of insects in ecosystem maintenance and functioning and of the complex processes, such as adaptive strategies, food behavior, or cascading trophic interactions, that may be disrupted by threats (*5*). Because even small ecosystem fragments have conservation value for insect biodiversity and ecosystem services, studies should focus on how to preserve forest heterogeneity, enhance the values of fragments by increasing forest connectivity, and promote habitat restoration favorable to insects. Experiments should investigate the consequences of extreme temperatures, which may reduce the fitness of predatory and parasitoid species. A better understanding and delineation of the species that need to be protected is also important. Taxonomic knowledge can be advanced by training more taxonomists and by developing DNA barcode libraries, which provide tractable and testable taxonomic frameworks (*11*).

PROTECTION MEASURES

Insects are of crucial importance for ecosystem functioning (including pollination and forest regeneration), for mitigation of pests, and as a source of protein for animals and humans (*7*). Effective protection measures can be implemented now to mitigate insect decline by examining the evidence available for temperate insects. If decision-makers fulfill their commitments toward the implementation of the 2015 Paris Agreement to mitigate global warming, threats to insect populations resulting directly from global climate change will be alleviated. In urban areas, policies that favor organic agriculture

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ILLUSTRATION: ADAM SIMPSON/HEART AGENCY

and insect-friendly gardens can greatly support insect species (*12*). Planting native species in urban environments such as parks, roofs, and backyards can also help to protect insect populations and deliver pollination services.

In rural areas, insect species would benefit from support for organic agriculture and permaculture, the reduction and more efficient use of pesticides, use of integrated pest management (*7*), and local-scale farming practices that nurture insect populations. Boosting the abundance, diversity, and continuity of floral resources and providing nesting sites are efficient ways to mitigate pollinator decline (*6*).

Efficient, appropriate, and permanent conservation measures for natural habitats (such as old-growth forests) and human-influenced areas of even very small sizes can support high insect diversity (*3*). National coordination, informed by scientific results, can lead to better conservation management, such as supporting effective landscape-scale ecological networks (*13*). Funding of long-term research activities on habitat conservation in general, and specifically on insect science and taxonomy, is especially important to evaluate and mitigate future changes in insect communities, obtain reliable insect time series, and discover species before they go extinct (*1*).

ENGAGING THE PUBLIC

In general, the public tends to appreciate aesthetic insects such as butterflies and the beneficial role of pollinators (*6*). These perceptions can be used to strengthen the conservation value of insects. However, bee and butterfly species represent only <4% of the insect species described worldwide (*1*). Many people have negative perceptions of insects in general and do not perceive them as separate species (*14*). Further, the roles of insects in ecosystem services can be difficult to comprehend (except for pollinators), as are the consequences of insect species loss and overall attrition of biodiversity.

Although public interest in insects varies from one country to another, biological education about the conservation of insects and their natural habitats is urgently needed at all levels of society, starting with field education programs (*14*). The extraordinary natural history of insects offers many opportunities in biological education and citizen science (*14*). Field surveys and experiments help the public to appreciate the importance of insects in terrestrial biodiversity (*14*). Such activities may promote greater empathy and curiosity toward insects and their habitats. Finally, promoting science through traditional and social media can spread enthusiasm and respect for insects and those who study them.

TROPICAL DATA GAPS

In the tropics, where most insect species live, circumstantial data exist, but long-term records are too sparse to support the conclusion of a global insect decline. Most tropical datasets (see supplementary materials) were collected in locations buffered from the effects of agricultural practices and habitat disturbance. Most of these studies do not unequivocally suggest a decline in insect abundance or species richness; rather, they point to contrasting patterns in population dynamics and to the possible impact of climate change. This may reflect an initial positive effect of rising temperatures or merely the dynamics of common species (see fig. S1 in supplementary materials). For example, the species richness of a community of leaf litter ants in Ecuador remained constant for a study period of 11 years, with little or no evidence of directional change toward a new community (*15*).

Longer time series including diverse taxa are urgently required to understand what is going on. However, tropical regions mostly composed of developing countries can only devote limited funds to research on nature conservation. Successful examples of conservation planning and public outreach in temperate regions could be shared with tropical regions and could help to guide insect conservation in those locations. International collaborations involving scientists from both developed and developing nations will be key to expertise sharing, as will be the development of global databases with open access.

A male weevil *(Rhinostomus barbirostris)* protects an egg-laying female in Panama.

PHOTO: YVES BASSET

OUTLOOK

No matter whether the insect apocalypse is global or not, immediate actions are necessary to mitigate insect decline. Here, more insect-friendly agricultural practices are key. Scientific research into the cost effectiveness of pesticide use will help to reduce unnecessary pesticide applications (*9*). Redistribution of eco-friendly subsidies to favor insect protection (*5*) can target integrated pest management, the use of pesticide and fertilizers only when necessary for food security and the protection of remaining natural habitats from land-use conversion. Changes of laws can be implemented quickly using bees or butterflies as the focus of attention, as recently demonstrated in Bavaria, Germany, where a grassroots citizen campaign and a state referendum led to a law necessitating drastic changes in agricultural practice to protect biodiversity.

Efforts to mitigate the effects of climate change, such as the boycott of harmful chemical products by both the public and governments, will also help insect populations to recover. To allow insect populations to prosper in both temperate and tropical areas, scientists and policy-makers need to rethink scientific and public priorities to reach out to the public and develop effective protection measures. We need a bioliterate society that protects insects to ensure humanity's own survival. ■

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SUPPLEMENTARY MATERIALS

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Supplementary Materials for

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This PDF file includes:

Supplementary Text
Fig. S1

Supplementary Text

Suggested further readings and notes. Studies (listed in chronological order) including continuous monitoring (> 5 years; as opposed to snapshot surveys) of wild terrestrial insects in the tropics, with notes:

[location; habitat; focal taxa; sampling period covered; number of years; main conclusions regarding population dynamics].

Tropical studies indicating or suggesting an insect decline:

A. Dejean *et al*., Climate change impact on Neotropical social wasps, *Plos One* **6**, e27004 (2011).
[French Guiana; social wasps; plantation; 1997-2009; 13 years; recent climatic changes may have depressed the number of wasp colonies because lowered wasp resistance to parasitoids and pathogens].

B. C. Lister, A. Garcia, Climate-driven declines in arthropod abundance restructure a rainforest food web, *PNAS* **115**, E10397-E10406 (2018).
[Puerto Rico; *Lamponius portoricensis* (walking stick); midelevation rainforest; 1991-2014; 24 years; decline in abundance of this species, probably due to climate warming].

D. H. Janzen, W. Hallwachs, Perspective: Where might be many tropical insects?, *Biol. Conserv*. **233**, 102-108 (2019).
[Costa Rica; various taxa; mostly dry and wet forests; 1953-2018; 66 years; gradual but very visible decline in insect density and species richness however not formally quantified].

Tropical studies indicating no obvious insect decline or contrasted species responses:

H. Wolda, D. W. Roubik, Nocturnal bee abundance and seasonal bee activity in a Panamanian forest, *Ecology* **67**, 426-433 (1986).
[Panama; Halictidae (nocturnal bees); undisturbed lowland rainforest; 1977-1983; 7 years; no noticeable changes in bee abundance but fluctuations probably related to seasonal flower abundance].

H. Wolda, Trends in abundance of tropical forest insects, *Oecologia* **89**, 47-52 (1992).
[Panama; various taxa (nocturnal insects); undisturbed lowland rainforest; 1974-1987; 14 years; species richness and abundance remained at the same level over the 14 years].

T. Itioka *et al*., Six-year population fluctuation of the giant honey bee *Apis dorsata* (Hymenoptera: Apidae) in a tropical lowland dipterocarp forest in Sarawak, *Annls Entomol. Soc. Am*. **94**, 545-549 (2001).
[Malaysia; *Apis dorsata* (giant honey bee); undisturbed lowland rainforest; 1992-1997; 6 years; populations increase rapidly in response to general flowering and are initiated by long-distance migration].

D. W. Roubik, Ups and downs in pollinator populations: when is there a decline?, *Conserv. Ecol.* **5**, 2 (2001).
[Panama; Euglossini (orchid bees); undisturbed lowland rainforest; 1979-2000; 22 years; the assemblage showed no detectable change in diversity and no overall decline in abundance over the study period, but responses of individual species varied, probably driven by ENSO].

A. K. Leidner, N. M. Haddad, T. E. Lovejoy, Does tropical forest fragmentation increase long-term variability of butterfly communities?, *PLoS ONE* **5**, e9534 (2010).
[Brazil; butterflies; fragmented and intact lowland rainforest; 1980-1991; 11 years; butterfly communities in fragmented tropical forests were more variable than in intact forest, but no obvious decline noticeable].

V. Grøtan *et al.*, Seasonal cycles of species diversity and similarity in a tropical butterfly community, *J. Anim. Ecol*. **81**, 714- 723 (2012).
[Ecuador; fruit-feeding butterflies; undisturbed lowland rainforest; 1994-2004; 10 years; undetermined processes maintained species diversity and high community similarity across years].

K. Kishimoto, T. Itioka, Seasonality in phytophagous scarabaeid (Melolonthinae and Rutelinae) abundances in an ‘aseasonal’ Bornean rainforest, *Ins. Conserv. Div*. **6**, 179-188 (2013).
[Borneo; Scarabaeidae (scarab beetles); undisturbed lowland rainforest; 1994-1999; 6 years; clear insect seasonality was prevalent, but no obvious decline in abundance or species richness].

A. Valtonen *et al*., Tropical phenology: bi-annual rhythms and interannual variation in an Afrotropical butterfly assemblage, *Ecosphere* **4**, 1-28 (2013).
[Uganda; fruit-feeding butterflies; midelevation rainforest; 2000-2011; 12 years; butterfly assemblages differed significantly between ENSO and non-ENSO years but overall decline was not noticeable].

V. Grøtan, R. Lande, I. A. Chacon, P. J. DeVries, Seasonal cycles of diversity and similarity in a Central American rainforest butterfly community, *Ecography* **37**, 509-516 (2014).
[Costa Rica; fruit-feeding butterflies; undisturbed lowland rainforest; 2003-2012; 9 years; community diversity and similarity did not decline with increasing time lag, lack of long-term changes in species abundances].

R. B. Srygley, R. Dudley, E. G. Oliveira, A. J. Riveros, El Niño, host plant growth, and migratory butterfly abundance in a changing climate, *Biotropica* **46**, 90-97 (2014).
[Panama; *Marpesia chiron* (migrating butterfly); undisturbed lowland rainforest; 1991-2007; 17 years; dry season rainfall and photosynthetically active radiation (related to ENSO) may be drivers of larval food production and butterfly population, no noticeable decline in the long-term].

F. R. N. Knoll, Variation in the abundance of Neotropical bees in an unpredictable seasonal environment, *Neotrop. Entomol*. **45**, 129-138 (2016).

[Brazil; Euglossini (orchid bees); anthropized savanna; 1993-1999; 7 years; limited bee seasonality, data suggest that the community and the populations studied were less stable when compared to undisturbed forests, no noticeable decline or effect of ENSO].

M. Lucas, D. Forero, Y. Basset, Diversity and recent population trends of assassin bugs (Hemiptera: Reduviidae) on Barro Colorado Island, Panama, *Ins. Conserv. Div*. **9**, 546-558 (2016).
[Panama; Reduviidae (assassin bugs); undisturbed lowland rainforest; 2009-2015; 7 years; no significant changes in the short-term population dynamics of most species].

Y. Basset *et al*., The Saturniidae of Barro Colorado Island, Panama: A model taxon for studying the long-term effects of climate change?, *Ecol. Evol*. **7**, 9991-10004 (2017).
[Panama; Saturniidae (moths); undisturbed lowland rainforest; 2009-2016; 8 years; contrasted species responses and increase of large species; other insect taxa at the same location show contrasted patterns after 10 years of monitoring, see Fig. S1 below].

D. A. Donoso, Tropical ant communities are in long-term equilibrium, *Ecol. Ind*. **83**, 515-523 (2017).
[Ecuador; leaf litter ants; undisturbed lowland rainforest; 2003-2013; 11 years; although species richness in the community remained constant, temporal turnover of species was high, but there was no or weak evidence of directional change towards a new community].

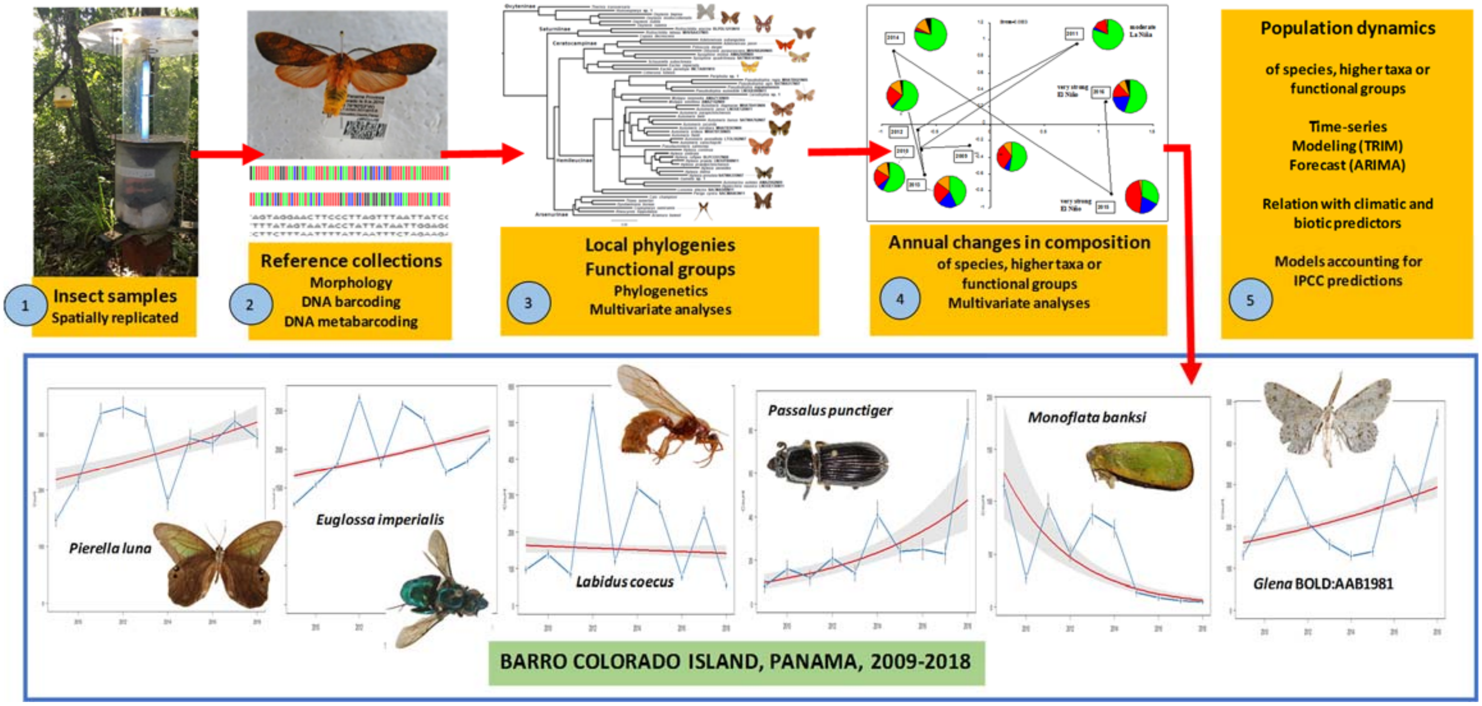

Fig. S1. Monitoring of poorly known and species-rich insect assemblages in the tropics. Item 5: recent population dynamics of the locally most common species of butterfly, orchid bee, army ant, passalid beetle, flatid bug and geometrid moth in a Panamanian rainforest. Methods follow (*10*).