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Entomology Serving Society: Emerging Technologies and Challenges

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The Significance of Diversity: New Challenges for the Entomologist

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TO TRULY APPRECIATE the species richness of this planet, one must sit at a microscope and sort through all the arthropods that can be collected from the crown of just one architecturally complex tropical tree. The average vine-ladened tree canopy in Amazonian Peru yields 5 pints of mixed arthropods, about 0.5 kg live wt. One such canopy (now under study), a rather small one only 25 m in height with a 100 sq m footprint and 1,100 cu m of foliage, is estimated to have more than 1,500 species of arthropods at any moment in time during the dry season (Erwin, in prep). The September, 1988, sample from this tree (now only about two/thirds sorted, but with more than 100,000 individuals) has more than 60 species of ants (Tobin, per comm) which represent 70% of the total arthropod individuals (Erwin, 1989); 514+ species of beetles representing 9% of the total individuals; 51+ species of true bugs representing 0.9% of the total individuals (Henry and Froeshner, per comm); 73+ species of lepidopteran caterpillars representing 0.7% of the total individuals (Solis, per comm); 36+ species of book lice (Psocoptera) representing 4% of the total individuals, 14+ species of mites representing 1.6% of the total individuals, and so on through 24 Orders and Classes of arthropods; 1,500+ species in a single small canopy! Additional collections made in 1989 show that each complex tree crown has a substantially different set of species. There are more than 550 tree crowns per hectare in Amazonian Peru, thus the total number of species in any one area must be staggering.

So what? Except from taxonomists and a few organismal biologists, this is the question I always get. Everyone wants to know the significance of this incredible diversity of life, no matter if it is five or thirty million species (Erwin, 1988; Raven, 1988).

Here, I attempt to answer this question, then going further, I touch on some ways emerging technologies might allow systematists to more rapidly provide all other biologists, both basic and applied, the comprehensive classificatory framework of what now appears to be an overwhelming richness of species; the framework in which data are organized and hypotheses erected and tested. If we succeed, we cannot but help widen the foundation on which entomologists might serve society in manifold ways.

Biological diversity, or in current short hand -- Biodiversity--in an historical context is used most frequently to denote richness of species (cf. throughout papers in Wilson, ed., 1988) and usually, richness at a particular place, for few have considered global diversity until recently (summary in R. May, 1988). This definition or usage, however, does not do justice to the reality of biological diversity, which certainly must be considered the total product of organic evolution, the diversity of life in all its manifestations (Erwin, in press), in other words, biodiversity is the sum of earth's species including all their interactions and phenetic and genetic variations within their biotic and abiotic environment in both time and space--what Lovelock (1972) has called the "biosphere" of Gaia.

Significance, from the title of this paper, is a word that can be taken in two ways. In part, if humans were non-interactive, "durable observers," we might explore the significance of non-humanoid biodiversity on itself; significance from a scientific point of view, i.e., biotic events happening due to something other than mere chance, if there is such a thing as randomness in the biosphere (J. Hubbard, in Gleick, 1987). Or, we might take the meaning to imply a measure of something based on human values. Since the theme of this conference is emerging technologies and challenges, it is necessary to focus on this second definition and describe the significance of diversity, biodiversity, in terms that are relative to ourselves, that is anthropocentrically.

Given that, perhaps then we should briefly review the history of the impact of biodiversity on human evolution and human thinking to better recognize our place. Secondly, and more significantly, we might ask "what is the place of the entomologist in this "significance" scheme of things, since 99.1% of biodiversity on this planet is studied and dealt with by us (Robinson, 1986)?"

The Rise to Dominance

In nature, before mankind, a state existed which is best described by the clown in *Twelfth Night; Or, As You Like It* (Act IV, ii), "that that is is." When *Homo sapiens* arose as one of the products of 4.9 billion years of evolution of the biosphere it was not only a product, it was also a part of nature. Although unique, that is, the only species that responds to Shakespeare's clown with "why?," we are, and always shall be, one with nature despite western cultural and religious denial of this inescapable fact (Nations, 1988). Whatever happens to the biosphere will affect both our physical and cultural evolution. We carry with us genes that help us adapt to natural events and trends; we also have, according to some, a "rational" mind that ofttimes allows us to override nature, at least in the short run. Never before has one species had such a global impact in such a short period of time on its fellow species. It is becoming increasingly clear that technology on the one hand gives us comfort, while on the other it affects some part of nature in a negative way. Seldom is it a benign impact!

Primitive *Homo* spp. used the diversity of life as food and shelter and was frightened by most of it. Rituals and religions proliferated in part to help cope with the unknown. Agrarian movements by *Homo sapiens* resulted in the use of about 7,000 wild species which were selected as resources (Myers, 1984), but time and effort were devoted to increasing productivity from only a few dozen of these resources as mankind began to multiply and dominate the land. The very architecture of ancient Greece, the perfect geometry of the Parthenon, symbolizes the human mind of the time; man over nature, order against irregularities. Biodiversity became the enemy, devouring the crops, harassing livestock and man, vectoring diseases, and even consuming the people of the time (lions and tigers!). In fact, biodiversity was not only the enemy, but the competition and the resource as well.

Trees got in the way of pasture land - so we cut them down. Wolves, cats, and eagles ate the livestock - so we shot them. Snakes might bite the children - so we hunt them down and club them to death (even in the comics!). Co-habitation, or true symbiosis, was impossible for early pastoral hominids because while there was apparently rational thought, there was little basis for an appreciation of their inclusive ecological context, the place of mankind in balance with nature. As B.D. Farrell put it (per comm), it's pretty difficult to write a conservation plan for the wolves at your door; and who wants to conserve boll weevils and corn earworms? Lately, however, the bigger picture of the interconnectedness of the biosphere is becoming recognized as critical to our own survival as a species, both as a life support system and an aesthetic backdrop for a healthy human mental balance.

Values and Responsibilities of the Dominant

The result of the agrarian movement was that biodiversity took on value, that is, economic significance. This can be described within an ethical framework as utilitarian, anthropocentric, and instrumentalist, in that humans assign values to species (anthropocentric) to the extent that humans want the species (utilitarian) and that all species are instruments for human satisfaction (instrumentalist) (Randall, 1988). Unfortunately for the environment now, and humans in the long run, this economic drive of our cultural evolution is underwritten by a paucity of knowledge about the real extent of biodiversity on the planet and just how it functions within and between what we recognize as ecological systems. Therefore, mismanagement and over-exploitation, for pleasure and profit, are too frequently the norm; for example as Janzen (1988) points out, of the 550,000 square kilometers of tropical dry forest present when the Spanish arrived in the Western Hemisphere "less than 2% is sufficiently intact to attract the attention of a traditional conservationist." Much of this dry forest was turned to pasture to supply cow meat to hamburger joints for profit (Myers, 1981; Uhl and Parker, 1986).

Economic not only connotes something commercial, it is also indirectly part of such things as health and happiness. For example, the medical impact of portions of biodiversity, i.e. vectors; or the lowered yield of crops due to a grand diversity of insect

pests, ergot and rust, and even passerines, crows, mice and other vertebrates. It is also important to remember that economic value may be regarded, in Wall Street jargon, as "futures," for example, conserving tropical biomes preserves evolutionary systems that might hold more profound answers to human health problems beyond the simple idea of finding new pharmaceutical derivatives in tropical plants. To cite one important example, Tom Scott at the University of Maryland is studying the evolution of malarial vectoring with tropical *Anopheles* mosquitoes. An understanding of how vectoring arose evolutionarily might provide answers as to how transmission of pathogens can be prevented. A study of the evolution of *Diabrotica* leaf beetle feeding mechanisms on tropical plants in the Capparales and Solanaceae and the transmission of plant viruses might lead to insights on how to control their severe impact on descendent and related temperate crops so important today in food production. Biodiversity, 90% or more in the tropics, is the repository of information about "natural systems" needed by humans to solve economic problems, and each species in the ecosystem is a repository of an immense amount of genetic information necessary for future biotechnology (Wilson, 1988). We need only glean that information. But we must begin with field work and collections, then systematics, including phylogenetics, apply laboratory techniques, and finally transfer technology to appropriate applied sciences. For basic science, more general questions can be addressed, such as "why is there relative distinctiveness in different canopy assemblages?" Their relative diversities and faunal sources may allow insight into the evolution of diversity in a manner not accessible to paleontologists (Farrell, per comm).

As Randall (1988:221) writes, "confusion, ignorance, and apathy among the laity typically reflect incomplete and dissonant signals from the specialists." If this is so, then it is certainly the responsibility of scientists to provide more and better documentation and analyses of biodiversity that can then be translated into economic policies and statements for our political leaders to sway the laity; and nobody needs to do that more than entomologists since we are involved through our research with so much of biodiversity (Erwin, 1982; Robinson, 1986), including much of which is of economic and medical importance. We have, without doubt, the greatest challenge of the biodiversity movement before us. How might we face this challenge? Adapting to and rapidly applying emerging technologies in our respective specialties is one part of the answer and as that is the theme of this symposium volume, I will confine the rest of my comments to such issues, especially the newly exciting field of systematic entomology.

Challenges for the Entomologist

Insects and their relatives constitute most of the biodiversity on this planet, for example the one tropical tree canopy in Peru mentioned earlier. Sampling trees and various ecosystems is not difficult in terms of the insect portion of biodiversity (Erwin, 1983, in prep), but there are at least two main challenges that have only recently been addressed. The first is that general collectors persist in collecting in a way that removes the specimens from their natural context, thus vital information is lost, or at least irretrievable without great expense. This problem has been addressed, although also not without substantial expense, by the co-occurrence bioinventory program in Latin America (BIOLAT) recently instituted by the Smithsonian Institution (Erwin, in press; Erwin and Kabel, in press). For example, collections from the crowns of known tree species, mapped for easy reference, contain assemblages, in real time, of near-relations of economic and medically important arthropods, plus their natural predators, parasites, and the pathogens they carry at the time of collection. In the tree mentioned earlier there are flea beetles, *Diabrotica*, mosquitoes, ticks, mites, noctuid, pyralid, and sphingid larvae and adults, plus a host of forest pests. The co-occurrence information is preserved because of new collecting, documenting, and processing technologies.

The second challenge faced by entomologists is the tremendous bottleneck between collecting and studying the specimens. That bottleneck is the preparation and sorting of the material into appropriate units and the distribution of them to the most competent scientists available in the systematics community. Such material not only has all those fun and exciting species taxonomist like to describe as new, but it also contains all those species of potential medical and economic importance and their relatives, in addition to a host of potential biological control agents. An emerging technology, that has the means to achieve a practical product, is the ANTSE concept now under development

and testing at the National Museum of Natural History. This Network and Tracking System for Entomology is designed to overcome the challenge of getting well-prepared material into the laboratories of researchers who will study the material, systematize, and classify it (Griffiths, 1974; Platnick, 1989). This naturally can lead to an extraction of valuable insights about how evolution continues and ecosystems function. Systematists, ecologists, and applied biologists all should participate in gleaning such insights (Erwin and Pearson, in press). Such knowledge is fundamental to all conservation efforts because knowledge of resident species, who they are and what they are doing, should form the basic rationale for ecosystem preservation (although this is not always so: cf. Brady, 1988). The same knowledge is also used in the systematics and biodiversity communities for basic scientific research. The name of the system, ANTSE, is more than an acronym, it is symbolic of how museums and taxonomists are becoming a superorganism, that is an ant's nest of interconnected activity, to achieve a reasonable understanding of what is alive (or fossilized) on the planet (cf. ICN Newsletter, various articles).

Little noticed by taxonomists, especially entomologists, is a growing resignation by the lay public and political decision makers, as well as funding agencies of all types, that it will be impossible as well as impractical to name even a fifth of extant species (Mound, 1983; Gagné, 1983). Resistance is building against our taxonomic methodology and its sluggish pace while the forests and streams, savannas and ponds, deserts and beaches, all become lost along with their resident species we want to describe, name, and study. People in general are aware of the problems facing the environment, yet we taxonomists are unaware of, or at least refuse to face, the overwhelming job in front of us, all the while insisting on using an outmoded methodology that was designed before even electricity was harnessed, let alone the invention of microchips. This problem is so obvious in some of the commentaries and current arguments over a National Biological Survey (cf. ICN Newsletter) where myopia is a bipolar character state!

Elsewhere (Erwin, in prep) I address the problem of the burdensome and outmoded taxonomic technology we must work under by offering an interim taxonomy system that will allow us to grapple with the rapidly disappearing biodiversity of the planet and meet the demands of those needing vouchered species and associated data in a more reasonable timeframe. The main element of the interim system involves assigning alphanumerics to the species and tracking them and their data through use of computers and voucher collections. The series of specimens representing each species is similar to syntypic series of the past. However, each specimen is labeled with a unique number, and it and its associated data are tracked by this number in the collection and data base. It is with this system that we handle all the canopy species (Erwin and Scott, 1981; Erwin 1983; Farrell and Erwin, 1988, in press). By no means does this system eliminate the need for specialized taxonomists who really know groups and can recognize species components. Rather, it speeds their task by temporarily removing the time consuming formalized rules of nomenclature necessary for uncovering the oldest name, trudging through valueless literature, studying types in remote and sometimes uncooperative museums or private collections, and so forth. By adopting this interim system, the taxonomic community could rapidly contribute to the pressing problems of registering biodiversity. Meanwhile, we can give ourselves time to choose what is good in the taxonomic system of the past and present, carry it forward into the advanced technology of the 21st century, and then discard those parts of the old methods which impede progress unnecessarily. F. C. Thompson is leading the charge on this and expects much to change in the decade of the nineties (Thompson and Knutson, 1987; Knutson, Thompson, and Carlson, 1987). It is certain that our rapidly changing planet will force society to obtain answers more rapidly about biodiversity, extinction rates, and economic value of species. Although I expect neither his nor my proposal to be immediately adopted, I do think they offer agendas that will allow taxonomists to meet the demands for the upcoming decade and the 21st century.

Given the facility to use the species, track electronically the data concerning them, and still maintain their vouchering state even though undescribed in a formal way, we can contribute to our immediate need to know what constitutes biodiversity on this planet, where it is located, and finally what good it is in terms of either ecologic service or immediate utility.

Eventually, some taxonomist will get around to the groups that have been set up in the interim system and apply either the presently used system with all the encumbering rules of nomenclature, or perhaps someday Thompson's proposed system. Regardless, one phase of this must be the descriptive process, that

is getting words on paper or into a medium that transmits the information to someone else. Then characters must be analyzed, cladograms drawn, figures made, and the whole thing put into some sort of manuscript. Erwin and Pogue (in prep) are testing a system using a combination of various software packages that allows the taxonomist to sit at the microscope, enter simple codes representing character states of specimens into the computer, and then receive back full descriptions and diagnoses, keys, cladograms, analyses of the cladograms, and bibliography -- everything except the drawings. In the past, species descriptions were usually inadequate and often lacked essential illustrations. This leaves today's taxonomists the task of not only redescribing and illustrating named species, but also dealing with the incredible amount of new species that are collected in the tropical regions of our planet. With the use of the computer and modern methods concerning phylogenetics and systematics we will make significant headway through the plethora of extant species.

By utilizing the computer and the systematic and phylogenetic programs available to the systematist, the job of describing and analyzing the phylogeny of a particular group is going to become more automated. The computer program DELTA (DEscriptive Language for TAxonomy), written by Dallwitz, is used to gather, edit, store, present, and update descriptive taxonomic data. These data can then be transcribed and run in PHYSYS, written by Mickevich and Farris, to detect apomorphies and produce phylogenetic trees for all taxa in the study. The apomorphies of each taxon detected by PHYSYS are used as a diagnostic combination, written by DELTA, and presented in the descriptive portion of the paper. By using only the apomorphies of a taxon, it is easier and less cumbersome to compare closely related species. The entire character matrix for each taxon is then presented in a table that is produced by computer graphics, thus making phylogenetic and other comparison between taxa much easier. These methods not only produce consistent descriptions within and between published manuscripts, but also minimize the length of the descriptions. At the same time, they make retrieval of phylogenetic information simpler. This system, developed in last year, speeds the taxonomic process several-fold and is allowing us to confidently work on a genus that has in excess of 2,000 species, with the knowledge we will soon finish. Other technical advances that have emerged over the last 20 years are supporting the efficiency of data gathering and processing, for example electronic measuring devises, Cal-Comp Plotter for automated distribution mapping, SEM microscopy, computer graphics, word processing software, xerography, and off-set printing.

Nature forms patterns and through time complexity flourishes in ever-increasing profusion, space becomes more finely dissected and smaller creatures evolve to occupy it; nowhere is that more evident than in the world of insects; nowhere in the living world is there a greater challenge to understanding the chaos of the underlying patterns. Advancements in technical theory, for example cladistics (Farris, 1983; Nelson and Platnick, 1981; Mickevich, 1978, 1982) and biogeographic maps (Erwin and Pogue, 1988; Mickevich, Pogue, and Erwin, in prep), have improved the predictive powers of classifications tremendously in the last few years. Our understanding of the evolution of characters has improved with this advancement in analytical techniques, thus our confidence in resultant classifications, with their increased predictive powers markedly enhanced, is more profound, and we are in a far better position to address what, to many less familiar with insects, now might be regarded as total chaos. With the rather recent broad recognition among leading-edge ecologists that a group's history is an important factor in explaining contemporary processes, there are the beginnings of truly synthetic evolutionary studies being published with ecologists and systematists working in partnership (Futuyma, 1988; Farrell and Mitter, in press), rather than taxonomists as merely the "identification service."

Time for Change

In summary, biodiversity is significant for the quality of human existence, firstly of short-term benefits for us as individuals, and secondly for the long-term well-being of our species as a whole (Nations, 1988) in providing ecological services (Ehrlich, 1988; Reid and Miller, 1989), to say nothing of continuing the evolutionary process itself (Erwin, 1985, in press; Myers, 1988) so that there is a biospheric future. In order to preserve the biosphere and at the same time use it, we need to know more about it. In order to know more about biodiversity, we need to form networks and partnerships for specimen collection and preparation, distribution to appropriate and highly productive

scientists, and storage and retrieval of both specimens and associated data. We need to apply advanced computer based data-gathering and analysis programs to make sense out of nature's patterns. And, very importantly, we must realize that biodiversity is phenomenally complex and diverse to the extent that such initiatives as the proposed National Biological Survey and the various tropical inventory inititives have to be parts of a common strategy; both represent geographic end points of what should be a common and strongly held broad stratagem. To understand evolution, a continuum of data points in diverse axes is necessary, thus petty arguments over the merits of one over the other detract from what we really need to accomplish. Whether we study in one area or the other, or in all areas at the same time, we need to take our taxonomic and systematic information and pattern analyses into socially useful arenas, or at least make the packets of information we produce comprehensible for the user community, which always has been the house of applied biology. This house recently became co-inhabited by the conservation movement. Both depend on a sound systematics base of information about species. Systematics now has the tool box of a master craftsman with enough biodiversity still in existence to build the Taj Mahal of an evolutionary-based classificatory framework! Do we have the openness of mind to see the benefits? Do we have the skills?

Of course we do! But, as F. C. Thompson has repeatedly pointed out in ESA conferences and elsewhere, we are going to have to change as the Age of Information increases its pressure on us for better and more efficient information gathering, retrieval, and exchange. It will behoove us to make those changes ourselves, to grab hold of emerging technologies and put them to use immediately, for the betterment of our profession and science; possibly even for the betterment of the natural world we have spent our life time studying.

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