Conservation of Terrestrial Invertebrates and Their Habitats in Brazil

THOMAS M. LEWINSOHN,*§ ANDRÉ VICTOR LUCCI FREITAS,*† AND PAULO INÁCIO PRADO‡

*Departamento de Zoologia, Instituto de Biologia, Universidade Estadual de Campinas (UNICAMP), C.P. 6109, Campinas 13083-970, São Paulo, Brasil

†Museu de História Natural, Instituto de Biologia, UNICAMP, Campinas 13083-970, São Paulo, Brasil

‡Núcleo de Estudos e Pesquisas Ambientais, UNICAMP, Campinas 13083-970, São Paulo, Brasil

Abstract: *As one of the world's prime megadiverse countries, Brazil holds an immense number of terrestrial invertebrates. Current knowledge of this biota is very heterogeneous. Several taxa are sufficiently well known to be used as indicators of ecological integrity or of endemism. The current Brazilian national and regional red lists include 130 terrestrial invertebrate species, of which 42% are butterflies. These lists are contingent on available knowledge, and many taxa that are omitted certainly include species at risk. Knowledge of various biomes and habitats is also quite irregular, with the Caatinga and Pantanal in need of more study, compared with the Atlantic Forest, the Amazon, and Cerrado. Canopy, host-associated, and soil faunas also need further intensive study. Invertebrate conservation will be promoted more effectively by habitat preservation and management rather than single-species initiatives. To this end, better geographic surveys of entire taxonomic or functional assemblages are needed. An improved understanding of the invertebrate role in ecosystem processes will strengthen enormously the case for their conservation.*

Conservación de Invertebrados Terrestres y Sus Hábitats en Brasil

Resumen: *Como uno de los principales megadiversos en el mundo, Brasil mantiene un número inmenso de invertebrados terrestres. El conocimiento actual sobre esta biota es muy heterogéneo. Varios taxa son suficientemente conocidos para ser utilizados como indicadores de integridad ecológica o de endemismo. Las actuales listas rojas nacionales y regionales incluyen 130 especies de invertebrados terrestres, 42% de las cuales son mariposas. Estas listas dependen de la información disponible, y muchos taxa que son omitidos seguramente incluyen especies en riesgo. El conocimiento sobre varios biomas y hábitats también es bastante irregular, la Caatinga y el Pantanal requieren de más estudios en comparación con el Bosque Atlántico, el Amazonas y el Cerrado. Las faunas del dosel, asociadas a huéspedes y del suelo también requieren de más estudios intensivos. La preservación y gestión del hábitat promoverá la conservación de invertebrados más efectivamente que iniciativas con especies individuales. En este sentido, se requieren mejores prospecciones geográficas de ensambles taxonómicos o funcionales completos. Un mejor entendimiento del papel de los invertebrados en los procesos del ecosistema reforzará el caso por su conservación significativamente.*

Introduction

The science of conservation biology is relatively new in Brazil, although concerns were voiced a century ago when Herman von Ihering, director of the Museu Paulista (now Museu de Zoologia da Universidade de São Paulo) emphasized the need for conservation of forests (Ihering 1911). The enormous wealth of plant and animal species, especially terrestrial invertebrates, in Brazilian forests has always deeply impressed visiting naturalists, including Darwin, Wallace, Bates, and Müller.

Some insects (butterflies, dragonflies, and metallic beetles) have been collected and bred for their brightly colored wings or elytra from the late nineteenth century until

§*email thomasl@unicamp.br*

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Table 1. Terrestrial invertebrates used or proposed for use in conservation planning, area evaluation, and biodiversity monitoring in Brazil.

Taxonomic group	*Species in Brazil*[a]	*Threatened species*[b]	*Kinds of information*[c]	*Degree of study*[d]
Lepidoptera (all)	26016	57	a,b,c	1
All butterflies	3288	55	a,b,c	3
Nymphalidae (bait attracted)	335	11	a,b,c	3
Nymphalidae (Ithomiinae)	54	9	a,b,c	3
Hymenoptera	12000	7	a,c	1
Formicidae—ants	2500	4	a,c	3
Apoidea—bees	3000	3	a	3
Coleoptera	30000	16	a,c	1
Scarabeidae	1777	1	a,c	2
Carabidae	1132	5	a,c	2
Cerambycidae	5000	2	a	2
Chrysomelidae	4362	3	a	2
Elateridae	590	0	c	2
Odonata	670	8	a	3
Isoptera	280	0	c	2
Araneae	4000	8	a,c	2
Opiliones	300	4	a,b	2
Myriapoda	150	4	a	1
Onychophora	4	1	a,c[e]	3
Annelida Oligochaeta	260	3	a,c	2
Mollusca Gastropoda (terrestrial)	670	11	a	2

[a] *Information in various chapters of Brandão and Cancello (1999). Estimated number based on described species (Brandão & Cancello 1999).*
[b] *Number of threatened species based on MMA (2003).*
[c] *Key: a, red lists; b, natural history; c, use for habitat evaluation and monitoring.*
[d] *Key: 1, little beyond species names; 2, some species and groups well studied (taxonomy, ecology); 3, very well studied (reliable source of environmental information).*
[e] *Used to establish a nature reserve (see text for details).*

today, especially in some southern Brazilian states (Brown & Freitas 2002). With this insect-based cottage industry requiring both captive breeding and the preservation of natural populations, the forest-dwelling people involved came to recognize the importance of special locations and habitat requirements for these insects. Brightly colored insects have the potential to be used as flagship groups in conservation programs and can serve as indicators of environmental quality. This was anticipated by early mentions of possibly endangered invertebrates in Brazil (D'Almeida 1966; Brown 1970, 1972). These same groups, which are conspicuous and relatively easy to recognize and identify, now figure prominently in the evaluation and monitoring of natural areas (Brown & Freitas 2000; Freitas et al. 2003, 2005).

Threatened Species

Recently, the conservation status of Brazilian terrestrial invertebrates has been summarized in threatened species lists at both the national (Bernardes et al. 1990; MMA 2003) and state levels (e.g., Casagrande et al. 1998; Machado et al. 1998; São Paulo State Government 1998; Bergallo et al. 2000). Although these lists have helped in setting up new and strategically placed reserves for rarely encountered species, their greatest use has been in landscape planning, in monitoring, and in the conservation of entire biotas, especially in the past few years as remaining pristine ecosystems have become progressively occupied.

Table 1 presents an overview of invertebrates on the official Brazilian list (MMA 2003) that have been used for conservation assessment. A few terrestrial species that have declined seriously since the early 1900s or that in some cases have not been recorded since this time are included. These species remain on the red lists in the hope that they may be rediscovered with more intensive efforts, even though natural habitat in their former ranges has been almost totally substituted by anthropic landscapes. Vast areas of still continuous natural forests exist on the steeper slopes in southeastern Brazil, over most of the Amazon, and in some areas of Cerrado, although the latter are rapidly being converted to soybean and other cash crops. In these areas, it is still possible to discover undescribed species of butterflies and ants. For other highly diverse but less conspicuous groups, discovery of new species is commonplace, even in urban areas. An average of 350 species of insects and arachnids were described each year in Brazil between 1978 and 1995 (Lewinsohn & Prado 2002). This is a modest figure because the description rate is bottlenecked by the insufficient number of specialists to extend collections and to organize and study existing holdings. Brazilian specialists are aware of their scarcity, and they estimate that three times the current number of taxonomists are needed (Lewinsohn & Prado 2002).

The contents of Brazilian red lists depended on the knowledge and interest in particular groups and the availability of particular specialists at the time each list was compiled. At present, the largest group by far is butterflies, representing 42% of the terrestrial invertebrates. Thus, although inclusion in a list can be taken as an indication of actual threat, absence of an entire taxonomic group from the list should be treated with circumspection because its omission could result from a lack of information rather than the absence of threat.

We excluded from Table 1 those groups that, although represented in red lists, are little known or not referred to in conservation initiatives: Amblypygi, Pseudoscorpiones, Collembola, Ephemeroptera, and Coleoptera-Dynastidae (16 species). The first three groups were listed as threatened because of endemic cave-dwelling species. The single ephemeropteran is listed because of its rarity in the freshwater immature stage. The scarcity of the listed species of Hercules beetles results largely from the interest they inspire from amateur collectors; hardly any usable scientific information is available as yet on this group.

Onychophora are a case apart. *Peripatus acacioi* Marcus et Marcus became a favorite research subject because of the group's intriguing systematic position and unique physiological and pharmaceutical features. Interested researchers used an opportune moment to propose a state nature reserve to protect this endemic species (Tripuí Reserve, created in 1978, comprises 500 ha of mainly second-growth forest in Minas Gerais). As far as we know, this is the only time that a terrestrial invertebrate flagship species has inspired the creation of a nature reserve in Brazil. This is worth noting because in Brazil invertebrates typically provoke revulsion. Accordingly arthropods, with few exceptions, are regarded as toxic, repellent, pests, or as disease vectors. Moreover, in several major groups, such as Diptera or Homoptera, taxonomic and ecological expertise is restricted or focused on species of economic or health importance.

The Brazilian literature contains three kinds of conservation studies: (1) assessments of status and threats to species (red lists), (2) descriptions of ecology, behavior, and demography (natural history) of threatened species, and (3) discussions of the use of biological indicators for habitat evaluation and monitoring. The first category summarizes the data of many specialists, is often anecdotal, and represents the primary source of information to establish a species' conservation status following defined protocols (e.g., IUCN 2001). The second category includes numerous field studies of threatened natural systems and species, which are fundamental for land-use planning. In the third category, studies of different functional and/or taxonomic groups provide important information for effective conservation and sustainable use of natural resources. These types of information are not equally distributed among the different species and groups (Table 1). Butterflies are the most represented in all three categories, followed by Hymenoptera, Odonata, and Coleoptera (with the most information in categories 1 and 3). The information relevant to conservation on many diverse and important groups of terrestrial invertebrates, however, is still largely limited to the profiles written for red lists (see Brandão & Cancello 1999; Lewinsohn & Prado 2002).

Taxonomic groups that are not on current threatened species lists but are deserving of evaluation as conservation indicators include Coleoptera (Carabidae, Staphylinidae, and Cicindelidae); some hemipteran groups, such as Pentatomoidea; various Diptera families, such as Drosophilidae, Tephritidae, and Bibionidae; and some moths, such as Geometridae and especially the fruit-feeding Noctuidae (Catocalinae).

Geographic Coverage—Biomes and Habitats

It is hardly necessary to expound on the vast differences in taxonomic knowledge among groups of terrestrial invertebrates. Given the size of Brazil, it is also unsurprising that sampling coverage is very unequal among biomes or ecoregions. Based on the number of recently published inventories and surveys, the least-known biomes are the Caatinga and Pantanal, whereas the Atlantic Forest, the Amazon, and Cerrado biomes are better studied (Lewinsohn & Prado 2002).

Even within the relatively better-studied biomes and taxa, geographic coverage is very restricted, and often only a few localities have been sampled adequately. Given the typically high species turnover among localities in tropical regions, extensive geographic coverage is essential for diversity and conservation assessments, but such data are available for very few taxa (e.g., Atlantic forest butterflies, Brown & Freitas 2000). There is clear need for more inventories designed to evaluate the local and regional components of species assemblages and inter- and intrahabitat species turnover (Lewinsohn 1991). They should, if possible, include a range of taxa and functional groups.

Current knowledge of, and research on, specific habitats is also inconsistent. For example, surveys of cave invertebrates are growing steadily (e.g., Prous et al. 2004), spanning taxa from harvestmen and pseudoscorpions to snails and earthworms. Studies of forest canopy faunas (e.g., Adis et al. 1984), on the other hand, are still scarce in Brazil compared with other tropical countries, given their importance and potential for revealing new species.

Rarity, Focal Inventories, and Coextinctions

Invertebrates that live in other organisms—parasites, parasitoids, herbivores, and symbionts—may comprise half of all living species (Lewinsohn et al. 2001) and include many of the least-known groups of terrestrial organisms, such as insects, mites, and nematodes. These animals, rarely found away from their hosts, are likely to be undersampled through traditional collecting methods. To reveal this huge fraction of terrestrial biodiversity, it is necessary to survey their hosts. Such focal inventories also yield information on trophic links between species, thus permitting evaluation of cascade effects on affiliate species resulting from the loss of host species. Many invertebrates, therefore, face the additional risk of coextinction (Koh et al. 2004), although the extent of this has yet to be evaluated.

A well-documented example of host-dependent invertebrates in Brazil can be found in the insects that breed in flower heads of the family Asteraceae (Lewinsohn 1991; Prado et al. 2002). Flower heads provide shelter and food for an extremely rich fauna of endophagous insects, which can be assessed only by collecting these plant parts and rearing the insects from them. An extensive series of host-focused inventories in Brazil revealed a total of 260 insect species, 53% of which were fruit flies (Tephritidae), currently the best studied group (Prado et al. 2002; T.M.L. et al., unpublished data). At least one-third of the tephritid species reared were previously unknown, and most do not have a single specimen in any important entomological collection (Prado et al. 2002, 2004).

A significant part of this hidden diversity was revealed only because our host-focused inventories included rare and endemic plants. An entire subtribe of Asteraceae, the Lychnophorinae, is restricted to mountaintops in central and southeastern Brazil. Despite their narrow geographical distribution and the small populations of many species, the Lychnophorinae harbor an extremely rich assemblage of endophages, none of which was known before our surveys. To date, five new tephritid species reared from Lychnophorinae have been described (Prado et al. 2004), and at least two other species and three new genera of fruit flies, as well as two species of agromyzids and two of Microlepidoptera, await description (Prado et al. 2002; T.M.L. et al., unpublished data).

These insects are strict specialists on rare plants and are thus restricted to the small areas where their hosts occur (Prado et al. 2002, 2004). They are therefore under the triple jeopardy of rarity at both the local and the regional scale and of their dependence on endemic hosts.

Invertebrates as Indicators

Biologists have relied mainly on vertebrates and higher plants as indicator groups of either ecological and landscape units or of particular sources of disturbance and their severity. Invertebrates, however, respond to finer-grained differences in both habitat features and impact intensity (e.g., Oliver et al. 1998). In general, invertebrates show faster demographic and dispersal responses than organisms with longer life cycles. They can also be sampled in larger numbers and at finer scales than larger organisms. These advantages are countered by taxonomic difficulties for many, if not most, taxa, and the time required to sort large samples.

Difficulties notwithstanding, arthropods are being increasingly used for assessing species diversity and composition in distinct habitats or physiognomies and in looking at responses to different disturbance or management regimes. In Brazil butterflies and ants feature as potential indicators in many reports (e.g., Brown et al. 1991; Brown & Freitas 2000; Schoereder et al. 2004), although a variety of other groups are also being assayed for the same purpose.

A theme favored in many recent studies is the response of various taxa to habitat fragmentation, notably in rainforest or cerrado. Apart from ants and butterflies, these studies focus on other groups such as termites (e.g., De-Souza & Brown 1994), dung beetles (e.g., Andresen 2003), and wasps and bees (e.g., Morato & Campos 2000). Fragmentation generally reduces species richness or changes species composition, but there are exceptions. For instance, Tonhasca et al. (2002) found no effect of fragment size on euglossine bee richness in the Atlantic Forest, possibly because of their high mobility and long-distance response to scent traps.

Most of the studies we have referred to describe changes in species richness or composition with fragmentation but do not probe possible causes for this, except through correlation with structural features of fragments. For example, although results from a number of studies show substantial and persistent decreases in predators such as insectivorous birds (Stouffer & Bierregaard 1995), their putative effect on prey assemblages has not been assessed.

Another theme in which invertebrates figure prominently relates to responses to different disturbance or land-management systems. Many, obviously, focus on soil organisms. For example species of termites and earthworms are noticeably different among different land-use systems in the Amazon (Barros et al. 2002), and earthworms exhibit varying responses to differences in tillage in the Atlantic Forest domain (Brown et al. 2003). In southern Brazilian forests, terrestrial flatworms decrease in species richness and change composition with increased disturbance (Carbayo et al. 2002).

Invertebrates as Ecosystem Service Providers

Conservation enterprises have moved from a focus on species or species groups at risk from various stressors to a more inclusive approach in which the effect of species assemblages or even of particular species on ecosystem processes are examined. With this shift in emphasis, species are regarded not solely as subjects affected by environmental conditions or changes but also as agents that modify or counteract such changes.

Comparative studies of soil organisms under different conditions or regimes, such as those cited in the preceding section, offer clear opportunities to evaluate the ecosystem effects of changes in species richness or composition, but to date few investigations have proposed to go that far. The importance of such analyses for conservation, however, is becoming more apparent, as the maintenance of functioning ecological entities is perceived as a prerequisite for long-term conservation.

Dung beetles in Amazonian forest fragments change in abundance, species richness, and composition with fragmentation. These changes have demonstrable effects on rates of dung decomposition (Klein 1989). Andresen's (2003) study of this system demonstrates that secondary seed dispersal and burial is also influenced by dung beetles, with potentially far-reaching effects on forest maintenance or regeneration.

Freitas et al. (2005) summarize a study that showed a notable increase of leaf-cutter ant nests in forest fragments. They attribute this to reduced pressure from predators and parasites, although bottom-up processes related to plant resources may also be involved. Because leaf-cutter ants have a strong impact on vegetation, their increase in smaller fragments may have substantial effects on fragment structure and long-term dynamics.

Apart from their services to nutrient recycling, including retention and flux regulation, invertebrates are also being scrutinized for their pollination services. The effectiveness of pollinators again varies with their abundance, diversity, and composition. It is becoming increasingly apparent that native faunas can be essential for the pollination of cultivated plants as well as of native vegetation (Fonseca & Dias 2004). Even under harsh climatic conditions, as in the Caatinga of the northeast, insects are pollinating agents for the majority of plants (Machado & Lopes 2004). Native bee conservation entails a rewarding combination of an essential ecosystem service with the production of honey and propolis, valuable cash products that can be sustainably exploited in many ecological settings. Insects are therefore key targets of the recently launched Brazilian pollinator initiative (Fonseca & Dias 2004).

Terrestrial invertebrate diversity and conservation offers significant challenges and opportunities. Evaluation of conservation priorities and needs based on single species seems applicable only under very particular circumstances. Clearly, as in other megadiverse countries, Brazilian invertebrate conservation will be better served by initiatives that target habitats or ecosystems. Surveys and analyses of taxonomic and functional assemblages are most effective for these ends. With this in mind, we suggest several priorities: (1) extensive geographic sampling (using a common protocol) of better-known taxa across habitats and ecoregions to improve assessments of spatial and ecological partitioning of species diversity and to identify endemics; (2) inventories focused on particular habitats, including plant and animal hosts, so as to include the "invisible majority"; and (3) more studies of taxa and groups known to be functionally important in ecosystems, including those (such as free-living nematodes) that are difficult to identify and typically largely ignored. The future of invertebrate conservation depends on conserving entire habitats and on a more thorough understanding of their roles in maintaining ecosystem processes.

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