Quantifying Biodiversity: Experience with Parataxonomists and Digital Photography in Papua New Guinea and Guyana

BY YVES BASSET, VOJTECH NOVOTNY, SCOTT E. MILLER, AND RICHARD PYLE

In recent years, there has been much interest in documenting biodiversity (e.g., Stork 1993, May 1994, Blackmore 1996, Janzen 1997, Cresswell and Bridgewater 2000). A large part of this biodiversity is represented by insect herbivores feeding on tropical vegetation (Wilson 1988). Many authors have commented on the theoretical and ethical aspects of this quest (e.g., May 1994, 1999) and on whether it can be achieved within a reasonable time frame given the taxonomic facilities available worldwide (e.g., Raven and Wilson 1992, Janzen 1993, Krishtalka and Humphrey 2000). However, few workers have proposed practical measures to inventory insect species in tropical rain forests (but see Hammond 1994, Oliver et al. 2000).

In this article, we describe a first step toward documenting this rich insect fauna: training local people in the basics of insect collecting, mounting, and sorting; in digital photography; and in simple, yet powerful, computer databases. The work of these trainees can yield high-quality insect material and data, which are also available for subsequent taxonomic studies, within a relatively short period of time. This speed is important because species depletion resulting from the reduction of tropical habitats is rapid (e.g., Reid 1992). We discuss training and use of parataxonomists with particular reference to insect herbivores, with examples from two research projects in Papua New Guinea (PNG) and Guyana. Identifying, describing, and storing insect specimens are separate issues, which we do not address (see Miller 1991, Raven and Wilson 1992, New 1998).

The research projects and their specific problems

The first research project began in 1994 in Madang, PNG, and focuses on the local species richness and host specificity of insect herbivores feeding on 60 species of rain forest trees in the Moraceae, Euphorbiaceae, Rubiaceae, and other plant families. The second project started in 1996 at Mabura Hill, Guyana, and investigates the influence of selective logging on insect herbivores feeding on seedlings in a forest plot of 1 km^2. Both studies face similar challenges that are typical for eco-entomological surveys of

Yves Basset (e-mail: bassety@tivoli.si.edu) is a Tupper Fellow at the Smithsonian Tropical Research Institute, Apartado 2072, Balboa, Ancon, Panama. Vojtech Novotny (e-mail: novotny@entu.cas.cz) is a research entomologist at the Institute of Entomology, Czech Academy of Sciences and Biological Faculty, University of South Bohemia, Ceske Budejovice, Czech Republic. Basset and Novotny study insect–plant interactions in the tropics. Scott E. Miller (e-mail: miller.scott@nmnh.si.edu) is presently Chairman of Entomology at the Smithsonian Institution, Washington, DC 20560-0105, and was formerly at the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, and Bishop Museum, Honolulu, HI. Miller studies moth taxonomy, biogeography, and the relationships between entomology and environmental issues. Richard Pyle (e-mail: deepreef@bishopmuseum.org) is a research assistant at the Bishop Museum, Honolulu, HI 96817-0916. He studies systematics of coral reef fishes.

tropical habitats: the insect faunas are extremely diverse; collecting over long periods of time and in several habitats yields large numbers of insect specimens; data reflecting the patchy temporal and spatial distributions of insects are complex and the insect species need to be cross-referenced among habitats, hosts, and sampling events; different life stages are encountered in sampling, of which usually only adults are tractable for taxonomic studies; and identifications are difficult, requiring differentiation of sibling and polymorphic species, while facing limited availability of taxonomic information and expertise.

In addition, entomologists studying the diversity of insect herbivores in rain forests often need data on insect host specificity and patterns of host use. Determining the host range of a species of herbivore may require years of massive sampling in the tropics (Marquis 1991). As a result, the host specificity of tropical insects is still a matter of conjecture and controversy (review in Basset 1992). With particular reference to communities of insect herbivores feeding on rain forest trees, four major problems hinder progress in the study of host specificity: distinguishing between herbivores and "transient" species (i.e., species resting on the foliage but not feeding on it); inadequate sampling programs without rearing and observation of live insects; lack of long-term presence in the tropics with sufficient seasonal and spatial replicates; and insufficient diversity of insect and plant taxa studied.

Thus, community studies of tropical insects require large sampling efforts to obtain interpretable data, which is often achieved (if at all) at the expense of measuring potentially interesting variables that could help the interpretation of insect data. This situation is unfortunate because most ecological data are contextual; information on specimens of certain species at a given place and time is only interesting if the circumstances in which it happened are known.

Infrastructure used in Papua New Guinea and Guyana

Laboratory space consists of a small building with power and air conditioning, 1 freezer, 2–3 insect cabinets, 2 stereo microscopes with fiber optics, 2–3 computers, and either a video camera or a digital camera, both suitable for digital photography. In both countries, a resident scientist trains 5–6 insect parataxonomists, in addition to his research duties. The above may represent the minimum infrastructure necessary to initiate small-scale eco-entomological projects.

Local informants, parataxonomists, museum technicians, and taxonomists

These different terms refer to specific jobs in relation to taxonomy. In view of frequent misunderstandings, we outline some common duties of each job.

Local informants: Using their traditional knowledge, local informants provide information on local names and natural history of plants and animals to taxonomists, who often employ them as efficient collectors. If trained, their training does not go beyond field-oriented tasks. In the context of our projects, they are referred to as "insect collectors."

Parataxonomists: Parataxonomists do not necessarily work physically with taxonomists or in a museum environment. They often build their own reference collections. Their expertise is in collecting specimens, mounting them, and performing preliminary sorting of the specimens to morphospecies. Their work results in quality material that can be deposited in national collections and used for taxonomic studies. The term was coined by Daniel Janzen, as a parallel to "paramedic" (Janzen et al. 1993). *Para* is a Greek prefix meaning "in a secondary or accessory capacity," which characterizes precisely the position of our trainees, who work independently and understand the broader context of their work but do not have access to taxonomic expertise as taxonomists and museum technicians do. The niche for parataxonomists is a distinct one and warrants a specific label, as opposed to the passive role of a local informant or "field assistant," at least as understood in many tropical countries. Parataxonomists cannot be seen as an alternative to professional taxonomists, and fear of such misunderstanding by the lay public may be responsible for the sometimes mixed response of the taxonomic community to the concept of parataxonomists. In fact, the work of parataxonomists can make that of taxonomists more efficient: parataxonomists truly stand "at the side" of taxonomists, as also implied by the name.

Museum technicians: Museum technicians work closely with taxonomists and with the support of museum collections. Their knowledge of the collections often enables them to identify specimens. Their tasks, as the name implies, are closely related to museum activities and are also often tailored by the specific studies of taxonomists or the needs of collections they maintain.

Taxonomists: Taxonomists collectively represent the taxonomic community or "taxasphere" (Janzen 1993). Their work relies extensively on the support of museum collections. Although they may participate at all levels of taxonomic activity (starting with collecting specimens), they focus on recognizing and defining species, establishing and understanding the phylogenetic relationships of species and higher taxa, curating collections, and creating identification tools (e.g., keys). Their extensive experience is often sought to rapidly identify specimens.

By training local people as field and laboratory technicians ("insect parataxonomists," see boxes on this and facing page and Janzen et al. 1993) and developing databases including digital pictures of insect specimens, it is possible to overcome most of the problems noted above and to evaluate the importance of selected host traits on insect data. Such objectives can be realistically achieved with modest budgets and infrastructures (see box page 900), as our experience in PNG and Guyana has shown.

Figure 1. Yves Basset (center) examining plant samples collected by parataxonomists and village collectors.

Insect collecting and processing

Our sampling methods usually include hand-collecting, beating, and using small aspirators (New 1998). These low-cost methods are relevant in our studies because specimens can be obtained alive for subsequent rearing and feeding experiments; their origin can be traced with precision, particularly when sampling the entangled foliage of trees and vines; sampling at night is possible; and frequent seasonal and spatial replicates of individual trees are easy to obtain (see Basset et al. 1997).

Live insects are usually tested in the laboratory for their ability to feed on the foliage of the host from which they were collected. All specimens that feed are killed, mounted, and assigned to morphospecies by the parataxonomists, using reference collections and a computer-aided identification guide. Morphospecies are later checked, and in many cases identified to genera and species, by expert taxonomists. Whenever applicable, we rear juvenile specimens to the adult stage. In PNG, we anaesthetize caterpillars with CO_2 to reduce mobility and shoot good pictures of them. After recovering, they are reared so that pictures of adults and caterpillars can be matched.

Studying insect host specificity and host traits

Our approach to studying insect host-specificity involves collecting live insects with the above methods, instead of techniques providing dead specimens and indirect evidence of the association with the host plant (e.g., light and Malaise traps, canopy fogging); massively sampling a few tree species with numerous spatial and seasonal replicates; rearing juvenile specimens to provide adult specimens tractable for taxonomic studies; and testing whether the insects collected on a particular host are able to feed on this host under laboratory conditions (relevant to leaf-chewing insects only; see Basset and Novotny 1999).

In addition, various host traits are measured, such as tree density, leaf expansion, palatability and pubescence, latex outflow, and enemy-free space. The person-hours required to perform these protocols are considerable and call for parataxonomist help.

Parataxonomists in current research projects

Although the term "parataxonomist" is increasingly being used in various contexts, the number of relatively large-scale, long-term research projects involving training of parataxonomists is rather limited. For example, we searched the World Wide Web by various search engines, using "parataxonomist" as a keyword, and found only seven sites that, to some extent, describe parataxonomist activities and training. This search has obvious limitations, such as the efficiency of the search engines, the reluctance of some researchers to publicize their activities, or the difficulties of access to the Web from many developing countries. In addition to the two sites describing our research activities, detailed information on parataxonomist programs can be found at the sites of INBio (National Institute of Biodiversity) and the ALAS (Arthropods of La Selva Project) project (Costa Rica). Programs also involving parataxonomists include various projects of the National Museums of Kenya, the University of Georgia, Athens (Insect Diversity Project), the National Herbarium of Tanzania, and the Missouri Botanical Gardens.

Our sites describing projects in Papua New Guinea and Guyana can be found at:
www.bishopmuseum.org/bishop/natsci/ng/ngecol.html
www.bishopmuseum.org/bishop/natsci/guyana
www.entu.cas.cz/png/index.html

Figure 2. Collecting insects in the field in Guyana (Henry James).

Parataxonomist training

Recruitment of parataxonomists must follow the economic needs and customs of the host country. The encyclopedic knowledge of the natural world of Papua New Guineans is well known and has been noted by several ecologists (Diamond 1989, Beehler 1994). Papua New Guineans typically know hundreds of plant and animal species living in their forests and they have developed detailed nomenclatural systems in their local languages. They have no problem applying this knowledge to the more esoteric ends of basic ecological research. Local villagers can be involved with our research project as either insect collectors or parataxonomists. They are usually young villagers with 6–10 years of formal education. Every potential collaborator starts as a collector, which entails brief training and subsequent independent fieldwork, following a specified protocol. The ability to collect even the smallest insects and to distinguish herbivores from nonherbivores in the field is crucial. The most capable and dedicated collectors are offered parataxonomist training.

Figure 4. Mounting insects in Papua New Guinea (Keneth Molem).

The situation is different in Guyana because there we operate in an area that traditionally lacks local resident populations. Instead, the parataxonomists are recruited from a nearby "logging town" established approximately 20 years ago. The Guyanese parataxonomists also include young people with little formal education, and their knowledge of rain forest habitats varies from case to case.

Figure 3. Rearing caterpillars in Papua New Guinea (Chris Dal).

To prepare all the parataxonomists for their rigorous tasks, they undergo extensive training. Our training programs follow the approach of the National Institute of Biodiversity (INBio) and Guanacaste Conservation Area in Costa Rica (e.g., Janzen 1992, 1998) and of the former Christensen Research Institute in PNG (Orsak 1993). The main difference between our protocols and those pioneered at INBio (e.g., Janzen 1992, Janzen et al. 1993), for example, reflects the scale of operations and the duties of parataxonomists. Our projects are primarily ecological, rather than taxonomic, and are restricted in terms of life span, infrastructure and research budget. As such, our parataxonomists must be able to perform a variety of tasks and to be relatively independent. In contrast, the INBio system uses a hierarchy of field collectors, "sorters," "labelers," and curators. Our approach is more similar to that of the Arthropods of La Selva Project (ALAS) and also shares a strong emphasis on using computers along the whole sequence of information processing (Longino 1994, Longino and Colwell 1997). In our case, the parataxonomists are trained by a resident scientist as part of the research protocols, but instead of undergoing a formal training period preceding data collecting, our training in the field or laboratory is opportunistic (Figure 1) and continuous. It includes:

- General entomology and other relevant biology topics.
- Insect collecting with a wide range of techniques, including canopy fogging (Figure 2).
- Use of single rope technique to gain access to tall trees and the insects feeding on them.
- Insect rearing (Figure 3).
- Insect mounting, including dissection and preparation of genitalia (Figure 4).
- Microscope work and sorting of insect herbivores to morphospecies (Figure 5).
- Curation and appreciation of the value of insect collections.
- Computing, particularly data input and management of databases.
- Use of digital photography and image processing software.

We see computer literacy as a necessary part of the training. By mastering this last step in the sequence of insect processing, the work of parataxonomists can become independent from hour-to-hour supervision and guidance. The ability to complete the whole processing of samples also improves motivation. Our experience is that computing is an attractive part of the laboratory work and that parataxonomist training must be challenging.

Figure 5. Parataxonomists assigning insect specimens with the help of the computerized insect databases in (top) Papua New Guinea (Martin Kasbal and William Boen) and (bottom) Guyana (Henry James).

Computing and digital photography

The correlation between the data generated in sorting insect material to morphospecies by nonspecialists (parataxonomists) and similar data obtained in sorting to species by expert taxonomists depends crucially on the standards of training and support, including provision of identification aids and quality control (e.g., Cranston and Hillman 1992). Modern database tools (Figure 6) can greatly enhance the ability of parataxonomists to efficiently recognize morphospecies (see also Oliver et al. 2000). In addition, our relational databases are also routinely used as research tools for teaching, preliminary analysis of field data, and storage of information. The databases include digital images of whole insect specimens and morphological details, scanned drawings of insect genitalia, text fields

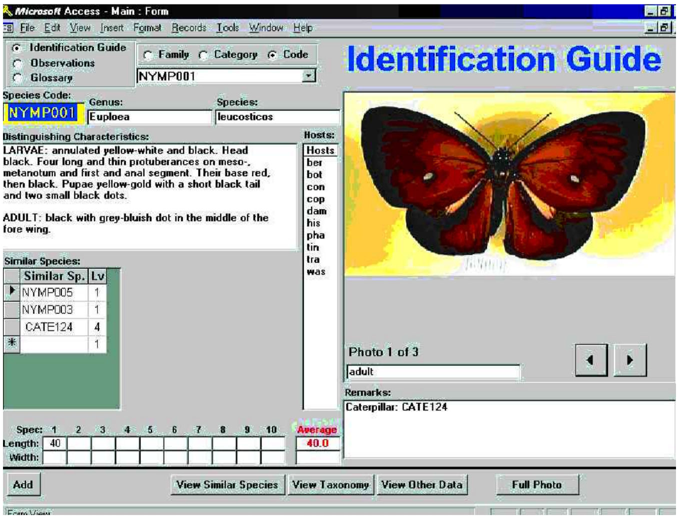

Figure 6. Sample template from the insect database in Papua New Guinea.

for morphospecies diagnosis, taxonomic and ecological information, links to similar morphospecies, multiple ways of sorting morphospecies according to taxonomic or ecological criteria, and an illustrated glossary of entomological terms. Each insect specimen is referenced by an individual specimen number. In short, the advantages of this powerful tool can be summarized as follows:

- Improved processing of insect material. Morphospecies that were not collected previously can easily be recognized and assigned accordingly.
- Improved processing of data, which is nearly simultaneous with data collection. The backlog of unprocessed specimens is greatly reduced. Immediate processing of samples is highly desirable because it enables adjustments in sampling protocols.
- Improved management of complex data sets because preliminary analyses can be performed with the click of a few buttons.

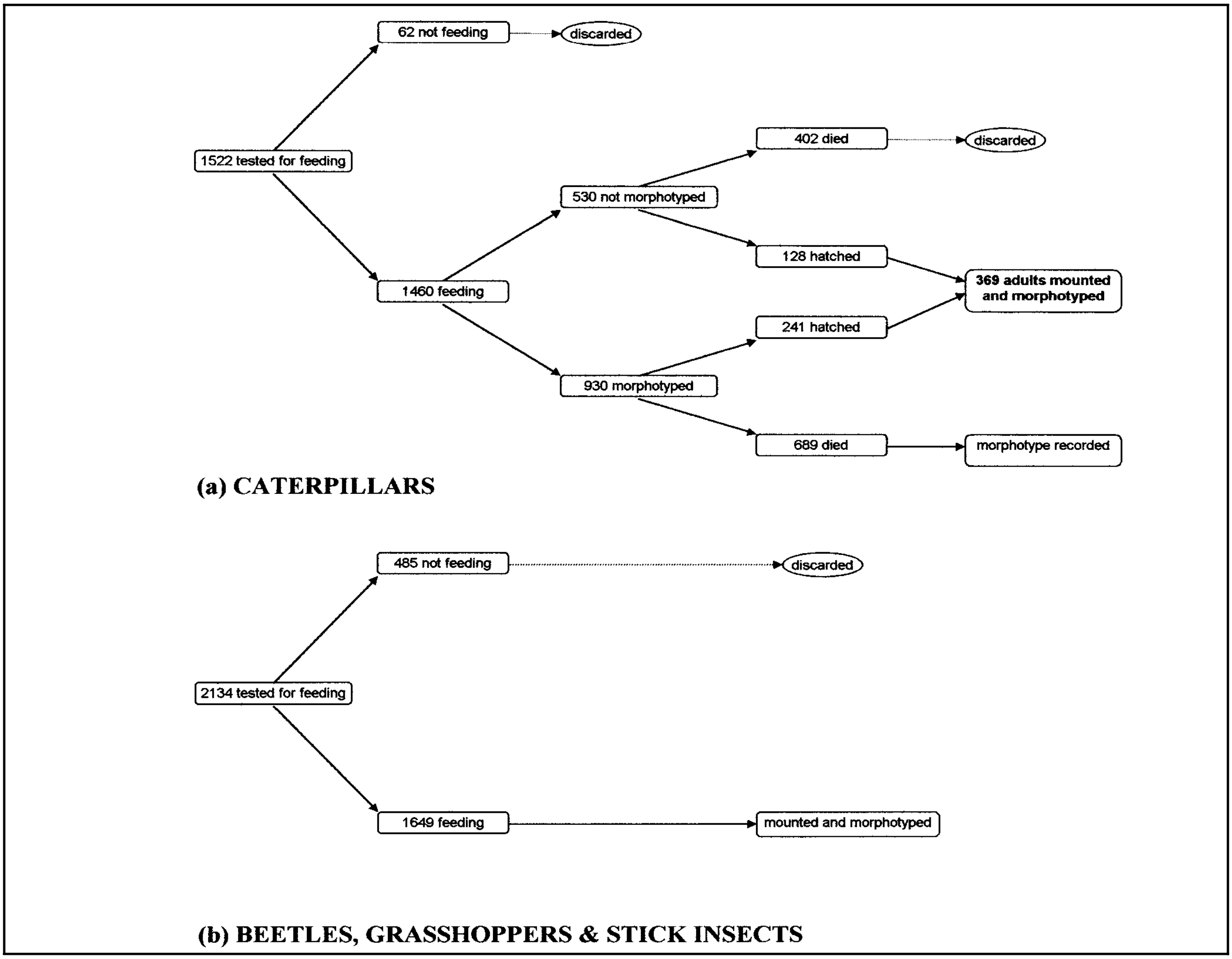

Figure 7. Flow of samples through the laboratory in Papua New Guinea: insect herbivores collected from the foliage of 15 euphorb tree species during 2 months (October–November 1996) and processed by four parataxonomists, supervised by one scientist. (a) caterpillars (b) other leaf-chewing insects.

- Improved training of insect parataxonomists. Because the display of the digital images is immediate, the databases are constantly used as "flip-books" by the parataxonomists. Using them in this way, parataxonomists quickly learn to recognize particular families or groups of similar morphospecies; they also quickly grasp essential characters.

Image editing by parataxonomists, using graphics tools, is significant because of the need to balance the quality of the pictures and the amount of memory space that they require. The software and hardware necessary for developing these insect databases are inexpensive (see box page 906). When we started our projects, we had to create our own databases (see box page 906), but *Biota* has been commercially available since 1996 and has many of these features (Colwell 1996). More recently, CSIRO and the University of Kansas have released two new database products suitable for this kind of work—*BioLink* (www.ento.csiro.au/biolink) and *Specify* (www.usobi.org/specify). For online use, *Ecoport* (www.ecoport.org) provides another option.

Rewards of parataxonomist training

The efficiency of fieldwork of village collectors in PNG is comparable with that of professional ecologists and allows collecting insects simultaneously at several locations. The volume of the material collected can be considerable (Table 1). Although the studies cited in the table vary in many details, a coarse index of sampling efficiency can be derived for insect herbivores feeding on particular hosts by considering the number of specimens collected per host and per year (Table 1). A higher index indicates that the insect community sampled was more likely to have been well sampled and to be representative. However, leaf-chewing and sap-sucking insects need to be considered separately because the latter are typically smaller and more numerous, and their feeding records are difficult to prove. For both insect groups, this simple comparison shows that data collected while working with parataxonomists are of high efficiency, even when studying rain forest seedlings, which support extremely low densities of insects (Table 1).

The experience of the other two large insect ecology projects using parataxonomists, at Guanacaste and La Selva, could not be condensed into Table 1 because their use of parataxonomists has evolved over many years (Daniel Janzen, Winnie Hallwachs, and Robert Colwell, personal communication). The Guanacaste project has accumulated 120,000 selective rearing records of Lepidoptera from 700 host plants since 1978 with 1–13 parataxonomists working at any given time. At present, there are 13 parataxonomists at Guanacaste rearing and doing the associated administration for approximately 17,000 caterpillars annually (Daniel Janzen, personal communication).

Parataxonomists can perform as well as museum technicians in mounting and labeling insects. Specimens collected alive and killed by freezing just before mounting, as well as reared moths and butterflies, represent high-quality

Table 1. Studies of communities of insect herbivores in the tropics, with an estimate of sampling efficiency per host plant.[a]

Location	Number of parataxonomists	Focal group[b]	Number of insect specimens	Number of host–plant species studied	Duration (years)	Efficiency[c]	References
Costa Rica	0	Chw	3500	9	~2	194	Thomas 1990
Panama	0	Chw	NA[d]	45	> 9	NA	Marquis 1991
Brazil	0	Chw	1000	31	1	32	Cytrynowicz 1991
Brazil	0	Chw	1000	4	2	125	Price et al. 1995
Peru	0	Chw	1302	≥ 12	1	≥ 109	Amedegnato 1997
Panama	0	Chw	4000	10	2	200	Barone 1998
Panama	0	Chw	35,479	50	1	710	Ødergaard 1999
PNG	2	Chw	3342	10	1	334	Basset et al. 1996
Guyana	5	Chw	1621	5	1	324	Basset 1999
PNG	12+3[e]	Chw	13,193	15	1	879	Basset and Novotny 1999
PNG	13+5[e]	Chw	14,458	15	1	964	Vojtech Novotny, Yves Basset, and Scott E. Miller, unpublished data
Guyana	5	Sap	7435	5	1	1487	Basset 1999
PNG	12+3[e]	Sap	44,900	15	1	2993	Novotny and Basset 1998

[a]Studies are listed according to whether they included parataxonomists or not and according to focal insect groups. Difference in the efficiency of studies on leaf-chewers with and without parataxonomists is significant ($P < 0.05$; n = 10, Mann-Whitney test).

[b]Chw = leaf-chewing insects, Sap = sap-sucking insects.

[c]Efficiency = number of insect specimens × number of host–plant species studied^{-1} × duration of study in years^{-1}.

[d]NA, Data unavailable.

[e]Village collectors and parataxonomists, respectively.

material ready for deposition in permanent systematic collections. For example, our research on leaf-chewing insects feeding on *Ficus* spp. in PNG produced approximately 7000 mounted insects, processed by three parataxonomists (see current flow of samples in Figure 7).

The ecological information associated with the insect material is also considerable. For example, work with 13 village collectors, five parataxonomists, and one resident scientist during 1 year in PNG at five different sites resulted in 7200 tree-visits, 14,478 event-based records (a particular insect individual feeding on a particular host at a particular location and time), 550 digital pictures of insect morphospecies, 180 surveys of abundance of the target 45 tree species in transects of 400 m × 4 m, 600 measurements of leaf expansion, and 320 bait experiments testing the importance of ants in enemy-free space for herbivores.

These protocols have boosted our ability to analyze preliminary data and have significantly reduced the time lag between the initiation of the study and the publication of the first scientific paper. For example, Erwin (1995) measured such a time-lag for a number of ecological studies of tropical canopy insects, which typically involve processing numerous insect specimens, and reported an average time-lag of 4.6 years. Our own studies in Australia and PNG in 1985–1992, performed without long-lasting support of parataxonomists, had a time-lag of 6–7 years, and the main body of papers was published 7 years after the initiation of the study (Novotny et al. 1997). A study in PNG in 1992–1994 with two parataxonomists drastically reduced this time lag to 2 years, with the main body of papers being published 4 years after the start of the study. Recent work in PNG and Guyana with more parataxonomists shows a similar trend, with increased insect-specimen processing and higher-quality data than in the previous study in PNG.

Finally, involving village communities in ecological research may demonstrate to them the value of undisturbed forests on their lands. This demonstration may be significant in PNG, where the customary land ownership means that local communities control forest use and conservation.

Accuracy of parataxonomists

In PNG, scientists and parataxonomists collect insects as well, providing an important quality check on the work of village collectors. The work of the parataxonomists is checked by the resident scientist and, ultimately, by expert taxonomists. This constant feedback at different levels is crucial to ensure high-quality data but makes it difficult to estimate *a posteriori* the accuracy of parataxonomists in morphotyping.

Studies quantifying the accuracy of students or technicians in morphotyping, such as those performed by Cranston and Hillman (1992) or Oliver and Beattie (1993), were designed specifically for this purpose, unlike ours. Our morphotyping problems were limited to a few groups, renowned to be taxonomically difficult, such as *Homona* spp. and *Adoxophyes* spp. (Tortricidae) in PNG or *Mysidia* spp. (Derbidae) in Guyana. In such situations, dissection of genitalia under the supervision of the resident scientist or expert taxonomists often resolved the problem, a strategy that was not considered by studies quantifying the accuracy of students or technicians.

It is our experience that with appropriate training and supervision, parataxonomists can sort insects into morphospecies, defined as valid species, which have not yet been identified or named (equivalent to the "interim taxonomy" of Erwin 1995). We found that a wider, less refined concept of morphospecies as entities easily distinguishable by conspicuous morphological characteristics (Oliver and Beattie 1993) was unnecessary and impracticable.

Software and hardware used for the development of insect databases

Our databases are being developed using Microsoft Access 97. Because Access has been developed for the Windows operating system, the databases can easily run on a variety of configurations. Flipping the pictures is immediate. We split the databases according to taxa, thus allowing convenient back-up on Iomega ZIP cartridges of 100 MB. Typically, databases hold approximately 250 species per 100 MB, depending on the number of pictures associated with each species.

We shoot digital pictures with either a SONY DXC 107 video camera (Papua New Guinea; PNG) or with a FUJIX DS-505 digital camera (Guyana), with similar results. In PNG, the video camera is connected to a television, which allows convenient setting of the insect specimen and of light sources. The screen is also helpful for teaching purposes. The main advantages of using digital photography over more conventional photographic slides and their subsequent scanning is the speed at which the definitive pictures can be included in the databases. This represents a significant improvement when collecting high numbers of specimens continuously, which need to be assigned immediately, and with no local means to process slides or negative films. Once the hardware has been purchased, digital pictures can be produced at almost no extra cost so that constant improvement of images is possible. This largely compensates for the loss of resolution when using digital photography as compared to slide-scanning. Digital photography can also produce greater depth of field for tiny specimens as compared to traditional photography.

Conclusions

Our experience shows that ecological research in the tropics can benefit from collaboration with local people. This is a viable alternative to working with local university students because such students are often not available. Projects in Costa Rica have noted that university students (or graduates) tend to tire of life in remote locations and desire to move back to more urban areas, whereas the parataxonomists are working near their traditional homes and are happy to have a profession that does not take them to the city (Robert Colwell, Daniel Janzen, and Winnie Hallwachs, personal communication). Another alternative, which was explored in Guyana, is a resident scientist supervising a local student who in turn trains parataxonomists. Training of students and parataxonomists in this way could be one strategy to quickly inventory the wealth of biodiversity in tropical countries.

Our sampling and processing protocols, which integrate low-cost collecting methods, training, and computer technology, are appropriate for our research goals and take advantage of three elements: knowledge of the environment by local people; recent developments in computer hardware (e.g., speed and mass storage), which make digital photography a useful tool available at a relatively low cost; and higher data quality due to the increased number of replicates and side experiments performed by the parataxonomists. The third element has not been appreciated enough by tropical ecologists. Because of the high spatial and temporal heterogeneity of ecological factors in rain forests, high numbers of replicates, even at the expense of lower accuracy, are likely to shed light on interesting biological patterns. We believe that, other things being equal, 1000 observations with an accuracy of 90%, as obtained by several parataxonomists, are preferred to 100 observations with an accuracy of 99%, as obtained by a single researcher.

Our self-contained approach may deserve further consideration and should not be limited to insect taxa (see Beehler 1994 and Janzen 1999 for examples of parataxonomists working in other kinds of biodiversity studies). We anticipate that scientists of both developing and developed countries will rely increasingly on local assistants or parataxonomists to carry out small-scale ecological projects in rain forest habitats.

Finally, with so many benefits, are there any disadvantages to working with parataxonomists? There is at least one; namely, that the amount of field data amassed by them is forcing ecologists to become desk-bound, number-crunching writers of research papers instead of enjoying themselves in the forest.

Acknowledgments

This paper is dedicated to our parataxonomists in PNG and Guyana: Milton Allicock, John Auga, William Boen, Chris Dal, Beverley Daniels, Shawn Fiffee, Samuel Hiuk, Brus Isua, Martin Kasbal, Wade Klencian, Richard Kutil, Henry James, Linsford La Goudou, Troy Lashley, Markus Manumbor, Marlon Mclennan, Keneth Molem, Dayl Thompson, Terrence Washington, Martin Williams, and Orin Williams. In PNG, we are also pleased to acknowledge the help of our insect collectors, too numerous to be cited individually here. The landowners Kiatik Batet, Hais Wasel, and Sam Guru kindly allowed us to collect in their respective villages. Larry Orsak, Anne Borey-Kadam, and the staff of the former Christensen Research Institute provided invaluable help with the logistics of the project. In Guyana, David Hammond, Elroy Charles, Raquel Thomas, and the staff of the Tropenbos-Guyana Programme helped with various conceptual and logistical aspects of the project. Other much needed administrative and logistical help was provided by the Tropenbos-Guyana Programme, the Overseas Development Administration, and Demerara Timbers Limited. Neal Evenhuis helped develop our World Wide Web presentations. The manuscript benefited from comments by Bruce Beehler, Robert Colwell, Dan Janzen, George Weiblen, and Joe Wright. Financial support to the research programs in PNG and Guyana was provided by US National Science Foundation (DEB-94-07297, 96-28840, and 97-07928), UK Darwin Initiative for the Survival of Species, Christensen Research Institute, Czech Academy of Sciences (grants C6007501 and A6007705/1997), Czech Ministry of Education (grant ES 041), National Geographic Society (grant 5398-94), British Airways (conservation travel scheme), and Otto Kinne Foundation.

References cited

Amedegnato C. 1997. Diversity of an Amazonian canopy grasshopper community in relation to resource partitioning and phylogeny. Pages 281–319 in Stork NE, Adis JA, Didham RK, eds. Canopy Arthropods. London: Chapman & Hall.

Barone JA. 1998. Host-specificity of folivorous insects in a moist tropical forest. Journal of Animal Ecology 67: 400–409.

Basset Y. 1992. Host specificity of arboreal and free-living insect herbivores in rain forests. Biological Journal of the Linnean Society 47: 115–133.

______. 1999. Diversity and abundance of insect herbivores foraging on seedlings in a rain forest in Guyana. Ecological Entomology 24: 245–259.

Basset Y, Novotny V. 1999. Species diversity of insect herbivore communities on *Ficus* in Papua New Guinea. Biological Journal of the Linnean Society 67: 477–499.

Basset Y, Samuelson GA, Miller SE. 1996. Similarities and contrasts in the local insect faunas associated with ten forest tree species of New Guinea. Pacific Science 50: 157–183.

Basset Y, Springate ND, Aberlenc HP, Delvare G. 1997. A review of methods for sampling arthropods in tree canopies. Pages 27–52 in Stork NE, Adis JA, Didham RK, eds. Canopy Arthropods. London: Chapman & Hall.

Beehler BM. 1994. Using village naturalists for treeplot biodiversity studies. Tropical Biodiversity 2: 333–338.

Blackmore S. 1996. Knowing the earth's biodiversity: Challenges for the infrastructure of systematic biology. Science 274: 63–64.

Colwell RK. 1996. Biota: The Biodiversity Database Manager. Sunderland (MA): Sinauer Associates. Available from: viceroy.eeb.uconn.ed u/biota.

Cranston P, Hillman T. 1992. Rapid assessment of biodiversity using 'biological diversity technicians.' Australian Biologist 5: 144–154.

Cresswell ID, Bridgewater P. 2000. The Global Taxonomy Initiative—Quo vadis? Biology International 38: 12–16.

Cytrynowicz M. 1991. Resource size and predictability, and local herbivore richness in a subtropical Brazilian Cerrado community. Pages 561–589 in Price PW, Lewinsohn TM, Fernandes GW, Benson WW, eds. Plant–Animal Interactions: Evolutionary Ecology in Tropical and Temperate Regions. New York: John Wiley & Sons.

Diamond JM. 1989. This-Fellow Frog, Name Belong-him Dawko. Natural History 98: 16, 18–20, 23.

Erwin TL. 1995. Measuring arthropod biodiversity in the tropical forest canopy. Pages 109–127 in Lowman MD, Nadkarni NM, eds. Forest Canopies. San Diego: Academic Press.

Hammond PM. 1994. Practical approaches to the estimation of the extent of biodiversity in speciose groups. Philosophical Transactions of the Royal Society of London B Biological Sciences 345: 119–136.

Janzen DH. 1992. A south–north perspective on science in the management, use, and economic development of biodiversity. Pages 27–52 in Sandlund OT, Hindar K, Brown AHD, eds. Conservation of Biodiversity for Sustainable Development. Oslo (Norway): Scandinavian University Press.

______. 1993. Taxonomy: Universal and essential infrastructure for development and management of tropical wildland biodiversity. Pages 100–113 in Sandlund OT, Schei PJ, eds. Proceedings of the Norway/UNEP Expert Conference on Biodiversity. Trondheim (Norway): Directorate for Nature Management and Norwegian Institute for Nature Research.

______. 1997. Wildland biodiversity management in the tropics. Pages 411–431 in Reaka-Kudla ML, Wilson DE, Wilson EO, eds. Biodiversity II: Understanding and Protecting our Biological Resources. Washington (DC): National Academy of Sciences.

______. 1998. How to grow a wildland: The gardenification of nature. Insect Science and its Application 17: 269–276.

______. 1999. Gardenification of tropical conserved wildlands: Multitasking, multicropping, and multiusers. Proceedings of the National Academy of Sciences 96: 5987–5994.

Janzen DH, Hallwachs W, Jimenez J, Gamez R. 1993. The role of the parataxonomists, inventory managers, and taxonomists in Costa Rica's national biodiversity inventory. Pages 223–254 in Reid WV, Laird SA, Meyer CA, Gamez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C, eds. Biodiversity Prospecting: Using Generic Resources for Sustainable Development. Washington (DC): World Resources Institute.

Krishtalka L, Humphrey PS. 2000. Can natural history museums capture the future? BioScience 50: 611–617.

Longino JT. 1994. How to measure arthropod diversity in a tropical rain forest. Biology International 28: 3–13.

Longino JT, Colwell RK. 1997. Biodiversity assessment using structured inventory: Capturing the ant fauna of a tropical rain forest. Ecological Applications 7: 1263–1277.

Marquis RJ. 1991. Herbivore fauna of *Piper* (Piperaceae) in a Costa Rican wet forest: Diversity, specificity and impact. Pages 179–208 in Price PW, Lewinsohn TM, Fernandes GW, Benson WW, eds. Plant–Animal Interactions: Evolutionary Ecology in Tropical and Temperate Regions. New York: John Wiley & Sons.

May RM. 1994. Past efforts and future prospects towards understanding how many species there are. Pages 71–84 in Solbrig OT, van Emden HM, van Oordt PGWJ, eds. Biodiversity and Global Change. Wallingford (UK): CAB International.

______. 1999. Unanswered questions in ecology. Philosophical Transactions of the Royal Society of London B Biological Sciences 354: 1951–1959.

Miller SE. 1991. Entomological collections in the United States and Canada. Current status and growing needs. American Entomologist 37: 77–84.

New TR. 1998. Invertebrate Surveys for Conservation. Oxford: Oxford University Press.

Novotny V, Basset Y. 1998. Seasonality of sap-sucking insects (Auchenorrhyncha, Hemiptera) feeding on *Ficus* (Moraceae) in a lowland rain forest in Papua New Guinea. Oecologia 115: 514–522.

Novotny V, Basset Y, Miller SE, Allison A, Samuelson GA, Orsak LJ. 1997. The diversity of tropical insect herbivores: An approach to collaborative international research in Papua New Guinea. Pages 112–125 in Lee BH, Choe JC, Han HY, eds. Taxonomy and Biodiversity in East Asia: Proceedings of International Conference on Taxonomy and Biodiversity Conservation in East Asia. Chonju (South Korea): Korean Biodiversity Council and Korean Institute for Biodiversity Research.

Ødegaard F. 1999. Host specificity as a parameter in estimates of arthropod species richness. PhD dissertation. Norwegian University of Science and Technology, Trondheim, Norway.

Oliver I, Beattie AJ. 1993. A possible method for the rapid assessment of biodiversity. Conservation Biology 7: 562–568.

Oliver I, Pik A, Britton D, Dangerfield JM, Colwell RK, Beattie AJ. 2000. Virtual biodiversity assessment systems. BioScience 50: 441–450.

Orsak LJ. 1993. Killing butterflies to save butterflies: A tool for tropical forest conservation in Papua New Guinea. News of the Lepidopterists Society 1993: 71–80.

Price PW, Diniz, IR, Morais HC, Marques ESA.1995. The abundance of insect herbivore species in the tropics: The high local richness of rare species. Biotropica 27: 468–478.

Raven PH, Wilson EO. 1992. A fifty-year plan for biodiversity surveys. Science 258: 1099–1100.

Reid WV. 1992. How many species will there be? Pages 55–73 in Whitmore TC, Sayer JA, eds. Tropical Deforestation and Species Extinction. London: Chapman & Hall.

Stork NE. 1993. How many species are there? Biodiversity and Conservation 2: 215–232.

Thomas CD. 1990. Herbivore diets, herbivore colonization, and the escape hypothesis. Ecology 71: 610–615.

Wilson EO. 1988. The current state of biological diversity. Pages 3–18 in Wilson EO, ed. Biodiversity. Washington (DC): National Academy Press.