Citation reference:

Janzen, D. H. 1993. Taxonomy: universal and essential infrastructure for development and management of tropical wildland biodiversity. In Proceedings of the Norway/UNEP Expert Conference on Biodiversity, Trondheim, Norway, O. T. Sandlund and P. J. Schei, eds., NINA, Trondheim, Norway, pp. 100-113.

Taxonomy: universal and essential infrastructure for development and management of tropical wildland biodiversity.

Daniel H. Janzen
Department of Biology
University of Pennsylvania
Philadelphia, PA 19104

FAX 215-898-8780
djanzen@mail.sas.upenn.edu

address from 24 April to 31 August 1992,

c/o INBio
3100 Santo Domingo de Heredia
Heredia
Costa Rica FAX 506 - 36-28-16

This manuscript was prepared to be delivered on 26 May 1993 to the "Norway/UNEP Expert Conference on Biodiversity" in Trondheim, Norway, 24-28 May 1993.

Abstract.

A tropical country's wildlands and their biodiversity can be major engines for national development through high-quality sustainable use of these wildlands by society, which is in turn the key to the implementation of the Biodiversity Convention. Taxonomy is basic, universal and indispensable technological infrastructure for this use. However, there are major taxonomic roadblocks throughout tropical biodiversity research and development. No matter what the form of sustainable use and development of a conserved wildland, a stable, accurate and phylogentically correct international taxonomy of the millions of species of organisms involved is essential, and will greatly improve the quality of the R & D. What we taxonomically know already is adequate to demonstrate that we cannot develop biodiversity without much more taxonomic understanding. What we know already also tantalizes us with the promise of what we could do if taxonomy were no longer a roadblock. Today we can sample the chemicals or the genes in the few hundred insect species that can be readily identified in a Costa Rican rainforest, but imagine what we could do if we could easily identify the 200,000 species that are neighbors to these few.

Ironically, the taxonomic roadblocks do not need to be there. They could largely be eliminated in about three decades on a reasonable budget of $2-3 billion/year for the <u>entire</u> enterprise for the <u>entire</u> world. This taxonomic organization (and much of the world's biodiversity inventory) can be done with the technology, administrative skills and human resources at hand or that can be generated through processes of training and planning already known and tried in society at large. And if this elimination of roadblocks is not performed, virtually all of our plans and efforts in sustainable tropical biodiversity R & D are going to yield woefully incomplete and confusing results.

The global and national taxonomic edifice is constructed of Conservation Areas, the user community, libraries and mental deposits of information, question-specific biodiversity research and development projects, the taxasphere - a community of international taxonomists, synoptic collections in the taxasphere, an emerging network of INBio-like processes, an emerging network of "All Taxa Biodiversity Inventory" projects, and an Internet-like process and full computerization of the processes occurring in these nine elements.

These elements work together to discover new biodiversity information and move it out into society both electronically and through hard copy. Simultaneously, they collate and repackage old and new information into new products and formats as new uses and users are discovered.

However, for this to occur the taxonomic community requires not only a substantial investment of financial resources and global political support, but also needs to reassess its protocols for allocating its time and human resources so that they become more sensitive to policy- and user-driven needs for taxonomic research and services.

Introduction

A tropical country's wildlands and their biodiversity can be major engines for national development. Some wildlands will be liquidated to meet short-term needs for cash, and often replaced with humans and their domesticates. Some will be conserved for wildland biodiversity development.

There are three overlapping steps in this conservation of wildland biodiversity: save it, find out what it is, and use it sustainably (Gámez 1991). All three steps, and their ramifications, are thoroughly embodied in the Convention on Biological Diversity, signed on 5 June 1992 at the United Nations Conference on Environment and Development (UNCED) and now being ratified (UNEP 1992). All three are becoming major areas of research and development for tropical countries, and are critical to the implementation of the Biodiversity Convention.

All three steps have a major indispensable technological element in common, irrespective of where and how the biodiversity is being saved, known and used. This element is scientific taxonomy, or systematics as it is often labeled1/. Taxonomy is basic, universal and indispensable technological infrastructure in the conservation of tropical wildland biodiversity through high-quality sustainable use by society. Better living through better taxonomy.

But there are major taxonomic roadblocks throughout tropical2/ biodiversity research and development.

In this essay I first examine the role of taxonomy in tropical biodiversity development (e.g. Hawksworth and Ritchie 1993, Anonymous 1993a), and then offer a specific proposal as to how the major taxonomic roadblocks can be removed. I am not a taxonomist. I am an ecologist seeking to facilitate the full-blown application of the power of taxonomy to tropical biodiversity conservation, development and management. Taxonomists have very much to gain from a strong liason with tropical society in general, and tropical society in general cannot possible reap the full benefits from its rich wildland biodiversity without major and wholehearted involvement by taxonomists.

The context: basic national planning

A tropical country may be likened to a corporation with a few hundred thousand to a few million km2 of renewable natural resources, among which are typically some tens of thousands of square kilometers of greenhouses. These greenhouses have long been thought of as "unoccupied" wildlands - forests, swamps, deserts, national parks, forest preserves, wildlife refuges, national heritage sites, etc. In a nation's wildland greenhouses are typically up to several million species of organisms, participating in many millions of interactions. And this corporation has a few million caretakers and shareholders, a CEO, a board, and corporate policy. The central theme of the Biodiversity Convention (UNCED 1992) is a general framework to facilitate sustainable and non-destructive national development of these greenhouses by the corporation, in a global context.

In a well-planned country, a significant portion of these wildland greenhouses are being, or could be, conserved and sustainably managed for the non-damaging use of their biodiversity. However, for this to occur, a shift in perspective needs to occur. A country generally has three kinds of land use: urban, agroecosystems, and conserved (or conservable) wildlands3/. Typically, the urban area and the agrosystems are viewed as "productive" and the wildlands as "conserved". This is wrong. Each of these three areas is potentially highly productive. It is just that the products are different, and research and development (henceforth referred to as R & D) has been differentially distributed among them. Each of these three land use types demands the same (and large) degree of investment, management, planning and care to realize its sustainable production potential. And it is in this context that taxonomy is essential infrastructure.

We have yet to glimpse how productive wildlands would be if humanity had invested ten millenia of life-or-death experiments in them, as we have in our agroecosystems. In the same vein, how productive would conserved wildlands be if we had annually invested the labor of many millions of people in them, as we do with our agroecosystems? But in humanity's youth, so to speak, confronted with the terror born of ignorance, we mostly removed the wildlands to make way for our domesticates or liquidated them to finance our bulwarks against the wilderness (Janzen 1973, 1984a).

These three land use production systems also differ in a way other than the products and their histories. As I just noted, in agroecosystems we have had 10,000-plus years of experiments in figuring out how to produce from them and care for them (irrespective of whether we actually apply this knowledge at any one time). We are approaching a ceiling to sustainable agroecosystem production per ha. In the urban habitat, there is yet considerable room for increased production. In the wildland conserved for sustainable and non-damaging use, our production is well less than 1% of potential. In the wildlands it is as though we were inside a Library of Congress and the Internet of some very advanced society, and do not have any idea of how useful it would be to learn to read or use a computer. We burn the books to keep warm and marvel at the dancing flames, and use the Internet wires to sew our clothes and make jewelry. Again, it is to move on past this stage in social development that taxonomy becomes essential and omnipresent infrastructure for conserved wildland management and sustainable development.

Better living through better taxonomy

No matter what the form of sustainable use and development of a conserved wildland - ecotourism, water production, carbon storage, erosion control, biodiversity prospecting, gene banking, gene generation, seed banking, education, intellectual stimulation, research, recreation, restoration, integrated pest management, human disease management, novel domesticates, climate amelioration, and many more as yet to be conceived - a stable, accurate and phylogentically correct international taxonomy of the millions of species of organisms involved is essential, and will greatly improve the quality of the R & D. And, though not directly the topic of this essay, such a taxonomic status is also of very great value in both conventional agroecosystems and the up-coming non-conventional agroecosystems that might be termed, perhaps, wild agroecosystems.

But do we already know enough taxonomically, so that there is no need to focus on taxonomy, but instead concentrate our efforts on those species whose taxonomic status does not appear to be much of a problem? No. To restrict our efforts to what we already know is to ignore most of what wildland biodiversity has to offer humanity. However, what we know already is adequate to demonstrate that we cannot develop biodiversity without taxonomic understanding. What we know already also tantalizes us with the promise of what we could do if taxonomy were no longer a roadblock. Yes, INBio can sample the chemicals or the genes in the few hundred insect species it can readily identify in a Costa Rican rainforest (e.g., Reid et al 1993), but imagine what INBio could do if it could easily identify the 200,000 species that are neighbors to these few.

We can and should build hard and fast with what we already know, with the species that escape the taxonomic roadblocks. But simultaneously our efforts should be redoubled to gain this and much more taxonomic understanding for the vastly more species of which we are still ignorant and for which we have no taxonomic framework on which to hang them and their information. To do otherwise is as though we were to decide that we have no need of literature, now that we know how to read a few advertisements.

A major activity in the initial stages of biodiversity R & D is becoming capable of distinguishing among species of organisms, attaching a name to them, and accumulating and organizing natural history information under these names. “Natural history” ranges from identifying their genes to showing how the ecosystem responds to their exinction. An equally important R & D activity is manipulating and communicating this information, with the names as handles. If all the biodiversity units and interactions to be discussed were in one place, had no variation, and did not evolve and change, then strictly speaking a scientific taxonomy would not be necessary. But the units - from genes to species to ecosystems - and the information about them, are extremely dispersed in time and space, display variation of many kinds, and have a past and future. This situation requires a scientific taxonomy that fixes a name on a standard (a “type” as known to the taxonomist) that potentially ensures that we all are referring to the same unit, no matter what country, month or society contains us or it.

The species are not arbitrary bits (as are machines, shirts and bottles), but rather are variously related genetically and thus variously have traits in common. The grouping of these species into “higher taxa” - genera, families, orders, etc. - according to their evolutionary relatedness (or “phylogenetic relatedness” as it is often expressed) thus becomes an extremely powerful inferential tool. That is to say, if a species of insect synthesizes interesting alkaloids, then a potential (though not unique) undiscovered new source for similar alkaloids is another insect species that has been placed - for quite other reasons - in the same genus by an insect taxonomist. If a plant has an interesting gene for enzyme synthesis, then its near relative - as suggested by phylogenetic relationships - may have a similar and even more interesting gene.

As ecotourism moves from its primitive stage of peering at bar-coded horses in East Africa to truly reading the millions of marvelous stories in nature's books, taxonomy is the access tool, the retrieval tool and the label on the book. As biotechnologists move from their first-grader's library of domestic plant relatives (that were themselves largely located and recognized by phylogenetic-based taxonomy) into the Library of Congress represented by a large conserved wildland, taxonomy is the reference librarian, the research assistant, the card catalogue, and the key word in the database of natural history traits that signal a gene's presence.

As the school child moves from seeing nature as itchy green to a most powerful Aesop's fable of mutualism, competition, aggression, negotiation, dominance, deceit, bliss, institutional structure, committee service, death and birth - taxonomy provides the vocabulary - the names of the players and suggests their pedigrees.

As the hydroelectric dam manager moves from simply clothing his watershed with natural forest to managing that forest as a multi-use and far more productive watershed, taxonomy is the language through which he will share information with his colleagues around the world about tree growth rates, rotation of recreational impact, selective logging, woody pharmaceutical crops, game ranching, ecotourism possibilities, etc.

As the integrated pest manager searches the tropical wildlands for a Central American caterpillar to eat down Australia's plagues of introduced weeds and for a parasitic wasp to control the next sugar cane borer in Brazil, taxonomy is a major guiding light to solutions.

Even the beginnings of conserved wildland biodiversity development and management (e.g., Pimentel et al 1992, Pimm and Gittleman 1992, Mills et al 1993, Pressey et al 1993, Hawksworth 1992a, 1992b, Hawksworth and Colwell 1992, Dalmeier 1992, Noss 1990, Reid et al 1993, Goodman 1993) demand the presence of taxonomy, information derived through the use of taxonomy as an inferential tool, and information located and shared - whether electronically or in hard copy - through the use of taxonomy. Even the indigenous hunter-gatherer is absolutely dependent on a home-made local taxonomy, a taxonomy that is only a faint shadow and ancestor to the power and reach of scientific taxonomy.

However, it is also true that the amount of taxonomic understanding necessary to make a serious beginning varies with the user, the products expected, and the ecosystem. Maintenance of a wildland solely as watershed protection requires substantially less taxonomic understanding than does the additional use of that wildland for biodiversity prospecting and ecotourism. Simple attempts to remove disease-carrying mosquitoes with massive application of pesticides require substantially less taxonomic understanding than does integrated pest management of the same mosquitoes with biological control agents, water manipulation and modification of host behavior.

Little taxonomy has been done with most tropical species, yet what has been done is much more than the world at large, or even the scientific community, seems to realize. However, the current system of organism identification and taxon-based information retrieval is impressively chaotic, fractured among languages, societies, political fiefdoms, personal agendas, commercial agendas, storage systems, etc. We have, however, built some interesting starts using this chaotic and woefully incomplete taxonomic base. Tropical taxonomy is, after two and a half centuries, at roughly the same level and future potential as was our level of computerization in 1950.

And throughout the terrestrial biodiverse tropics today, no matter what kind of sustainable wildland biodiversity development is cranked up, major taxonomic roadblocks do appear immediately. One cannot readily identify the organisms, know if they have been identified, find and manipulate the information extant about them or their relatives, and/or store and share the new-found information about them. How could one construct and develop a computer industry if most of the parts had no name, the blueprints were mostly in the heads of engineers that met once a decade, there was no retrieval system for the patents and trade secrets, the purchasers had no catalogues of prices and items, and the investors were rarely shown the products, rarely received dividends on their shares, and rarely studied the stock market? And to culminate this litany, imagine that the purchasers did not know what to do with the computers and software?

Ironically, the taxonomic roadblocks do not need to be there. They could largely be eliminated in about three decades on a reasonable budget of $2-3 billion/year for the entire enterprise for the entire world (Anonymous 1993a). This taxonomic organization (and much of the world's biodiversity inventory) can be done with the technology, administrative skills and human resources at hand or that can be generated through processes of training and planning already known and tried in society at large. And if this elimination of roadblocks is not performed, virtually all of our plans and efforts in sustainable tropical biodiversity R & D are going to yield woefully incomplete and confusing results, and biotechnology is going to turn the tropics' conserved and conservable wildlands into neoagroecosystems for their neodomesticates (Janzen 1987), neoagroesystems with far less than 1% of the economic, intellectual and social value they would have as a fully developed system of biodiverse wildlands.

A specific proposal for the removal of the taxonomic roadblocks

There are nine primary tools in the global and national taxonomic edifice (Figure 1, 2), with reference to biodiversity development and management.

• **Conservation Areas** - the wildlands that are now conserved, that have some chance of becoming conserved (or restored). The wildlands contain, for practical purposes, the organism pool4/. They are like the total set of books in all libraries of the world. As with books, the organisms occur as species (a book title), individuals (single books), populations (an edition), type specimens (the author's personal copy), higher taxa (all books about....., all books by a single author), habitats (local library), ecosystems or biomes (a national library system, all the books in one language), etc. They can be xeroxed, plagarized, stolen, loaned, donated, sold, edited, reprinted, burned, damaged, paraphrased, abridged, abstracted, cryophilized, split up, grouped, etc.

• **the user community** - all sectors of society that potentially or actually make use of wildland biodiversity objects and information about those objects, singly or in aggregates. It is the nature of this user community that sets the priorities for their R & D and determines the formats of the taxonomic products. The scientific community is a terribly important member of the user community - and as such strongly affects the format of taxonomic communication - but still it is only one among many potential users.

• **libraries and mental deposits of information** - an enormous body of information that is miscellaneous, organized, tenuous, frail, fractured, unavailable, incorrectly filed, gathered on a multitude of agendas, public, private, parastatal, erroneous, accurate, reliable, unreliable, continuing, discontinued, permanently lost with each dying biologist, redundant, annually rediscovered, stored, being computerized, in museums, in libraries, in botanical gardens, etc. Strip away the taxonomic structure, and virtually all of it dissolves into a meaningless and mostly unrecoverable jumble of hieroglyphics, personal databases and single events. Computerized, this information would be measured in thousands of terabytes. However, with full taxonomic organization of biodiversity, and with this information organized in information bases in a truly public and electronic domain, society can take a giant step forward in sustainable wildland development and management.

• **question-specific biodiversity research and development projects** - sprinkled across the tropical landscape, there are small to large projects in ecology, evolutionary biology, taxon-specific inventory, natural history, agriculture, forestry, conservation, physiology, genetics, taxonomy, restoration biology, environmental monitoring, indicator species, etc. They generate an enormous miscellany of biodiversity information that is daily being added to the extant information mentioned previously, and has the same disorderly characteristics. There are tens of thousands of these projects, spread among many institutions, sites and working circumstances. A host of familiar institutional and project names have their origins in efforts to bring coherence to these efforts - FAO, IUBS, SCOPE, UNESCO, DIVERSITAS, UNEP, TNC, WWF, UNDP, CIAT, CABI, ASC, SMASCH, BIOCON, CONNECT, SA2000, BIONET, SBN, ETI, ERIN, USNM, SEL, TNHM, etc.

• **the taxasphere** - a community of international taxonomists. As individuals and as a community the members and processes of the taxasphere have taken us part of the way towards the construction of an organized taxonomic edifice, but the pace is too slow for the need upon us. With a few conspicuous exceptions, the taxaonomic advance has not embraced and benefitted all of society as a user and financer of their products and their research. The results have been poorly disseminated and unequitably exploited - though the activities of the taxasphere are also one of the outstanding examples of long-standing technology transfer from developed to undeveloped countries. The reputation for imperialistic or national behavior by the members of the taxasphere, a reputation that is disappearing rapidly, was very understandable since virtually all of their support was personal, imperialistic or national in origin. Additionally, until very recently, tropical countries have showed a paucity of interest in synergism with the community of taxonomists.

However, with relatively minor adjustments and major financing proportional to its true importance to biodiversity R & D, the taxasphere is a major and essential member of the team that will remove the taxonomic roadblocks. There are thousands of taxonomists - though not nearly enough - spread among many institutions and working circumstances. The bulk - though by no means all - are housed in and paid for by the tax bases, commerce and personal interests of extra-tropical developed countries.

• **synoptic collections in the taxasphere** - these are global "as-complete-as-possible" collections of all species in a taxon, synoptic collections that are designed and managed to speed and facilitate further taxonomic work in both primary description and phylogenetic research that is aimed at better use and understanding of inter-specific relationships. These collections are not only physical objects but also need to be thoroughly wrapped with with collective information bases, such as the world database of taxonomic names, the locations and status of types, the content of key literature, the locations of all biodiversity collections and projects, etc.

Synoptic collections and their associated processes are critical to a) basic taxonomic research, b) planning and setting priorities, c) starting work on any taxon, and d) cost-effective taxonomic research on an industrial scale. The taxasphere's synoptic collections are likely to be largely, but not entirely, located in a relatively small number of strongly focused taxonomic institutions (The Natural History Museum (London), USNM, Bishop Museum, American Museum, Missouri Botanical Gardens, Kew Gardens, culture collections, etc.). These institutions should receive substantial world-level support for the development and maintenance (and continuous updating and researching) of these synoptic collections, as well as for their critical institutional role in providing taxonomic identification services to developing countries for both the agroecosystem and wildland biodiversity development.

• **an emerging network of INBio-like processes** - these national upwellings of tropical national wildland biodiversity inventory for sustainable use and management are transformations of long-established taxonomic processes (national museums, botanical gardens - e.g., Jarvie 1993) and new amalgamations of these efforts (CONABIO, INBio (e.g., Gámez 1991, Anonymous 1993b, Janzen 1991, 1992, Reid et al 1993)). To a certain degree, the new US Biological Survey of the Department of Interior may be viewed as an extra-tropical example. The tropical INBio-like processes are based on applying rural paraprofessional resources in collaboration with national professional staff to provide the basic information and specimens needed to organize the national portion of the taxonomic edifice, know where what biodiversity is located nationally, and begin to move this information out into the hands of national society (e.g., Gámez 1991, Janzen 1991, Reid et al 1993). As such, they are key to the implementation of the Biodiversity Convention. There are currently four of these in the tropics (Kenya, Mexico, Costa Rica, Indonesia) but there are at least a dozen more incipient. Each national inventory is a slower and more thorough and complex follow-on, precursor and complement to the big step taken by an ATBI (see below). And each is fully integral with the rapid increase in interest in global inventory and monitoring (e.g., May 1988, Hawksworth 1992a, Hawksworth 1993, UNEP 1992, Wilson and Raven 1992, Dalmeier 1992, di Castri et al 1992, Pressey et al 1993, Yoon 1993).

• an emerging network of "All Taxa Biodiversity Inventory" projects - an All Taxa Biodiversity Inventory (ATBI) is a white-hot focus of taxonomic inventory applied to all the hundreds of thousands of species in a large biodiverse site for a 5-year period with a multi-million dollar budget (Yoon 1993, Janzen and Hallwachs 1993). An ATBI becomes a national base site on which to build and hang a wide variety of biodiversity R & D (which are themselves "uses" as well) as the taxonomic roadblock becomes largely removed, the location of the organisms becomes known, and information accumulates about their traits. An ATBI simultaneously has the goal of establishing a known biodiversity universe and deep reference4 point against which to develop and test a host of scientific hypotheses, and develop a swarm of synergisms among biodiversity users from all social sectors. An ATBI becomes a centerpiece effort in a nation's overall inventory conducted by an INBio-like process. It simultaneously and somewhat serendipitously organizes a major part of the taxonomic tangle for that geographic region/ecosystem/biome, since many tropical species have very broad distributions. A generic ATBI battle plan is being written (Janzen and Hallwachs 1993), at least one specific ATBI is already visualized, and perhaps another 20 ATBIs are incipient around the tropics (Janzen and Hallwachs 1993). While the sum (and network) of all ATBIs does not constitute a complete global taxonomic process, it is a major portion of that process and is highly synergistic with it.

• an Internet-like process and full computerization of the processes occurring in the above eight tools - as indicated earlier, it is simply impossible to do justice to the potential of biodiversity development and management without full computerized integration of the highly particulate and extremely diverse information involved (e.g., Canhos et al 1992). Taxonomy provides the base to this structure, a structure on which the power of computerization can then collectively hang the huge number of interrelative data points and processes that are involved in biodiversity use. Ten million rice farmers can communicate largely through distributing rice seeds, market economy and word of mouth. Ten million wildland biodiversity farmers need ten million opportunities to trade and collate information on ten million species of wild biodiversity.

One salient trait of transfer of taxonomic information needs special mention. No matter how often an opportunity appears for cost-recovery, or even profit, from the packaging and dissemination of computerized taxonomic information, the reality is that biodiversity development and management demands fluid, rapid and eager exchange of incredibly varied taxonomic information throughout the world. This information will be of importance to all sectors of society and nations. As such, the general costs of the taxonomic process and its computerization - like health and education - need to be largely born by world-level cost-distribution processes rather than individual direct payments per unit service.

How do these nine tools work together?

Imagine a national surface (Figure 1) with big green patches (e.g., 15-20% of surface area) - the Conservation Areas - floating in the agroecosystem. This entire national surface is also scattered with fine points of uptake of biodiversity information from individual question-specific projects (as well as with information-generating projects and "libraries" of extant information). The national surface is also punctuated by an INBio-like process that is conducting the national biodiversity inventory, and one of the Conservation Areas is punctuated by an ATBI. All of this national surface is overlain by the global taxasphere and connected by Internet-like networking.

Here I focus on some of the salient characteristics of the taxasphere, bringing up the other elements largely vis a vis their primary actions in supporting, guiding, growing, stabilizing (e.g., Bisby and Hawksworth 1991), and facilitating the taxonomic process as it facilitates biodiversity development and management. Other essays are needed to focus on each of the other tools in the same manner.

The taxasphere, an international process of taxonomic activities

I focus on the taxasphere in two ways. First, I begin with a single specimen in a Conservation Area in Costa Rica and walk it and its information through the taxonomic process until the taxonomist's immediate descriptive involvement has largely ended. "Ending" means getting it to the point where further biodiversity R & D on it and its relatives and interactants are largely conducted by specialists in areas other than taxonomy. This R & D is largely unimpeded by alpha taxonomic roadblocks - though it will continue to accumulate taxonomic refinement and ever-greater inter-taxon understanding through phylogenetic studies. Next, I suggest an organization for a portion of the community of taxonomists that will facilitate the movement down this pathway for virtually all species.

The single specimen trajectory

Today, a biodiversity prospector, for example, happily labeled a bottle of fresh-frozen moths from the field and sent them off to a major pharmaceutical company for research on the primary and secondary chemicals they contain. This event meant a $1000 national return on that country's investment in saving its wildland forest, and potentially a yet greater return if one of those chemicals becomes a patentable drug and if it can best be produced by raising the moth as microlivestock (e.g., Reid et al 1993). How did that moth and sample get a scientific name, thereby linking it to a host of other knowledge and allowing us to communicate among ourselves about it and what we are doing with it and its products?

1. From the conserved wildland to the INBio-like process. As part of an ATBI, national inventory project, or question-specific project, a parataxonomist (Janzen 1991) hangs a light in the forest, collects a female saturniid moth (e.g., Rothschildia lebeau, Janzen 1982) attracted to it, returns it to her Biodiversity Office, mounts and dries it, and

packs it in an insect box with other moths from the same light. At the end of the month, she takes these boxes to the national inventory processing center in her country's INBio-like process. At that time she is encouraged by the national inventory managers5/ to either seek more of what appears to be the same as that moth species, to be opportunistic about further collection, or to explicitly ignore further specimens of that species. Which option is selected depends on the perceived current taxonomic and inventory status of that species.

2. In the door. The box of incoming mounted moths is temporarily frozen to kill potential contaminant pests. As is also the case with its neighbors in its box, our female saturniid moth receives an individual traditional printed label (with date, locality, collector) as do all the other specimens in her box, and receives an individual unique bar code label (unique identifier number), both put on by technicians at the INBio-like process. All of this information, plus any other (collecting method, natural history notes) is computer-captured at the time by the inventory managers and technicians working together. Our moth is then sorted, first into a family level pool and then to morphospecies ("look-alikes") by parataxonomists, technicians and inventory managers.

To this point, no international taxonomist has been directly involved, but many will have been indirectly involved through training personnel and through having provided (during the past several centuries as well as recently) much of the taxonomic information and understanding that is used - descriptions, monographs, identification guides, phylogenetic analyses, processing technologies, etc. (e.g., Lemaire 1978, Janzen 1982).

3. Processing the specimen pool. Our female saturniid, with its congeners and confamilials, is now part of a large pool of specimens clustered in this or that collection scattered across the world's surface. She and the other members of her specimen pool are examined by an international taxonomist and/or the inventory manager either in situ in the facilities of the INBio-like process or (less frequently) after being sent somewhere else. She is categorized as described and then identified, as a problem requiring further study, or as undescribed.

a) If she is found to be already described and identified (e.g., Rothschildia lebeau in Lemaire 1978), she now becomes a resident "inventory voucher"6/ for the computerized specimen-based information about her and resides in the INBio-like process for future uses (extraction of genes, extraction of chemicals, proof of correct identification, comparative measurements, study of intra-specific variation, donation to a world-level synoptic reference collection, construction of field identification tools, use in phylogenetic relationship analyses, basis for drawings, etc.).

b) If it is found that applying a name to her is a taxonomic problem, she may be subject to comparison with other specimens or more destructive analysis until identified.

c) If she is found to be undescribed, she and others of her species are described by a member of the taxasphere in collaboration with the staff of the INBio-like process, and hence enters the global as well as national "identified" pool.

An important caveat for the specimen-based data bases that originate in this manner is that if the specimen was destructively processed to where there is no longer a "specimen", its data is not lost and it is still specimen-based data. The same applies to a specimen that was initially not even collected but rather was only observed and identified in the field, and the data are associated with the observation in a database (e.g., as might occur with a rare and endangered species of vertebrate that should be inventoried without collecting).

Note also that throughout this process, the various identifications require some kind of "certainty ranking". This uncertainty of correct identification should not be confused with species-level (or greater) uncertainty as to whether a given species has been correctly placed in a higher taxon.

4. Processing the specimen-based data. Our moth's information is now part of a set of national specimen-based data bases, which may contain everything from the raw field data to photographs, drawings, literature references to specimens cited in general species accounts, all comments and additionally recorded data on the way to being identified, the history of the identification, and all uses of this information and specimen. And these data bases are derived from national data and from the world's collections, literature and computer storage. These databases are put together by paraprofessionals, inventory managers, and other kinds of university-level professionals, working with international professionals of all kinds, including taxonomists. They can be partly supported (and updated) through funding generated by especially heavy users, and partly supported by world-level society-wide taxation. These databases are connected electronically, largely through Internet-like communications networks.

From these databases or via these databases can be drawn, at least,

a) at least one geographic and ecological locality in the forest where our Rothschildia lebeau can be found, at least at one time of year, and by at least one method; anyone can get more of them for whatever reason,

b) any and all publically available information from the world about the biology of Rothschildia lebeau, wherever it occurs (in this case, from the southern US to Brazil),

c) if any be, inferential information about related moths, information that will guide and speed the further accumulation of information about national Rothschildia lebeau,

d) an expert system identification tool that will allow any possessor of a specimen of R. lebeau to know that is what he or she has in hand, and thereby open the door to all that is known about it and allow the storage of any newly-acquired information about it,

e) as a byproduct, statistics such as how many species of confamilials are known to occur in the same geographic or ecological unit, whether it is known to occur in a given geographic or ecological unit, with what other organisms and physical conditions it cooccurs, and any other information that has been recorded for it or its point of collection, and

f) electronic and hard copy reports summarizing the information in a) through e) above in formats for users ranging from the innocent schoolchild who has just found a Rothschildia lebeau on the way to school to the research scientist who is frenetically searching for the developmental genes that monitor the environment when this species produces rust-colored moths in the dry season and dark chocolate-colored moths in the rainy season (Janzen 1984b).

The semi-final, and definitely usable, products of this taxonomically- and inventory-supported chain of events are
- national and local research and reference collections,
- identification for any user biodiversity user or purpose,
- a massive information base for further systematics research,
- full electronic public distribution of all information about the specimens (and hence their species),
- an on-going permanent and updateable electronic data stream (information bases),
- a taxonomically clean framework on which to continue to build and manipulate the biodiversity development process for all the wildland organisms in aggregate,
- a national sense of custodianship of this biodiversity,
- a national awareness of what biodiversity information is there and is lacking, and
- an international vision of inter-country variation in this taxon.

And if a taxonomist should later decide that the moth should have been placed in the genus Hyalophora instead of Rothschildia, the electronic databases can be updated. Likewise, if it is later found that our moth was really Rothschildia orizaba instead of Rothschildia lebeau, then the error is electronically corrected. And if it is later found in some other country that the species Rothschildia "lebeau" is in fact three sibling species of Rothschildia, then a national curator goes back to the specimen, determines which of the three it is, and makes the appropriate changes in the data base. This kind of updating will be needed into perpetuity and demands some kind of society-wide support, given that there will be society-wide benefits.

The above process is one that can be envisioned as simultaneously occurring with hundreds of thousands of species for each INBio-like process, species pools that in aggregate across the terrestrial tropics will be at least 20 million species ranging from bacteria to insects to elephants; at least half of these would be probably be microbes, fungi and protists. Not all species nor major taxa start through this process on the same date; when it is that a group enters any stage in this process chain, and how rapidly (and continuously) it moves from process to process is dependent on numerous well-understood variables that there is not space to describe here.

For the tropics as a whole, the entire package of terrestrial macrospecies and most microspecies could probably be moved through this process in a 30-year period at an annual cost of about $5 million per average national INBio-like process (which, however, conducts much other biodiversity R & D at the same time) and $25 million per average ATBI (spread over five years). In addition the taxonomic layer or "taxasphere" to be outlined below needs (and can absorb) about $60 million/year for the first three years, expanding to $120 million/year for the remaining 27 years. I must quickly note, however, that such cost estimates for the taxasphere are somewhat static in that they do not include the costs of training new taxonomists nor the maintenance of the world-level synoptic collections that are critical to the proper functioning of the taxasphere. Additionally, a doubling of funding might be able to shorten this time period significantly for those groups whose treatment is particularly labor-intensive (e.g., insects, microbes). The entire cost could be estimated at $2-3 billion per year for 30 years (Anonymous 1993a).

However, it is clear that the taxononomic community as a whole would need to substantially rethink its way of doing business were it to enter into a social contract of this very great importance and cost. Below I offer a few thoughts as to potential points of reorganization.

A new organization of a portion of the taxonomic community

The above-described process for Rothschildia lebeau is really a portion of a draft of an industrial-strength plan to remove the taxonomic roadblock through national (or local regional) inventory by INBio-like processes, ATBIs and question-specific projects spread strategically across the countryside, and supporting (and supported by) the taxasphere. It requires a scaling up of some international taxonomic processes that are already in operation, and a sharpened focus in others. It also requires a variety of quite novel taxonomic processes, ones that could eventually render this activity a new area, inventory science. Below I address such a scaling up.

The taxonomist. This scaling up needs to recognize certain traits of the taxasphere:

- taxonomy for virtually any large group of organisms is an international process - many species range across many countries, and organizing and conducting the taxonomy of the species in any one country requires consideration of the species occurring in other countries,
- it is possible to get most if not all groups to the level of taxonomic organization that reptiles, birds, nymphaline butterflies, mammals, and legumes, for example, enjoy today by using the technologies in hand,
- a Ph.D.-level taxonomist costs about 10 years and $500,000 to produce,
- there already are a moderate number of enthusiastic taxonomists who would be happy to make a career out of doing truly full-time goal-oriented taxonomy aimed at removing the tropical taxonomic roadblock,
- the bulk of good taxonomists today are spending only 0-20% of their time actually doing taxonomy, but would be quite happy to have the opportunity to invest their lives full-time in taxonomy,
- most of the taxonomic human resource is not administrated so as to be aimed at the products described in the previous section, but rather is spent on on labor-intensive

actions that could be done by others, antiquated technology, and administrative and workplace inefficiencies,
• taxonomists traditionally have worked in exile, late at night, on weekends and in other forms of isolation rather than as members of a taxonomic team or as managers of a "laboratory" replete with support personnel,
• much of the initial and quite descriptive labor of taxonomy on a given species is a one-time process (e.g., a genitalia drawing has to be done only once, usually), a process that later gives way to phylogenetics, genetics, behavior, natural history, biotechnology, evolutionary biology, etc.,
• much of a taxonomists' time is spent on diffuse add-on projects in natural history, genetics, physiology, behavior, in large part because they cannot get funding to do taxonomy and build on that base,
• much of what a taxonomist spends time on when doing taxonomy can be done faster and in greater amounts by the national inventory process characterized above with Rothschildia lebeau than by single taxonomists working alone, no matter how well financed, and
• most taxonomists are very fond of their organisms and enjoy working in the taxonomic process, and as such tend to undervalue and underprice their contributions.
.

A Steering Committee. An important first step in scaling up the taxasphere would be to form a world-level Steering Committee to hold several intense meetings to prioritize the major taxa according to consideration such as

a) need for a taxonomy that is adequate to address society's needs,
b) degree to which they have been organized already,
c) availability of zealous and dilligent taxonomists for that taxon,
d) technical and political ease of moving strongly into the inventory of the taxon,
e) availability of training possibilities for taxonomists, etc.

This Steering Committee should contain at least 30-50 members drawn from all areas of society, with not more than 60% representation by taxonomists and taxonomic institution administrators. Steering Committee members should have the resources to call numerous special technical subcomittees to address particular points that demand detailed technical knowledge. The Steering Committee should meet at least several times per year, and function as a governing board for the Taxonomic World Action Resource (T-WAR). Each year it would determine the next cohort of major taxa to come on line and review annual progess reports for ongoing programs. The T-WAR Executive Director and staff will have a major support and facilitation role to the T-WAR Steering Committee.

General funding. Once a first list of about 200 priority taxa has been identified, the Steering Committee should call for project proposals to address these taxa. The first cohort of projects should cover approximately 100 major taxa. Once a match has been made between a taxonomist and a work plan, and a particular focal taxon, the project is guaranteed an average of $500,000-$1,000,000/year for a predetermined number of years (e.g.,1-5) and an average of $200,000/year for a predetermined number of wind-up and wind-down years (2-4). A general fund pool should also be available to cover one-time necessary start-up costs, such as full computerization of the taxonomist's home operating base.

The funding should be in the form of an annual direct payment, as a minimal-overhead contract to the home institution (which may range from someone's home to the Smithsonian Institution). Annual financial and narrative reports should be made electronically, and the products and progress always should be available electronically through the Internet. The financial reporting should be made according to a simple electronic bookeeping format formulated in detail by the T-WAR framework, designed to minimize within-project bureacracy.

The costs of the centralized world-level synoptic collections for a given taxon, and the identification and updating activities associated with it, should largely be met by scaled contributions from the INBio-like processes that are scattered around the world. That is to say, if for example an INBio receives $5 million/year for its national or local inventory activities from the Global Environmental Facility or from national sources, then it can expect to be contributing several hundred thousand dollars/year to each of several major world-level repositories as a compensation for the world-level custodial services rendered by these institutions. Additionally, a GEF-like process should endow certain world-level depositories (developed from old or constructed anew for this purpose) of synoptic collections wherever they may be. This endowment should be for both the physical maintenance of the specimens and for the electronic updating and manipulation of their associated databases. Enormous benefits to the development of tropical scientific capacity can be envisioned through explicitly establishing some of these centers in tropical areas.

<u>The taxon-specific projects</u>. Each taxon-specific project should be individually tailored to the circumstances of that taxon, taxonomist(s), support staff, home institution, etc. However, all projects would be designed within a general framework that is designed to produce the consequences and products of an organized taxonomy for national inventory and other biodiversity R & D. The project funding should generally cover taxonomists' salaries, assistants, direct technical help, travel and operations. Many of the project "assistants" would be Ph. D.-level graduate students in taxonomy serving in an apprenticeship role, and conducting some portion of this process as a thesis. There would need to be some additional funding available to cover the logistics and operational costs of these students, irrespective of where they are housed. Funding for the INBio-like processes would cover the collection and processing and sorting of the raw new inventory material and other paraprofessional-curatorial processes.

It is important to emphasize here that each taxon-specific project is working with specimens and information drawn from the world-level synoptic collections, taxon-specific collecting efforts, and ATBI's (and other forms of national inventory). No one of these four sectors is sufficient to support the global taxonomic process alone.

The size of a taxon that will make a reasonable project will be a balance between speed of completion and size. If someone takes on Curculionidae, the world's largest family of beetles, we are probably looking at 15 years of primary funding in addition to wind up and wind down funding. Ants, on the other hand, could probably be done with 3-4 years of primary funding. What is left to be done in bird taxonomy might require no more than one year of primary funding and a year of wind down. The grasses might require five years of primary funding. The fungi might well require 20 years of primary funding, or, if greater speed was desired, the fungi could be broken into several major taxa and a 5-year project made of each. The bacteria will definitely require 20 years of primary funding for several major clusters. Some "taxa" might be somewhat artificial clusters of families, such as "the primarily leaf-mining families of microlepidoptera" or "the families of beetles that have members generally less than 2 mm in length".

Much judgement will be required by the Steering Committee and its assessors to determine what taxa to place in the original "wish list" and the size (scope) of taxa may well be negotiated on a case by case basis. For example, it might be decided that Braconidae should be a focal taxon, but a taxonomist says "I will do just half of the subfamilies of Braconidae"; the final contract would be negotiated, with the justification for the time budget and funding budget being a major consideration. On the other hand, the Steering Committee, and its assessors might choose to operate under the principle of "we want it done now, and it therefore it may be better to wait a year or two for a very high-intensity project than to agree now to a slower paced or narrower scope". It will be especially desirable for large and/or complex taxa to be taken on by small teams of taxonomists, both for synergism and to lend continuity should a taxonomist turn to other activities or otherwise retire from the scene.

As soon as possible the process should be supplemented with a special fund for start-up projects by students, re-tooling senior professionals, and exploration of totally unknown (often orphan) taxa.

Some of the notable elements of the generic framework for the operation of the taxasphere are that

• the Ph.D.-level taxonomist is a coordinator and director of a very mission-oriented small team, some of whom may well not be from the same country as the lead taxonomist,
• research teams are expanded both horizontally (Ph.D.'s working in consort) and vertically (more involvement by personnel with minimal initial training, on-the-job development of human resources, national capacity building),
• the entire process is largely carried out by nationals, from living organism in the wildland Conservation Area to the "final" node of databased electronic information about the organism to the insertion of this information into larger information constructs (e.g., an identification guide for ecotourists, a biodiversity prospect project),
• the products are focused on the removal of the taxonomic roadblocks, a serious first-draft of the species-level inventory for a country, and full participation by a national biodiversity R & D process in the global burgeoning network of electronic and democratic biodiversity information development and management,

• most taxonomists organize a focal taxon and then either move on to subsequent development of taxonomic information about that taxon, or move laterally to process another taxon,
• at one time the taxonomist team will pull together (in a variety of ways) virtually all of the specimensl for a given group from extant collections around the world, taxonomically update these specimens along with much of the new specimens from national efforts, and electronically capture all of their associated information,
• the new national inventory collections being worked with will be geographically thorough, extremely deep in certain locations, rich in resolving power for questions of variation, etc.,
• primary type specimens will generally be deposited in their respective INBio-like processes, but paratypes will be broadly distributed among pertinent INBio-like processes and the global synoptic and research collections, wherever they might be (in those cases where there is only the type specimen - hopefully a rare occurrence in national intensive inventory - there are compelling reasons for the type to be deposited in the synoptic collections, wherever they may be),
• any given project will be highly and maximally computerized from the bar-coded specimen data (for both the new and museum specimens) and information tracking, to Delta-like information processing and expert-systems for identification purposes, to illustrative materials, to the generation of the electronic on-going database (with its occasional hard copy reports, identification guides, natural history accounts, etc.), and
• any given project will have a defined termination date; at that time the Steering Committee will have to decide to fund continuation, or declare that group "done", or placed in the category whereby it can be adequately handled through ongoing custodianship between the INBio-like processes and the world level synoptic collections.

It is clear that not all taxonomists in the world will wish to enter into a very intensive activity of this nature. However, a given taxon-specific project may well incorporate some level of participation by "partly-involved" taxonomists, though it is imperative that there be a minimum of one lead taxonomist who is willing to be an aggressive executor of the project. Likewise, a partly-involved taxonomist may well seek funding from some national agency (e.g., the US National Science Foundation) to allow him or her to specifically become an add-on to a given taxnomic project, thereby allowing that project to cover a larger taxon than would be otherwise possible on global funds for the taxasphere. In the same vein, there may well be cases where an ecologist, physiologist, gene manipulator, etc. may find it advantageous to become a separately-funded add-on to such a taxon-specific project, both for the synergistic effects and for the economy of scale in specimen processing and sampling. Finally, specific megaprojects in phylogenetic techniques (practice or theory), and other kinds of general processes in systematics for troublesome or especially instructive groups, should be financed independently on a merit that is independent of the particular taxon that provides their examples.

It is doubtful that increasing the number of taxa under consideration at any one time will create conflicts among them, and there are many obvious ways in which they will synergize each other both in the field and in participating institutions. However, as the

T-WAR process increases in size, it will also need an increase in the number of permanent administrative/organizational staff, as well as increased funding for more and/or larger meetings of the Steering Committee. This T-WAR process may also grow through collaboration with various kinds of follow-up and add-on projects to the basic taxonomic clean-up process described here.

When is a taxonomist "done"? As a the first stage efforts for given taxon is finished, most taxonomists will either move on to other biological specialties (including phylogenetic relationships) on their specialty taxon, or move laterally to work up another taxon. But whatever the process, the world-level need for the initial descriptive taxonomic work per se should steadily decline over the 30 year period, while there should be a steady increase in the need for persons processing and developing biodiversity information about a set of species with (now) a somewhat stable initial taxonomy. At the lowest national level, this progression may mean parataxonomists evolving into paraecologists. At the top, it may mean some taxonomists turning into geneticists or ecosystem managers, for example.

Administration. The T-WAR core administration could be extremely simple. An Executive Director would be needed at the Ph.D. level in biology and with broad international experience in whole-organism biology (both taxonomy and other areas), and a flair for motivating/organizing groups of highly disparate persons. There should be a Ph.D.-level (or experience) five-member permanent staff, with their backgrounds covering electronic biological data management, organism identification and biodiversity data manipulation, conservation and wildland management issues, and institutional structures. All six should be at least bilingual. The focus would be on facilitating the actions in the entire process and not on being active researchers/doers in any of the taxonomic projects.

There should also be five two-year rotating internship-positions that will be filled with earlier in their biodiversity careers. This team of eleven should be backstopped by eight full-time assistants and an operations budget that is sufficient for a fully computerized operation and ease of travel among sites and institutions. This entire operation would probably cost out at about $1,600,000/year. It is imperative that this office be located at one of the INBio-like processes in a biodiversity-rich tropical country, and might be asked to rotate among them at five year intervals. The "permanent" positions would be filled by the Steering Committee and be re-evaluated at five year intervals.

The choice of a tropical area for the primary and subsequent T-WAR offices at first glance appears counter-productive, but will be very important in generating a sense of participation among the developing countries. There should also be T-WAR branch offices in major synoptic collections, and each INBio and ATBI would have a liason person to explicitly liason with T-WAR.

It would require approximately one year to crank up the entire planning and execution process from the date that funds were guaranteed for a T-WAR initiative (including the nomination of the Steering Committee and getting it set up to request proposals). It would take another half year to evaluate proposals and decide on the first set of 100 major taxa.

Acknowledgments

This manuscript has benefitted greatly from discussions and editorial comments by W. Hallwachs, M. S. Foster, F. C. Thompson, J. Jimenez, C. K. Yoon, R. Gámez, E. Framstad, R. Tiffer, R. Blanco, M. Stowe, G. Davis, P. Rauch, E. Hoagland, S. Miller, N. Platnik, R. K. Colwell, I. D. Gauld, N. Chalmers, D. Miller, J. Cracraft, J. Edwards, J. S. Burley, R. W. Flowers, L. Krishtalka, Q. Wheeler, E. E. Lindquist, R. L. Chapman, D. Lipscomb, L. Speers, J. Lundberg, J. Beach, V. Funk, P. Raven, E. O. Wilson, S. Miller, R. Colwell, J. Llorente, H. Benítez, A. Chapman, M. A. Donnelly, E. F. Stoermer, J. F. Rieger, H. Arita, M. Smith, J. J. Pipoly, S. Mori, R. Cypessf, A. Y. Rossman, V. Heywood, D. Hawksworth, J. Coddington, U. Svensson, T. Anderson, T. M. Lewinsohn, K. Baadsvik, O. T. Sandlund, I. Gauld, N. Chalmers, R. Pellew, V. R. Ferris, W. U. Brigham, K. Miller, R. Olembo, M. Pyhala, V. Heywood, E. S. Nielsen, J. Croft, J. Soberon, H. Mooney, D. E. Wilson, M. A. Ivie, J. A. Powell, D. A. Brooks, T. L. Yates, J. M. Tiedje, J. Humphries, and many others.

Literature cited

Anonymous 1993a. Systematics Agenda 2000. Charting the biosphere. 11 May 1993 report, SA2000, Department of Ornithology, American Museum of Natural History, New York, 10 p.

Anonymous 1993b. Legislative proposal seeks to wed biodiversity conservation and economic growth. Diversity 8(4):24-25.

Bisby, F. A. and D. L. Hawksworth 1991. What must be done to save systematics? In Improving the stability of names: needs and options, D. L. Hawksworth, ed., Koeltz Scientific Books, Konigstein. pp. 323-336.

Blum, E. 1993. Conservation profitable. Environment 35:17-45.

Canhos, V., D. Lange, B. E. Kirsop, S. Nandi and E. Ross, eds. 1992. Needs and specifications for a biodiversity information network. UNEP, Nairobi, 265 pp.

Dallmeier, F. 1992. Long-term monitoring of biological diversity in tropical forest areas. UNESCO, Paris, 72 pp.

di Castri, F., J. R. Vernhes and T. Younes 1992. A proposal for an international network on inventorying and monitoring of biodiversity, Special Issue 27, Biology International, IUBS, 27 pp.

Gámez, R. 1991. Biodiversity conservation through facilitation of its sustainable use: Costa Rica's National Biodiversity Institute. TREE 6:377-378.

Goodman, B. 1993. Research community swats grasshopper control trial. Science 260:887.

Grassle, J. F. 1991. Deep-sea benthic biodiversity. BioScience 41:464-469.

Hawksworth, D. L. 1992a. Biodiversity in microorganism and its role in ecosystem function. In Biodiversity and global change, eds. O. T. Solbrig, H. M. van Emden and P. G. W. J. van Oordt, IUBS, Paris, 83-93.

Hawksworth, D. L. 1992b. Litmus tests for ecosystem health: the potential of bioindicators in the monitoring of biodiversity. In Plant genetic resources for sustainable agriculture, eds. S. Jana and M. S. Swaminanthan, Macmillan, India, pp. 1-21.

Hawksworth, D. L. and R. R. Colwell 1992. Microbial Diversity 21: biodiversity amongst microorganisms and its relevance. Biodiversity and Conservation 1:221-226.

Hawksworth, D. L. and J. M. Ritchie 1993. Priorities for biosystematic research in support of biodiversity in developing countries: microorganisms and invertebrates. CAB International, Wallingford, Oxon, UK, 73 pp.

Janzen, D. H. 1973. Tropical agroecosystems. These habitats are misunderstood by the temperate zones, mismanaged by the tropics. Science 182:1212-1219.

Janzen, D. H. 1982. Guia para la identificación de mariposas nocturnas de la familia Saturniidae del Parque Nacional Santa Rosa, Guanacaste, Costa Rica. Brenesia 19/20:255-299.

Janzen, D. H. 1984a. The most coevolutionary animal of them all. Crafoord Lectures, Royal Swedish Academy of Sciences, Stockholm, Sweden, p. 2-20.

Janzen, D. H. 1984b. Weather-related color polymorphism of Rothschildia lebeu (Saturniidae). Bulletin of the Entomological Society of America 30 (2):16-20.

Janzen, D. H. 1987. Conservation and Agricultural Economics. Science 236:1159.

Janzen, D. H. 1991. How to save tropical biodiversity. American Entomologist 37:159-171.

Janzen, D. H. 1992. A south-north perspective on science in the management, use, and economic development of biodiversity. In: Conservation of biodiversity for sustainable development, O. T. Sandlund, K. Hindar and A. H. D. Brown, eds., hScandanavian University Press, Oslo. pp. 27-52.

Janzen, D. H. and W. Hallwachs 1993. Highlights of the NSF-sponsored "All Taxa Biodiversity Inventory Workshop", 16-18 April 1993, Philadelphia. Internet, Biological Systematics Discussion list <taxacom@harvarda.bitnet>. 9 pp.

Jarvie, J. 1993. Strategy for Indonesian flora conservation unveiled at International Conference. Diversity 8(4):21.

Lemaire, C. 1978. Les attacidae Americains. C. Lemaire, Neuilly-sur-Seine, France, 238 pp.

May, R. M. 1988. How many species are there on earth? Science 241:1441-1449.

May, R. M. 1992. Bottoms up for the oceans. Nature 357:278-279.

Mills, L. S., M. E. Soulé and D. F. Doak 1993. The keystone-species concept in ecology and conservation. BioScience 43:219-224.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

Pimentel, D., U. Stachow, D. A. Takacs, H. W. Brubaker, A. R. Dumas, J. J. Meaney, J. A. S. O'Neil, D. E. Onsi and D. B. Corzilius 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42:354-362.

Pimm, S. L. and J. L. Gittleman 1992. Biological diversity: where is it? Science 255:940.

Pressey, R. L., C. J. Humphries, C. R. Margules, R. I. Vane-Wright and P. H. Williams 1993. Beyond opportunism: key principles for systematic reserve selection. TREE 8:124-128.

Raven, P. H. and E. O. Wilson 1992. A fifty-year plan for biodiversity surveys. Science 258:1099-1100.

Reid, W. V., S. A. Laird, C. A. Meyer, R. Gámez, A. Sittenfeld, D. H. Janzen, M. A. Gollin and C. Juma 1993. Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, D.C., 341 pp.

Yoon, C. K. 1993. Counting creatures great and small. Science 260:620-622.

UNEP 1992. Convention on biological diversity, June 1992. Environmental Law and Institutions Programme Activity Centre, No. 92-8314, Nairobi, 52 pp.

Wille, C. 1993. Riches from the rainforest. Nature Conservancy 43(1):10-17.

Endnotes:

1/ "Taxonomy" as used here refers to scientific taxonomy, a formal scientific nomenclature, rather than the multitude of folk taxonomies and "common names" invariably invented by society (including working scientists) for the manipulation of object-based information in their environment. "Taxonomy" is used here, rather than the word "systematics", which is generally preferred by taxonomists, because "taxonomist" and "taxonomy" are more widely understood in society at large.

2/ The adjective "tropical" as applied to biodiversity need not be repeated indefinitely, even though the focus here is on the tropics and the examples behind the generalizations are tropical. Nearly everything said here applies qualitatively to extra-tropical zones as well. However, for social, economic, biological or historical reasons such statements would often be substantially quantitatively different from the same statements about the tropics.

3/ This essay is focused on the taxonomic bottlenecks associated with the terrestrial and freshwater tropics. The marine world will probably require some additional administrative structure and somewhat different technical approaches, owing to the international nature of much of the marine habitat and the difficulty of getting to it and working in it (e.g., Grassle 1991, May 1992).

4/ Virtually all species found in agroecosystems occur also in wildlands, and the taxonomic organization and inventory of wildland biodiversity will cover virtually all of the non-domesticates in the agroecosystem. However, it is obvious that the wild species - both beneficial and pests - that also occur in agroecosystems merit priority attention in the overall taxonomic process, just as do those used in biodiversity prospecting, ecotourism, domestication programs, etc.

5/ "Inventory managers" are national members of the biodiversity inventory and taxonommic process who are charged with organizing, coordinating, and carrying out a large portion of the more urban portions of the taxonomic and inventory process that is traditionally conducted by Ph.D.-level specialized taxonomists. Inventory managers generally have B.S. or B.A. degrees in biology from national universities, and in the INBio-like process, carry out virtually all of the functions of a curator, collections manager, taxonomist, graduate student in taxonomy and other museum personnel. However, they carry out these functions in the context of conducting the national biodiversity inventory rather than getting a Ph.D., becoming a world-level taxonomic specialist on a given taxon, maintaining a museum, etc. Some of them will in fact move onward to higher degrees in taxonomy and work in the international taxasphere rather than nationally. The inventory manager is an essential link between the very numerous parataxonomists and the field collecting effort, and the many fewer international taxonomists in the taxasphere. Normally, each inventory manager is responsible for a defined taxa or set of taxa, and strongly collaborative with the international taxonomists responsible for those taxa.

6/ Strictly speaking all correctly labeled specimens in a collection are vouchers for the observation that a specimen of that species once existed at a point in time and space. However, more traditionally the word "voucher" ("testigo" in Spanish) has been used for a specimen that has additional data accumulated about it. In a national inventory, it will be necessary to agree on a set of terms - inventory voucher, rearching voucher, prospecting voucher, etc.

Figure 1. Schematic representation of the nine major elements in R & D for sustainable development and management of biodiversity, with emphasis on the taxonomic element coursing through all.