Challenges and opportunities in understanding and utilisation of African insect diversity

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Approximately 100 000 species of insects have been described from sub-Saharan Africa. Largely as a result of Africa's colonial history, the region's insect fauna is probably better known than that of other tropical regions, but information is often more difficult to locate. Few centres of expertise on insect diversity and systematics exist in tropical Africa, while most large insect collections are housed in South Africa, Europe and the United States. Recent surveys of in-country resources show that human resources are also thinly distributed in tropical Africa. Yet, there is urgent need for basic information on insect diversity for pest management related to plant, livestock and human health, as well as conservation and environmental management. Invasive (alien) species represent a newly recognised threat that cuts across traditional sectors. Recent work shows the potential of different approaches to these challenges, including compilation and synthesis of pre-existing data and research targeted at strategic needs. Information can also be applied in novel ways to promote 'environmentally friendly' income-generating schemes such as silk and honey production, ecotourism, butterfly farming and bioprospecting. The Global Taxonomy Initiative of the Convention on Biological Diversity provides an opportunity to expand these experiments to better meet the needs.

INTRODUCTION

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 utilised to relieve poverty and achieve economic stability. The challenge lies in rapidly acquiring the required knowledge of the biodiversity resource: defining the critical species, where they occur, understanding their natural history, and establishing sustainable resource use patterns.

While Africa is most renowned for its highly charismatic megafauna, the greatest concentration of African biological diversity lies in other animal taxa, which ultimately facilitate the existence of these 'flagship species'. Insects and other arthropods compose more than 70% of the world's fauna and contribute by far the largest number of taxa to biological diversity both in Africa (Figure 1) and the rest of the world. By performing critical 'service' functions within ecosystems, these species are central to ecosystem stability (Coleman & Hendrix 2000). Many insects provide a direct economic return (e.g., silkworms, honey bees), produce chemicals for medicinal use, constitute an important protein source in the diet of rural peoples (Van Huis 1996), play predatory and parasitic rôles that regulate pests, or help maintain soil fertility (Black & Okwakol 1997). Arthropods are key in providing pollination services to natural and man-made ecosystems. Solutions to many major impacts on human welfare lie within the resources of biological diversity and, more specifically, within the area of insect diversity (Herren 1998; Hill 1997). Among these issues are over-

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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 (42500 Groombridge 1992: 66); land snails (6000 van Bruggen 1986); insects (150 000); fishes (1800 Groombridge 1992: 116); amphibians (627 Duellman 1993); reptiles (1400 Bauer 1993); birds (1500 Vuilleumier & Andors 1993); mammals (1045 Cole *et al.* 1994). Inspirational thanks to Quentin Wheeler's 1990 world speciescape. Graphic by Barbara Gemmill.

use and depletion of agricultural lands and adjoining forests, human and animal diseases carried by insect vectors, migrant pest outbreaks such as locusts (Orthoptera: Acrididae) and armyworms *Spodoptera* spp. (Lepidoptera: Noctuidae), and toxic residues from pesticides.

The monetary values of the ecosystem 'services' provided by insects are exceedingly hard to estimate for a variety of reasons, but some examples follow (*vide* Daily 1997). Approximately one third of the world's crop production depends directly or indirectly on pollination by insects. The overall value of pollination in the world, mostly by insects, has been estimated at around US$117 billion per year. The overall value of natural biological control, again mostly by insects, is over US$400 billion per year. The value of nutrient cycling in terrestrial ecosystems is over US$3 trillion per year (Costanza *et al.* 1997). Much of the nutrient cycling is undertaken by insects and related arthropods, which may compose half the animal biomass in some tropical forests (Fittkau & Klinge 1973).

The cultural and spiritual values of biodiversity to the peoples of Africa must also be appreciated. As stated by Kipelelo Walker in Botswana, "*An economist and I are two incomparable people in terms of the perception of the long term …. If we depend on the natural resource, its sustainability is not related to the income you can get now*" (this and other statements by indigenous people in Posey 1999). Fairhead & Leach (1999) describe the complex interactions of people, termites and the environment in West Africa.

No invertebrate species have yet been documented as becoming extinct in Africa during historic times due to direct or indirect human activities, although several butterflies (Lepidoptera) and lacewings (Neuroptera) may have become extinct in South Africa (Siegfried & Brooke 1995), and several dragonflies (Odonata) are threatened in South Africa (Samways 1999). Invertebrates are, however, generally so poorly known that even probable extinction is difficult to determine. With insects in particular, we risk losing important aspects of biodiversity without fully knowing the identity and function and value of these organisms.

In this paper the term 'systematics' is here used in the broad sense, and implies taxonomy, encompassing inventory, phylogeny and information management (Cracraft 2000). 'Africa' is used for the African continent and adjoining islands (including Madagascar). 'Afrotropical' is used as a biogeographical region (formerly called Ethiopian) encompassing Africa south of the Sahara, including Madagascar (Crosskey & White 1977). 'Tropical Africa' refers to the Afro-tropical Region minus the temperate parts of southern Africa.

INTERNATIONAL POLICY CONTEXT

Biodiversity has become something of a politically charged 'buzz word'. The term has diverse definitions as many constituencies have claimed it as their own. In its original and broadest sense, biodiversity encompasses the full range of diversity of life on earth, encompassing three levels. This paper focuses primarily on the diversity of species of insects and related arthropods (the traditional scope of taxonomy or biosystematics), but it must be remembered that these species are assembled into communities, ecosystems and landscapes (the traditional realm of ecology), and that these species include genetic diversity (including the area of biodiversity on which agriculture focuses).

A new term, 'agrobiodiversity' or 'agricultural biodiversity', has recently been defined by Decision V/5 of the Fifth Conference of the Parties to the Convention on Biological Diversity, as including "… *all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem* " [as well as variability at genetic, species and ecosystem levels] (http://www.biodiv.org). This includes ecological services such as nutrient cycling, pest and disease regulation (natural biological control), pollination, wildlife habitats, hydrological cycle, carbon sequestration, and climate regulation as well as cultural aspects, including tourism. In Africa, as the majority of species interact in some way with agriculture, forestry or fisheries, it is hard to differentiate between biodiversity and agrobiodiversity - *vide* Aarnink *et al.* (1999), CAST (1999), Janzen (1998a, 1998b, 1999) and Thrupp (1998) for further discussion.

The recent international interest in biodiversity has spawned a confusing array of acronyms representing various international organisations (Hawksworth 1997 provides a useful guide). This provides a major opportunity to promote the scope of systematic biology while taxonomy is on the minds of international decision-makers.

Another exciting change on the international political scene was that the Fifth Conference of the Parties of the Convention on Biological Diversity also endorsed the Global Taxonomy Initiative (GTI) in its decision V/9. Although what the GTI will be remains to be defined exactly (*vide* American Museum of Natural History 1999; Australian Biological Resources Study 1998a, 19998b; Cresswell & Bridgewater 2000; Recommendation VI/6 of The Subsidiary Body on Scientific, Technical and Technological Advice available at http://www.biodiv.org), this represents a major step in the recognition of the importance of systematics issues to conservation and sustainable use of biological diversity. The important funding issue is that now systematics and taxonomy should become part of actual agendas of donor agencies and development agencies in a way that it has not previously done. Another development in parallel is the creation of the Global Biodiversity Information Facility (GBIF) (Redfern 1999, http://www.gbif.org).

WHAT DO WE KNOW ABOUT AFRICAN INSECTS?

Largely as a result of Africa's colonial history, there is probably more known about the African insect fauna than that of the New World and Asian tropics. Nevertheless, this same history makes information on the African insect fauna very difficult to obtain. The information is mostly stored in European museums and libraries, in a variety of languages and intellectual traditions that have not been concatenated (Cotterill 1997). A modern checklist of insects has been published for only one of more than 50 African countries (Nigeria). Many of the museums and libraries holding this information are eager to make such information available to the World (e.g., Kaiser 1999; Kress *et al.* 2001; Normile 1999), but lack the resources to do so. There are problems of synthesising the various language-based bodies of literature and in the logistics of handling literature and specimens. For these reasons, it is far more cost-effective to undertake data compilation for the Afrotropical Region as a whole, rather than on a country by country basis (*vide* Ruiz *et al.* 2000 for discussion of practical issues). But how can these resources be unlocked to make information readily available for use?

It is more cost-effective to make accessible what is already known than to recreate basic information on biodiversity (Soberon *et al.* 1996; Nielsen & West 1994). An enormous body of information is at least theoretically available, but is highly dispersed in an extraordinary variety of forms and is largely unavailable in most of Africa. Recent developments in information technology provide the means to achieve a co-ordinated information base on the African insect fauna and an efficient means of dissemination of such information. The task requires effective collaboration of expertise and stakeholders, beginning with the process of cataloguing and continuing through the use and management of biodiversity (Krishtalka & Humphrey 2000; World Conservation Monitoring Centre 1996).

A major issue from a scientific standpoint is that we basically do not know what is known about biodiversity. Global systematic studies have been undertaken for over two hundred years, but we do not actually know how many species have

Table 1. Some major entomological collections within the Afrotropical Region. *Vide* Arnett *et al.* 1993 and Eardley 1998 for details. This includes only the large collections with broad geographic and taxonomic coverage of afrotropical insects - many additional collections have smaller holdings, especially in South Africa.

Country	City	Institution
Angola	Dundo	Museu do Dundo
Kenya	Nairobi	National Museums of Kenya
Namibia	Windhoek	National Museum
Senegal	Dakar	Institut Fondamental d'Afrique Noire
South Africa	Cape Town	South African Museum
South Africa	Grahamstown	Albany Museum
South Africa	Pietermaritzburg	Natal Museum
South Africa	Pretoria	Plant protection Research Institute
South Africa	Pretoria	Transvaal Museum
Uganda	Kampala	Kawanda Research Station
Zimbabwe	Bulawayo	Natural History Museum

Table 2. Some major afrotropical entomology collections outside of Africa. *Vide* Arnett *et al.* 1993 for details. This includes only the large collections with broad geographic and taxonomic coverage of afrotropical insects - many additional European and American institutions have smaller holdings of afrotropical material.

Country	City	Institution
Belgium	Tervuren	Royal African Museum
England	London	Natural History Museum
France	Paris	Museum National d'Historie Naturelle
Germany	Berlin	Museum für Naturkunde der Humboldt Universität
Hungary	Budapest	National Museum
Italy	Florence	Centro di Studio per la Faunistica ed Ecologia Tropicali
United States	Chicago	Field Museum
United States	New York	American Museum of Natural History
United States	Pittsburgh	Carnegie Museum
United States	San Francisco	California Academy of Science
United States	Washington	Smithsonian Institution

been described, and there is no convenient way to extract such information. Without this working knowledge of the described fauna we are unable to identify gaps to be filled. Most practising taxonomists regard this as an overwhelming challenge, but the creation and maintenance of, for example, a telephone directory for Greater London, or an inventory control system for a large supermarket chain indicates that the technology to do so is not the major stumbling block. In order to achieve this, resources must be allocated above the level normally associated with systematic work.

In 1998, the International Centre for Insect Physiology & Ecology (ICIPE) together with collaborators initiated a project to compile a checklist of described afrotropical insects as a 'backbone' for information management activities. Despite funding difficulties, approximately 25% was completed by the end of 2000 and is available on the Internet [http://entomology.si.edu:591/entomology/Subsahara/index.html]. Dependent on funding, we seek to complete the data input and disseminate the product in online, CD-ROM and paper formats. The insect orders that have been completed at the time of writing are Odonata, Ephemeroptera, Plecoptera, Trichoptera, Hemiptera (*s.l.*), and the majority of Hymenoptera.

A major obstacle to Africa-based scientists working on any aspect of African insects is ascertaining what information has been previously published on a particular group. This is especially important when species' identification is required, as taxonomic works are often published in low circulation journals or books; many key papers pre-date abstracting services' electronic databases and therefore cannot easily be traced. To overcome this obstacle, ICIPE began compiling a database of the key published works on African insects. The eventual product shall be a multi-access, annotated list of publications, including information on biology, ecology, distribution, and economic importance together with identification and taxonomy. Wherever possible, texts on ethnobiology and indigenous names for insects are also incorporated. By providing Africa-based scientists with rapid access to information on major publications, fears of initiating studies through not being familiar with the literature shall be overcome; the starting point for studies will be enhanced; and, time wasted on rediscovering what is already known shall be reduced. The International Centre for Insect Physiology & Ecology and its collaborators have compiled and made available a bibliography of over 7000 citations (http://entomology.si.edu:591/entomology/AfricaBib/search.html, and soon within the Ecoport database), but further work is required to make it a truly useful 'pre-digested' guide to the most important literature. The final version shall be distributed in paper and CD-ROM formats, in addition to the Internet. Meyer *et al.* (1997) provide a product for southern African plants that is similar to what we envision for entomology.

A rich literature on African insects exists, but it is in various languages and much of it in journals that are now difficult to locate. In addition to the corporate serials of the institutions listed in Tables 1 & 2, some of the other major journals for African systematic entomology include the publications of the East Africa Natural History Society, Entomological Society of Southern Africa, Institut Fondamental d'Afrique Noire, Royal Entomological Society of London, and the periodicals *Bulletin of Entomological Research*, *Faune de Madagascar*, *Garcia de Orta* (*serie de zoologia*), *Journal of African Zoology, Revista de Entomologia de Moçambique*, and *South African Animal Life*.

There are also many useful compilations of knowledge on insects associated with agriculture and forestry, including the following key references:

- Burundi: Buyckx 1962
- Cameroun: Nonveiller 1984
- Congo: Buyckx 1962
- East Africa: Gardner 1957, Le Pelley 1959 (Kenya, Tanzania, Uganda)
- Eritrea: Nastasi & Wolden-Haimanot 1967
- Ethiopia: Hill 1966, Tsedeke Abate 1991, Walker & Boxall 1974
- Ghana: Forsyth 1966; Wagner *et al.* 1991
- Madagascar: Reckhaus 1997
- Mauritius: Mamet 1992; Mamet & Williams 1993
- Niger: CIDA 1983
- Nigeria: Medler 1980; Roberts 1969; Toye 1986
- northeast Africa: Gentry 1965; Schmutterer 1969
- Reunion: Vayssieres *et al.* 2001

- Rwanda: Buyckx 1962
- Seychelles: Kingsland & Shepard 1983
- South Africa: Annecke & Moran 1982; Swain & Prinsloo 1986
- southern Africa (wood-feeding beetles): Ferreira & Ferreira 1951-1957
- Tanzania: Bohlen 1978
- Uganda: Brown 1967

Important non-agricultural regional treatments and major expedition reports include Chagos Archipelago (Barnett & Emms 1999), Côte d'Ivoire (Paulian 1947), Madagascar (*Faune de Madagascar* series), Northwestern Sahara (Pierre 1958), Senegal (IFAN 1956, 1961, 1969), Uganda (British Museum Ruwenzori Expedition reports), and the Belgian surveys of various parks in Congo, Rwanda and Burundi.

Recent reviews of economically important insects by subject include:

- Biological control agents: Greathead 1971, 1986, 1989; Greathead & Greathead 1992
- Cereal stem borers and associated insects: Polaszek 1998
- Cocoa: Entwistle 1972
- Coffee: LePelley 1968
- Cotton: Pearson 1958
- Crop pests: Prior 1985
- Freshwater: Davies *et al.* 1982
- Medically important arthropods: Coetzee 1999; Lane & Crosskey 1993
- Stored products pests: Harney 1993

HOW MANY INSECTS HAVE BEEN DESCRIBED FROM AFRICA?

Prior to the ICIPE checklist project, only crude estimates of the number of described insect species in Africa existed. Only one large order (Diptera) had a modern catalogue for Africa (Crosskey 1980). A synthesis of entomological knowledge was only available for one region (southern Africa) and a published checklist for only one country (Nigeria - Medler 1980). Coaton (1974) published the proceedings of a 1971 meeting of experts reviewing the status of taxonomy of insects of southern Africa (also discussed by Holm 1975 and Scholtz 1999). This was summarised and expanded by Scholtz & Holm (1985) and Scholtz & Chown (1995), who tabulated about 44 000 described species in southern Africa.

Based on comparisons between species known from the Afrotropical Region in various insect families and orders now completed for the checklist, and the recently completed North American checklist (Poole & Gentili 1997), we expect that there are presently about 100 000 valid species of insects in the Afrotropical Region (excluding synonyms). Comparisons of numbers of species for various orders and families for the afrotropics and North America show considerable variance, some groups with more species in the afrotropics or *vice versa*, but the overall tendency is for the total number of species to be similar.

How do these numbers of described species relate to the eventual total of species that exist in the Afrotropical Region? Previous estimates included 1 000 000 (Stork 1993) and a range from 300 000 to 9 000 000 proportional to world figures from two to 30 million (Gaston & Hudson 1994). In a recent review, May (2000) settled on a 'best guess' of four million insect species in the world, which would correspond to some 600 000 in Africa using the conservative approximations of Gaston & Hudson (1994).

Scholtz & Chown (1995) analysed taxonomic knowledge of insects in southern Africa and considered "*… a doubling in* [species] *numbers to be the upper limit of the increase in species richness*" in the region. They reached this conclusion on the basis of recent revisions of insects in which some tended to double the number of known species, whereas in others, such as Anthophridae and Buprestidae (Coleoptera), the number was actually reduced due to changes in synonymy. In a detailed review of our present knowledge of ants (Hymenoptera: Formicidae) of tropical Africa, Robertson (2000) suggests that about half the afrotropical species have been described.

Dudley (1996 unpubl.) counted 7500 insect species recorded from Malawi in publications and local collections, and suggested that the total number of insect species in Malawi may range from 129 000 to 558 000 dependent on the magnitude of world estimates.

If the estimates of Scholtz & Chown (1995) for southern Africa hold true for the entire Afrotropical Region, then the total number of insect species would be several hundred thousand. There are 'hotspots' of species diversity in Africa (Myers *et al.* 2000), including the Eastern Arc Mountains (Burgess *et al.* 1998; Rogo & Oguge 2000) and the Cape Province (Picker & Samways 1996), but nowhere in Africa does species diversity reach the extreme levels of the Andean region (e.g., Robbins & Opler 1997), and many of the dry areas exhibit fairly low diversity for many taxa. Small soil-inhabiting insects (and especially the related mites - Acari), can be extremely diverse and may drive the figures higher following adequate sampling and further taxonomic studies (André *et al.* 1992; Lasebikan 1988; Usher 1988). Gupta (1991) shows the uneven distribution of knowledge of African insects - the number of species of Ichneumonidae (Hymenoptera) known from African countries varies from three to 458! Gupta's analysis also shows the important impact that intensive local sampling can have in increasing our knowledge.

STATUS OF INFRASTRUCTURE AND HUMAN RESOURCES FOR AFRICAN ENTOMOLOGY

Few centres of expertise on insect diversity and systematics exist in tropical Africa, while most of the large collections are housed in South Africa, Europe and the United States. The resources associated with the study and use of biodiversity are not distributed equally in the world, nor is their distribution even correlated. The biodiversity resource itself is distributed unevenly, as is the knowledge about biodiversity, the human potential to deal with it, the technology and tools to use it, and the supporting funding. One of the challenges we must face is how to find positive ways to move forward and make the most of the situation.

Surveys of collections and identification services in Africa have been undertaken many times in the last 30 years, but most were undertaken through mail questionnaires and were not comprehensive. Only the recent survey by SAFRINET (the southern African unit of BioNet International) for southern African countries can be considered comprehensive, as it included visits to many of the collections (Eardley 1998). The surveys of botanical resources for southern Africa by Smith & Willis (1999), Smith *et al*. (1999) and Mössmer & Willis (2000) provide models for what is needed in entomology. In chronological order of publication, the surveys have been:

- Akingbohungbe *et al.* (1981 and associated papers in the same volume)
- Ritchie (1987)
  Arnett *et al.* (1993); Arnett & Samuelson (1986) (also available partially updated at http://www.bishopmuseum.org/bishop/ento/codens-r-us.html)
- Hawksworth & Ritchie (1993) summarised data from these sources and CAB International data
- Yitaferu (1996) summarised data for Ethiopia and some other African countries
- Robertson (1997) from various sources, strongest for southern Africa
- Eardley (1998) detailed survey by SAFRINET for southern African countries
- Scholtz (1999) and Coetzee (1999) for South Africa only

These surveys show that there are a few excellent collections located within in the Afrotropical Region, but some of these suffer from severe lack of associated human resources (for example the collections in Dakar, Senegal, and Kampala, Uganda) and the status of at least one (Dundo, Angola) is uncertain because of civil war. Many

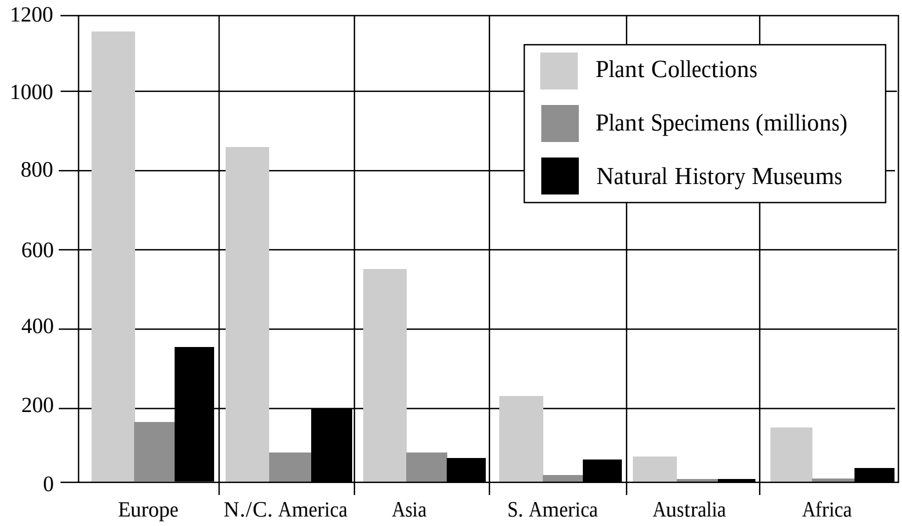

Figure 2. Relative taxonomic infrastructure in different regions, represented by plant collections, plant specimens (millions), and natural history museums. Simplified from Cracraft (2000).

countries have one or more collections associated with agricultural or forestry research stations, but often these have been given little attention since colonial times. Most collections require improvements in physical housing, quality of identifications, human resources and associated resources such as libraries and computers (*vide* Miller 1991). Several new specialised collections are being developed to support identification services such as at ICIPE in Kenya and the International Institute of Tropical Agriculture (IITA) in Benin. Figure 2 shows the poor representation of plant collections and natural history museums in Africa, relative to other regions (simplified from Cracraft 2000). The values of collections, the diverse uses to which they can be applied and the issues involved in their care and development are addressed in Drinkrow *et al*. (1994), Duckworth *et al.* (1993), Krishtalka & Humphries (2000), and Nudds & Pettitt (1997).

In 1979, the 'African Association of Insect Scientists' convened a workshop that reviewed the situation in Africa and proposed a strategic plan for regional insect identification and taxonomic research centres in Africa, as well as an '*African Insect Survey Series*.' Unfortunately, this plan never became reality. Ritchie (1987) reviewed the plan, including a model project in Nairobi. BioNet International (through its regional networks, SAFRINET, EAFRINET (the eastern African unit of BioNet International), and others) have again reviewed the problems in recent years and proposed some of the same answers. We hope that the Global Taxonomy Initiative will finally provide the political interest and funding opportunities necessary to proceed.

Over the past ten years, the economics of the way that systematics and identification services are paid for and distributed has changed dramatically (e.g. Herbert 2001; Mann 1997). One of the reasons for this is the concept that "… *all politics are local* " (Miller 2000). Many of the museums and research organisations of the world have been forced by their own financial problems to increasingly focus on provincial issues that are of greatest interest to the people who pay the bills for their institution. As a result of this and compounded by other factors, world productivity in systematics appears to be on the decline since 1990 (Winston & Metzger 1998).

The sad reality is that at the time when we need the greatest global interaction and the broadest vision in order to solve systematics problems, most of the institutions with resources to do so, irrespective of which country they are in, have become much more inwardly focussed. This is where we need to find partnerships through organisations like the Global Taxonomy Initiative (GTI) and BioNET International, in order for these institutions to make contributions that are seen as valuable, both to the people paying the bills at home, and add to the global synergy of solving the problems that we all face. Unfortunately, the needs for identification services described by Akingbohungbe *et al.* (1981) and Ritchie (1987) only increase!

Recent surveys of in-country resources by ICIPE, CABI (Hawksworth & Ritchie 1993) and BioNet International (Eardley 1998) show that human resources are also thinly distributed in Africa. In addition to the simple need for funded positions, there are additional needs for training at all levels, as well as for operating funds. Stuckenberg (1964) noted two disturbing trends - although most of the systematic activity on afrotropical insects was being undertaken by specialists at institutions outside Africa, only about 7% of the world's insect systematists indicated an interest in the afrotropical fauna. Gaston & May (1992) found similar trends - only about 4% of practising ecologists and 7% of insect systematists were located in the Afrotropical Region. Grazia *et al.* (2000) found only 0.8% of the world beetle researchers in their sample resided in Africa. In an analysis of the origins of scientific papers in general, Galvez *et al.* (2000) found that only 0.73% of their sample from 1991-1998 originated from African authors. Although Scholtz (1999) found a strong systematic entomology community in South Africa, he documented a series of problems facing the human resources and funding base. Coetzee (1999) reviewed the strong history of medical entomological systematics in South Africa and documented the dramatic decline in human resources. Herbert (2001) documented the problems in funding for systematics research and museum collections in South Africa.

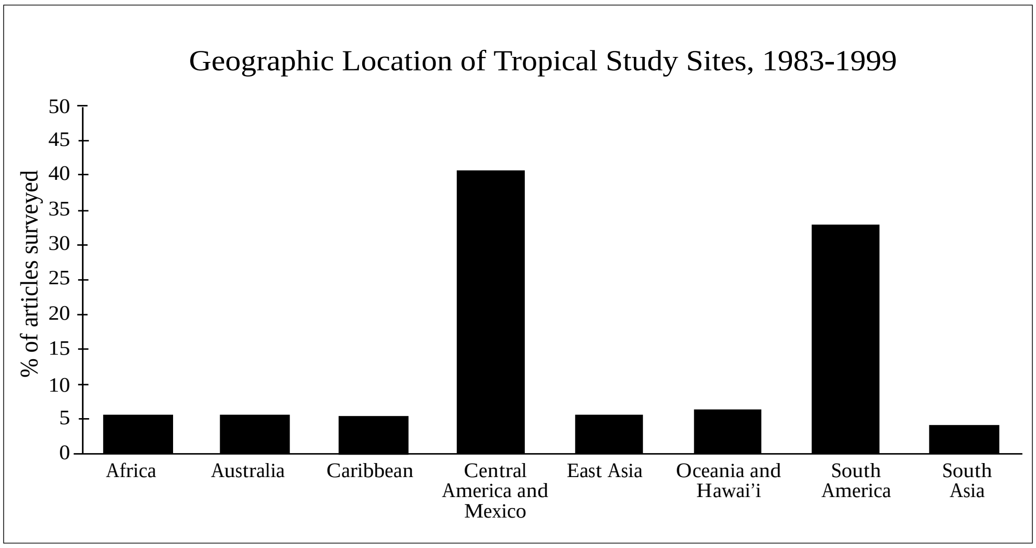

Figure 3. Geographic location of tropical study sites based on surveys of publications in 1983, 1989, and 1999. Simplified from Braker (2000).

Similar trends emerge in the analysis of tropical biology field stations or ecological projects. Africa was very poorly represented in a study of geographic locations of tropical ecology field studies based on reviews of selected journals for 1983, 1989, and 1999 (Braker 2000, summarised here in Figure 3). In a comprehensive review of studies of insects in tropical forest canopies, Basset (2001) found that although some of the earliest such studies were undertaken in Africa by medical entomologists, Africa is tremendously under-represented in recent studies.

There are many famous sites of long term biodiversity studies in tropical Africa, but many of these studies have focused on large mammals in savannas, with insects being generally ignored. Medical entomology has driven long-term insect studies at sites such as Zika Forest, near Entebbe, Uganda, overlooking Lake Victoria. Zika has been the site of relatively intensive biodiversity research since 1946 by the Yellow Fever Research Institute (then East African Virus Research Institute, now Uganda Virus Research Unit), including studies of vegetation, biting flies, dragonflies, other insects, birds, and mammals from a stationary tower erected in 1960 (Sempela 1981). The Lamto station in Côte d'Ivoire has hosted many systematic and ecological studies of savanna insects over many years (Lamotte 1990). But, at least in recent years, afrotropical field stations have not had as much impact on development of ecological theory as some of the famous field stations elsewhere in the tropics, such as La Selva in Costa Rica, Barro Colorado Island in Panama and Danum Valley Field Centre in East Malaysia (Chazdon & Whitmore 2001).

CHALLENGES

There are two key gaps in understanding and in utilising the positive aspects of insects in African biodiversity: a general neglect of insects in biodiversity research, and an overemphasis on their negative impacts in all other biological research areas. Wilson (1987) called insects "*The little things that run the world* …" because of their key rôles in ecosystem function. Yet most biodiversity and conservation programmes currently operating in tropical Africa focus on vertebrates, or secondarily, flowering plants, usually ignoring insects. A 1994 survey of biodiversity data sets available for East Africa included only 12 for insects, while mammals and plants had more than 50 each, and birds and fish had more than 40 each (WCMC 1994). Almost all research on insects in tropical Africa focuses on the negative aspects of insects (e.g., problems in agriculture, forestry, livestock, and human health) which are caused by less than 1% of insect species and ignores the remaining 99%. For example, of the more than 100 000 species of insects known from the Afrotropical Region, less than 500 species were mentioned between 1990 and 1995 in the journal *Insect Science and its Application* (a major African entomology journal) and 97% of the articles focused on economic/pest topics (Miller *et al.* 2000).

A survey of arthropod biodiversity research in Africa, undertaken by ICIPE in 1996, indicated that most of the current projects were based outside of Africa, most of the information on African biodiversity is stored in institutions in the Northern Hemisphere, and only a fraction of the gathered information is published (Rogo & Xia 1998).

Yet, as noted above, there is a crucial need for basic information on insect diversity for pest management related to plant, livestock and human health, as well as conservation and environmental management. Invasive (alien) species represent a newly recognised threat that cuts across traditional sectors (Braack *et al.* 1995; Lyons & Miller 2000) and places new demands on identification capabilities.

Unless entomologists take action to educate policy makers and be involved actively in the formulation of their policy, another issue that may retard the development of the kind of communication that we need to achieve is permits for research and specimen export (e.g., Yuan *et al.* 1997). As the present regulatory situation evolves, we shall find sending, for example, a leaf-hopper for identification will require not only an agriculture permit (phytosanitary permit or equivalent), but also a wildlife permit and possibly a Convention on International Trade in Endangered Species (CITES) permit. We must ensure that the needs and interests of individual owners of biological material as well as the countries involved are protected (*vide* Gollin 1999 for a review of intellectual property rights issues), but also that the interchange of scientific information to promote critical issues is promoted and enhanced, not dampened by unwieldy bureaucracy.

OPPORTUNITIES

Recent research in Africa by several organisations shows the potential of different approaches to these challenges, including compilation and synthesis of pre-existing data and research targeted at strategic needs. A present irony of biodiversity conservation initiatives is that while scientists are continually refining skills to document the value of ecosystem services provided by biodiversity, few governments or legal entities are prepared to pay for the conservation of these services which up until now have been exploited 'for free' by human societies.

No single African country has resources to initiate a continent-wide insect biodiversity programme. The task is a formidable one and the benefits so widely distributed and so diffuse as to be lost in a sea of competing priorities. Only a highly targeted cost effective programme co-ordinating resources and disseminating the benefits on a wide, regional or continental scale can return the expected outcomes. A practical philosophical framework was laid out by Wilson (1992): (1) survey the world's flora and fauna; (2) create biological wealth; (3) promote sustainable development; (4) save what remains; and (5) restore the wildlands.

Based on an extensive consultative process, ICIPE identified a range of projects that provide a cost-effective foundation for understanding insect diversity, insect rôles in natural systems, and ways to more effectively manage those interactions. The plan included three main components (Miller *et al.* 2000): (1) An information management programme to organise and make available a large volume of information that already exists but is not accessible to users. This must be co-ordinated with other activities already underway in the museum, systematics, and conservation communities, and should be carefully targeted to fill key gaps in insect-focused information management. (2) A series of field projects evaluating the use of insects as indicator organisms and quantifying their rôles in ecosystem processes. Successful approaches from South Africa and the Northern Hemisphere can be applied with appropriate modifications to tropical Africa. (3) Training and participatory technology transfer, building on ICIPE's existing training programmes, including the African Regional Postgraduate Programme in Insect Science (ARPPIS).

The Internet and the World Wide Web (WWW) is a rapidly developing area which is drastically changing the world we live in (Dyson 1997). Internet provides an amazing tool for communication and access to information that was not previously available, but some problems remain (Anon 1999; Miller 1993). One problem is that it will take some time before all parties and individuals have access to the Internet, although in Africa the speed at which Internet connectivity is growing is truly impressive. As of August 2000, all 54 countries and territories in Africa had Internet access in their capital cities (*vide* African Internet Connectivity statistics at http://demiurge.wn.apc.org:80/africa/). Another problem is that the Internet is drowning in raw data that lacks a synthetic framework and quality control, so the quality of the information you may find is not always clear. Recent experiments concluded that there are at least 800 million web pages of information on the WWW (not including the searchable data bases), but even the best available search engines see less than 16% of the available information (Lawrence & Giles 1999). This means that most of the information available on Internet is not very useful, because its accessibility is limited. Moreover, many web sites are clogged with elaborate graphic images, lack useful information, and take an inordinate amount of time to download. One particularly interesting exception is Ecoport (http://www.ecoport.org), which has evolved from the Food and Agriculture Organisation of the United Nations (FAO) Global Plant and Pest Information System (GPPIS). Ecoport offers some novel approaches to, among other things, a dual distribution model. Ecoport (and GPPIS before it) is primarily disseminated on the WWW, but is also issued on CD-ROM to serve a broader community.

Some of the opportunities for entomology in the Afrotropical Region:

- Evolutionary theory, including aspects such as mimicry (e.g. Clarke *et al.* 1995; Owen 1971; Pinhey 1978).
- Tropical ecology (e.g. Chazdon & Whitmore 2001).
- Biogeographic studies, especially of better known taxa such as dragonflies (Odonata), termites (Isoptera), grasshoppers (Orthoptera), butterflies (Lepidoptera), dung beetles (Coleoptera: Scarabaeoidea), and fruit flies (Diptera: Tephritidae) applying tools such as Worldmap (e.g. Brooks *et al*. 2001; Lees *et al.* 1999; Lovett *et al.* 2000; Vane-Wright 1997). There have been few continent-wide biogeographic papers covering diverse insect taxa since the seminal analysis of butterflies by Carcasson (1964), but see for example, Nonveiller (1996) and Tsacas *et al.* (1981). The isolated high mountains (the Afroalpine) also present interesting biogeographic questions (Beron 2000; Bruhl 1997).
- Pest management related to agriculture, forestry, livestock and humans, including novel approaches to habitat management (e.g. Khan *et al.* 1997).
- Non-target impacts of pesticides and their residues (e.g. Douthwaite & Tingle 1994).
- Prevention and management of invasive (alien) species (e.g. Braak *et al.* 1995; Lyons & Miller 2000; Richardson *et al*. 2000).
- Impacts of global climate change, especially on pest management (e.g. MacDonald *et al*. 1999; Epstein 2000; Giliomee 2000; Richardson *et al*. 2000; van Jaarsveld & Chown 2001).
- Water resources management, including development of water quality indicators and biological control of weeds. Population growth (with demands for agriculture and hydroelectric power) is combining with climate change to create water stress in Africa (Schoneboom 1998; Schultze *et al*. 2001; Vörösmarty *et al.* 2000), that is often exacerbated by invasive species (Marais *et al.* 2000).
- Conservation, through planning (biogeographic studies, e.g. van Jaarsveld *et al*. 1998, Reyers *et al*. 2000), assessment (e.g. Grimaldi *et al*. 2000; Rogo & Odulaja 2001) and monitoring (e.g. Agosti *et al.* 2000; McGeoch 1998; Reyers & van Jaarsveld 2000; Slotow & Hamer 2000).
- Ecosystem function: there are recent reviews of savanna studies at Lamto, Côte d'Ivoire, and elsewhere in Bourlière (1983) and Lamotte (1990), but much more research needs to be undertaken on insect rôles.
- Alternative livelihoods, including insects as food (e.g., protein and honey), fiber (e.g. silk - Raina 2000; Raina & Kioko 2000), cash crops (e.g. butterflies or chemical extraction), mini-livestock (Odhiambo 1977) and ecotourism. Termite nests are also used for building materials (Swaney 1999: 435). For example, many of these facets are included in an integrated conservation programme at Kakamega Forest in Kenya (Rogo *et al.* 2000).
- Natural products research, especially novel chemical aspects of insect-plant interactions and arthropod venoms (e.g. Iwu 1996; Torto & Hassanali 1997; Weiss & Eisner 1998).

> The influence of insects on soil chemistry may even be utilised in prospecting for minerals (e.g. Watson 1974).

It is worth noting some of the conclusions of a recent review of terrestrial zoology research in South Africa (Chown & McGeoch 1995): "*The future weaknesses … are likely to be a lack of internal and external communication, poor judgement concerning irrelevant, but 'fashionable' research trends, and a tendency to place too high a value on certain research directions. … The elaboration of sound theoretical and practical guidelines for the integration of conservation and other land use practices (especially agriculture) is the greatest challenge …*"

CONCLUSION

By developing a foundation of knowledge and trained personnel, ecological monitoring strategies and sustainable development applications could be established that draw on the strengths of the African arthropod resource base. In a continent which has historically been remarkable for the co-existence of human societies with a rich and varied wildlife, the challenge is to direct natural resource development along lines that foster this co-existence with the more ubiquitous but less noticed aspects of biodiversity such as insects and other arthropods. These are often the organisms that most directly impinge on human welfare, thus the success of biodiversity conservation may well hinge on how well we meet this challenge. In the largely intact, undeveloped landscapes of Africa, we still have tremendous potential for conserving the fine fabric and delicate linkages of nature in and among human development. The task before us is to document its existence and importance before it is lost. The Global Taxonomy Initiative of the Convention on Biological Diversity provides an opportunity to expand the experiments discussed above so that, as envisioned by Wilson (2000), all these information sources become readily available to, and support wise decisions by, biodiversity managers in the field.

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REFERENCES

AARNINK, W., BUNNING, S., COLLETTE, L., & MULVANY, P. (eds) 1999. *Sustaining agricultural biodiversity and agro-ecosystem functions: opportunities, incentives and approaches for the conservation and sustainable use of agricultural biodiversity in agro-ecosystems and production systems*. Food and Agriculture Organization of the United Nations, Rome, xiii+1-30+[14] pp. [also at http://www.fao.org/sd/epdirect/EPre0063.htm].

AGOSTI, D., MAJER, J., ALONSO, L. E. & SCHULTZ, T. R. (eds). 2000. *Ants: standard methods for measuring and monitoring biodiversity*. Smithsonian Institution Press, Washington, D.C., xix+1-280 pp.

AKINGBOHUNGBE, A. E., AGGUNDEY, A., HAFEZ, M., KUMAR, R., ODHIAMBO, T. R., PANT, C. & SANDS, W. A. 1981. Report and recommendations of the working committee of the workshop on insect identification services and taxonomic research centres in Africa, 6 December 1979. *Insect Science and its Application* 1: 421-424.

AMERICAN MUSEUM OF NATURAL HISTORY. 1999. *The Global Taxonomic Initiative: using systematic inventories to meet country and regional needs.* Center for Biodiversity and Conservation, American Museum of Natural History, New York, 1-18 pp. [also at http://research.amnh.org/biodiversity/acrobat/gti2.pdf].

André, H. M., Lebrun, P. & Noti, M.-I. 1992. Biodiversity in Africa: a plea for more data. *Journal of African Zoology* 106: 3-15.

Annecke, D. P. & Moran, V. C. 1982. *Insects and mites of cultivated plants in South Africa*. Butterworths, Durban/Pretoria, xiv+1-383 pp.

Anon. 1999. Information and communication technologies: a remarkable revolution! *Spore* 79: 4-5.

Arnett, R. H. Jr. & Samuelson, G. A. 1986. *The insect and spider collections of the world*. E.J. Brill/Flora & Fauna Publications, Gainesville, Florida, 1-220 pp.

Arnett, R. H. Jr., Samuelson, G. A. & Nishida, G. M. 1993. *The insect and spider collections of the world*. Sandhill Crane Press, Inc., Gainesville, Florida, vi+1-310 pp.

Australian Biological Resources Study. 1998a. *The Global Taxonomy Initiative: shortening the distance between discovery and delivery*. Australian Biological Resources Study, Environment Australia, Canberra, 1-18 pp.

Australian Biological Resources Study. 1998b. *The Darwin Declaration*. Australian Biological Resources Study, Environment Australia, Canberra, 1-14 pp.

Barnett, L. K. & Emms, C. 1999. The insects of the Chagos Archipelago (pp. 241-247). In Sheppard, C. R. C. & Seaward, M. R. D. (ed). *Ecology of the Chagos Archipelago*. Linnean Society, London.

Basset, Y. 2001. Invertebrates in the canopy of tropical rain forests: how much do we really know? *Plant Ecology* 153: 87-107.

Bauer, A. M. 1993. African-South American relationships: a perspective from the Reptilia (pp. 244-288). In Goldblatt, P. (ed). *Biological relationships between Africa and South America*. Yale University Press, New Haven & London, ix+1-630 pp.

Beron, P. 2000. Non-insect arthropoda (Isopoda, Arachnida and Myriapoda) on the high mountains of tropical Africa. *Bonner Zoologische Monographien* 46: 153-188.

Black, H. I. J. & Okwakol, M. J. N. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of termites. *Applied Soil Ecology* 6: 37-53.

Bohlen, E. 1978. *Crop pests in Tanzania and their control*. Revised edition, Parey, Berlin, 1-142 pp.

Bourlière, F. (ed) 1983. *Ecosystems of the world 13. Tropical savannas*. Elsevier, Amsterdam, xii+1-730 pp.

Braack, L. E. O., Maggs, K. A. R., Zeller, D. A. & Horak, I. G. 1995. Exotic arthropods in the Kruger National Park, South Africa: modes of entry and population status. *African Entomology* 3: 39-48.

Braker, E. 2000. The changing face of tropical biology? *Tropinet* 11(1): 1-2.

Brooks, T., Balmford, A., Burgess, N., Fjeldsa, J., Hansen, L. A., Moore, J., Rahbek, C. & Williams, P. 2001. Toward a blueprint for conservation in Africa. *BioScience* 51: 613-624.

Brown, K. W. 1967. *Forest insects of Uganda; an annotated list*. Government Printer, Entebbe, v+1-98 pp.

Bruhl, C. A. 1997. Flightless insects: a test case for historical relationships of African mountains. *Journal of Biogeography* 24: 233-250.

Burgess, N. D., Clarke, G. P. & Rodgers, W. A. 1998. Coastal forests of Eastern Africa: status, endemism patterns and their potential causes. *Biological Journal of the Linnean Society* 64: 337-367.

Buyckx, E. J. E. 1962. *Praecis des maladies et des insects nuisibles rencontres sur les plantes cultivees au Congo, au Rwanda et au Burundi*. l'Institut national pour l'etude agronomique du Congo, Bruxelles, 1-708 pp.

Carcasson, R. H. 1964. A preliminary survey of the zoogeography of the African butterflies. *East African Wildlife Journal* 2: 122-157.

Cast. 1999. *Benefits of biodiversity*. Council for Agricultural Science and Technology Task Force Report 133, vi+1-33 pp.

Chazdon, R. L. & Whitmore, T. C. (eds). 2001. *Foundations of tropical biology: key papers and commentaries*. University of Chicago Press, Chicago, in press.

Chown, S. L. & McGeoch, M. A. 1995. South African terrestrial zoology: strengths, weaknesses and opportunities. *South African Journal of Science* 91: 189-196.

Cida. 1983. *Catalogue de la collection entomologique nationale du Niger*. Pluritec LTEE for Canadian International Development Agency, Ottawa, 1-414 pp.

Clarke, C. A., Clarke, F. M. M. & Gordon, I. J. 1995. Mimicry and other controversial topics in East African Lepidoptera. *Journal of East African Natural History* 84: 3-18.

Coaton, W. G. H. (ed). 1974. Status of the taxonomy of the Hexapoda of southern Africa. *Republic of South Africa, Department of Agricultural Technical Services, Entomology Memoir* 38: 1-124.

COETZEE, M. 1999. The historical and current state of medical entomology systematics in South Africa. *Transactions of the Royal Society of South Africa* 54: 65-73.

COLE, F. R., REEDER, D. M. & WILSON, D. E. 1994. A synopsis of distribution patterns and the conservation of mammal species. *Journal of Mammalogy* 75: 266-276.

COLEMAN, D. C. & HENDRIX, P. F. (eds). 2000. *Invertebrates as webmasters in ecosystems*. CAB International, Wallingford, 1-320 pp.

COSTANZA, R., D'ARGE, R., DE GROOT, R., FARBER, S., GRASSO, M., HANNON, B., LIMBURG, K., NAEEM, S., O'NEILL, R. V., PARUELO, J., RASKIN, R. G., SUTTON, P. & VAN DEN BELT, M. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260 [reprinted *Ecological Economics* 25: 3-15, 1998]

COTTERILL, F. P. D. 1997. The second Alexandrian tragedy, and the fundamental relationship between biological collections and scientific knowledge (pp. 227-241). In NUDDS, J. R. & PETTITT, C. W. (eds). *The value and valuation of natural science collections: proceedings of the international conference, Manchester, 1995*. Geological Society, London, 1-230 pp.

CRACRAFT, J. 2000. Charting the biosphere: building global capacity for systematics science (pp. 374-386). In RAVEN, P. H. & WILLIAMS, T. (eds). *Nature and human society: the quest for a sustainable world. Proceedings of the 1997 forum on biodiversity.* National Academy Press, Washington, D.C., xii+1-625 pp.

CRESSWELL, I. D. & BRIDGEWATER, P. 2000. The Global Taxonomy Initiative - *Quo vadis*? *Biology International* 38: 12-16.

CROSSKEY, R. W. (ed). 1980. *Catalogue of the Diptera of the Afrotropical Region*. British Museum (Natural History), London, 1-1437 pp.

CROSSKEY, R. W. & WHITE, G. B. 1977. Afrotropical Region: a recommended term in zoogeography. *Journal of Natural History* 11: 541-544.

DAILY, G. C. (ed). 1997. *Nature's services: societal dependence on natural ecosystems*. Island Press, Washington, D.C. & Covelo, California, xx+1-392 pp.

DAVIES, B. R., DAVIES, T., FRAZER, J. & CHUTTER, F. M. 1982. *A bibliography of African inland water invertebrates (to 1980)*. South African National Science Programmes Report 58, x+1-418 pp.

DOUTHWAITE, R. J. & TINGLE, C. C. D. (eds). 1994. *DDT in the tropics: the impact on wildlife in Zimbabwe of ground-spraying for tsetse fly control.* Natural Resources Institute, Chatham, England, viii+1-95 pp.

DRINKROW, D. R., CHERRY, M. I. & SIEGFRIED, W. R. 1994. The role of natural history museums in preserving biodiversity in South Africa. *South African Journal of Science* 90: 470-479.

DUCKWORTH, W. D., GENOWAYS, H. H. & ROSE, C. L. 1993. *Preserving natural science collections: chronicle of our environmental heritage*. National Institute for the Conservation of Cultural Property, Washington, D.C., iv+1-140 pp.

DUDLEY, C. 1996. How many species of insects does Malawi have? *Nyala* 19: 13-16.

DUELLMAN, W. E. 1993. Amphibians in Africa and South America: evolutionary history and ecological comparisons (pp. 200-243). In GOLDBLATT, P. (ed). *Biological relationships between Africa and South America*. Yale University Press, New Haven & London, ix+1-630 pp.

DYSON, E. 1997. *Release 2.0: a design for living in the digital age.* Viking, London, viii+1-307 pp.

EARDLEY, C. D. (ed). 1998. *Biosystematic resources in the SADC sub-region: towards a strategic plan*. SAFRINET Document 6. SAFRINET c/o Plant Protection Research Institute, Pretoria, South Africa, ii+1-57 pp.

ENTWISTLE, P. F. 1972. *Pests of cocoa*. Longman Group Ltd., London, England, xxiv+1-779 pp.

EPSTEIN, P. R. 2000. Is global warming harmful to health? *Scientific American* 283(2): 50-57.

FAIRHEAD, J. & LEACH, M. 1999. Termites, society and ecology: perspectives from West Africa (pp. 235-242). In POSEY, D. A. (ed). *Cultural and spiritual values of biodiversity. A complementary contribution to the global biodiversity assessment.* Intermediate Technology Publications (for United Nations Environment Programme), London, xx+1-731 pp.

FERREIRA, M. C. & FERREIRA, G. da V. 1952-1957. *Entomologia florestal de Moçambique: Contribição para o estudo dos insectos xilofagos*. Junta de Exportação de Moçambique, Lourenço Marques. 3 volumes, the first two concurrently published in English as Forest entomology of Mozambique: Contribution to the study of the xylophagous insects. [Covers Bostrichidae, Lyctidae, and Cerambycidae (Coleoptera)].

FITTKAU, E. J. & KLINGE, H. 1973. On biomass and trophic structure of the Central Amazonian rain forest ecosystem. *Biotropica* 5: 2-14.

FORSYTH, J. 1966. *Agricultural Insects of Ghana: A list of insects recorded in Ghana on field crops and stored produce with their host plants, damage caused, locality, parasites and predators where known, together with references to the literature for Ghana and neighbouring countries covering the period 1910-1960*. Ghana Universities Press, Accra, Ghana, 1-163 pp.

GALVEZ, A., MAQUEDA, M., MARTINEZ-BUENO, M. & VALDIVIA, E. 2000. Scientific publication trends and the developing world: what can the volume and authorship of scientific articles tell us about scientific progress in various regions? *American Scientist* 88: 526-533.

GARDNER, J. C. M. 1957. An annotated list of East African forest insects. *East African Agriculture and Forestry Research Organisation, Forestry Technical Note* 7: 1-48.

GASTON, K. J. & MAY, R. M. 1992. Taxonomy of taxonomists. *Nature* 356: 281-283.

GASTON, K. J. & HUDSON, E. 1994. Regional patterns of diversity and estimates of global insect species richness. *Biodiversity and Conservation* 3: 493-500.

GENTRY, J. W. 1965. Crop insects of northeast Africa-southwest Asia. *Agriculture Handbook, Agricultural Research Service, United States Department of Agriculture* 273: 1-210.

GILIOMEE, J. H. 2000. Native insects expanding their ranges and becoming more abundant. *South African Journal of Science* 96: 474-504.

GOLLIN, M. A. 1999. New rules for natural products research: dwindling natural resources have spurred tighter regulations for biodiversity prospecting. *Nature Biotechnology* 17: 921-922.

GRAZIA, J., BARROS DE CARVALHO, C. J., MASSUTTI DE ALMEIDA, L., CASAGRANDE, M. M. & MIELKE, O. H. H. 2000. A biodiversidade de insetos no Brasil no terciero milenio: Dificuldades e perspectivas. *Entomologia y Vectores* 7: 123-141.

GREATHEAD, D. J. 1971. A review of biological control in the Ethiopian Region. *Technical Communication, Commonwealth Institute of Biological Control* 5: 1-162.

GREATHEAD, D. J. 1986. Opportunities for biological control of insect pests in tropical Africa. *Revue de Zoologie Africaines* 100: 85-96.

GREATHEAD, D. J. 1989. Present possibilities for biological control of insect pests and weeds in tropical Africa (pp. 173-194). In YANINEK, J. S. & HERREN, H. R. (eds). *Biological control: a sustainable solution to crop pest problems in Africa*. International Institute of Tropical Agriculture, Ibadan, Nigeria, xii+1-210 pp.

GREATHEAD, D. J. & GREATHEAD, A. H. 1992. Biological control of insect pests by insect parasitoids and predators: the BIOCAT database. *Biocontrol News and Information* 13: 61N-68N.

GRIMALDI, D. A., QUINTER, E. L. & NGUYEN, T. 2000. Fruit flies as ecological indicators: species diversity and abundance of Drosophilidae (Diptera) along an altitudinal transect in the Parc National de Marojejy, Madagascar. *Fieldiana Zoology* 97: 123-135.

GROOMBRIDGE, B. (ed). 1992. *Global biodiversity: status of the Earth's living resources*. Chapman & Hall, London, xviii+1-585 pp.

GUPTA, V. K. 1991. The parasitic Hymenoptera and biological control and our knowledge of the African Ichneumonidae. *Insect Science and its Application* 12: 9-18 (erratum 13: 11, 1992).

HARNEY, M. 1993. *A guide to the insects of stored grain in South Africa*. Plant Protection Research Institute Handbook 1, vii+1-129.

HAWKSWORTH, D. L. & RITCHIE, J. M. 1993. *Biodiversity and biosystematic priorities: microorganisms and invertebrates*. CAB International, Wallingford, England, 1-120 pp.

HAWKSWORTH, D. L. 1997. Biosystematics: meeting the demand. *Biology International* 35: 21-24.

HERBERT, D. G. 2001. Museum natural science and the NRF: crisis times for practitioners of fundamental biodiversity science. *South African Journal of Science* 97: 168-172.

HERREN, H. R. 1998. Global environmental and food security: importance of arthropod diversity. *Man & Development* 20: 94-108.

HILL, B. G. 1966. Insects of cultivated and wild plants, Harar Province, Ethiopia, 1960-1964. *Bulletin of Entomological Research* 56: 659-670.

HILL, D. S. 1997. *The economic importance of insects*. Chapman & Hall, London, x+1-395 pp.

HOLM, E. 1975. Insect taxonomy in South Africa: how can we cope? (pp. 35-40). In *Proceedings of the First Congress of the Entomological Society of Southern Africa*. Entomological Society of Southern Africa, Stellenbosch, 1-273 pp.

IFAN. 1956. Le Parc National du Niokolo-Koba. Fascicule I. *Mémoires de l'Institut Français d'Afrique Noire* 48: 1-267, plates I-XIV.

IFAN. 1961. Le Parc National du Niokolo-Koba. Fascicule II. *Mémoires de l'Institut Français d'Afrique Noire* 62: 1-379.

IFAN. 1969. Le Parc National du Niokolo-Koba (Sénégal). Fascicule III. *Mémoires de l'Institut Fondamental d'Afrique Noire* 84: 1-487.

IWU, M. M. 1996. Biodiversity prospecting in Nigeria: seeking equity and reciprocity in intellectual property rights through partnership arrangements and capacity building. *Journal of Ethnopharmacology* 51: 209-219.

JANZEN, D. H. 1993. Taxonomy: universal and essential infrastructure for development and management of tropical wildland biodiversity (pp. 100-113). In SANDLUND, O.T. & SCHEI, P.J. (eds). *Proceedings of the Norway/UNEP expert conference on biodiversity.* Directorate for Nature Management and Norwegian Institute for Nature Research, Trondheim, Norway, 1-190 pp.

JANZEN, D. H. 1998a. Gardenification of wildland nature and the human footprint. *Science* 279: 1312-1313.

JANZEN, D. H. 1998b. How to grow a wildland: the gardenification of nature. *Insect Science and its Application* 17: 269-276.

JANZEN, D. H. 1999. Gardenification of tropical conserved wildlands: multitasking, multicropping, and multiusers. *Proceedings of the National Academy of Sciences USA* 96: 5987-5994.

KAISER, J. 1999. Searching museums from your desktop. *Science* 284: 888.

KHAN, Z. R., AMPONG-NYARKO, K., CHILISWA, P., HASSANALI, A., KIMANI, S., LWANDE, W., OVERHOLT, W. A., PICKETT, J. A., SMART, L. E., WADHAMS, L. J. & WOODCOCK, C. M. 1997. Intercropping increases parasitism of pests. *Nature* 388: 631-632.

KINGSLAND, G. C. & SHEPARD, B. M. 1983. *Diseases and insects of fruit and vegetable crops in the Republic of Seychelles*. Ministry of National Development, Victoria, Mahe, iii+1-106 [loose leaf pages].

KRESS, W. J., MILLER, S. E., KRUPNICK, G. A. & LOVEJOY, T. E. 2001. Museum collections and conservation efforts. *Science* 291: 828-829.

KRISHTALKA, L. & HUMPHREY, P. S. 2000. Can natural history museums capture the future? *BioScience* 50: 611-617.

LAMOTTE, M. 1990. Presentation des travaux des chercheurs de Lamto (Côte-d'Ivoire) 1962-1989. *Ecole Normale Superieure, Publications du Laboratoire de Zoologie* 36: 1-158.

LANE, R. P. & CROSSKEY, R. W. (eds) 1993. *Medical insects and arachnids*. Chapman & Hall, London, xv+1-723 pp.

LASEBIKAN, B. A. 1988. Studies in soil fauna in Africa: current status and prospects. *Revue de Zoologie Africaines* 102: 301-311.

LAWRENCE, S. & GILES, C. L. 1999. Accessibility of information on the web: search engines do not index sites equally, may not index new pages for months, and no engine indexes more than about 16% of the web. *Nature* 400: 107-109.

LE PELLEY, R. H. 1959. *Agricultural insects of East Africa: a list of East African plant feeding insects and mites, with their host plants, their parasites and predators, giving distribution by territories and references to the literature, together with lists of stored products insects and introduced insects, mainly covering the period 1908 to 1956*. East Africa High Commission, Nairobi, Kenya, x+1-307 pp.

LE PELLEY, R. H. 1968. *Pests of coffee*. Longmans, London, England, xii+590 pp.

LEES, D. C., KREMEN, C. & ANDRIAMAMPIANINA, L. 1999. A null model for species richness gradients: bounded range overlap of butterflies and other rainforest endemics in Madagascar. *Biological Journal of the Linnean Society* 67: 529-584.

LOVETT, J. C., RUDD, S., TAPLIN, J. & FRIMODT-MOLLER, C. 2000. Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. *Biodiversity and Conservation* 9: 37-46.

LYONS, E. E. & MILLER, S. E. (eds). 2000. *Invasive species in Eastern Africa: proceedings of a workshop held at ICIPE, July 5-6, 1999*. International Centre of Insect Physiology and Ecology, Nairobi, [v]+1-108 pp. [also http://www.biodiv.org/doc/meetings/cop/cop-05/information/cop-05-inf-33-en.pdf].

MACDONALD, J. A., JEEVA, D., EGGLETON, P., DAVIES, R., BIGNELL, D. E., FOWLER, D., LAWTON, J. H. & MARYATI, M. 1999. The effect of termite biomass and anthropogenic disturbance on the CH4 budgets of tropical forests in Cameroon and Borneo. *Global Change Biology* 5: 869-879.

MAMET, J. R. 1992. *Bibliographie de l'entomologie des iles Mascareignes: 1771-1990*. Mauritius Sugar Industry Research Institute, 1-318 pp.

MAMET, J. R. & WILLIAMS, J. R. 1993. The recorded foodplants of Mauritian insects. *Mauritius Sugar Industry Research Institute Occasional Paper* 35: 1-202.

MANN, D. G. 1997. The economics of botanical collections (pp. 68-82). In NUDDS, J. R. & PETTITT, C. W. (eds). *The value and valuation of natural science collections: proceedings of the international conference, Manchester, 1995*. Geological Society, London, 1-230 pp.

MARAIS, C., WILLEMS, T. & HANKS, K. 2000. Invasive species and the National Working for Water Programme: linking sustainable development with economic empowerment in South Africa (pp. 25-38). In LYONS, E. E. & MILLER, S. E. (eds). *Invasive species in Eastern Africa: proceedings of a workshop held at ICIPE, July 5-6, 1999*. International Centre of Insect Physiology and Ecology, Nairobi, v+1-108 pp.

MAY, R. M. 2000. The dimensions of life on Earth (pp. 30-45). In RAVEN, P. H. & WILLIAMS, T. (eds). *Nature and human society: The quest for a sustainable world. Proceedings of the 1997 forum on biodiversity*. National Academy Press, Washington, D.C., xii+1-625 pp.

McGeoch, M. A. 1998. The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* 73: 181-201.

Medler, J. T. 1980. *Insects of Nigeria - checklist and bibliography*. Memoir of the American Entomological Institute 30, viii+1-919 pp.

Meyer, N. L., Mossmer, M. & Smith, G. F. (eds). 1997. Taxonomic literature of southern African plants. National Botanical Institute, South Africa. *Strelitzia* 5, iii+1-164 pp.

Miller, S. E. 1991. Entomological collections in the United States and Canada: current status and growing needs. *American Entomologist* 37(2): 77-84.

Miller, S. E. 1993. The information age and agricultural entomology. *Bulletin of Entomological Research* 83: 471-474. [Also at http://www.bishopmuseum.org/bishop/HBS/BER.html].

Miller, S. E. 1994. Development of world identification services: networking (pp. 69-80). In Hawksworth, D. L. (ed). *The Identification and characterization of pest organisms.* CAB International, Wallingford, xvii+1-501 pp.

Miller, S. E. 2000. Keynote address: taxonomy for understanding biodiversity - the strengths of the BioNet International model (pp. 13-18). In Jones, T. & Gallagher, S. (eds). *Proceedings of the Second BioNet-International Global Workshop (BIGW2)*. BioNet International, Egham, Surrey, England, xxii+1-344 pp.

Miller, S. E., Gemmill, B., Rogo, L., Allen, M. & Herren H. R. 2000. Biodiversity of terrestrial invertebrates in tropical Africa: assessing the needs and plan of action (pp. 204-212). In Raven, P. H. & Williams, T. (eds). *Nature and human society: the quest for a sustainable world. Proceedings of the 1997 forum on biodiversity*. National Academy Press, Washington, D.C., xii+1-625 pp.

Mössmer, M. & Willis, C. K. 2000. Plant taxonomic expertise: an inventory for southern Africa. *Southern African Botanical Diversity Network Report* 10: 1-350.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858.

Nastasi, V. & Wolden-Haimanot, A. 1967. *A list of insect pests found on plants, their parasites and predators in Eritrea - 1954-1967*. Imperial Ethiopian Government, Department of Agriculture, Asmara, 1-10 pp.

Nielsen, E. S. & West, J. G. 1994. Biodiversity research and biological collections: transfer of information (pp. 101-121). In Forey, P. L., Humphries, C. J. & Vane-Wright, R. I. (eds). *Systematics and conservation evaluation*. Clarendon Press, Oxford, xxvi+1-438 pp.

Nonveiller, G. 1984. Catalogue des insectes du Cameroun d'interest agricole. *Institut pour la Protection des Plantes Memoires, Beograd, Yugoslavia* 15: 1-210.

Nonveiller, G. 1996. Types de repartition dans la region afrotropicale bases sur l'etude des Mutillides (Hymenoptera, Mutillidae). *Bulletin de la Societe Entomologique de France* 101: 89-112.

Normile, D. 1999. Culture collections seek global help. *Science* 283: 1240-1241.

Noss, A. J. 1997. Challenges to nature conservation with community development in central African forests. *Oryx* 31: 180-188.

Nudds, J. R. & Pettitt, C. W. (eds). 1997. *The value and valuation of natural science collections.* Geological Society Publishing House, Bath, England, 1-230 pp.

Odhiambo, T. R. 1977. Entomology and the problems of the tropical world (pp. 52-59). In *Proceedings of the XV International Congress of Entomology*. Entomological Society of America, College Park, Maryland, viii+1-824 pp.

Odindo, M. O. (ed). 1995. Beneficial African insects: a renewable natural resource: *Proceedings of the 10th meeting and scientific conference of the African Association of Insect Scientists.* African Association of Insect Scientists, Nairobi, Kenya, iii+1-251 pp.

Owen, D. F. 1971. *Tropical butterflies: the ecology and behaviour of butterflies in the tropics with special reference to African species.* Clarendon Press, Oxford, xiv+1-214 pp.

Paulian, R. 1947. Observations ecologiques en foret de Basse Côte d'Ivoire. *Encyclopedie Biogeographique et Ecologique* 2: 1-147.

Pearson, E. O. 1958. *The insect pests of cotton in tropical Africa.* Empire Cotton Growing Corporation and Commonwealth Institute of Entomology, London, x+1-355 pp., plates I-VIII.

Picker, M. D. & Samways, M. J. 1996. Faunal diversity and endemism of the Cape Pennisula, South Africa. *Biodiversity and Conservation* 5: 591-606.

Pierre, F. 1958. *Ecologie et peuplement entomologique des sables vifs du Sahara Nord-Occidental*. Centre National de la Recherche Scientifique, Paris, 1-332 pp.

Pinhey, E. C. G. [1977] 1978. A preliminary survey of insect mimicry and aposematism in Africa. *Journal of the South African Biological Society* 18: 23-41.

Polaszek, A. (ed). 1998. *African cereal stem borers: economic importance, taxonomy, natural enemies and control*. CAB International, Wallingford, 1-592 pp.

POOLE, R. W. & GENTILI, P. (eds). 1997. *Nomina Insecta Nearctica: a check list of the insects of North America*. Entomological Information Services, Rockville, Maryland, CD-ROM [also published as check list in four paper volumes, 1996-1997].

POSEY, D. A. (ed). 1999. *Cultural and spiritual values of biodiversity.* Intermediate Technology Publications (for United Nations Environment Programme), London, xx+1-731 pp.

PRIOR, C. (ed). 1985. *Distribution maps of major crop pests and diseases in Africa*. Inter-African Phytosanitary Council (IAPSC), Yaounde, Cameroon, [320 maps in looseleaf binder].

RAINA, S. K. (ed). 2000. *The economics of apiculture and sericulture modules for income generation in Africa.* ICIPE Science Press, Nairobi, v+1-86 pp.

RAINA, S. K. & KIOKO, E. N. 2000. Harvesting wild silkmoths of the African continent: implications on biodiversity and community development. *International Journal of Wild Silkmoth & Silk* 5: 307-310.

RAMBERG, L. 1993. African communities in conservation: a humanistic perspective. *Journal of African Zoology* 107: 5-18.

RECKHAUS, P. 1997. *Maladies et ravageurs de cultures Maraicheres: a l'exemple de Madagascar.* Margraf Verlag, 1-402 pp.

REDFERN, J. 1999. Bioinformatics: OECD to set up global facility on biodiversity. *Science* 285: 22-23.

REYERS, B. & VAN JAARSVELD, A. S. 2000. Assessment techniques for biodiversity surrogates. *South African Journal of Science* 96: 406-408.

REYERS, B., VAN JAARSVELD, A. S. & KRÜGER, M. 2000. Complementarity as a biodiversity indicator strategy. *Proceedings of the Royal Society of London B* 267: 505-513.

RICHARDSON, D. M., BOND, W. J., DEAN, W. R. J., HIGGINS, S. I., MIDGLEY, G. F., MILTON, S. J., POWRIE, L. W., RUTHERFORD, M. C., SAMWAYS, M. J. & SCHULZE, R. E. 2000. Invasive alien species and global change: a South African perspective (pp. 303-349). In MOONEY, H. A. & HOBBS, R. J. (eds). *Invasive species in a changing world*. Island Press, Washington, D.C., xv+1-457 pp.

RITCHIE, J. M. 1987. Insect biosystematic services in Africa: current status and future prospects. *Insect Science and its Application* 8: 425-432.

ROBBINS, R. K. & OPLER, P. A. 1997. Butterfly diversity and a preliminary comparison with bird and mammal diversity (pp. 69-82). In REAKA-KUDLA, M. L., WILSON, D. E. & WILSON, E. O. (eds). *Biodiversity II: understanding and protecting our biological resources*. Joseph Henry Press, National Academy of Sciences, Washington, D.C., v+1-551 pp.

ROBERTS, H. 1969. Forest insects of Nigeria with notes on their biology and distribution. *Commonwealth Forestry Institute Paper* 44: 1-208.

ROBERTSON, H. G. 1997. Entomological organisations and institutions in Africa (pp. 229-255). In ROBERTSON, H. G. (ed). *Insects in African economy and environment: proceedings of the joint congress of the Entomological Society of Southern Africa (11th Congress) and the African Association of Insect Scientists (12th Congress), Stellenbosch, 30 June - 4 July 1997*. Entomological Society of Southern Africa, Pretoria, 1-255 pp.

ROBERTSON, H. G. 2000. Afrotropical ants (Hymenoptera: Formicidae): taxonomic progress and estimation of species richness. *Journal of Hymenoptera Research* 9: 71-84.

ROGO, L. M., LWANDE, W., MILLER, S. E., HERREN, H. & CHAPYA, A. [1999] 2000. Kakamega Forest: an integrated conservation project. *Bulletin of the East Africa Natural History Society* 29(3): 9-13.

ROGO, L. M. & ODULAJA, A. 2001. Butterfly populations in two forest fragments at the Kenya coast. *African Journal of Ecology* 39: 266-275.

ROGO, L. M. & OGUGE, N. 2000. The Taita Hills Forest remnants: a disappearing world heritage. *Ambio* 29: 522-523.

ROGO, L. M. & XIA, Y. 1998. Generation of information on the current status of arthropod biodiversity research in Africa (pp. 198-199). In *ICIPE annual scientific report 1995-1997*. International Centre of Insect Physiology and Ecology, Nairobi.

RUIZ, M., POOMA, R., JENKINS, M. & TEN KATE, K. 2000. *Going home: a manual on the repatriation of information from ex-*situ *conservation and research institutions to countries of origin*. Royal Botanic Gardens, Kew, 1-28 pp.

SAMWAYS, M. J. 1999. Diversity and conservation status of South African dragonflies (Odonata). *Odonatologica* 28: 13-62.

SCHMUTTERER, H. 1969. *Pests of crops in northeast and central Africa with particular reference to the Sudan.* Gustav Fischer, Stuttgart, 1-296 pp.

SCHOLTZ, C. H. 1999. Review of insect systematics research in South Africa. *Transactions of the Royal Society of South Africa* 54: 53-63.

SCHOLTZ, C. H. & CHOWN, S. L. 1995. Insects in southern Africa: how many species are there? *South African Journal of Science* 91: 124-126.

SCHOLTZ, C. H. & HOLM, E. (eds). 1985. *Insects of southern Africa.* Butterworths, Durban, South Africa, 1-502 pages, 12 plates.

SCHONEBOOM, J. (ed). 1998. *Emerging water management issues.* American Association for the Advancement of Science, Washington, D.C., vi+1-73 pp.

SCHULZE, R., MEIGH, J. & HORAN, M. 2001. Present and potential future vulnerability of eastern and southern Africa's hydrology and water resources. *South African Journal of Science* 97: 150-160.

SEMPALA, S. D. K. 1981. The ecology of *Aedes* (*Stegomyia*) *africanus* (Theobald) in a tropical forest in Uganda: mark-release-recapture studies on a female adult population. *Insect Science and its Application* 1: 211-224.

SIEGFRIED, W. R. & BROOKE, R. K. 1995. Anthropogenic extinctions in the terrestrial biota of the Afrotropical Region in the last 500,000 years. *Journal of African Zoology* 109: 5-14.

SLOTOW, R. & HAMER, M. 2000. Biodiversity research in South Africa: comments on current trends and methods. *South African Journal of Science* 96: 222-224.

SMITH, G. F. & WILLIS, C. K. 1999. Index herbariorum: southern African supplement. Second edition. *Southern African Botanical Diversity Network Report* 8: 1-181.

SMITH, G. F., WILLIS, C. K. & MÖSSMER, M. 1999. *Southern African herbarium needs assessment*. Southern African Botanical Diversity Network Report 6, xvi+88 pp.

SOBERON, J., LLORENTE, J. & BENITZ, H. 1996. An international view of national biological surveys. *Annals of Missouri Botanical Garden* 83: 562-573.

STORK, N. E. 1993. How many species are there? *Biodiversity and Conservation* 2: 215-232.

STUCKENBERG, B. R. 1964. Remarks on regional specialization in insect taxonomy and its bearing on entomological research in South Africa. *SAMAB (South African Museums Association Bulletin)* 8: 116-122.

SWAIN, V. M. & PRINSLOO, G. L. 1986. *A list of phytophagous insects and mites on forest trees and shrubs in South Africa*. Republic of South Africa, Department of Agriculture and Water Supply, Entomology Memoir 66, vi+1-91.

SWANEY, D. 1999. *Zimbabwe, Botswana & Namibia. Third edition*. Lonely Planet, Hawthorn, Australia, 1-817 pp.

THRUPP, L. A. 1998. *Cultivating diversity: agrobiodiversity and food security*. World Resources Institute, Washington, D.C., vii+1-80 pp.

TORTO, B. & HASSANALI, A. 1997. Progress in the search for anti-arthropod botanicals. *Recent Research Developments in Phytochemistry* 1: 475-488.

TOYE, B. O. 1986. Bibliography of entomological research in Nigeria 1900-1973: First supplement 1973-1983. *Occasional Publication, Entomological Society of Nigeria* 28, xxiii+1-113 pp.

TSACAS, L., LACHAISE, D. & DAVID, J. R. 1981. Composition and biogeography of the afrotropical drosophilid fauna (pp. 197-259) In ASHBURNER, M., CARSON, H. L. & THOMPSON, J. N. Jr., (eds). *The genetics and biology of* Drosophila. Volume 3a. Academic Press, London.

TSEDEKE ABATE. 1991. Entomophagous arthropods of Ethiopia: a catalog. *Institute of Agricultural Research, Addis Ababa, Technical Manual* 4, vi+1-50 pp.

USHER, M. B. 1988. Soil invertebrates: a review of species, populations, communities, modelling and conservations with special reference to the African Continent. *Revue de Zoologie Africaines* 102: 285-300.

VAN BRUGGEN, A. C. 1986. Aspects of the diversity of the land molluscs of the Afrotropical Region. *Revue de Zoologie Africaines* 100: 29-45.

VAN HUIS, A. 1996. The traditional use of arthropods in sub Saharan Africa (pp. 3-20). In SOMMEIJER, M. J. & FRANCKE, P. J. (eds). *Proceedings of the Section Experimental and Applied Entomology of the Netherlands Entomological Society (N.E.V.), Seventh Meeting*. Netherlands Entomological Society, Amsterdam.

VAN JAARSVELD, A. S. & CHOWN, S. L. 2001. Climate change and its impacts in South Africa. *Trends in Ecology and Evolution* 16: 13-14.

VAN JAARSVELD, A. S., FREITAG, S., CHOWN, S. L., MULLER, C., KOCH, S., HULL, H., BELLAMY, C., KRÜGER, M., ENDRÖDY-YOUNGA, S., MANSELL, M. W. & SCHOLTZ C. H. 1998. Biodiversity assessment and conservation strategies. *Science* 279: 2106-2108.

VANE-WRIGHT, R. I. 1997. African Lepidopterology at the Millennium. *Metamorphosis Supplement* 3: 11-27.

VAYSSIÈRES, J. F., DELVARE, G., MALDES, J. M. & ABERLENC, H.-P. 2001. Inventaire preliminaire des arthropodes ravageurs et auxiliaires des cultures maraicheres sur l'Ile de la Reunion. *Insect Science and its Application* 21: 1-22.

VÖRÖSMARTY, C. J., GREEN, P., SALISBURY, J. & LAMMERS R. B. 2000. Global water resources: vulnerability and population growth. *Science* 289: 284-288.

VUILLEUMIER, F. & ANDORS, A. V. 1993. Avian biological relationships between Africa and South America (pp. 289-328). In GOLDBLATT, P. (ed). *Biological relationships between Africa and South America*. Yale University Press, New Haven & London, ix+1-630 pp.

WAGNER, M. R., ATUAHENE, S. K. N. & COBBINAH, J. R. 1991. *Forest entomology in west tropical Africa: forest insects of Ghana*. Kluwer Academic Publishers, Dordrecht, Boston, London, xii+1-210 pp.

WALKER, D. J. & BOXALL, R. A. 1974. An annotated list of the insects associated with stored products in Ethiopia, including notes on mites found in Harar Province. *East African Agricultural and Forestry Journal* 39: 330-335.

WATSON, J. P. 1974. Termites in relation to soil formation, groundwater, and geochemical prospecting. *Soils and Fertilizers* 37: 111-114.

WHEELER, Q. 1990. Insect diversity and cladistic constraints. *Annals of the Entomological Society of America* 83: 1031-1047.

WEISS, C. & EISNER, T. 1998. Partnerships for value-added through bioprospecting. *Technology in Society* 20: 481-498.

WILSON, E. O. 1987. The little things that run the world (the importance and conservation of invertebrates). *Conservation Biology* 1: 344-346.

WILSON, E. O. 1992. *The diversity of life*. Harvard University Press, Cambridge, USA, 1-406 pp.

WILSON, E. O. 2000. On the future of conservation biology. *Conservation Biology* 14: 1-3.

WINSTON, J. E. & METZGER, K. L. 1998. Trends in taxonomy revealed by the published literature. *BioScience* 48: 125-128.

WORLD CONSERVATION MONITORING CENTRE. 1994. *Availability of biodiversity information for East Africa.* Food and Agriculture Organization of the United Nations, Dar es Salaam, Tanzania, xi+1-24+[10]+5+K1-K59+T1-T86+U1-U41+Ea1-Ea162+33 pp.+computer disk.

WORLD CONSERVATION MONITORING CENTRE. 1996. *Guide to information management in the context of the Convention on Biological Diversity*. United Nations Environmental Programme, Nairobi, Kenya, v+1-69 pp.

YITAFERU, K. 1996. Insect biosystematic services in Africa, with emphasis on the current status and future prospects in Ethiopia (pp. 54-61). In BEKELE, E., ABDULAHI, A. & YEMANE, A. (eds). *Proceedings of the third annual conference of the Crop Protection Society of Ethiopia, 18-19 May 1995*. Crop Protection Society of Ethiopia, Addis Ababa, Ethiopia.

YUAN, D., XUE, D. & JI, L. 1997. The biosystematic situation in China's mainland: its strength, deficiency, and need with special reference to insects. *Korean Journal of Biological Sciences* 1: 447-450.

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