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FORUM

Conservation and biological monitoring of tropical forests: the role of parataxonomists

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Summary

1. The demise of tropical rain forests will lead to a large-scale extinction of genetic diversity, particularly of arthropods. Curtailing these trends might be facilitated by (i) reducing rates of habitat loss and degradation, (ii) enhancing systematics and (iii) increasing the flow of primary information on tropical biodiversity.
2. We emphasize the need to examine alternative approaches that could generate a constant stream of data from tropical ecosystems. We argue that data collecting by parataxonomists (local assistants trained by professional biologists) represents one of the most efficient approaches to the study of tropical ecosystems available to date.
3. Parataxonomists can provide high-quality biological specimens and ecological information; statistical power will be high due to large sample sizes of data; database growth will be rapid and results will be published in a timely manner; and there will be collateral education of local people in conservation biology by the parataxonomists themselves.
4. We stress that training local parataxonomists to inventory and monitor biodiversity is a promising and efficient strategy that deserves more attention in conservation biology. In particular, it may be one of the most feasible approaches for the biological monitoring of small and cryptic organisms in species-rich environments, such as invertebrates in tropical rain forests.
5. *Synthesis and applications.* Permanent botanical plots yield a wealth of data on the organization of tropical forests, and their numbers should be increased to monitor tropical biodiversity. Likewise, augmenting the number of local parataxonomist groups in various tropical countries and networking these contingents to monitor functionally diverse taxa may provide an efficient biological monitoring system in tropical forests.

Key-words: arthropods, biodiversity, rain forests, taxonomy.

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Introduction

Consider the four following facts. (i) Tropical rain forests are disappearing at alarming rates world-wide, now exceeding 1–4% annually of their current area (Laurance 1999). (ii) The pace at which biodiversity is inventoried within these forests, especially arthropods, is not accelerating, so that many organisms may go extinct before they are known to science. A large-scale extinction of genetic diversity is underway (Wilson 1992, 2000; Novacek & Cleland 2001). (iii) We know next to nothing of the majority of species' interactions within tropical rain forests and therefore how vulnerable they may be to anthropogenic disturbance, how quickly they will be lost and what can be attempted to slow down these extinctions (Lawton & May 1995).

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(iv) The scientific community is spending more on the search for extra-terrestrial life than on exploring strategies to stem the loss of biodiversity on Earth (Alberch 1993; Wilson 2000). In order to respond to these challenges, the scientific community needs to seek scientific tools that may improve some of its current efforts in conservation biology, systematics and applied ecology.

The inability of the scientific community to document tropical species diversity, and hence its decline, is hugely detrimental to the credibility of the conservation movement (Mann 1991). Although biologists can provide indirect evidence for ongoing extinction (e.g. from species–area curves and decrease in the area of a particular habitat; Lovejoy 2002), these arguments can be insufficient as a basis for the costly and socially disruptive conservation measures often required to save the endangered habitats and their (mostly unknown) species. Funding agencies are unlikely to channel large grants into protecting 'hypothetical' species that have never been seen, which do not have names, and whose pictures biologists cannot show to the public and decision makers. The hypothetical species also do not have any tangible, measurable effect on our lives, but part of the scientific community believe that they exist and that they may be important (e.g. by providing important 'ecosystem services'; Lawton 1997). However, it is difficult to arouse widespread concern about unknown species going extinct, be they hypothetical or real. The general public and the decision makers are unimpressed by putative mass-scale extinction, unless species losses are demonstrated by biologists.

Recognizing species before attempting to conserve them would certainly help many issues in conservation biology (Wilson 2000). The latest case in point is the problems faced by conservation biologists in countering Lomborg's optimistic arguments in his book *The Skeptical Environmentalist* (Lomborg 2001; Grubb 2001; Pimm & Harvey 2001; Lovejoy 2002). The discussion generated has been very passionate, mostly because emotions become substitutes for data. In particular, the lack of robust data makes it hard for conservation biologists to dispute with any credibility Lomborg's claims that extinction rates are in fact lower than widely believed.

Tropical ecosystems are renowned for their high heterogeneity in space and time, particularly rain forests (Connell 1978; Gentry 1990). Consequently, the results and implications from a local inventory cannot be easily generalized to other locations in the tropics. Efforts in systematics, particularly in descriptive taxonomy, need to be sustained over many taxa and in different biogeographical areas. Unfortunately, whilst phylogenetic systematics is flourishing today, descriptive taxonomy faces a lack of prestige and funding (Godfray 2002). Some workers perceive descriptive taxonomy to be a purely classificatory exercise producing a scatter of limited-scope taxon descriptions in taxa selected mostly according to the idiosyncratic preferences of the taxonomists, with major taxonomic revisions taking in the order of tens of years to complete. As has been amply demonstrated during recent decades, this approach has failed and continues to fail in attracting major funding. One way to overcome this funding impediment (see also discussions in Cracraft 2000; Godfray 2002) may be for taxonomists to become directly involved in large-scale projects aimed either at a comprehensive (multitaxic) description of local faunas or at a large-scale, for example continental or global, description of certain taxa. This also emphasizes the quality of the primary information needed for such projects, i.e. the acquisition of specimens originating from habitats poorly surveyed in the past but vanishing quickly (e.g. the canopies of pristine lowland forests). This often requires substantial collecting effort. A series of recent international initiatives have recognized the decline of global taxonomic capacity and the need to provide a solid taxonomic infrastructure for conservation and other activities (Miller & Rogo 2002). These initiatives include the Global Taxonomy Initiative of the Convention on Biology Diversity (Klopper, Smith & Chikuni 2001; http://www.biodiv.org), the Global Biodiversity Information Facility (www.gbif.org) and BioNet International (www.bionet-intl.org).

Reliable data on the vulnerability of species to extinction and their extinction threats also require sound biological monitoring of tropical ecosystems, which is not limited to a few flagship or umbrella species. Information on extinction rates is particularly scarce regarding the largest (but least popular with the public) component of biodiversity, namely the invertebrates. While applied ecologists have been quite successful in devising sound recipes based on the biological monitoring of invertebrates in aquatic systems (e.g. the index of biological integrity of Karr 1991), such recipes and any consensus on them are almost non-existent for terrestrial arthropods, particularly in the tropics. The lack of primary information on the ecology of most terrestrial arthropods in the tropics appears to be the principal obstacle to the rapid development of practical recommendations for the conservation of rain forest ecosystems.

Under these circumstances, how can we respond to the four concerns listed in the opening paragraph? Beside reducing rates of habitat loss and degradation, it is crucial that we rehabilitate systematics as a fashionable discipline and increase its global capacity (Cracraft 2000; Wilson 2000; Godfray 2002). Parallel efforts should also aim to improve the flow of primary information on tropical biodiversity. In this paper, we focus on the latter and stress that training local 'parataxonomists' to inventory and monitor biodiversity, particularly invertebrate and other small taxa, is a promising strategy that deserves more attention in environmental management. Further, this approach can be achieved at comparatively low costs per item of information gained.

The parataxonomist trade

As the name implies and was originally defined (Janzen 1991; Janzen *et al*. 1993; Basset *et al*. 2000), parataxonomists stand 'at the side' of taxonomists and the taxonomic process. Through iteration, their mostly rural career is to conduct, magnify and improve the processing of specimens and collateral information collection in the field. The expertise of parataxonomists lies in collecting specimens, preparing them, preliminary sorting into morphospecies, and databasing the associated information. 'Morphospecies' represent species diagnosed with standard taxonomic techniques but not necessarily named (Cranston 1990; the 'interim taxonomy' of Erwin 1991). Although sorting only to higher taxa or 'functional groups' may be appropriate for some studies, we feel that it is both logistically possible and scientifically preferable to apply rigorous morphospecies concepts rather than the less rigorous concepts applied by some authors (Beattie & Oliver 1994; Pik, Oliver & Beattie 1999). Parataxonomists often work from their own reference collections and from database images on field computers. Their work results in quality material that can be deposited in national collections and used for taxonomic studies. Although their role is more demanding than that of local informants (e.g. tree-spotters), they are not an alternative to professional taxonomists in the field or laboratory, but rather enhance their activities and capacities.

The term parataxonomist has been used in different contexts and this is a potential source of confusion. Ultimately, any personnel involved in the collection and study of biological specimens may be viewed as parataxonomists: from local collectors, students, professional zoologists and botanists focusing on ecological studies, to taxonomists operating outside of their range of expertise. Here our emphasis is on local people living in relatively rural areas of the tropics, who have been specifically trained for parataxonomist duties (see above) by professional biologists, within the context of research projects (Janzen 2004). We also note the unfortunate alternative use of the term parataxonomy for the classification of parts of disarticulated fossils (Bengtson 1985).

Parataxonomists, as we perceive them, operate mainly in biodiversity inventories and assessments (Janzen *et al*. 1993; Beehler 1994; Longino & Colwell 1997; Burns & Janzen 2001; Schauff & Janzen 2001; Takeuchi & Golman 2001), ecological research (Janzen 1988, 1993; Janzen & Gauld 1997; Janzen, Sharkey & Burns 1998; Novotny & Basset 1998, 1999, 2000; Basset & Novotny 1999; Basset 1999, 2000; Novotny *et al*. 1999a, 1999b, 2002a, 2002b; Novotny & Missa 2000), conservation planning (Janzen 2000) and, much more rarely, biological monitoring (Cranston & Hillman 1992; Basset *et al*. 2001; Fore, Paulsen & O'Laughlin 2001).

The work of parataxonomists is usually most cost-efficient with relatively large numbers of small and species-rich taxa that may require microscopic observation and/or specific preparation for deposition in museums (e.g. herbarium specimens, card-mounted or pinned insects and preparation of their genitalia). Although the parataxonomist concept has most often been applied to the collection of plants (Beehler 1994; Balkwill & Phillipson 1996; Takeuchi & Golman 2001), fungi (Bills & Polishook 1994), terrestrial arthropods (Janzen 1988; Longino & Colwell 1997; Novotny *et al*. 2002a, 2002b) and benthic macroinvertebrates (Fore, Paulsen & O'Laughlin 2001), it would be equally applicable to the study of many other taxa, including vertebrates (Bickford 1997).

Development of the parataxonomist concept

Daniel Janzen and Winnie Hallwachs created the first parataxonomist course in 1989 in Costa Rica, followed by two more courses in collaboration with the Instituto Nacional de Biodiversidad (INBio). The term parataxonomist was coined as a parallel to 'paramedic'. It first appeared in print in 1991, and was formally defined later (Janzen 1991, 2004; Janzen *et al*. 1993). The success of the courses and of INBio quickly established Costa Rica as a leading centre and model for biodiversity studies and bioprospecting (Gámez 1991). This prompted similar efforts in Costa Rica, including the Arthropods of La Selva (ALAS) project and further inventory of the Area de Conservación Guanacaste, where the first parataxonomist courses were taught (Table 1). Beyond Costa Rica, the concept was advanced by the Missouri Botanic Garden in Tanzania and by Larry Orsak and Bruce Beehler in Papua New Guinea (Orsak 1993; Beehler 1994), resulting eventually in the formation of the Parataxonomist Training Center in Papua New Guinea (Table 1).

The idea flourished in the early 1990s and served as a foundation for larger schemes of inventories as background for bioprospecting, such as the All Taxa Biological Inventory (ATBI) in Costa Rica (Tangley 1990). The failure to initiate the ATBI, due to internal dissension (Kaiser 1997), probably slowed down the enthusiasm for parataxonomists. Another obstacle to the development of the concept was the resistance from some members of the taxonomic community, who were concerned about data quality and feared that funding may be diverted from more fundamental systematic studies towards parataxonomy (Janzen *et al*. 1993). This unfortunate misunderstanding might have been fuelled by the ideas of 'taxonomic minimalism' and 'rapid biodiversity assessment' promoted by Beattie & Oliver (1994) and Oliver & Beattie (1996) during the same period. In fact, the opposite may be true. We believe that parataxonomist programmes represent an opportunity for taxonomists to obtain additional funding, through involvement in large-scale projects such as the ATBI. Significant amounts of fieldwork, best performed by parataxonomists, are a necessary first step in these projects.

Currently, despite much discussion and the relative hype surrounding the term, sometimes even in official policy documents (UNEP 2001, 2002), it must be acknowledged that few research projects routinely involve parataxonomists, especially in the tropics (Table 1). Although the work programme of the Global Taxonomy

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Table 1. Examples of scientific and educational projects including the participation of parataxonomists. These WWW sites were selected on the basis of higher occurrence within the 230 hits generated by the search engine Google™ (http://www.google.com), with the search words 'parataxonomist' and 'para-taxonomist'. Note that some sites may be overlapping in content

Project/course	Description and country	URL
(a) Diverse taxa		
INBio	Instituto Nacional de Biodiversidad, Costa Rica	www.inbio.ac.cr/
National Museums of Kenya	Plants, insects and birds, Kenya	www.museums.or.ke/
Discover Life In America	Great Smoky Mountains National Park – All Taxa Biodiversity Inventory, USA	www.discoverlife.org/
(b) Fungi and plants		
Manual de Plantas de Costa Rica	Botanical inventory in Costa Rica	www.mobot.org/MOBOT/research/edge/
Macrofungi of Costa Rica	Inventory of fungi in Costa Rica	www.nybg.org/bsci/res/hall/
Tanzania Botanical Training Programme	Improving botanical capacity in Tanzania	www.ru.ac.za/affiliates/herbarium/tbtp/tbtp.htm
(c) Invertebrates		
Biodiversity inventory of the caterpillars and adult Lepidoptera of the Area de Conservación Guanacaste	Biological inventory of Lepidoptera in Costa Rica	janzen.sas.upenn.edu/
Arthropods of La Selva	Biological inventories at La Selva, Costa Rica	viceroy.eeb.uconn.edu/alas/alas.html
The Parataxonomist Training Center	Training of parataxonomists in Papua New Guinea, eco-entomological research, biological inventories and land awareness	www.entu.cas.cz/png/index.html www.bishopmuseum.org/research/natsci/ng/ngecol.html
The Parasite Database	Inventory of Eukaryotic Parasites of Vertebrates in Guanacaste, Costa Rica	brooksweb.zoo.utoronto.ca/index.html
The Insect Diversity Project	Biological inventories and comparisons between temperate and tropical systems	dial.pick.uga.edu/
Faunistic survey of Dynastinae	Inventory of scarab beetles in Central America	www-museum.unl.edu/research/entomology/scarabcentral.htm
SIMAB Gamba Project	Biological monitoring in Gamba, Gabon. Sub-project to study the effects of anthropogenic disturbance on arthropods	www.si.edu/simab/Gabon.htm
(d) Education		
University of Connecticut	Course in field entomology, USA	www.eeb.uconn.edu/courses/eeb252/eeb252su00/1eeb.html

Initiative of the Convention on Biological Diversity strongly encourages the development of parataxonomist programmes (see Recommendation VI/6 of the Subsidiary Body on Scientific, Technical and Technological Advice and Decision VI/8 of the Conference of the Parties of the Convention of Biological Diversity, available at http://www.biodiv.org), this advice has rarely been followed. A search in Biological Abstracts™ (1969–2002) provided only seven records for variations of the keyword 'parataxonomist'. Further, in a recent review of the state-of-the-art of entomological research in tropical forest canopies (Basset *et al*. 2003), only one of the contributed papers relied substantially on work with local parataxonomists (Janzen 2003).

Why? We believe that despite the appeal of the concept, many workers may still be suspicious of the quality of the data that may be recorded and archived by parataxonomists (discussed in Fore, Paulsen & O'Laughlin 2001). By 'data quality' (i.e. the overall quality of the data set) many workers imply 'data accuracy' (i.e. the average accuracy of an observation within the data set) but these are two different issues. Scientific methods in natural sciences differ from those in nuclear physics. For example, due to the high spatial and temporal heterogeneity of ecological factors in tropical rain forests, high numbers of replicates, even at the expense of lower accuracy, are likely to shed light on interesting biological patterns. An additional issue is cost-effectiveness, as parataxonomists are most cost-effective in long-term projects unless already trained adequately. In the following sections, we emphasize that (i) although parataxonomist work may result in lower accuracy of data, the quality of data may be higher than that arising from the traditional work of taxonomists and ecologists alone, due to increased replicates and observations; and (ii) it may be one of the most feasible strategies for the biological monitoring of small and cryptic organisms in species-rich environments, such as invertebrates in tropical rain forests.

Studying tropical ecosystems

Studies of the structure of complex tropical ecosystems face methodological problems similar to studies of complex genomes, i.e. they require very large amounts of relatively simple data to be collected and analysed. The exploration of genomes started with limited studies laboriously sequencing short DNA fragments deemed particularly interesting; it entered its mature phase only when cheap, fast and reliable methods of mass DNA sequencing were developed, allowing the study of entire genomes (Zweiger 2000). Similarly, disciplines studying tropical ecosystems, still largely immature, have to develop efficient methods to collect large amounts of data on the spatial and temporal distribution of individual organisms in order to proceed to more comprehensive analyses.

Large spatial and temporal variability within and among ecosystems calls for studies that are highly replicated at a range of spatial scales, from local patches to continents. We need a 'superabundance' of ecosystem data, with tens to hundreds of replicates for each studied phenomenon (such as ecosystem change along altitudinal gradient, in response to logging), rather than isolated case studies from a few research stations where most of the current tropical research is concentrated.

In brief, at least a hundred-fold increase in the efficiency of data collection is required if tropical ecology is to proceed beyond its current embryonic stage. This goal is not unrealistic. Although ecological studies can serve numerous purposes and follow variable protocols, the final structure of their data is remarkably uniform, i.e. they include spatiotemporal data on individual organisms. Depending on each study, spatial data may include various experimental treatments, host-plants, microhabitats, etc. Information on individual organisms, in addition to conspecific traits, may also include sex, development stage, behavioural observations, parasitic load, etc. Methodological improvements in acquiring this type of organism-related data are thus paramount to advance tropical ecology.

With automated sorting and identification, paralleling automatic sequencing machines of molecular biologists, still far in the future for most purposes (Weeks & Gaston 1997), alternative approaches that could generate a constant stream of data from tropical ecosystems have to be examined. Data collecting by parataxonomists represents one of the most efficient approaches to the study of tropical ecosystems available to date, for the reasons discussed below.

Advantages and rewards of the parataxonomist strategy

Our views on this issue stem from experience obtained in three entomological projects relying on parataxonomists in the tropics (Table 1). Each project is located in a different biogeographical zone (Papua New Guinea, Guyana, Gabon) and subject to different social issues. Although the infrastructure and the personnel available for these projects vary greatly, there is broad convergence in the rewards that result from the routine work of parataxonomists. These advantages have been discussed in detail elsewhere (Novotny *et al*. 1997; Basset *et al*. 2000) and can be summarized as follows.

1. The efficiency of fieldwork is comparable to that of professional biologists and allows collecting at simultaneous locations with higher number of replicates. The amount of biological material collected may be considerable (Table 2) and sample sizes are significantly higher in projects working with parataxonomists than in those not relying on them (Basset *et al*. 2000). Note that it is difficult to quantify the output of the large open-ended projects relying on parataxonomists (e.g. INBio, ALAS; Table 1), as they have incorporated different activities over many years. The feasibility of more ambitious projects with complex protocols is enhanced and allows, for example, simultaneous

Table 2. Examples of output generated by parataxonomists involved in entomological projects in the tropics

Project (category)*	Country	Duration	No. parataxonomists	Output (not accounting for databases and papers published)	Reference
Caterpillars of the Area de Conservación Guanacaste (I, E, M)	Costa Rica	*c.* 24 years	Up to 16	181 000 selective rearing records of Lepidoptera and parasitoids 900 host-plants surveyed Database increase of 20 000 caterpillar records annually	Janzen (1988, 2003); Janzen & Gauld (1997)
National Biodiversity Inventory (INBio) (I, E, M)	Costa Rica	13 years	*c.* 95	More than 3 000 000 insect specimens collected and curated to morphospecies, with many hundred of thousands identified to species National plant inventory nearly finished All plant and invertebrate specimen-based data computerized, and most available on the web	Gámez (1991)
Moth fauna of the Kikori Basin (I)	Papua New Guinea	7 months	4	43 435 specimens sorted into 1602 morphospecies	Orsak & Easen (1995)
Host-specificity of leaf-chewing insects feeding on rain forest trees (I, E)	Papua New Guinea	6 years	6–7	2500 person days of fieldwork 71 tree species surveyed 86 000 feeding insects sorted into 1200 species 21 000 caterpillars successfully reared to adults > 40 000 insects pinned > 3500 digital pictures available on WWW 180 surveys of abundance of the target tree species 320 bait experiments testing the importance of ants in enemy-free space for herbivores	Novotny *et al.* (2002a,b)
Influence of selective logging on insect herbivores in rain forests (M)	Guyana	3 years	5	1114 person days of fieldwork Monthly monitoring of 250 sites and 9500 seedlings during 2 years 27 735 insects collected and sorted into 604 species (despite the extremely low insect densities) > 15 000 insects pinned > 500 digital pictures Responses of 35 insect species to selective logging analysed in detail	Basset *et al.* (2001)
Fruitfly rearing project (I, E)	Papua New Guinea	18 months	2	31 801 fruits collected (total weight = 535 kg) 150 tree species surveyed 7727 fruitflies reared Pictures of fruits of > 100 tree species	V. Novotny *et al.*, unpublished data

Table 2. *Continued*

Project (category)*	Country	Duration	No. parataxonomists	Output (not accounting for databases and papers published)	Reference
Figs and fig-wasps of the Madang area (I, E)	Papua New Guinea	4 years	1	> 1000 fig wasps reared from 400 trees including 50 *Ficus* species 78 morphospecies of Agaonidae, including 58 new to science, reared from 15 *Ficus* species studied in detail	Weiblen 2001; van Achterberg & Weiblen 2000
Effects of anthropogenic disturbance on arthropods in Gamba (I, M)	Gabon	4 months	6	Weekly survey of 128 traps over 12 sites and 4 habitats > 120 000 arthropods sorted in 228 families 6500 insects pinned and sorted to 672 morphospecies 800 additional insects pinned as reference collection	Y. Basset *et al*., unpublished data
Moths in various rain forest habitats (I, M)	Papua New Guinea	2 years	2	Light trap surveys of various, often remote, rain forest habitats 15 000 moths pinned, databased and sorted in 1800 species	V. Novotny *et al*., unpublished data

*I, inventory; E, ecological research; M, biological monitoring.

inventories and biological monitoring within the study areas (Table 2).

2. The high quality of biological material prepared for deposition in permanent systematic collections may be comparable to that achieved by museum technicians. Local preparation of specimens may sometimes be advantageous. For example, moths and butterflies reared from caterpillars and killed just prior to mounting often represent better specimens than those collected by light trapping or other destructive methods.

3. The ecological information associated with the biological material collected by parataxonomists may be considerable (Table 2). Knowledge of the local environment may be essential and profitably integrated in research projects. In addition, parataxonomists can be trained to perform simple experiments that may be of great benefit in the interpretation of distribution data (Novotny *et al*. 1999a). In this sense, parataxonomists may become 'parabiologists' or 'paraecologists' (Janzen *et al*. 1993). Wilson (2000) reaffirmed that the improvement of ecological data associated with extant species is crucial for the future of conservation biology.

4. The time-lag between the initiation of the study and the publication of results, often rather long for studies of very diverse systems (Erwin 1995), may be significantly reduced (for examples see Basset *et al*. 2000). This may be a particular advantage for conservation studies in which there is urgent need for action.

5. Public outreach opportunities are enhanced through the training of 'citizen scientists'. The indirect, positive effects of local involvement in research should not be underestimated (Thibault & Blaney 2001). Involvement of local communities in ecological research affirms the value of biological conservation. Collateral education of local people by fellow parataxonomists may also be significant.

How to refine the training and accuracy of parataxonomists

The correlation between the data generated in sorting insect material to morphospecies by non-specialists (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 (Cranston & Hillman 1992; New 1996; Fore, Paulsen & O'Laughlin 2001). Several tactics can ensure successful training of parataxonomists. First, the feedback of professional taxonomists during the lifetime of the fieldwork is essential, in order to validate the morphospecies assignment of problematic groups (but not necessarily to name or describe species at that stage). Secondly, recent developments in computer hardware make digital photography a useful tool available at a relatively low cost. Digital pictures of specimens and characters can be routinely included in sophisticated databases, and this information can be circulated readily among colleagues over the Internet and World-Wide

Web (WWW). Large public databases, such as Ecoport (http://www.ecoport.org), and taxonomic tools, such as IntKey (Laman & Weiblen 1998; http://www.herbaria.harvard.edu/software/navikey/figkey.html), are now available on the Internet. For an optimistic vision of the development of taxonomic tools related to information technology, see Weeks & Gaston (1997), Oliver *et al*. (2000) and Wilson (2000). All of these modern tools can greatly enhance the ability of parataxonomists to work efficiently and with accuracy. Finally, parataxonomist training should be continuous and can be improved by using richly illustrated taxonomic introductions and interactive compilations available on CD-ROM. For example, such products exist for parasitic wasps (Noyes 1997), beetles (Lawrence *et al*. 1999), katydids (Naskrecki 2000) and plants (Jorna 2001), and are likely to increase considerably in the future (Godfray 2002).

Parataxonomists often work on research projects initiated, funded and lead by overseas academic institutions. It is our experience that short training stays of parataxonomists at these institutions not only improves their skills, but are also important for a broader understanding of the scientific and conservation issues involved in such projects. Often, this includes the politicized question of why overseas countries are interested in the study and conservation of local biodiversity.

Parataxonomists and biological monitoring

The usual goal of a species inventory is to catalogue as completely as possible the taxonomy and ecology of taxa within a certain area. In contrast, biological monitoring usually seeks to assess the effects of disturbance (anthropogenic or not) on small groups (or guilds) or subsets of a taxon, which are thought to be responsive to the disturbance factor being studied. Monitoring usually implies specific protocols, such as nested or replicated samples, time–series or before/after-control/impact designs (BACI; Stewart-Oaten, Murdoch & Parker 1986). Long-term monitoring is best achieved with non-destructive, non-disturbing methods producing seasonal and annual replicates of the same sampling units. These protocols call for prolonged stays in the field, and parataxonomist input.

For monitoring purposes, data on short-lived invertebrates are adequate to detect significant changes in density after disturbance (Schroeter *et al*. 1993; Brown 1997). Because of their short generation time, invertebrates respond quickly to modifications of their environment (Kremen *et al*. 1993; Basset *et al*. 2001) and may be more discriminating in this regard than vertebrates (Moritz *et al*. 2001). Invertebrates may be informative when monitoring responses to important ecological perturbations, for example forest disturbance (e.g. logging; Hill & Hamer 1998; Nummelin 1998; but see Watt 1998). However, because concepts of surrogacy, such as indicator taxa or umbrella species, seem to be equivocal (Lawton *et al*. 1998; Moritz *et al*. 2001), monitoring the effects of forest disturbance *per se* on invertebrates should be promoted in its own right (Basset *et al*. 1998, 2001).

However, there are three major impediments to using invertebrates in biological monitoring. First, it is increasingly clear that a multispecies approach, including functional guilds, appears to be better than using indicator species to monitor the responses of invertebrates to disturbance (Flather *et al*. 1997; Didham *et al*. 1998; Lawton *et al*. 1998; Basset *et al*. 2001). For example, even congeneric insect species show variable responses to selective logging in the tropics (Basset *et al*. 2001). Further, some of the advocated 'indicator' taxa, such as tiger beetles (Carabidae: Cicindelinae, Pearson & Cassola 1992), are not particularly species-rich and are not directly related to forest productivity. Secondly, the taxonomy of species-rich taxa, especially in the tropics, is often troublesome (Erwin 1995). Lastly, the whole strategy is time-consuming because it requires long-term surveys to account for invertebrate seasonality, and therefore commitments by scientists to spend relatively long periods in the field.

A team of parataxonomists, adequately trained with appropriate feedback from expert taxonomists, can ease two of the above obstacles. With the help of parataxonomists, some of the most time-consuming but inexpensive sampling methods become viable alternatives to more expensive methods of biological monitoring. It also becomes feasible to include several taxa or guilds within the sampling protocol. We believe that this represents a promising alternative to the monitoring of species-poor taxa over relatively short periods of time.

For example, with the help of parataxonomists in Guyana, we were able to achieve one of the first BACI experiments that proved unequivocally the influence of selective logging on rain forest insects (Basset *et al*. 2001; Table 2). This strategy proved feasible despite the excessively low insect densities in the study system (Basset 1999). In Gabon, we are working with parataxonomists to investigate the influence of anthropogenic disturbance on arthropods at a scale rarely seen before in Africa: 22 target taxa including representatives from various orders and functional guilds, 12 sites representing four major habitats, weekly surveys of 128 traps, etc. (Table 2). Within 1 year of field work, we have accumulated data for 13 680 trap days (431 000 arthropods collected), including 1368 trap days with Malaise traps. This effort compares favourably with that of Lawton *et al*. (1998) in Cameroon, who used 56 trap days with Malaise traps to characterize the aerial beetle fauna along a disturbance gradient.

Possible limitations of the parataxonomist career

We see four major limitations to expanding the parataxonomist trade, especially in conservation biology, although they can all be overcome with adequate support.

1. The accuracy of parataxonomists is dependent upon the adequacy of their training, the availability of identification tools (such as taxonomic keys and field-friendly computerized databasing of images and collateral data), and the feedback of professional taxonomists (cf. above). A minimum level of accuracy needs to be secured so that the data generated by parataxonomists are strongly correlated with those produced by expert taxonomists (Cranston & Hill 1992; Fore, Paulsen & O'Laughlin 2001). This perhaps represents an opportunity to reinforce links between professional ecologists and taxonomists (New 1996; Novotny *et al*. 1997), and between scientists of developed and developing countries.

2. The decline in systematics research activity (Cracraft 2000; Miller & Rogo 2002) means that fewer taxonomists will be able to provide feedback to parataxonomists. Ultimately, the best parataxonomists could be trained and employed as taxonomists, but this will probably depend on local economics and foreign funding. Transfer of taxonomic research capacity to developing countries rich in biodiversity is essential if a complete catalogue of life on Earth is to be achieved (Samper 2001).

3. The costs involved may be high, although much lower than if similar work was to be performed by expatriate or even local scientists. It is difficult to project costs involved with parataxonomist work, as they are likely to vary widely from one country to another. Erwin (1997) and Lawton *et al*. (1998) commented on the high costs involved with biodiversity surveys in tropical systems but they did not consider including local parataxonomists in their protocols.

4. The transition of newly trained parataxonomists into professional life may be difficult and may depend on the local demand for their services. For example, in Costa Rica large numbers of parataxonomists have been trained and many have since taken up opportunities in ecotourism and conservation (D.H. Janzen, personal communication). In Tanzania, the experience of Missouri Botanical Garden is that plant parataxonomists obtain jobs as fast as they are trained, again mostly in ecotourism and conservation (P.B. Phillipson, personal communication). In Papua New Guinea, we are trying to establish a parataxonomist team as an independent sustainable unit financing itself by performing biodiversity surveys for various research and conservation projects. This long-term activity with multiple funding sources has employed 10 parataxonomists since 1994. Seven of them continue to work with us. Of the other three, one parataxonomist is now a university biology student, the second has joined a non-governmental organization, a feasible source of employment in this country, and the third works as a technician in agricultural research. Out of five parataxonomists trained in Guyana with a single source of funding, two are still involved actively with biological research. Our project in Gabon started too recently to comment on this issue.

Conclusion

We are convinced that the training and work of parataxonomists could profitably be put to use in conservation biology and in subsequent biodiversity management, especially in biological monitoring, biodiversity prospecting, production of environmental services, education, etc. Participation of parataxonomists may be particularly effective when studying invertebrate taxa, but not limited to them. In recent years, tropical botanists have gained much insight from analysing long-term data from permanent botanical plots (Condit 1997; Condit *et al*. 2000; Plotkin *et al*. 2000). The permanent plot approach is also promising for biological monitoring (Dallmeier 1996) and has been suggested as the way forward for studying tropical insects (Godfray, Lewis & Memmott 1999). We believe that augmenting the number of local parataxonomist groups in various tropical countries and networking these contingents to monitor functionally diverse taxa may also support an efficient biological monitoring of tropical systems.

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