BIODIVERSITY OF TERRESTRIAL INVERTEBRATES IN TROPICAL AFRICA: ASSESSING THE NEEDS AND PLAN OF ACTION

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THE CHALLENGE

BIOLOGICAL RESOURCES are the basis of the prosperity of the developed world, yet the biologically rich underdeveloped nations of Africa are the economically poorest in the world. Africa's biodiversity, if conserved and developed sustainably, can be used to relieve poverty and achieve economic stability. The challenge lies in rapidly acquiring the required knowledge of the biodiversity resource: knowing what the critical species are and where they occur, obtaining information about their natural history, and establishing sustainable patterns of resource use.

Although the continent of Africa is most renowned for its highly charismatic megafauna, the greatest contributions to its biodiversity (as elsewhere) in fact lie in its other taxa, which ultimately facilitate the existence of these flagship species. Insects and other arthropods compose more than 70% of the world's fauna. Insects contribute the largest number of taxa by far to biological diversity in both Africa and the world (figure 1). Many major effects on human welfare—human and animal diseases carried by insect vectors; outbreaks of migrant pests, such as locusts and armyworms; destruction of food by plant pests; toxic residues from pesticides; and overuse and depletion of agricultural lands and adjoining forests—are problems whose answers lie well within the field of biodiversity and, more specifically, insect diversity (Hill 1997). By performing critical "service" functions within ecosystems, insects are key to the stability of ecosystems. Many insects provide a direct economic return (for example, silkworms and bees); others produce chemicals for medicinal use. Some constitute an important source of pro-

FIGURE 1 Afriscape: An imaginary landscape of the Afrotropical realm (terrestrial and freshwater) in which the size of taxa is proportional to the number of species currently known in the group it represents. Data sources include vascular plants (42,500, Groombridge 1992:66); land snails (6,000, Bruggen 1986); insects (150,000); fishes (1,800, Groombridge 1992:116); amphibians (627, Duellman 1993); reptiles (1,400, Bauer 1993); birds (1,500 Vuilleumier and Andors 1993); mammals (1,045, Cole and others 1994). Inspirational thanks to Quentin Wheeler's 1990 world speciescape. Graphic by Barbara Gemmill.

tein in the diet of rural peoples; others play predatory and parasitic roles that regulate pests (Odindo 1995). Arthropods are key in providing pollination services to both natural and human-made ecosystems.

No African invertebrate species have been documented yet as becoming extinct either directly or indirectly because of human activities during historical times, although several butterflies and lacewings might have become extinct in South Africa (Siegfried and Brooke 1995). However, invertebrates are generally so poorly known that even probable extinction is difficult to detect. With insects more than with any other taxa, we risk losing aspects of biodiversity without ever knowing their value.

THE APPROACH

This paper outlines an approach to putting terrestrial invertebrates on the agenda for conservation of biodiversity in Africa. We seek to fill two key gaps in the understanding and use of the positive aspects of insects in African biodiversity. First, almost all research on insects in tropical Africa focuses on the negative aspects of insects—for example, the problems in agriculture, forestry, livestock, and human health that are caused by less than 1% of the species of insects—and ignores the remaining 99% of insect species. Of the more than 100,000 described species of insects in the Afrotropical region, fewer than 500 species were mentioned between 1990 and 1995 in the journal *Insect Science and its Application*, one of the major African entomology journals, and 97% of the articles over this time focused on pest or other economically important species.

Most programs of biodiversity studies and conservation currently operating in tropical Africa focus on vertebrates or, secondarily, flowering plants and ignore insects, which E.O. Wilson (1987) has called "the little things that run the world" because of their key roles in ecosystem function. For example, in 1994, a survey of sets of biodiversity data available for East Africa included only 12 for insects, whereas mammals and plants had more than 50 each and birds and fish had more than 40 each (World Conservation Monitoring Centre 1994).

SOME PREMISES

Through extensive consultation, we have reviewed many programs around the world that have dealt, successfully or unsuccessfully, with similar challenges (for example, Hawksworth and Ritchie 1993; Miller 1994). By this process, we have identified some basic premises that have guided the development of our program.

First, if we are to protect biodiversity, it must have utility for human societies, and if it is to be used sustainably, it must be understood. This premise is the basis for several conservation initiatives in Costa Rica and Africa (see Janzen paper in this volume; see also Ramberg 1993 and Noss 1997). The developed-country model of protecting biodiversity in national parks is not sustainable in developing countries. Long-term protection of biodiversity depends on making it useful and valuable to the people who live amid and around it. This means that some of the biodiversity must be used to provide the means for supporting and managing the rest. Sustainable use of biodiversity requires knowing how to find what you need, understanding the implications of that use, and learning how to encourage the regeneration or recovery of the resource to support its continued use.

A second premise is that systematics provides the framework for organizing and communicating basic information about biodiversity (Janzen 1993). Thus, the involvement of the taxasphere, the international infrastructure for biological systematics, including the natural-history museums that hold most of the collections of specimens, is vital. We also expect to integrate our activities with those at smaller (for example, national or local) and larger (for example, international) levels, including BioNet International, Systematics Agenda 2000 International, and Species 2000 (Hawksworth 1997).

Finally, it is more cost-effective to use what we already know than it is to recreate basic information on biodiversity (Nielsen and West 1994; Soberon and others, 1996). An enormous body of information is theoretically available, but it is highly dispersed, extraordinarily varied in form, uncoordinated, and largely unavailable in most of Africa. Much of this information is in museum collections (Cotterill 1997). Recent developments in information technology have provided the means to achieve a coordinated information base on African insect fauna and an efficient means of disseminating that information. The task requires effective collaboration of experts and stakeholders from all aspects of the process, from the discovery through the management and use of biodiversity (World Conservation Monitoring Centre 1996).

AN ORGANIZATIONAL STRUCTURE FOR A CONTINENTWIDE BIODIVERSITY INITIATIVE

One irony of current biodiversity-conservation initiatives is that while we continually are refining our skills to document the value of the ecosystem services that biodiversity provides, few governments or legal entities are prepared to pay for the conservation of these services, which, until now, have been exploited freely by human societies. An example that is specific to our program is that no country in Africa has the resources to initiate a program of conserving insect biodiversity; the task is formidable, and the benefits are so basic and diffuse that they become lost in a sea of competing priorities. Only a highly-targeted, cost-effective program that can coordinate the resources and disseminate the benefits on a wide scale (regional or continental) can return the expected outcomes.

The leadership for such a program has been assumed by the International Centre for Insect Physiology and Ecology (ICIPE), an international institute that is situated centrally on the continent in Kenya. ICIPE is a major international institution that has more than 27 years of experience in research and monitoring of arthropods. It has developed integrated pest and vector-management techniques and biological-control strategies for insects that are disease vectors and plant pests. The institution combines research with interactive training of scientists, technicians, and farmers and herders at both national and subregional levels, and it provides training programs for graduate students from universities throughout Africa. ICIPE has memorandums of understanding with more than 20 sub-Saharan countries, and more than 30 countries worldwide have signed its charter. With an established structure in place for joint training and research with the major taxonomic and biodiversity institutions of Europe and the United States, implementation of a collaborative program would be possible without untimely delays.

THE PLAN

We have identified a mixture of projects that provide a cost-effective foundation for understanding the diversity of insects, the roles they play in natural systems, and ways to manage those interactions more effectively. Our initiative includes three main components. First, an information-management program will organize and make available a large volume of information that already exists but is not readily accessible to users. This will be coordinated with other activities that are already under way in the museum, systematics, and conservation communities and will be targeted carefully to fill key gaps. Second, a series of field projects will evaluate the use of insects as indicator organisms and will quantify their roles in ecosystem processes. In many cases, these projects will take approaches that have been successful in South Africa and the Northern Hemisphere and will apply them, with appropriate modifications, to tropical Africa. Third, training and participatory technology transfer will build on ICIPE's existing training programs, including the African Regional Postgraduate Programme in Insect Science (ARPPIS).

Information Management

An initiative for reviewing the literature and creating a database of specimens will repatriate 200 years' worth of information collected in sub-Saharan Africa and now housed in museums in the United Kingdom, France, Belgium, Germany, elsewhere in Europe, South Africa, Kenya, elsewhere in Africa, and the United States and Canada. This initiative will support individual projects and applications within the ICIPE program and will provide relevant information to a wide audience in Africa. One of the first and most important steps in managing the biodiversity of African insects is to find and organize what we already know. As we have stated, a tremendous amount of information is available but not in a cohesive and accessible form; recent developments in information technology will allow us to compile an information base on African insects; they will also allow efficient dissemination of this information (Vane-Wright 1998). Note the continuing growth of the technology from, for example, the discussion of early Internet tools in Miller (1993) to those in Helly and others (1996). As a result, gaps in our knowledge will become apparent, allowing us to establish priorities for further work. Our checklist of insects known from Africa is in progress, and an interim product is on the World Wide Web (www.icipe.org/environment/biodiversity_index.html).

Pilot Projects and Applications of Conservation Biology That Focus on Insects

A series of experiments, surveys, and applications will be designed to investigate the role of key groups of insects in the function and management of ecosystems and to provide information on the conservation and sustainable management of the insect resource. The major foci will include identification of high-priority areas for conserving biodiversity, using butterflies, fruit flies, dragonflies, and termites; impact assessments, using insects as "indicators"; and identification of the roles of insects in pollination, soil processes, and the organization of tropical-forest ecosystems.

Training and Participatory Technology Transfer

An important element in the overall program is capacity-building: producing trained technicians and scientists who will be able to implement the information-management and research tasks. In the multidisciplinary field that is inherent to conservation of biodiversity—from taxonomy to database management to field techniques—individual and institutional capacity spans every activity. This feat will be achieved through partnerships with universities, museums, advanced-research laboratories, and national institutions throughout the world. Developing an African and overseas reciprocal research exchange within Africa will ensure a permanent conduit for technology transfer. Many of the students trained through this program will become interns in museums and research centers throughout

Europe and North America, thus effecting the transfer of skills, as well as information.

Formal university training will be conducted through the ARPPIS PhD program at ICIPE, in which students undergo three years of research training. The ICIPE provides a thesis project, research facilities and supervision, and a training fellowship to support the students' maintenance, university fees, and research costs, for a total of US$30,000 per student per year. Students are registered at participating African universities, which examine the students and award them their degrees. The program has, at any one time, 20–40 students at various stages of their thesis work at ICIPE. To date, 131 scholars from 25 African countries have enrolled in the program, and 91 have graduated. The success of the ARPPIS program has stimulated the interest of universities; 18 universities have renewed their agreements with ICIPE. ICIPE is proud that after they have graduated, almost all former ARPPIS scholars have stayed in Africa to work toward solving the continent's insect-related problems. Most graduates are employed by national research systems, universities, or science-based international organizations.

Training means more than formal university training, however. Two other major activities are the enhancement of national capacities for the diffusion, adoption, and use of technology and the facilitation of the dissemination and exchange of information.

EXAMPLES OF RESEARCH ON INSECT BIODIVERSITY IN AFRICA IN SUPPORT OF SUSTAINABLE DEVELOPMENT

Recent research initiatives undertaken in Kenya have shown that basic research on the biodiversity of arthropods can contribute in substantial ways to sustainable agricultural development.

The Role of Habitat in the Agroecosystem of Maize

Losses of maize, sorghum, and other cereals caused by stemborers remains one of the biggest threats to the security of the food supply in eastern and southern Africa. Maize yields in Africa are less than half the average yield worldwide. Especially damaging is the moth *Chilo partellus* (Lepidoptera: Crambidae), an intruder from Asia that was introduced accidentally into Africa in the 1930s and has now displaced indigenous pests. This exotic species soon became infamous for causing losses of 20–80% of crops.

Native predators may play an important role in suppressing stemborer populations. Studies conducted in Kenya's Coast Province revealed that ants are the most abundant predator. The abundance and diversity of predators increased with the age of the plants and was highest at the tasseling stage of maize. An even broader—and very promising—view is being taken by looking not just at the farmer's field, but also at the surrounding environment (Khan and others 1997).

ICIPE's project on the role of wild habitat in the invasion of gramineous crops by stemborers already is yielding hard data on the benefits of preserving and managing biodiversity in small and medium-size farms. The project is developing a novel approach to pest management that uses a stimulus-deterrent ("push-pull") diversionary strategy. A better understanding of the relationship between diversity of habitat and resilience to pest challenge is being developed, as are ideas for modifying the habitat to contain this challenge.

Several plants that lower the density of stemborers by the "push-pull" strategy have been identified, resulting in higher crop yields. Especially promising in this respect are Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanens*), and molasses grass (*Melinis minutiflora*). These three important fodder grasses act as traps by "pulling" or attracting the borers and serving as reservoirs for the natural enemies of the stemborers. Furthermore, Sudan grass increases the efficiency of the natural enemies. The rate of parasitism on larvae of the spotted stemborer, *Chilo partellus*, more than tripled, from 4.8% to 18.9%, when Sudan grass was planted around maize in a field. Napier grass has its own defense mechanism against crop borers: When the larvae enter the stem, the plant produces a gum-like substance that kills the pest. Molasses grass releases volatiles that not only repel (or "push") stemborers, but also attract parasitoids. Both whole live plants of *M. minutiflora* and its volatiles were shown to attract the natural enemy of the wasp, *Cotesia sesamiae* (Hymenoptera: Braconidae). Intercropping with *M. minutiflora* increases parasitism, particularly by the larval parasitoid wasp and the pupal parasitoid *Dentichasmis busseolae* (Hymenoptera: Ichneumonidae). Analysis of the volatile oils from molasses grass shows that they contain several physiologically active compounds. Two of these inhibit egg-laying in *Chilo*, even at low concentrations. In contrast, *Chilo*'s host plants (maize, sorghum, and Napier grass) have been found to contain volatile compounds, such as eugenol, that attract *Chilo* and stimulate egg-laying. Molasses grass also emits a chemical that summons the borers' natural enemies. This same substance is released by whole plants as a distress signal when they are being damaged by pests. The results of this study have opened up the new and intriguing possibility of using intact plants that have an inherent ability to release these stimuli. Such plants will be useful in ecologically based crop-protection strategies.

Commercial and Sustainable Production of Wild Insects

Wild insects long have been part of the diet of humans in Africa; termites and locusts are two highly valued food items among the arthropods. Wild insects also are husbanded for the products they create. If harvesting and use of wild insects are to be sustained with increasing population, however, they will need to be studied carefully and rationally. ICIPE currently undertakes studies of African honeybee culture and wild silk production (ICIPE 1997).

Apiculture is a traditional occupation in most African communities, but centuries-old practices of harvesting honey are inefficient and often cause the death of the colony; the aggressiveness of African honeybees has been attributed to these management practices. ICIPE is introducing improved methods of beekeeping to farmers and to women's groups, supported by research to solve the problems of queen-rearing and African honeybee aggressiveness and to improve the production of honey and other valuable hive products. Linking honey production to floral calendars can help local producers understand the direct benefit of habitat conservation.

Similarly, production of wild silk moths can provide a strong economic incentive for rural communities to adopt sound wild-land management practices as an adjunct to subsistence agriculture. Currently, silk moth larvae and pupae are harvested in bulk as a source of dietary protein, but no mechanisms exist to replenish the silkworms (the moth larvae). Techniques of sericulture (the deliberate rearing of silk moths for harvesting of the pupal cases) are unknown at the village level, yet at least three species of moth that yield high-quality wild silk have been identified. ICIPE has undertaken a project to develop methods of sericulture that are appropriate for Africa and that also will assist in conserving the valuable wild species of moths. The interest shown by authorities from national parks and by communities in East Africa is proof of the timeliness of this project and augurs well for the future of a strong conservation industry built around wild silk moths.

CONCLUSION

We expect that the foundation of knowledge and trained personnel that will be generated by this new initiative will enable sophisticated strategies of ecological monitoring and applications of sustainable development that draw on the strengths of the resource base of African arthropods. In a continent that until now has been remarkable for the coexistence of a rich and varied wildlife with human societies, we are challenged to direct development along lines that also foster the coexistence with the ubiquitous but less-noticed aspects of biodiversity, such as arthropods. Because these aspects most directly impinge on human welfare, the success of biodiversity conservation may depend on how well we meet this challenge. In the largely intact, undeveloped landscapes of Africa, we still have a tremendous chance to conserve the fine fabric and delicate linkages of nature in and with human development if only we can document its existence and importance before we have lost it.

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