THE SIGEO-CTFS ARTHROPOD INITIATIVE

Background

More than 25 years ago the **Smithsonian Tropical Reseach Institute** (STRI) established a large-scale forest research plot on 50 hectares of lowland tropical forest on **Barro Colorado Island** (BCI), in Panama. Within the plot, every free-standing tree with a diameter at breast height of at least 1 cm was tagged, measured, mapped, and identified to species. The large scale and standard forest census methods developed on BCI proved to be a powerful approach to studying the dynamics of tropical forests. By 1990 scientists around the world had replicated the STRI methods, and a global network of research plots emerged.

The network was initially named the **Center for Tropical Forest Science** (CTFS; http://www.ctfs.si.edu/) and although administered by STRI, individual forest plots are led and managed in each country by one or more partner institutions. CTFS coordinates research activities using standardized methods on forest plots ranging from 2 – 52 hectares that now include **47 sites in 31 countries**, mostly in Latin America, Africa, and Asia. This international collaboration is now monitoring the growth and survival of 4.5 million trees in over 6,500 species – over 16% of all known tropical tree species. The CTFS system has now matured to the point where there is a tremendous and unique opportunity to expand the program into a truly interdisciplinary research endeavor that will enable the world's scientists to investigate key indicators of global environmental health.

The Smithsonian Institution is now in the process of transforming its network of tropical forest plots into the **Smithsonian Institution Global Earth Observatories** (SIGEO, http://biogeodb.stri.si.edu/bioinformatics/sigeo/). This includes three main approaches: (a) a global carbon research program will provide in situ measures of above- and below-ground carbon and how it is changing in response to rising CO2; (b) the establishment a series of large-scale temperate plots that will permit direct comparison to the expanding tropical plot network; and (c) **expanding the tree monitoring program** by assessing the impact of global change on biodiversity through focused surveys of vertebrates, invertebrates, and microbes across the Global Earth Observatories. Item (c) includes an **arthropod initiative** that is monitoring key assemblages over long-term and study insect-plant interactions over the SIGEO network.

Map showing the 47 established SIGEO sites.

The SIGEO-CTFS arthropod initiative: rationale

Arthropods represent the most diverse group of terrestrial organisms on the planet. They play crucial roles in forest dynamics, such as **herbivory**, **seed predation**, **pollination**, **parasitism/mutualism, decomposition** and **nutrient cycling**. The CTFS plots, with their global biogeographic coverage and detailed local spatial data on the tree communities over large areas, provide a unique opportunity to address fundamental questions about the structure and dynamics of arthropod communities, and their functional roles. The new arthropod initiative was developed by an international team of 26 experts (full report available on request). It will integrate with ongoing monitoring of plant dynamics within the CTFS network, cause 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. These include: **termites** (decomposers), selected **moths and butterflies** (herbivores, pollinators), tephritid **fruit flies** (fruit feeders), litter-dwelling **ants** (various roles), **bees** (pollinators, pollenophages), selected **parasitoids**, and **seed predators**. The first year of the program should be devoted to a **'baseline' survey** to serve several purposes, notably:

(a) developing taxonomic and other partnerships, establishing initial inventories of each priority assemblage, and constructing a molecular barcode library for target taxa;
(b) obtaining estimates of diversity and taxonomic composition for basic pattern analysis across the participating CTFS;
(c) comparing local and regional arthropod pools across sites; and
(d) refining the methodology and the definitive choice of assemblages, or subsets of them.

This baseline survey will involve replicated, repeated sampling programs using light traps (moths, termites and other assemblages), Winkler extraction of litter (ants), McPhail traps (fruit-flies), colony census and baits (bees) and transect sampling for termites and butterflies (i.e., based on a mixed set of procedures). **'Key' comparisons among CTFS sites** for priority assemblages should be organized along key gradients viz. **Biogeography** (Neotropics vs. Afrotropical vs. Oriental), **rainfall seasonality** (mainland Asia), and **fertility/productivity** (Neotropics). These comparisons should involve more intensive sampling of priority assemblages within selected sites, subject to availability of funding.

This baseline survey will be 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 will be directed to detecting long-term changes, as reflected in priority assemblages, driven by climatic cycles, climatic change and landscape scale habitat alteration. Methods will be similar to those used in the initial baseline survey, but with lower sampling intensity. An understanding of the interactions between arthropods and plants is essential to an understanding of the dynamics of the forest community as a whole. Changes in interactions can also be as sensitive or even more sensitive indicators of long-term changes than changes in species richness or abundance. A sub-program of process studies should, therefore, be carried out at selected sites based on key vegetation-related interactions. This **food web approach** should in particular include:

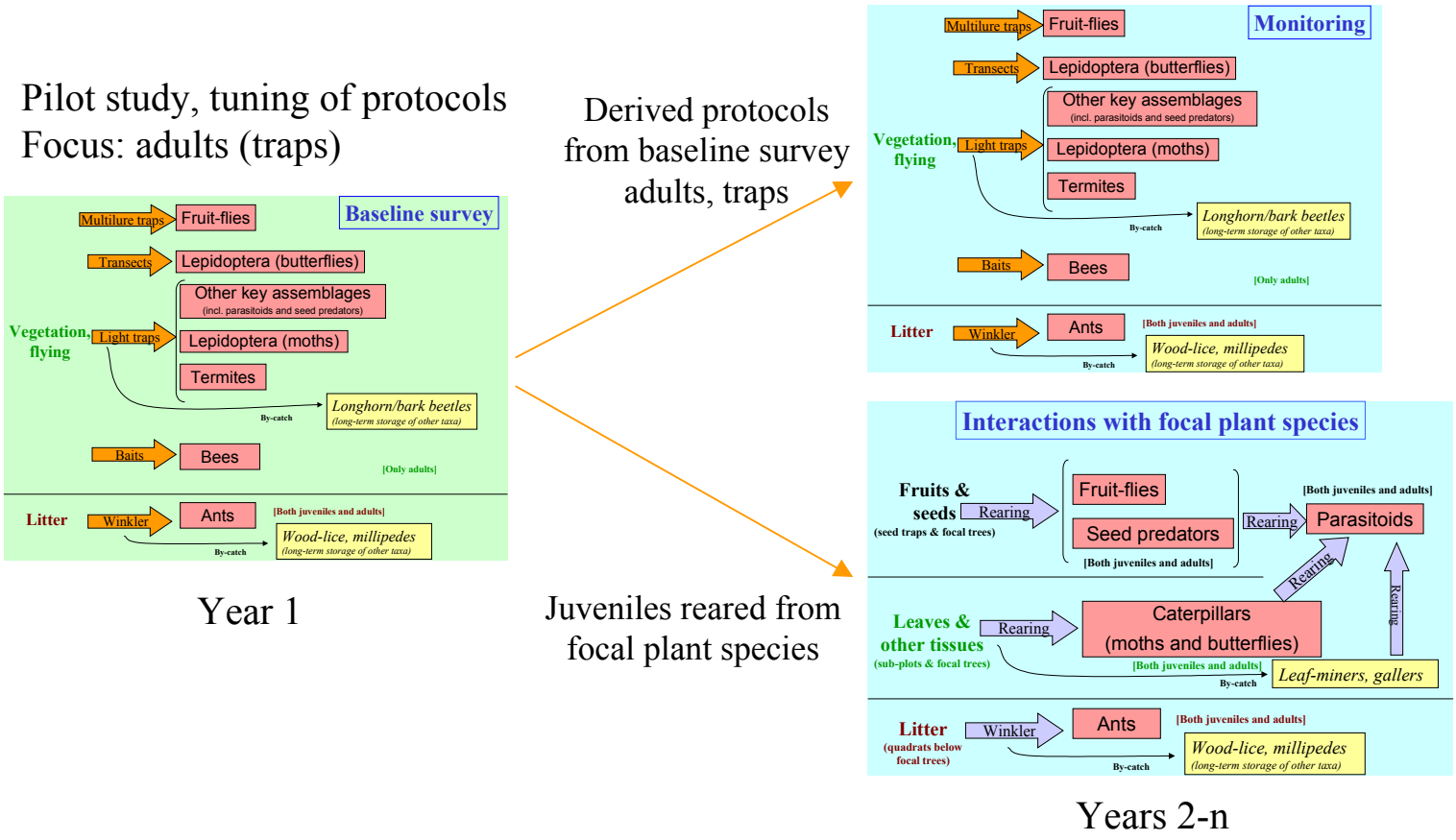
(a) studies of host specificity and parasitism within the Lepidoptera using caterpillar rearing and barcoding analyses;
(b) comparisons of herbivore assemblages associated with target tree species within and across sites, designed to answer important questions: viz. differences between herbivore assemblages on closely related tree species across sites, the role of plant phylogeny in determining herbivore species richness, the role of plant functional traits in determining herbivore load and diversity;
(c) the nature and rate of seed predation based on rearing programs of seeds collected occasionally and/or in a subset of the pre-existing seed traps, and;
(d) the impact of leaf litter characteristics (composition, amount, chemistry) on the composition of the associated arthropod assemblage, particularly ants.

Such studies will be initiated on a small subset of local plant species (such as perhaps ten focal tree species). When deemed appropriate, a new subset of focal plant species will be chosen, **expanding progressively the study system** and the **ecological knowledge of CTFS plots**. The main questions addressed by the interaction studies and monitoring program have deep implications for ecological theory, for example:

(a) does insect diversity, composition or abundance vary more in space or time at more diverse or more heterogeneous CTFS plots?
(b) how is variability in food web structure ('connectivity' and other measures of insect interaction structure and relative insect abundance, including host-specificity) affected by the phylogenetic structure of plant communities (formed from different regional species pools), rainfall and productivity?
(c) what are the relative importance of plant phylogeny and functional traits in shaping the abundance and diversity of herbivore and detritivore communities?

As far as possible, further externally-funded studies should be invited to exploit the special opportunities provided by the CTFS plots. The arthropod program will require a vigorous **training component** dedicated to local **capacity building** (training

parataxonomists or students), educational development (participation of local CTFS plot partners, arthropod PIs and their students) and **technology transfer** (e.g. DNA barcoding).



Outline of the monitoring and interactions sub-programs. Since adults are easier to survey than juveniles, the monitoring scheme targets adults, surveyed by traps. Since juveniles are often more intimately associated with plants than adults, interaction studies focus mainly on juveniles reared from focal plant species. The baseline survey, reference collections and barcoding library will help to match juveniles with adults.

Activation of the initiative and the near future

In 2008 CTFS provided **seed money** to start implementing the initiative at **Barro Colorado Island** (Panama) and **Khao Chong** (Thailand). Specifically this funding allowed performing the **baseline survey** in full on BCI and KHC: litter ants, selected moths, butterflies, bees, termites and fruit-flies (seed predators, parasitoids and caterpillars are not targeted in this initial effort but will be studied when starting monitoring and interaction studies in 2009). In addition, the Environmental Protection Agency (EPA) is funding **mosquito** monitoring at BCI and will work closely with the arthropod initiative.

As of October 2012, we own three full years of monitoring data at BCI (2009-2011) and one full year at KHC (2011). We also have started baseline surveys at the site of Wanang in Papua New Guinea. In the near future, we hope (a) to **consolidate** and **expand** arthropod studies at BCI, Khao Chong and Wanang; and (b) to expand the arthropod initiative to **other and future CTFS plots**, pending on both additional funds available to us and interest of local plot PIs.

In-site implementation at BCI, Agua Salud and other plots

There are very few successful insect monitoring programs in the tropics, apart from those directed to specific pests. One of the main challenges is the long-term processing and identification of countless number of species, which tend to wear both staff and budget of even the largest institutions (T. Erwin, pers. comm.). The experience accumulated by Basset, Miller and colleagues during three insect projects in Papua New Guinea, Guyana and Gabon over 19 cumulative study years lead us to propose a different strategy for particular plots. In Panama, this approach involved a **site coordinator** training **local assistants**. For other plots, **other strategies** may need to be implemented (see below).

The first study year represented both a pilot study of different protocols and a baseline survey, during which assistants were trained. Monitoring per se and interaction studies, as agreed by the CTFS arthropod workshop group, started after refining protocols, during the second year. The baseline survey (and subsequent derived protocols for monitoring) targeted only particular insect groups collected by particular methods that can be applied consistently over the network of CTFS plots. Hence, we target **common species** that are **well collected** with **consistent methods**, which is reasonable as rare species will not be amenable to statistical analysis of long-term monitoring trends.

Taxonomists associated with the arthropod initiative are asked to provide **taxonomic feedback** to the assistants so that the latter are able (with additional **DNA barcodes** for cryptic species) to identify the most common insect species collected in their surveys. This is achieved by preparing **local reference collections**. In essence, after adequate taxonomic feedback and **quality control** (which may vary between arthropod focal groups), the assistants are able to monitor themselves common insect species. Thus, taxonomists are flooded with an endless supply of similar material. Rather, their interest is kept alive from the study of a **varied insect material** resulting from the interaction studies and the **rotation of focal tree species** within the CTFS plots.

Working with **students** is rewarding in the short-term but not in the long-term as they invariably leave to pursue their careers, and training needs to be resumed with different staff (note that this may also be the case for well-trained parataxonomists but the momentum is longer in this case). In Panama, students are not involved in the monitoring sub-program of our initiative, but rather in additional and **more rewarding research activities** within the plots and in the interaction studies sub-program of our initiative. In Panama, we are collaborating with the Maestria de Entomologia of the National University. We are also hoping to attract the interest of entomologist colleagues and their students from U.S.A. or Europe, to be involved either in Panama or elsewhere in the SIGEO- CTFS network.

Our implementation strategy will need to be modified at locations where **student training** is more feasible or sought after. In addition, the situation for future temperate plots in the U.S.A. or Europe is entirely different, for three main reasons: (a) high salaries precluding local employment; (b) presence of **local entomological societies**, often backed up by local museums or academic institutions; (c) lower insect diversity than in the tropics. Item (b) is significant, as members of these societies may be keen **to team up on a volunteer basis** to a collaborative project supervised by in-country entomologists. It probably represents the best option of implementing the SIGEO- CTFS arthropod initiative (or part of it) at future U.S. or European plots.

Benefits of the SIGEO-CTFS arthropod initiative

Apart form the more obvious benefits of local capacity training and technology transfer, the arthropod initiative may benefit in diverse ways local collaborators and institutions associated with this long-term endeavor:

- Ecologists: access to results obtained over the SIGEO-CTFS network and related to arthropod **monitoring** and arthropod **food webs** centered on focal tree species.
- Taxonomists: varied entomological material of mostly tropical origin; access to barcoding information and opportunities to develop **global phylogenies**.
- Academic institutions: opportunities to develop **particular entomological projects** over the SIGEO-CTFS network; comparisons of temperate and tropical faunas; emulation of local entomological societies.
- Entomological societies: **collaborative project**, under strict scientific supervision provided by local academic institutions; opportunities for individual or joint collaboration at tropical plots; being part of an ‘entomological network’, which will expand.

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Plate I. Representative activities for the CTFS Arthropod Initiative in 2011: (1) Logo of one sponsor for KHC in 2011; (2) topographic map of the Wanang 50 ha plot; (3) one page of the new KHC butterfly field guide; (4) *Embiratermes chagresi*, a termite species from BCI; (5) *Graphium arycles*, a common papilionid at KHC; (6) Winkler samples at KHC; (7) view of the lab at KHC; (8) insect rearing from seeds and fruits at BCI; (9) part of the crew at KHC; (10) *Elysius* sp. 1YB, a collection specimen at BCI; (11) diagram of the new transects at KHC; and (12) Y. Gonzalez looking at BCI butterflies.

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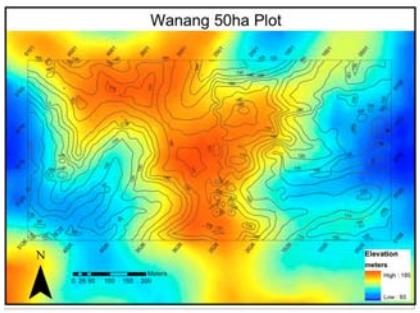

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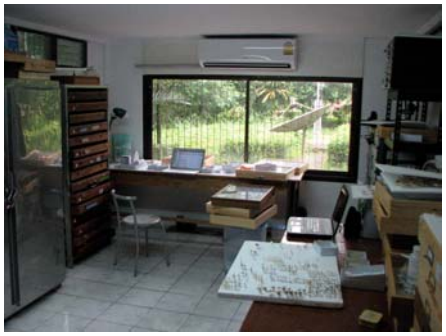

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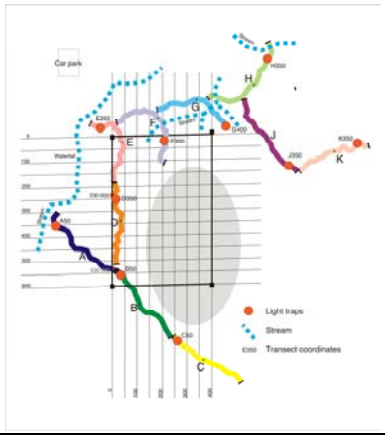

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