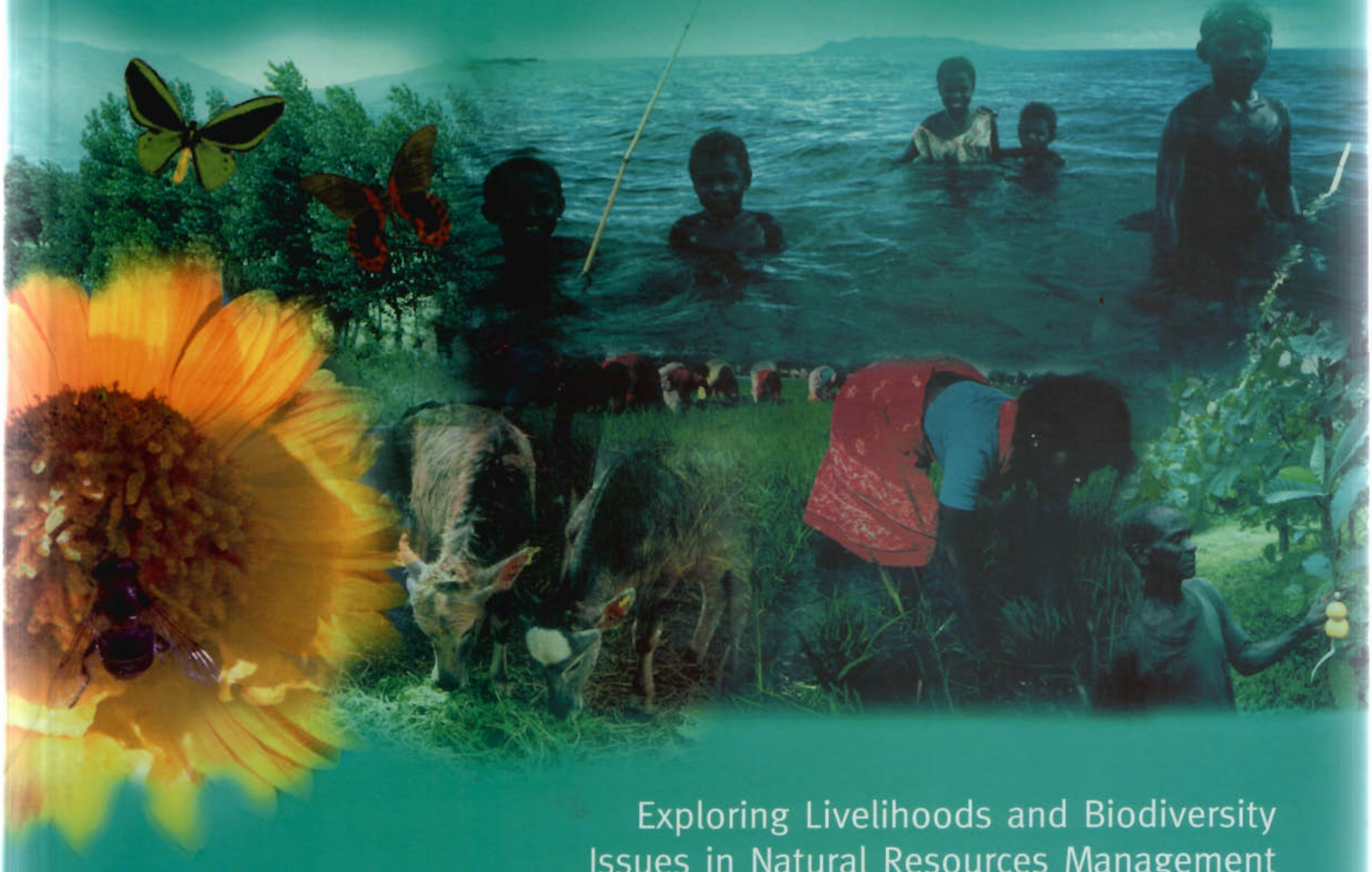
Living Off Biodiversity



Exploring Livelihoods and Biodiversity Issues in Natural Resources Management

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1.1 Introduction

Most people think they know what an insect is, but confusion is widespread and many animals, such as spiders and woodlice, are often referred to as 'insects', when in fact they are only distant relatives. In this paper, the term insect will refer to this strictly zoological sense, though the concepts discussed will have relevance to other groups of terrestrial invertebrates. For example, the role of predatory insects, such as ground beetles (Coleoptera: Carabidae) in the biological control of pests of agriculture, is described in section 2.3.2. Spiders are not insects, but their same roles may be of equal importance to pest management. Similarly, when the conservation of tropical butterflies is discussed in section 2.2.1, the systems for promoting the natural habitats of butterflies will equally well help to conserve other much less familiar groups, such as rainforest invertebrates from centipedes (Arthropoda: Uniramia) to leeches (Annelida: Hirudinea).

Table 1 Major subdivisions of the Arthropoda

Phylum ARTHROPODA		
Sub-phylum CHELICERATA		
		spiders, scorpions, ticks, mites
Sub-phylum CRUSTACEA		
		crabs, prawns, barnacles, woodlice
Sub-phylum UNIRAMIA		
	Super-class MYRIAPODA	
		centipedes, millipedes
	Super-class HEXAPODA	
		springtails, bristletails, **insects**

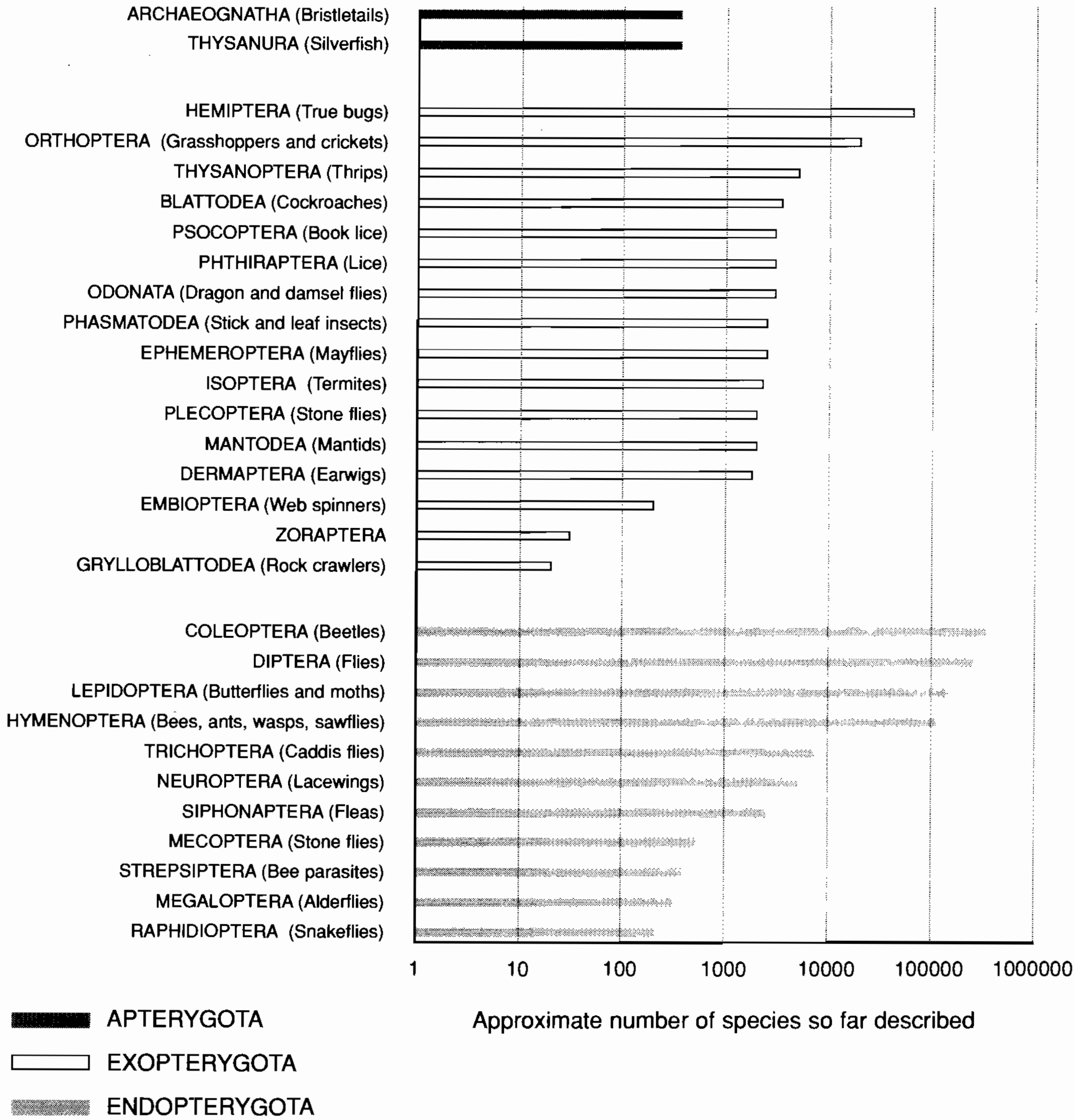
What is an insect? Table 1 shows a simple taxonomic tree for the phylum Arthropoda, showing the relatedness (or otherwise) of major and familiar members. Many of the commonest and most well-known invertebrates appear in the Arthropoda – this phylum may in fact not reflect true relatedness or ancestry, but merely a convenient assemblage of animals with rather similar structures and ways of life. The class Insecta is a sub-division of the super-class Hexapoda, suggesting that not all arthropods with six legs are in fact insects. Most indeed are, but some such as the Collembola (springtails), whilst having analogous ecologies, are not classified as true insects because of morphological and physiological differences. Arthropods do not need to be true insects in order to have a significant impact. For example, Collembola, removed from the class Insecta because of irregular structures, are nonetheless vital components of detritivore food webs in tropical and temperate ecosystems, and thus have great significance for natural turn over and nutrient cycling – they have even been termed 'the plankton of the forest'.

In the main, there are two major subdivisions of insecta (Table 2), the Exopterygota and the Endopterygota, the former lacking a true pupal stage, the latter having one. It is clear that the evolution of a pupal stage has been an enormous boost in the success of insects – more than 80% of all insect species are Endopterygotes – but it must not be assumed that

Table 2 A classification of the Insecta

Class INSECTA		
Sub-class APTERYGOTA (wingless insects)		
Sub-class PTERYGOTA (winged insects)		
	Division EXOPTERYGOTA	
		e.g. grasshoppers, aphids, cockroaches, etc.
	Division ENDOPTERYGOTA	
		e.g. butterflies, beetles, wasps, bees

Figure 1 Major orders of Insecta



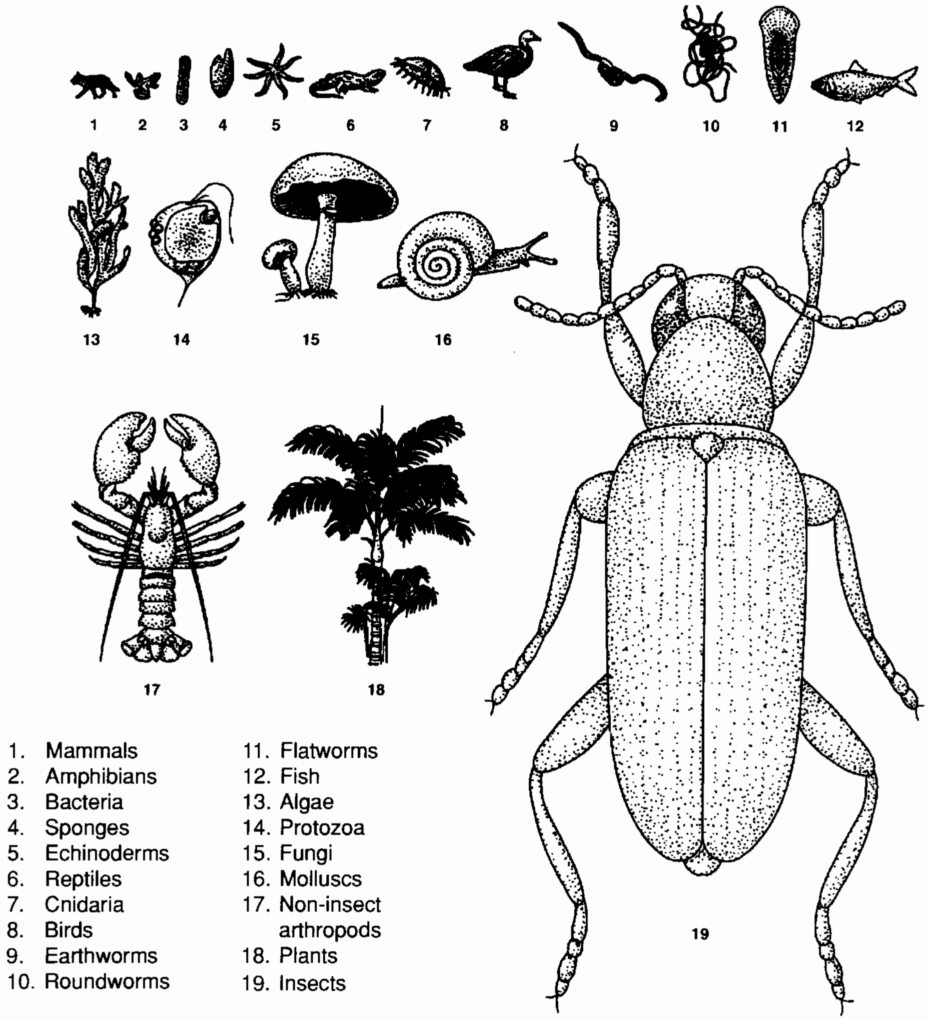
Source: Estimated number of described species from Speight *et al.* (1999)

exopterygotes are of no consequence for humans. In terms of aesthetics, few people would deny the beauty and elegance of adult dragonflies (Odonata: Anisoptera), and even fewer would ignore the unwelcome attentions of bloodsucking adults and nymphs of bedbugs (Hemiptera: Cimicidae). In the majority of cases where insects affect mankind, either in beneficial or destructive ways, the endopterygotes have most impact, or at least make people most aware of their presence. Thus, bees as honey producers and pollinators, butterflies as tourist attractions, or moth caterpillars as silk producers, are well known to enhance livelihoods in one way or another, whilst mosquitoes as disease vectors, weevils (one family of beetle) as crop pests, or fly maggots have detrimental effects.

1.1.1 Numbers of insects – species

Figure 1 presents a summary of the major orders of insects, together with rough estimates of the numbers of species so far described within each. Note that the numerical horizontal axis is logarithmic. There are an inordinate number of beetles, with many more still to be identified. In just one field study from Sabah, northeast Borneo, of over 1700 different species of beetle sampled over a 2-year period, between 60% and 80% were unknown to science (Chung and Speight,

Figure 2 Relative species richness (size proportional to the number of species)



Scale: 1/8 inch square equals 1000 species

Source: May (1992)

1999, unpublished). Today, the consensus of opinion puts the number of insect species in the world at 4–6 million.

Figure 2 compares this number of species with other major groups of living organisms. The numbers of species of plants, birds and mammals (indeed all the vertebrates) pales into almost total insignificance, when compared with the insects.

The success of a group of organisms and, perhaps by inference, its impact on humankind is not just measured in terms of the number of species accrued in the group. It can also be discussed as the range of habitats or food types dealt with, the extremes of environments in which they are able to live, how long the group has been extant, and the sheer abundance of individuals. Ecologically, it may be more useful to break down the insect orders into functional groups according to life style of feeding strategies, rather than merely to count the number of species. Numerous attempts, however, have been made to estimate the numbers of individual insects either globally or locally, and the literature is full of statistics describing how many insects are to be found in certain habitats.

1.1.2 Numbers of insects – individuals

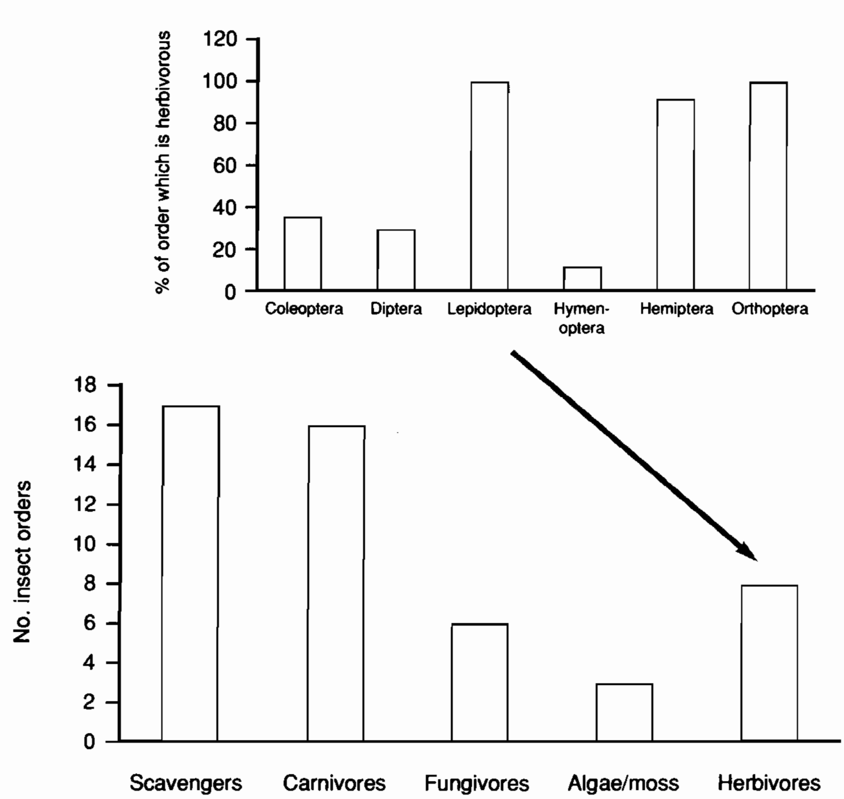
A number of individuals (abundance) of a species is more difficult to obtain than merely to score the species present or absent from a habitat (species richness). Common but immobile or concealed species such as aphids or soil and woodborers may be underestimated or even undiscovered by most ecological sampling systems. The densities of insects which commonly act as disease vectors include mosquitoes, tsetse flies and aphids. They are especially significant when it is considered that these are low-density pests, where only a few (as few as one) individuals are required to pass on diseases such as malaria, sleeping sickness or potato leaf curl.

1.1.3 Life styles of insects

Southwood (1973) described the life styles of the major insect orders in terms of their main food supplies, thus defining their general 'trophic slots'. If it is assumed that each order has evolved but once, and that all species within the order are to some extent related so that they represent a common ancestral life style, then it can be seen that the major life styles were detritivory followed by carnivory. Herbivory (or phytophagy), feeding on living plants (or the dead parts of living plants such as heart wood), is represented by only eight major orders, suggestive of what Southwood (1973) called an 'evolutionary hurdle'. Significantly, however, over 50% of all insect species occur within the herbivore orders, suggesting that once the 'hurdle' was overcome, rapid and expansive species radiation was able to take place.

Each of the major feeding guilds described here can have an enormous impact on livelihoods. Scavengers such as termites (Isoptera) are vital components of nutrient recycling in tropical forest and savanna ecosystems, and only impinge negatively on humans in the minority of cases where they attack and destroy farm and forest crops, or buildings. Carnivores may play important roles in natural biological pest control programmes where, for example, predatory ladybird beetles (Coleoptera: Coccinellidae) suppress populations of plant-feeding aphids. Blood-feeding carnivores, such as tsetse flies (Diptera: Glossinidae), can cause immense suffering and death to people and

Figure 3 Major feeding guilds of Insecta showing dominance of herbivory



Source: Southwood (1973)

their livestock because of their role as vectors of sleeping sickness. Herbivores are massive competitors with humans for crops, when they become farm, orchard or forest pests, but when pollen and nectar collectors pollinate crops and produce honey and wax, they are extremely beneficial.

1.2 Insect biodiversity

Biodiversity may be defined as "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD, 1992). Both the numbers of species, and the abundances of each one, are important parameters in describing both the success of insects, and the various ways in which insects affect humans for both good and bad.

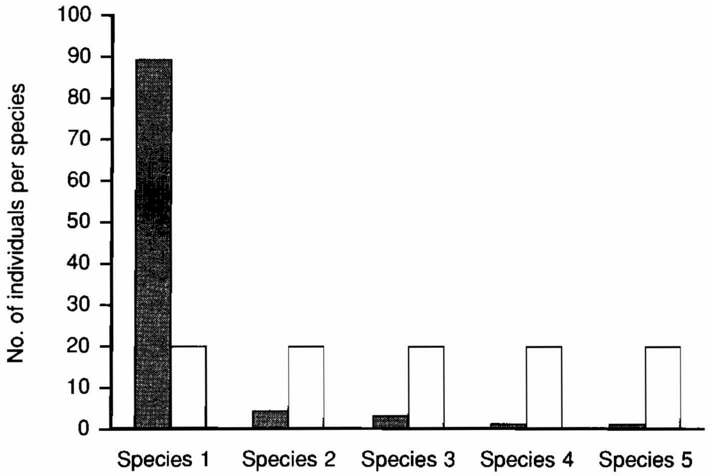
It is often forgotten just what the term species (bio)diversity means ecologically. In the hypothetical example shown in Figure 4, five species are sampled from two habitats. The *species richness* of both habitats is, by definition, five. However, the abundance of each species differs between the two habitats – species 1 in habitat 'A' is much more common than in habitat 'B', for example. *Species diversity*, when used in its proper, scientific manner, is a mathematical integration that combines richness and abundance to give unitless data that can be used to compare habitats and samples. One diversity index, that of Shannon-Weiner, calculates the species diversity of habitat 'A' to be 0.19, and that of habitat 'B' to be 0.69. In other words, despite having the same richness, habitat 'B' is much more diverse. Clearly then, biodiversity has something to say about the rarity or evenness of a habitat or sample, and perhaps its stability in space and time, and not just about the number of species present. As far as humans are concerned, all these concepts may be important in one scenario or another.

1.2.1 Biodiversity indicators

The myriad of insects in the world, their average small size, and the huge numbers still unknown to science, make assessment of insect diversity in most habitats both problematic and time consuming, especially in tropical countries (see also Watt, 1999). The need for biodiversity information has led to the development of biodiversity indicators and a range of rapid biodiversity assessment techniques. Biodiversity indicators may be defined as a genetic measurement, a species or species guild, a measurement of habitat structure or some other feature that provides a relative estimate of total biodiversity (Watt, 1999).

The simplest form of indicator is that of a single species which can indicate the presence of a certain type of biodiversity. Among several insect groups recommended as indicators are the coleopteran families Scarabaeidae (chafers and dung beetles) (Halffter and Favila, 1993) and Cicindelidae (tiger beetles) (Pearson, 1994). Pearson and Cassola (1992) suggest that the latter group of beetles are able to indicate regional biodiversity patterns by virtue of

Figure 4 Hypothetical demonstration of the term 'species diversity'



world-wide distribution, their presence in a wide range of habitat types and specialisation of individual species within habitats, and the facts that their taxonomy and ecology are well known. Another important point is that they are easy to sample compared with many other insect species. Hence, the value of using tiger beetles, rather than other taxa, is that the number of species can be reliably estimated in a short space of time.

Other authors support the use of different insects. For example, it may be possible to use a single butterfly group as an indicator of overall butterfly diversity, and Beccaloni and Gaston (1995) suggest the use of ithomiine butterflies (Nymphalidae: Ithomiinae) which comprise an average of 4.6% of all butterflies. More generally, Brown (1991) reviewed a long list of criteria for insect indicator groups and suggested that heliconid butterflies and ants are the best indicator groups, followed by termites and certain families of Coleoptera and Hymenoptera. Though biodiversity indicators may speed things up, in the final analysis we must ask why it is important to measure biodiversity anyway – is it merely 'stamp collecting', or is there a greater worth?

1.2.2 The ecosystem context of insect diversity

Insects play so many roles in terrestrial ecosystems that it is near to impossible to cover every scenario where this role has ecological significance. One example is the role of insects in tropical rainforest ecology. Figure 5 shows a simplified food web diagram produced by extensive research in a rather simple type of rainforest in Puerto Rico. Nowhere in this diagram are insects mentioned by name: they appear in so many parts of the food web, and form the majority of arboreal invertebrates, large numbers of litter invertebrates, and of course all the termites. It is quite clearly entirely unrepresentative to depict such minor groups as frogs and rats in any way as abundant as insects, but the problem is that vertebrates such as birds and frogs are much easier to sample, identify and generally assess for biodiversity.

It can be seen from the figure that insects occur predominantly in the first three consumer trophic levels. The primary consumers comprise of the insect herbivores, chewers and sapfeeders, discussed above. The vast majority of canopy herbivory in a rainforest is the responsibility of defoliating orders such as grasshoppers and crickets (Orthoptera), stick and leaf insects (Phasmida), sawflies and ants (Hymenoptera), beetles (Coleoptera) and moths (Lepidoptera), and the sapfeeding orders such as the aphids, hoppers and scale insects (Hemiptera) and the thrips (Thysanoptera). Even within one insect order, herbivory can take many forms and involve a large number of insect species, for example, beetles associated with herbivory (phytophagy) on a single individual tree fill every conceivable niche, all of which gives rise to very high measurements of species richness ('biodiversity').

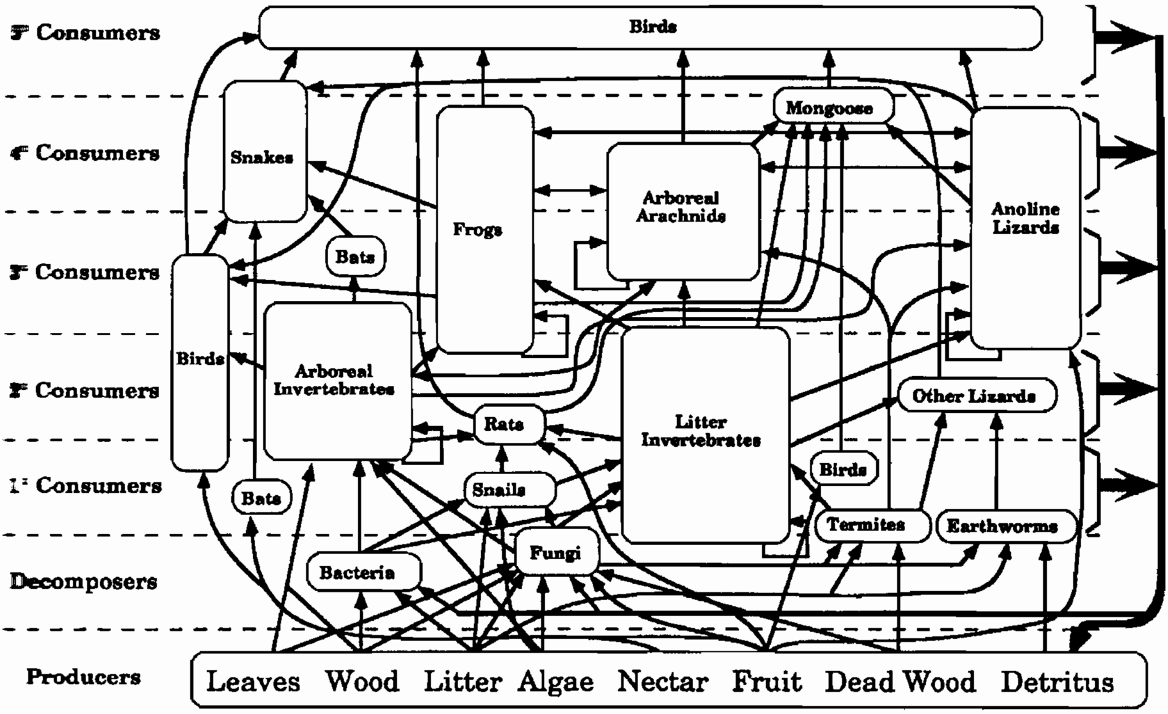
Feeding upon the herbivore trophic guild are the predatory and parasitic insects, who themselves can have enemies. Whether or not such insects have a regulatory role on the herbivore trophic levels below them, hence acting as natural biological control agents, is a vital but little understood concept in its own right. Nevertheless, all levels of insect populations can also be food for other animals; many bird species rely almost entirely on insect food (mainly leaf-feeding larvae) on which to rear their young. The diagram from Puerto Rico cannot present subsets of insect activities that may be found in such a rainforest habitat. These will include the pollinators such as bees and butterflies, the detritivores such as dung beetles, and the scavengers such as burying beetles.

Is every single species in this rainforest food web actually required to maintain and protect the stability of the system? What would happen if several of these insect species were removed from the system? There is probably considerable redundancy in these complex systems – such high diversities are not required for the efficient functioning of the rainforest. Take termites, for example, Lawton *et al.* (1996) looked at the diversity of these soil and wood insects in a rainforest in Cameroon, and concluded – speculatively – that it would be possible to lose a large number of species without significantly impairing the rates of soil mineralisation or litter decomposition. Functionally, we might not need very high biodiversity, it is what the insects in an ecosystem do which counts, not how many species there are.

1.2.3 Patterns of insect diversity

The number of species within a specific insect group can vary markedly from one part of the world to the next, according to latitude, longitude and altitude. There are, for example, less than 70 species of butterfly in the UK, around 300 in Europe, and over 700 in one

Figure 5 Aggregated food web for the El Verde Rainforest in Puerto Rico



Source: Waide and Reagan (1996)

area in Brazil (Robbins and Opler, 1997). Biodiversity in general tends to increase from the poles to the tropics, for a variety of reasons, such as environmental stability and predictability, productivity, number of habitats, evolutionary time and the obvious factor of increased sunshine (Rohde, 1992). There are, of course, exceptions to this rule. Most aphids, for example, are found only in temperate regions, though some species are endemic to the tropics and are well adapted to tropical conditions (Dixon *et al.,* 1987).

2 Insects and livelihoods

While conserving biodiversity may be perceived as a goal in itself, many people, particularly poorer people, depend on the goods and services that biodiversity provides. To most people in the world, animals and plants are of no interest unless they have some use, and that very few indeed are actually perceived as useful. Lovejoy (1994) sums up this basic approach when he says that "whilst people may be willing to acknowledge that as living entities, they need biological resources, most labour under the illusion that all that really matters is a handful of plant and animal species used as foods enlivened by a few more used as spices, with a couple of domestic animals such as dogs and cats thrown in for amusement". However, more recent work emphasises the importance of a wide range of benefits that are derived from biodiversity. Table 3 describes some of the marketed and non-marketed benefits of insects. For poorer people especially, there may be a greater dependence on a broader range of uses, than say wealthier groups, including wild sources of food and medicines, soil fertility, crop protection, as well as commercial production for local and export markets. These all provide important and valuable alternative sources of a wide range of goods and services where access through markets may be severely constrained, as well as a variety of low-cost, income generating opportunities.

We may distinguish between two levels of insect use, the first with individual or single species or related groups, and the other with whole communities. Following are examples of each, although impacts may

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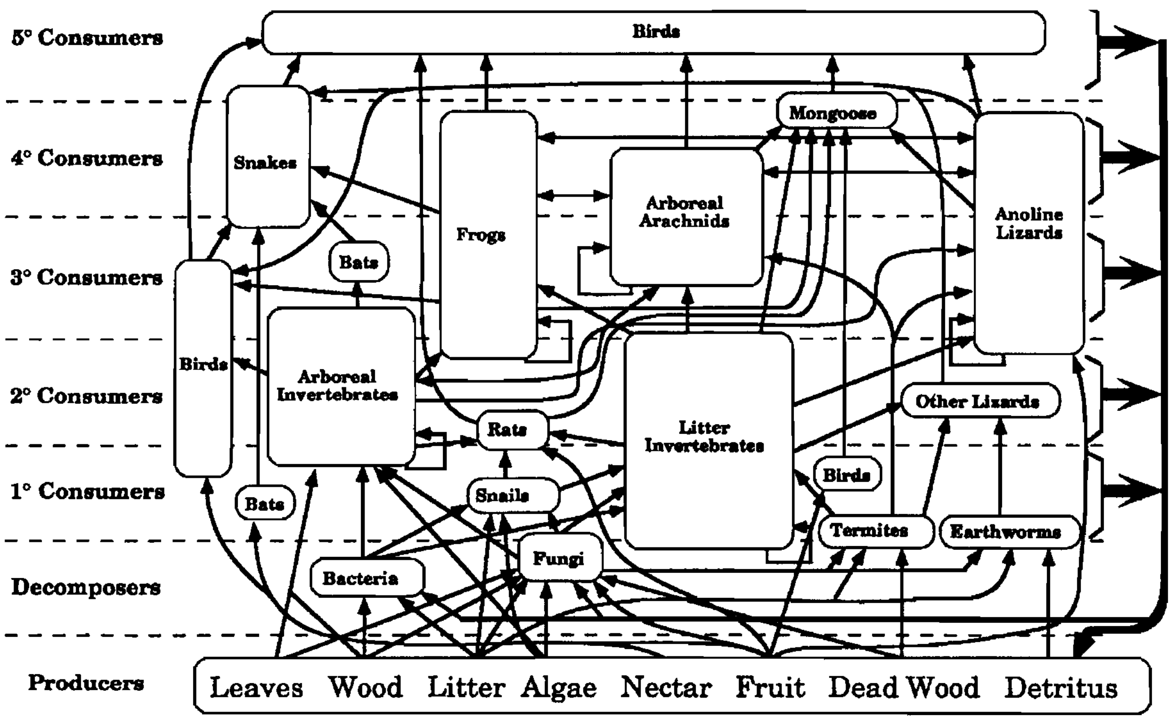

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Table 3 Perceived uses of insect diversity

Ecosystem services
Direct use
extractive use, e.g. collection of insects for food
non-extractive use, e.g. recreation or tourism
Indirect use
e.g. pest management, pollination, soil decomposition, food web components
Individual organism services (material goods)
Direct use
e.g. silk, honey, cochineal, lac production
Indirect use
e.g. ecosystem monitoring for pollution and recovery
Source: Edwards and Abivardi (1998); Lovejoy (1994); Myers (1996)

overlap from the single species to community level. For example, pollination of crop plants may be carried out by honey bees specifically (single species) and/or by a myriad of background, wild pollinating insects (community level). On the other hand, parasitic wasps seeking out pest insects in a biological control programme may also incidentally act as pollinators.

2.1 Singles species (beneficial)

2.1.1 Silk farming

Although wild silk is produced from a variety of moth species, only the silkworm is reared in huge numbers. Cherry (1998) suggests that this insect has been domesticated for so long that it probably no longer survives in the wild. The scale of the export trade in silk in selected countries of the South is still very significant. In 1997, it yielded US$ 463,764,000 from processed silk sales and exports and US$ 16,439,000 from silk producing cocoons (FAO, 1998) (Table 4). China is still the main producer and exporter, but the value of the silk moth to many other countries is of major importance. While the majority of the benefits that may accrue from silk production occur at a national level, the structure of silk production provides low cost opportunities for small farmers to participate in the industry. For example, in Kerala State, southwest India, local farmers, as in many other countries, cultivate mulberry bushes to feed the silkworms. Their 1998 projections plan to produce over 200 t of raw silk a year from 12,500 acres of mulberry. An individual farmer could make between Rs 2000 and Rs 6000/month, depending on the quality of silk produced, by growing the bushes and rearing silkworm cocoons to sell to the State Sericulture Co-operative Federation in Kerala. In this way, local people are able to make a dependable living in collaboration with a larger body which processes the farmers' produce. In 1998 in Kerala, nearly 4500 farmers benefited from silkworm production, but the number of local growers making a living from sericulture could easily exceed 10,000 if prices become competitive with silk imports (Indian Express Newspapers, 1998).

A comparable silk project in Bangladesh illustrates other beneficial aspects to local people. The government of Bangladesh is being supported by the World Bank to restructure and revitalise the country's silk industry. One of the major benefits will be to increase the income of small-scale producers and rearers, whose daily earnings are expected to triple over the period of the project. In addition, there should be increased employment opportunities in all areas of silk

Table 4 International silk exports for 1997

Country	Value (US$ 1000)	Quantity (t)
(a) Processed silk		
Brazil	6790	905
China	312457	14382
China (Hong Kong)	103786	4501
India	5701	806
Malaysia	1454	100
Thailand	1836	244
Vietnam	1400	60
Total developing countries	463764	24098
(b) Silk producing cocoons		
Brazil	3295	88
China	11926	293
China (Hong Kong)	202	12
Total developing countries	16439	448
Source: FAO (1998)		

production. Finally, and most significantly, since around 80% of small-scale silk producers in Bangladesh (and many other countries also) are women, the project is expected to have a positive impact on the empowerment of women, helping them not only to become financially self-sufficient, but also to become established entrepreneurs (World Bank, 1998).

2.1.2 Honey production

The collection of sweet honey from wild bees is the oldest positive association between insects and humans. The raiding of bee colonies by foragers dates back hundreds of thousands, if not millions, of years. To this day, people in many countries rely on wild honey not just as food, but also to treat illnesses and to provide external sources of income (Costa, 1998). The culture of the honey bee, *Apis mellifera* (Hymenoptera: Apidae) and its relatives is a rural industry the world over. Clearly some countries have a higher density of hives than others, particularly in parts of Africa.

The size of the export market varies greatly. Some countries such as Ethiopia produce honey primarily for domestic consumption and export relatively little. Mexico, on the other hand, which up until 1991 was the world's fourth largest producer of honey, exports a large proportion of its harvest (Netcall, 1998). The most valuable type of honey in Mexico is produced by bees that are able to forage on wild flowers, blossoms and other natural vegetation. This clear amber honey, called Colima, is nearly twice as expensive as the cheapest sort. This is one example of where conservation of natural habitats in which bees can forage may generate considerably more revenue.

Honey is obviously an important cash crop, and many local people are keen to take up its production, albeit on a fairly small scale. In the Garwhal mountains of Himalayan India, large mammals including the snow leopard and black bear, are endangered because of over-grazing and excessive harvesting of fuelwood and fodder (BCNet, 1999a). Local communities are being encouraged to use their forest resources sustainably through income generating activities including wild silk and honey production. Local bee species (*Apis cerana*) forage for nectar in natural forests and alpine meadows (as well as agricultural land), and new beehives are deployed around houses. Villagers, especially women, will thus be provided with sustainable revenues and the local biodiversity conserved. In contrast, honey production in Malawi is already an important source of revenue for rural communities. Indeed over a quarter of all people questioned showed a keen interest in becoming involved (Table 5). Clearly, honey has an important role to play in the alleviation of poverty in such areas, and the essential low-technology approach to this industry requires the maintenance of natural habitats to provide nectar sources.

However, honey production, has had some problems. Not all honey bees are equally productive in different

Table 5 Resources of interest to communities around Kasunga National Park, Malawi

Benefits	Subsistence famers (% total positively interested)	Commercial farmers (% total positively interested)	Townsfolk (% total positively interested)
Honey	27	21	4
Caterpillars	26	20	4
Firewood	18	15	16
Materials	18	13	13
Mushrooms	20	18	4
Land	12	16	1
Meat	11	4	13
Fish	16	3	2
Ivory	1	0	1
Recreation	0	0	1

Source: Mkanda and Munthali (1994)

countries, for example, the European honey bee *Apis mellifera* does well in the US but is not so successful in South America. To overcome this problem of low productivity, in the mid-1950s, Brazil imported some queens from a highly productive but also very aggressive strain of bees (*Apis mellifera scutellata*) from Central Africa. Inter-breeding programmes between the so-called 'African killer-bee' and the more docile European strain failed, and the Africanised bees escaped and began to move north and west (Agnew, 1998). Attempts by Mexico and the US to eradicate all these bees in a narrow part of Mexico failed, and by 1990 the bees were established in Texas and Arizona. Not withstanding the threat to human life and health, the major worry about Africanised bees is their seemingly relentless spread through the US, and their ability to out-compete and eradicate indigenous bee species (Griswold *et al.,* 1998). The impact of the Africanised honey bee on honey production and pollination has yet to be assessed, but since they are much more difficult to handle, honey production and all that goes with it may be severely constrained.

2.1.3 Gaz, cochineal and lac production

Three rather dissimilar products are derived from insects in the tropical world, all with their niche markets, but from which people can derive substantial revenues on both local and national scales. Gaz is one of the most popular traditional sweets in Iran. This nougat is made with a sweetening agent, gaz of Khunsar, exuded by the last instar nymph of a small insect, *Cyamophila astragalicola* (Hemiptera: Psyllidae), which feeds on a spiny shrub, *Astragalus adscendens* (Leguminosae), that grows wild in western-central Iran. Biblical *manna* comes from a similar source on tamarisk bushes in Sinai. The host plant grows wild in areas with a temperate but arid climate, and it is often the dominant species in natural gullies and slopes. Natural habitats (and hence biodiversity) are maintained since local people have felt, until recently at least, that cutting the gaz-bearing shrubs would bring bad luck – sheep and goat grazing was prevented for the same reason. Annual revenues from the production of gaz in Iran reached a peak in the mid-1970s, but there has been a steady decline into the 1980s. Problems with exchange rates against the US dollar cause difficulties in assessing these declines (Grami, 1998). However, populations of natural enemies of the psyllid may have increased, reducing population densities. Even the expanding honey industry may be a culprit, in that the honeydew and sugar exudates which the psyllid produces and which people collect to make gaz are collected instead by foraging honey bees when nectar is in short supply.

Cochineal is a natural red (or carmine) dyestuff produced by a scale insect, *Dactylopious coccus* (Hemiptera: Coccidae), which feeds on prickly pear cactus, *Opuntia ficus*, in South America. It was found in both the pre-Hispanic cultures of Mexico and Peru, and the latter is now the biggest producer in the world. Local industries produce around 650–700 tons of dried cochineal annually, of which about 340 tons are exported. The rest is made locally into carmine (Colca APX, 1998). Whilst never reaching huge proportions, the people who farm the cacti and collect and process the dyestuff make a good living from the insect. However, as the systems become more industrialised, the need for habitat biodiversity becomes less and less significant.

Lac, or shellac, a non-timber forest product (NTFP) from Asia, is a natural resin secreted by the lac insect, *Laccifer (=Kerria) lacca* (Hemiptera: Tachardidae). This insect is a sapfeeder on a sub-Himalayan Indian tree, and uses the resin as a hard protective shell under which it feeds and grows. Twigs supporting the insect are collected by local people to produce sticklac, which is then washed and cleaned to render seedlac. At this stage, the product is taken to factories where it is refined into shellac. India is the largest producer and exporter, earning approximately £5 million a year in exports. Shellac may be used for varnishes, polishes, ink formulations, glues, cements, emulsions and cosmetics (Allandetrobert, 1999; Sequeira and Bezkorowajnyj, 1998).

However, the production and export of lac from India has declined markedly over the last 50 years or so. The authors suggest that this type of decline is typical of NTFPs destined for industrial use, where industry attempts to bring production volume and costs under control by either replacing supplies from wild sources by those from plantations, or, as in the case of lac, by synthetics. Sequeira and Bezkorowajnyj (1998) also suggest that a possible contribution to the reduction in lac production, notwithstanding heavy competition from other countries such as Thailand, is the reduction in forested areas in India. In southern Rajasthan, the principal reason given by villagers for stopping lac collection was the severe reduction of tree cover in the area. Lac insects only produce harvestable quantities of lac from mature host trees, so in order to preserve and promote the lac industry, sustainable management of natural forest systems in the region is essential. Undoubtedly, small-scale industries such as the production of shellac can have important impacts on poor people. In India, shellac is an agricultural export along with other commodities such as tobacco, cashew nuts and sesame seeds, and the Government of India has perceived such exports as having "the greatest potential for raising farm incomes, tackling unemployment and earning foreign exchange. The impetus for accelerated growth in agricultural exports is envisaged through enhanced infrastructure support and by building up a conducive policy environment" (Economic Survey of India, 1997). The major problem concerns the marketing cycle, which begins at the small producer, flows through the trader in the village market, through middlemen to bigger merchants and eventually to manufacturers who process the raw material. The refined material is then exported, but any fluctuations or perturbations in the market result in ripples flowing back down the chain, such that the producer in the village who forms the weakest link, suffers the most when things go wrong (Rao and Singh, 1990). One of the best ways to produce lac in a subsistence system is to combine it with agroforestry, so that the insect host trees can form part of the overall production system, and remain useful (fuel, fodder, shade, etc.) even if the insect is absent. In the highlands of Yunnan province in southern China, ethnic communities practise various forms of agroforestry which incorporate shellac production. In this way, if the unstable shellac market drops, the host trees are still preserved until prices rise again – a system which demands no work and no investment (Saint-Pierre, 1991).

2.2 Multiple species (beneficial)

2.2.1 Butterfly farming

International laws maintained by CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), enforce strict regulations on the export from source countries and the import into sink countries of many species of plant and animal, either as live material or as dead and/or processed bodies. Increasing demand for butterflies can be met by the local (indigenous) rearing of butterfly specimens, in ways that not only produce lucrative quantities of dead and live stock, but also insist on the preservation of natural habitats (and hence local biodiversity). Natural vegetation is required: (a) to produce copious quantities of food plant for caterpillars to be reared under semi-artificial conditions; (b) to provide genetic heterogeneity in the insect populations by harbouring wild populations of species of butterfly from which to invigorate the cultures.

Butterfly farming is said to be a wholly appropriate set of technologies for local people in poorer rural communities: it is easily understood by the people

Box 1 Butterfly farming in Asia

Papua New Guinea is the only country in the world whose constitution designates insects as a renewable natural resource. It has developed an agency, the Insect Farming and Trading Agency, to develop this insect resource sustainably, which now sells nearly US$ 400,000 worth of Papua New Guinea insects yearly to collectors, naturalists and scientists. It buys these insects exclusively from villagers. The income is of the order of several hundreds of dollars per year, critical in a country where there is only 15% formal employment. This helps local people realize that the forest is an important source of income as long as it is left alone and nature allowed to flourish (Orsak, 1998).

Irian Jaya, Indonesia, forms Papua New Guinea's neighbour on the island of New Guinea, and is even more remote. Butterfly farming projects are being set up in the Arfak Mountain Nature Reserve (AMNR) as a joint venture with the World Wide Fund for Nature (WWF) and are funded by the Biodiversity Conservation Network (BCN), part of the Biodiversity Support Programme of USAID. This reserve is a mixture of lowland rainforest and montane moss forests, sheltering a large diversity of rare and endemic species, such as tree kangaroos, birds of paradise and birdwing butterflies. The local people who live on the edge of the reserve practise subsistence agriculture, the collection of wood for fuel and construction, and historically at least, poaching (BCNet, 1999b). The project represents a large shift in local attitudes to income and economics. International commerce is a new concept, and there must be some speculation about whether or not such a project will remain viable and self-sustaining once the overseas advice and funding has ceased. Finally, it has to be assumed that an international market will persist.

who are using it, it is environmentally non-destructive, uses locally available materials and is economically and environmentally sustainable. Furthermore, it generates local employment, supports rural economies, stems rural to urban migrations, especially of younger people, and it encourages local communities to have a vested and long-term interest in a national park or forest reserve. Finally, but very importantly, butterflies can generate foreign exchange income for hard currency starved economies (Brinckerhoff and Sabido, 1998). However, butterfly farming cannot be a cure-all for butterfly-rich but cash-poor countries, and the market can easily become saturated. Nevertheless, some countries have succeeded with butterfly farming, including Malaysia, Philippines, Thailand, Taiwan, Kenya, Madagascar, US, El Salvador, Costa Rica, Papua New Guinea and Indonesia.

On a wider scale, tourists, both local and foreign, are prepared to pay for exotic holidays and expeditions to far-away places, wherein insects (at least some of them) add to the biodiversity curiosity. However, this source of income is limited. Not every country with a patch of intact rainforest can offer it to such visitors, and even if it did, butterflies and other attractive insects are only a small part of the biodiversity interest.

2.2.2 Insects as food

Table 6 reviews some of the major groups of insects used as food in various parts of the developing world. DeFoliart (1995) suggests that maybe more than 1000 species of insect form substantial parts of the diets of indigenous people. It is also somewhat ironic to note that serious crop pests (see below), such as locusts and grasshoppers, for example, have been included in the diets of almost every culture with any history of food-insect use. Insects provide a vital source of protein and other nutrients. However, it has been suggested that the aversion of Westerners to eating insects and the diffusion of Western farming methods ignore or undermine local practices in the South (DeFoliart, 1999). For example, the Tukanoan Indians of the northwest Amazon consume over 20 species of insect, the most important being beetle larvae, ants, termites and caterpillars (Dufour, 1987). They provide up to 12% of the crude protein derived from animal foods in men's diets, and 26% in those of women. Insects may also be used as animal feeds. Termites, for example, are frequently used in villages as natural food supplements for chickens or guinea-fowl, via the simple expediency of breaking open termite nests which abound in the area and allowing the fowl to forage to their hearts content (Hardouin, 1995).

Probably the best example of the use of edible insects is the mopane worm, larvae of the mopane (or mopanie) emperor moth, *Gonimbrasia belina* (Lepidoptera: Saturniidae). In southern Africa, this caterpillar has become a cash 'crop', with an annual market of tens of thousands of tonnes, and caterpillars fetching around £3/kg in rural areas and up to £15/kg in urban areas (Bartlett, 1996). Ironically, it is possible that conservation projects attempting to boost populations of large grazing mammals in game

Table 6 Insects as food

Common name	Countries
Longhorn beetle	Indonesia, Philippines, Papua New Guinea, Sri Lanka
Weevils	Colombia, Venezuela, Papua New Guinea
Chafers, rhino and dung beetle	India, Burma, East Africa, Thailand, Philippines
Bees	Brazil, Mexico, Democratic Republic of the Congo, Thailand
Ants	Northern South America, South and Central Africa, India, Burma, Thailand, Papua New Guinea
Termites	Angola, Nigeria, Uganda, Zimbabwe
Silk moths	Botswana, Nigeria, Zambia, Zimbabwe, Democratic Republic of the Congo, South Africa, Mozambique
Witchetti grubs	Papua New Guinea
Grasshoppers	Mexico, Thailand, southern Africa

Source: DeFoliart (1995)

reserves may deprive locals of this food source in that, in Botswana at least, local absences of mopane worm may be caused by extensive herbivory on their host plant (Styles and Skinner, 1996). The consequences for the local ecology are severe if locals collect too many mopane worms: population crashes of the insect have been observed in South Africa and Mozambique, for example, with severe consequences for local people as well as the natural ecology. As foodstuffs, they are high in crude protein, about 65% of their dry weight. They are undoubtedly equivalent to meat or fish, and of course are much less trouble to rear, cultivate or collect – in fact, they are preferred to beef in some localities.

2.3 Community level (beneficial)

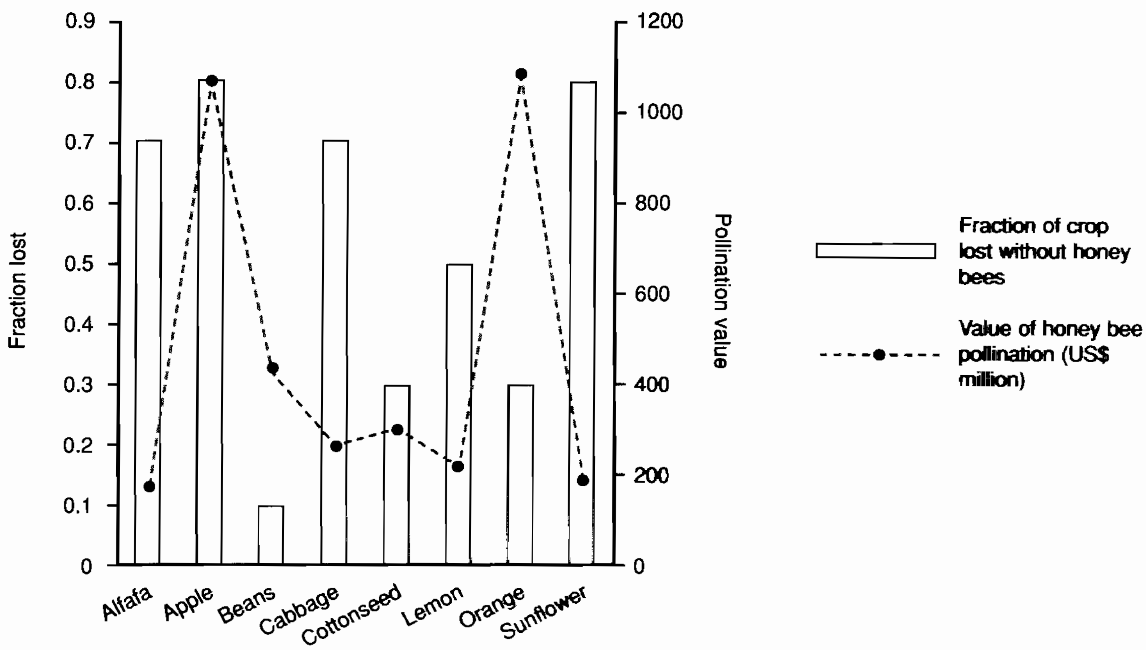
2.3.1 Pollination

Hundreds of species of agricultural plants in 40 plant families, including around 400 agricultural crops world-wide, are pollinated at least in part by bees (Southwick and Southwick, 1992). It is difficult to put a value on pollination on a global scale. Figure 6 shows some estimates for certain crops in the US, but only for honey bees. The scale of the system is clearly enormous.

On occasion, there have been spectacular success stories with insect pollinators in other parts of the world. Many tropical countries, such as Malaysia, Indonesia and New Guinea, have benefited enormously from the importation and release of a small weevil called *Elaeidobius kamerunicus* (Coleoptera: Curculionidae). This beetle is a vital pollinator of oil palm, *Elaeis guinensis,* both of which are natives of West Africa. In countries where oil palm is an exotic, no insects were available to pollinate the plant, and so several weevil species were collected and released during the 1980s. Table 7 shows the distinct improvement in crop production after insect pollinators were introduced into Indonesia.

No economic value can be calculated for natural pollination in non-managed habitats. In fact, it is estimated that about 220,000 out of 240,000 species of plant for which the mode of pollination has been recorded require an animal of some sort – this includes

Figure 6 Economic value of pollination in the US



Source: Southwick and Southwick (1992)

Table 7 Impact of pollinating weevil on oil palm production in Indonesia

Parameter	% increase (range) when compared with absence of pollinator
Average bunch weight (a)	20–67
Average bunch weight (b)	89
Average bunch weight (c)	100
Fruit set	17–42

Sources: Chairani *et al.* (1989); Taniputra and Muluk (1987, 1989)

about 70% of the agricultural crop species that feed the world (Nabham and Buchmann, 1997). Most of these animals are insects, ranging from bees to flies, butterflies, beetles and many other orders. If it is assumed, on a rough estimate, that one third of all human food is derived from products pollinated by wild pollinators, then if these pollination 'services' were removed, the effect on humans would be catastrophic. Undoubtedly, modern agricultural methods can have deleterious effects on pollinator populations: within agricultural environments, activities such as land clearance, cultivation, irrigation, pesticide usage, overgrazing and the spread of monocultures have all contributed to a substantial decline in numbers of insect pollinators (Richards, 1993). Whether or not actual high biodiversity is required is rather more difficult to determine. Certainly for generalist plants which do not rely on any specific insect species for pollination (this includes most of our common farm and horticultural crops), it could be argued that any pollinator will do, as long as there are plenty of them. Stingless bees, for example, extremely common tropical and sub-tropical flower visitors, tend not to be generalist nectar gatherers, and probably are not important as pollinators of most plants (Heard, 1999). However, in natural habitats such as rainforests where pollination ecology and adaptation is extremely specialised, the loss of only a little biodiversity might destroy all the essential pollinating insects for a plant species, with the resultant demise of that plant.

2.3.2 Biological control

Biological control is defined as the "action of natural enemies on a pest population such that the pests are maintained at a density lower than that if the enemies were absent" (deBach, 1965). Several definitional problems arise – what is an 'enemy'?, how do we define 'maintained'?, and how low is low enough for economically significant results? Three general types of enemy can be recognised, i.e. predators (mammals, birds and especially other insects, such as ladybirds and lacewings), parasitoids (wasps and flies whose larvae feed on or in the bodies of pest insects, killing them within one generation), or pathogens (fungi, viruses, bacteria or nematodes). In most cases, the success or failure of a biological control programme hinges on the relative importance in pest (herbivore) population dynamics of either 'bottom-up' regulation (influence of the host plant on the herbivore), or 'top-down' regulation (influence of natural enemies). For long-term, dependable biological control, relationships between the pest and its enemies must act in a density-dependent fashion, i.e. an increase in the density of pests must be followed by a proportional increase in the mortality caused by the enemy.

Biological control is not the instant 'green' answer to pest management. It is frequently inappropriate and too weak to play an economically viable role in pest management in intensive agriculture or horticulture, where fast growing single species are cultivated for high yields. Insect natural enemies have limitations. Predators, whether they be mice or ladybirds, have a fundamental problem of satiation – they simply cannot eat more than a maximum per unit time, assuming that they have already managed to find and kill the pest. A parasitoid is a special type of parasitic insect where the larva of a wasp or fly consumes the body of its host so that the host dies within one generation of the parasitoid. Parasitoids tend to be limited by their host-finding ability (usually more specific than that of generalist predators), and their fecundity (number of eggs per female). Both predators and parasitoids tend to be unable to regulate pest populations when the latter reaches high, epidemic levels.

One recent example from the tropics of successful biological control involves the cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae). Cassava (*Manihot esculenta*) is a vitally important food security crop for smallholder farmers in areas of the tropics where climate, soils or social problems otherwise limit food production. The mealybug is a sap-feeding insect, related to aphids, whose native home is South America, and like so many other exotic pests, it was introduced accidentally into Africa in the late 1960s or early 1970s (Herren, 1990). The mealybug causes stunting of the growing shoots of cassava. Peak densities of the pest vary a great deal, from 600 to 37,000 bugs/plant (Schulthess *et al.*, 1991), an enormous infestation at the top end. Yield losses were of the order of 52% to 58% when compared with non-infested plants (Schulthess *et al.*, 1991). In 1981, the South American parasitic wasp, *Epidinocarsis lopezi* (Hymenoptera: Encyrtidae) was imported into Nigeria, where it was reared in an insectary before being released into cassava crops. Further releases were carried out, so that by 1985, the parasitoid was established over 420,000 km^2 in West Africa and 210,000 in Central Africa (Herren *et al.*, 1987). After this, densities of cassava mealybug were very much reduced. In Chad, for example, average pest numbers were around 1.6/shoot (Neuenschwander *et al.*, 1990), and the biological control programme resulted in yield increases of around 2.5 t/ha in savanna regions of West Africa (Neuenschwander *et al.*, 1989). However, the introduction of a single exotic parasitoid species into a huge region of ecological diversity typified by the African cassava growing region may not solve the pest problem entirely (Fabres and Nenon, 1997). Now, some 20 years after the first parasitoid introductions, this biological control is decreasing in efficiency.

It has long been suggested that if crop systems can be more heterogeneous, then fewer pest problems might be expected. One good example of the role of biodiversity in crop pest management comes from rice, the most widespread crop in the world which feeds about half of the world's population. Intensification of irrigated rice has of course occurred apace, and with it has come the usual increases in the use of insecticides and concomitant additional pest problems (Way and Heong, 1994). The brown planthopper, *Nilaparvata lugens* (Hemiptera: Delaphacidae), has risen from the relative obscurity of a so-called secondary pest to the status of one of the most serious pests of rice, and there is a strong suggestion that this change of status is closely linked to increased insecticide use. It remains unproven, however, that this is due to the destruction of natural enemy complexes; increases in chemical use go hand in hand with changes in rice varieties, cultivation technology and the use of intensive monocultures.

Nevertheless, it is thought that various components of biodiversity are relevant and useful in the field of rice pest management. These range from the small-scale associations between the pest and its host plant (the crop) all the way to the large-scale diversity of the ecosystems in which the crop is grown. The latter diversity encompasses the rice crop itself, as well as other crops (everything from other food crops, such as cassava or maize, to multipurpose trees, and beyond, to wild land in and around the farms and villages). This final diversity may consist of remnant natural vegetation, or especially planted and maintained plant communities. The key questions will centre on:

- how the pests and their associated natural enemy populations are linked within these patchworks of more or less continuously available rice;
- how dispersal both locally and at a regional scale distributes pests and to a lesser extent, their enemies, amongst established rice crops and to new ones;
- how background predators adjacent to and within the crops really influence the likelihood of pest outbreaks;
- how far rice crop systems will need to be modified (reduced pesticide inputs, decreased monocultures, etc., in order for biodiversity-based pest management to work. At the end of the day, all new management systems, such as that envisaged for rice, have to be appropriate for local-level implementation.

Other research provides conflicting results. Since many insects that are allegedly useful as biological control agents feed on pollen and nectar as adults, sources of these foodstuffs (known as companion plants) can be grown around or even within crops to increase the density and diversity of predators and parasitoids (Bowie *et al.*, 1995). In practice, the actual impact on crop pests may not be significant. Field margins can be thus manipulated so that insect diversity is significantly elevated relative to the adjacent crop, but these conservation strips seem in many cases to have no effect on crop yield or the incidence of insect (and pathogen) pests in the field (Grubb *et al.*, 1996).

Finally, if a pest management technique is too complex or demands too much time or effort from crop producers, then it will simply not be accepted. In Box 2, some of the basic requirements for adoption of innovative techniques, such as integrated pest management (IPM), in South East Asia are presented. The use of biodiversity maintaining or enhancing

Box 2 Prerequisites for the adoption of innovations in South East Asian agriculture

- Target growers and problems, including pests, must be carefully identified
- Innovations must work under specific (local) conditions
- Innovations must be at least equal to, or better than, existing management systems
- Current and future costs of new systems must not be excessive
- Efficient communication from research to extension and then to growers is essential

Source: Fujisaka (1991)

procedures for biological control are certainly innovations, but as yet the knowledge base and especially the advisory or education systems are not in place.

2.3.3 Nutrient cycling

Many insects play important roles in the recycling of nutrients in natural and man-managed ecosystems, but undoubtedly the most important group in this respect is the Isoptera, or termites. Termites are immensely common in tropical ecosystems, and it has been suggested that they make up as much as 10% of all animal biomass in these areas, and up to a staggering 95% of soil insect biomass (Watt *et al.*, 1997).

Termites are vital in the decomposition of vegetation, and hence in nutrient release and energy flow, and subsequent crop performance (Grace, 1994). In tropical rainforests, they are hugely influential in the decay of timber and leaf litter (Songwe *et al.*, 1995; Didham *et al.*, 1998). Though many species exist, they can be split into four major functional groups (Bignell *et al.*, 1997), i.e. soil feeders, wood/soil feeders, wood feeders, and litter/grass foragers; the latter two groups are probably the most important for nutrient cycling, and in fact, greenhouse gas production. Termites produce so much carbon dioxide and methane from the breakdown of their food materials, that Eggleton and Bignell (1995) suggest that termites in tropical forests may be responsible for around 1.5% (CO_2) and 15% (CH_4) of total global production from all sources! Ironically, one sure way to reduce atmospheric pollution by methane would be to fell tropical rainforests, thus removing large numbers of termites, though even in agricultural land, termites have important roles to play. In semi-arid regions, termites are able to improve the nutrient content and physical properties of crusted soils. In experiments, termites were removed from certain areas, and both these and control plots where termites remained were treated with cattle dung or straw mulches. Crops such as cowpeas sown subsequently on both sites produced significantly higher biomasses and seed yields on the termite-rich sites (Mando, 1998).

2.4 Single species (detrimental)

The harmful effects of insects on human populations are so well documented that they can be described briefly. A few examples only will be provided for comparisons with the foregoing sections. As with the beneficials, most examples of insects exacerbating poverty or suffering involve one or maybe a few species at once, disease vectors such as mosquitoes and tsetse flies, and crop pests such as locusts being major examples from both developed and developing worlds.

2.4.1 Mosquitoes

Adult female mosquitoes (Diptera: Nematocera) are probably responsible for more human suffering and mortality than any other animal in the world because of their universal abilities to act as vectors of disease-causing pathogens such as protozoa and viruses. Malaria is undoubtedly the most serious and widespread human disease vectored by insects in the world. Around 300 million people are infected (Collins and Paskewitz, 1995), and 120 million clinical cases are estimated globally each year (Coluzzi, 1994). Nearly 40% of the world's population live in regions where malaria is endemic (Collins and Paskewitz, 1995), but sub-Saharan Africa accounts for a large percentage (maybe up to 80%) of the reported cases. In this region, more than 1 million children below the age of 5 years are thought to die of the disease annually (Sexton, 1994). Since climate change appears to be the driving force in natural disease epidemiology (as opposed to anthropogenic manipulations), it is possible that predicted increases in global temperatures may once again change the geographic distribution of insect vectors. In addition to malaria, other insect-vectored diseases such as yellow fever, dengue and encephalitis may also change (McMichael and Beers, 1994; Rogers, 1996).

Far from declining in the late twentieth century, malaria appears to be increasing rapidly on a global scale, with the alarming appearance of vectors resistant to insecticides, and parasites resistant to drugs (Sharma *et al.*, 1996). A shift in the dominance of species of *Plasmodium* has also been observed in many countries, with an increase in the most dangerous and potentially fatal, *P. falciparum*. The most acute and frequently lethal form of this disease, cerebral malaria, is becoming commonplace, especially in parts of Africa and Oceania. It is thought to be responsible for 2 million deaths annually (Reeder and Brown, 1996). Very disturbing figures from Malawi, for example, show 39% of pregnant women infected with *P. falciparum* at their first antenatal visit (Brabin *et al.*, 1997). Many species of malarial parasite are now showing resistance to classic anti-malarial drugs. Work in India in 1994 for instance, found that 95% of *P. falciparum* isolates from people in an epidemic in Rajasthan were showing resistance to chloroquine (Sharma *et al.*, 1996).

2.4.2 Tsetse flies

Tsetse flies belonging to the genus *Glossina* (Diptera: Glossinidae), vector protozoan parasites called trypanosomes, hence the general name of the syndrome, tyrpanosomiasis. In sub-Saharan Africa, these parasites cause two related diseases, sleeping sickness in people and nagana in livestock. Because of their activities as vectors, tsetse flies are a major constraint to animal production and human health over an area of approximately 10 million km^2 (Rogers and Randolph, 1991), with annual livestock losses estimated to amount to US$ 5 billion (Kettle, 1995). In livestock, infected animals may die within a few weeks, but those that survive may exhibit chronic infections for years, acting as parasite reservoirs from which to infect fresh hosts. In this case, habitat diversity in the form of moist, riverine vegetation provides abundant resting places for adult tsetse flies, which benefit tremendously from the fact that these sites are also popular with game, livestock and people alike. In theory, therefore, reductions in this diversity would ease the problem of trypanosomiasis, but would in practice be clearly out of the question. However, because tsetse flies flourish in lush vegetation, their distribution and hence the likelihood of epidemics of the disease can be plotted and predicted by following the development of suitable vegetation types using remote imagery based on normalised difference vegetation indices (NDVIs) (Rogers and Williams, 1994).

2.4.3 Locusts

Locusts are a classic example of the phenomenon of eruptive pests. Globally, many species of locust erupt into plagues from time to time, the most common being the desert locust, *Schistocerca gregaria*, the migratory locust, *Locusta migratoria*, the tree locust, *Anacridium melanorhodon*, and the Australian plague locust, *Chortoicetes terminifera* (all Orthoptera: Acrididae) (Wright *et al.*, 1988; Showler, 1995). Various species of *Schistocerca* are also serious pests in South America (Hunter and Cosenzo, 1990). Locust plagues have been ravaging crops for many centuries. In the 1990s, successive generations of locusts gave rise to localised eruptions for 18 months as far west as Mauritania and as far east as India (Showler, 1995). The damage caused by these eruptions is enormous, as is the cost of control. During one desert locust plague in Africa, 15 million litres of insecticide were used, at a cost of around US$ 200 million (Symmons, 1992).

2.5 Multiple species/community level (detrimental)

2.5.1 General crop pests

It is quite impossible to assess accurately the damage done by general insect pests to crops, livestock and people the world over. Between 25% and 50% of all crops grown are eaten or otherwise destroyed by insects, if no attempts at pest control are mounted. Table 8 gives some examples of agricultural crops where loss estimates have been provided. This list mainly considers individual species, not background pest complexes, though the last two examples from Rwanda and Nigeria merely mention pests in general. The concept of biodiversity of course has no relevance here – it is simply the amount of yield lost (gross production), or its value (net profit) that counts.

It is difficult to compare the clear and enormous losses caused by insects in the developing world with the nebulous and so far mainly unproven beneficial effects for the vast majority. A simple cost-benefit analysis will

Table 8 Maximum crop losses due to insects

Insect	Common name	Crop	Country	Annual yield loss
Antitrogus consanguineus (Col.: Scarabaeidae)	Sugarcane white grub	Sugarcane	Australia	35%
Apheliona maculosa (Hem.: Jassidae)		Soyabean	India	35.4%
Calocoris angustatus (Hem.: Miridae)	Sorghum head bug	Grain sorghum	India	66%
Conopomorpha cramerella (Le.: Gracillariidae)	Cocoa pod borer	Cocoa	Sabah	40%
Isoptera	Termites	Yam and cassava	Nigeria	5 t/ha
Phenacoccus manihoti (Hem.: Pseudococcidae)	Cassava mealybug	Cassava	Nigeria	58%
Tibraca limbativentris (Hem.: Pentatomidae)	Rice stem stink bug	Rice	Brazil	65.2 kg/ha
Insect pests		Common bean	Rwanda	233 kg/ha
Insect pests		Cowpea	Nigeria	75%

exemplify the point. If a bean farmer in Rwanda is faced with a loss of around 230 kg/ha (see Table 8), then he is simply not going to be interested in any increase in insect diversity unless it is proven conclusively that to encourage this biodiversity will reduce his losses.

2.5.2 Alien introductions

A whole host of insects are now causing severe losses to crops in countries where they are exotic, having reached their new homes via accidental ('alien') introductions. Crop species are planted in many different parts of the world (take the example of cassava mentioned above), and unless infrastructures are established to provide comprehensive and efficient screening or quarantine procedures, insects, which fed upon these crops in their native homes may find their way to the new country. Many examples exist but most at risk are small island communities whose indigenous fauna cannot cope with aggressive newcomers. Thus, islands like Guam, Hawaii and Mauritius, now have a large number of exotic insect pest species, which are likely to seriously affect native biodiversity, either via competition or predation. This is especially serious because, on such islands, biodiversity is likely to have been unusual, fragile and perhaps unique (Desender and Baert, 1996; Marutani *et al.*, 1992; Schreiner, 1991; Facknath, 1989).

3 Causes of change in insect diversity

Insect diversity changes may occur either though natural events or because of anthropic manipulations. The magnitude of natural events should not be underestimated. For example, we know that the richness and diversity of many insect groups was lowest, everything else being equal, immediately post-glacial, i.e. after the last Ice Age, and subsequently rose (Leveseque *et al.*, 1996). In natural ecosystems, species richness of most organisms decreases as ecological succession progresses. Various studies in European forests show that macro-arthropod (mostly insect) diversity diminishes as climax communities are approached (Paquin and Coderre, 1997). Mention has already been made of the fact that there are more termites (individuals and species) in secondary forests and even plantations than in primary ones. This latter example provides evidence to support the general view that primary (climax) forests are less biodiverse than secondary (early successional stage) ones.

3.1 Habitat modification

Clearly, much current concern about the diminution of insect diversity centres on habitat modification and change. Major alleged causes of such change include urbanisation, agricultural intensification, deforestation and general habitat fragmentation. Table 9 summarises published work on the effects of these types of habitat change, and as can be seen, no general conclusions can be made. Indeed, it would seem that some modification of natural habitats, especially lare in succession, actually helps to promote insect diversity. It may be convenient to examine changes in insect biodiversity under three separate but interlinked headings, i.e. disturbance, fragmentation, and edge effects. Each subsequent topic is to some extent a consequence of the former.

3.1.1 Disturbance

Any disturbance to an ecosystem might be expected to influence the animals and plants that live in it. Some

Table 9 Effects of habitat change on insect diversity

Type of change	Insect groups	Effect of change	Country	Reference
Logging of primary rainforest	Butterflies	Species diversity highest in unprotected secondary forest	Indonesia	Hamer *et al.* (1997)
Forest fragmentation	Butterflies	No significant loss in species richness	Trinidad	Singer and Ehrlich (1993)
Changes in grassland management	Grasshoppers	Increase insect species richness with grass species richness	South Africa	Samways and Moore (1991)
Planting of exotic conifer (cypress) patches within grassland	Grasshoppers	Increased grasshopper species richness and abundance	South Africa	Samways and Moore (1991)
Fragmentation of agricultural land (red clover)	General herbivores	Isolated populations experienced decreased parasitism	US	Kruess and Tscharntke (1994)
Logging of primary rainforest and replacement with other forest types	Litter and understorey beetles	Secondary forest not dissimilar to primary; acacia and especially oil palm plantations species poor	Sabah	Chung and Speight (1999)
Selective logging of primary rainforest followed by secondary regeneration	Lepidoptera	Little significant change in richness	Malaysia	Intachat *et al.* (1999)
Grassland habitat, bisection, perforation fragmentation	General grassland insects	Species richness increased	US	Collinge and Forman (1998)
Forest fragmentation by road-building	Ground beetles	No influence on species distribution	Korea	Kwon (1996)
Fragmentation caused by modern agriculture	Butterflies	Reduction in species richness	Spain	Stefanescu *et al.* (1996)
Tropical forest fragmentation and increase in edge habitats	Beetles	No change in species richness, but significant change in species composition	Amazonia	Didham *et al.* (1998)

types of disturbance are natural and indeed essential for the continuation of the system, so that the creation of open patches within a rainforest by the deaths of trees from natural causes, such as wind or old age, are vital dynamic events in the life of the forest. Even fire can be a perfectly normal phenomenon in some forest systems, such as fire-climax sclerophyll forests, but tropical plants and animals are ill adapted to extensive felling and the removal of large mature trees of modern day timber extraction. Selective logging, where only certain sizes and species of tree are removed, can be highly disturbing to the inhabitants of a primary forest, even when modern techniques of reduced-impact logging (RIL) are employed; clear-felling, where every tree is removed, is locally catastrophic. Disturbance in an ecosystem like a forest may affect the biodiversity of animals in different ways, according to their position in a food chain. Increased disturbance produces high species diversity in primary producers, intermediate diversity for herbivores, and least for carnivores (Huston, 1994). If we consider a hypothetical example from a tropical forest, this means that after logging, and either replanting or allowing natural regeneration, we should expect the highest number of species of plant, more species of insects feeding on the plants and relatively few predators or parasites of these insects. In simple terms, the whole balance of the community will change, which might also have important implications for pest dynamics.

In 1998, Lawton *et al.* looked at the changes in species richness of various insect groups in Cameroon, West Africa, according to the levels of disturbance: habitat A was near-primary forest (as undisturbed as possible in the area); habitat B was old-growth second forest (unlogged for 40 years or so); habitat C was old-growth secondary forest with some plantation and manual clearance; habitat D the same as C but with some bulldozer clearance; and habitat E was manually cleared farm fallow, as far from primary forest as possible. Even with these extreme variations, no clear patterns emerged. The butterfly species richness dropped with increasing disturbance, the flying beetles increased their species richness, and leaf litter ants showed some sort of peak in richness halfway along the disturbance continuum.

3.1.2 Fragmentation

Fragmentation occurs when a single continuous habitat is split into two or more separate units, divided by some sort of dispersal barrier, such as a road or crop. One problem associated with reducing the size of a patch or fragment concerns the number of individuals, i.e. abundance of insects, in the patch. There must be a reduction in resources such as space and food when a habitat is shrunk, so that the carrying capacity, or the maximum number of individuals within a species that can be supported, must also decline. Coupled with these problems comes that of demographic instability, whereby smaller populations are more prone to genetic drift and inbreeding or worse still, to extinction, during environmental perturbations. Working on populations of the army ant, *Eciton burchelli* (Hymenoptera: Formicidae) from Panama, Partridge *et al.* (1996) concluded that the size of the equilibrium population of this species was related to the habitat size, and that as habitat size increased, there was an exponential increase in the time to extinction.

It must not be assumed that high species richness is impossible in small forest patches. Indeed in a 1 km^2 area of lowland dipterocarp rainforest in Brunei, northwest Borneo, Orr and Hauser (1996) estimated 464 species of butterfly, nearly half of the entire fauna of Borneo. This patch of rainforest was not isolated, in fact it formed part of a continuous tract of forest; the effect on real fragmentation is less encouraging. Decomposer organisms such as termites and dung beetles exert a major influence on nutrient supplies in a forest ecosystem (Didham *et al.*, 1996), and hence the knock-on effects of forest fragmentation on such insects may have fundamental consequences for the functioning of these systems.

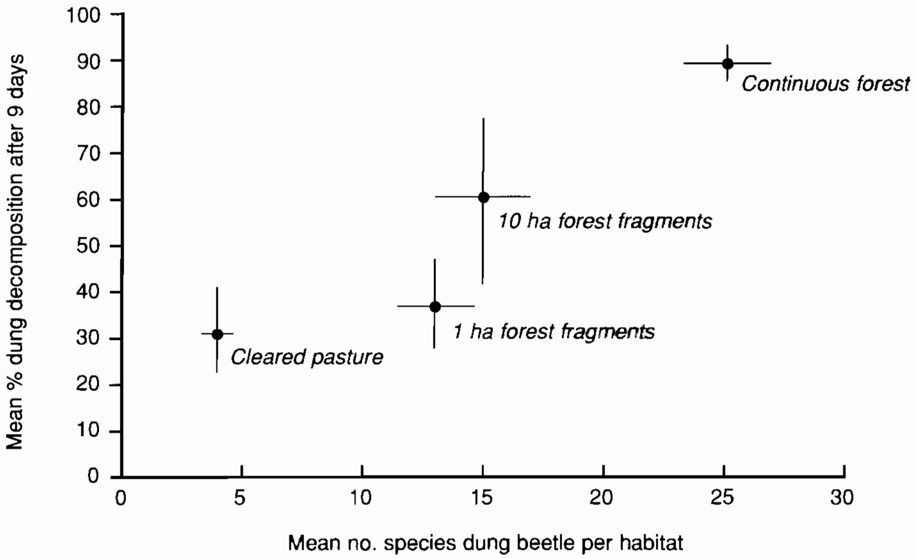
Figure 7 illustrates the influence of forest fragment size, compared with continuous cover, for dung beetle (Coleoptera: Scarabaeidae) species from Amazonia (Klein, 1989, in Didham *et al.*, 1996). Smaller fragments have markedly lower population densities and numbers of species. Species number is in turn related to the amount of dung decomposed in a given time, and though from a functional point of view, a decrease in population density may be more important than that of species richness, both elements of general biodiversity suffer greatly. Not all the effects of habitat fragmentation are for the worse, at least from the insect's point of view. The degree of dissimilarity between habitats within the fragment and its matrix is all important. If animals are able to use the matrix, either as a corridor from one fragment to the next or as alternative places to live, then the forest fragment will function differently (Mawdsley, 1996). Herbivores, including potential pests, may be more abundant in small patches of their host plant than in continuous cover. In more general terms, isolation of fragments of clover in Europe resulted in more colonisation by herbivorous insect species than parasitic ones; essentially, the pests in the fragments were released from biological control (Kruess and Tscharntke, 1994). Neither of these latter examples are tropical, but their lesson is clear: forest fragmentation may be deleterious for biodiversity and conservation, but it might be rather advantageous for pests.

3.1.3 Edge effects

A final problem with fragments of habitat is that of edge effects. An edge effect is a recognisable gradient of an abiotic effect such as temperature or humidity, or a biotic one such as the abundance of plants and animals, away from a recognisable habitat edge (different crop, road, etc.) into the patch of habitat. Abiotic edge effects can be complex. In a tropical forest in central Amazonia, Camargo and Kapos (1995) found the highest values of soil moisture just inside a forest edge that had been created by cutting, with zones of reduced moisture actually at the edge, and again 40–80 m into the forest. Distributions of vegetation might be expected to respond to these edge effects too, and are likely to have fundamental influences on animals such as insects. Species diversity is greatest at the edges of forests and least in the middle for some insect groups. Butterflies tend to be edge or gap species in the main, where the light is brighter, the temperatures warmer, and there is more space in which to move around. In northern Guatemala, for example, Austin *et al.* (1996) recorded 535 species of butterfly from forest sites; the largest number of species occurred in forest edge habitats, and the smallest number in continuous, forested habitats. There is in fact an argument that suggests that sun-loving insects, such as butterflies, are not typical forest insects at all, since they prefer open habitats within forest or woodland sites, and that they receive too much effort and emotion from forest conservationists (Hambler and Speight, 1995). If nothing else, however, they are easily recognized and usually favourably received by the public, and as such may act as keystone species that help the preservation of less subjectively attractive but more important animals and plants in forests.

Natural forests can sometimes play important roles as reservoirs of insect pest species for agricultural and forest crops planted in their vicinity. The banana-spotted bug, *Amblypelta lutescens* (Hemiptera: Coreidae), which can cause serious damage and dieback to pawpaw (papaya), is much more serious

Figure 7 Influence of biodiversity on ecosystem function: rate of dung composition and number of dung beetle species in forest fragments of central Amazonia



Source: Data +/- s.e. Didham *et al.* (1996) after Klein (1989) when the crop is planted next to remnants of rainforest when compared with other sites isolated from natural forests (Ryan, 1994). These are two ends of a potential edge effect spectrum, and it can easily be envisaged that a gradient of risk to the crop will occur according to distance from the forest. The extent of this effect will depend to some extent on the dispersal powers of the insect in question. Changes in insect diversity in the tropics because of habitat change, disturbance and fragmentation, therefore, do not always cause drastic declines in biodiversity.

4 Managing insect diversity

From the above descriptions of the goods and services provided by some insect species, we may conclude that rural livelihoods do benefit on occasion from enhanced or preserved insect biodiversity; more realistically, certain insect species play significant roles in the lives of local people. The questions that this poses then are how best to manage diversity through, for example, alternative land use options, to ensure that these values are captured and how to manage the possible trade-offs between the different values which do not place undue burdens on poorer people especially.

4.1 Protected areas

A protected area is a patch of habitat which is in some way governed by national or international legislation to restrict exploitation and to enhance conservation. Some use is allowed, usually through some mechanism of sustainable management. Although such areas often make up only a small percentage of total land in a country or region, they can be useful for biodiversity maintenance, whilst at the same time, allowing local people to prosper. This prosperity is likely to arise from so-called market-oriented conservation; the collection of wild honey or wild breeding stocks of Lepidoptera to enrich butterfly farm stocks are two examples.

The long-term success of such schemes requires that economic benefits derived, in this case, from standing forests, are increased to the point where they out-compete alternative, destructive, land uses (Crook and Clapp, 1998). These authors go on to say that, in other words, the sustainable extraction of useful organisms or their products must, over the long term, produce greater profit than destructive activities. In the present economic climate it is difficult to see how indigenous uses of insects and their products could accomplish this when compared with the undoubted short-term gains to be made from logging, or other destructive activities, such as oil drilling or bush meat hunting (Brugiere, 1998). In addition, the resource must be more cheaply and reliably produced in a natural forest than in a plantation.

One of the main difficulties with the maintenance of protected areas such as natural tropical forests is that they are likely to be beset with "the tide of environmentally impoverishing human activities" (Myers, 1994). Local people can make more of an income by intensively managing land and resources, especially by farming or commercial forestry. In west Sumatra, Indonesia, for example, the Taman Hutan Raya forest park is a protected area which is surrounded by a buffer zone in which nearly 90% of local people are farmers (Zuraida, 1997). It seems that these people do not use the biodiversity in the protected area, and continue instead to intensively manage the buffer zones, wherein general insect biodiversity is, as usual, likely to be disadvantageous. It is possible that advice and education would enable the farmers to view the natural forest as a source of extra prosperity, wherein insects and their products come to be viewed more favourably.

4.2 Reduced-impact logging

One possible way to maintain tropical forest biodiversity, such that it can still provide insect diversity benefits to local people, whilst still exploiting it for timber, is by the use of reduced-impact logging (RIL). Vines and other climbers which interconnect the canopies of tropical forest trees increase the damage to adjacent trees when a tree is felled during selective logging (Vidal *et al.*, 1997). Falling trees drag others down with them, resulting in larger canopy gaps and threatening future harvests. If these vines are cut before felling, then the damage to the surrounding forest can be much less. The authors found that, in eastern Amazonia, the canopy gaps created by felling could be twice as large if vines were not cut, but the drawback was that the cutting process cost around US$ 16/ha, equivalent to 8% of the profits of a typical logging operation in the area. Similarly in east Kalimantan, Indonesia, Sist *et al.* (1998) reports a 50% reduction in forest damage using RIL techniques compared with conventional logging, but obviously, the cost of the process must be set against any benefit from the conservation of biodiversity. Insects in the forest may benefit from the reduced habitat disturbances, but it may prove difficult to persuade commercial logging companies to cut their net profits for the somewhat ephemeral benefit of locals, always assuming that the latter group actually want to use NTFPs in a sustainable manner.

4.3 Agroforestry and social forestry

Agroforestry can loosely be defined as a set of land use systems which include various combinations of agriculture, horticulture, forestry and animal husbandry, either simultaneously or sequentially, applying management practices that are compatible with the cultural pattern of the local population (Nair, 1993). The objective of integrating trees with crops and/or animals is to reduce risk and increase productivity via a more efficient utilisation of natural resources. Social forestry concentrates more on tree production than agroforestry, but it is still small scale, local, and integrated with agriculture within a village or community context. The use of perennial plants such as so-called multipurpose trees, intermixed with annual food crops, may provide locals with some of the benefits of natural forests in terms of their insect associations, whilst still ensuring that fairly intensive agricultural production continues. It may well be that insect diversity is increased in these types of farmed areas if mosaics of different land uses are created (Roth and Rathcke, 1994). In eastern and western Africa, more butterfly species were found in farmed and grazed land than in wild, forested, habitats (Reid *et al.*, 1999).

Certainly, agroforestry systems may provide extra insect biodiversity in crops. In Costa Rica, it was found that when coffee agroforestry systems which use trees to provide shade for the coffee were converted to capital intensive monocultures by removing the shade trees, the biodiversity of arthropods, including insects, in the farming system and especially in the coffee bushes was significantly reduced (Perfecto *et al.*, 1997). It is not reported, however, whether pest damage or biological control changed accordingly.

As mentioned many times earlier, overall insect biodiversity is not likely to be of paramount interest to many local livelihoods; only certain insect groups may be of use in agroforestry or social forestry. An example of the benefits to local people from insects in such production systems comes from India, where tribal people produce tasar silk (Kapila *et al.*, 1991). This type of silk (see also section 2.1.1) is produced from the silk moth *Antheraea mylitta*, whose larvae feed on a variety of native tropical forest tree species, such as *Shorea robusta* and *Terminalia tomentosa*. Deforestation for new farmland and commercial logging results in the danger of a critical loss of these food plants, and appropriate small-scale reforestation measures have been urged, as part of an anti-poverty programme. Social forestry block plantations of *Shorea* and *Terminalia* have been established to provide food for the silkworms, helped by agencies such as the Integrated Rural Development Programme (IRDP). Local people manage these plantings alongside their normal cultivation programmes, and it is estimated that a family could earn an annual income of Rs 3000 from 1 ha of a plantation of *Terminalia* (Prasad *et al.*, 1991). Once again, the last thing that such a project needs is a thronging general insect biodiversity in these trees; natural enemies of the silkworms, such as predatory and parasitic insects, are entirely undesirable.

5 Conclusions

Arguments for the conservation of insect diversity can be summarised as follows:

- individual species are the basis of 'smokeless' industries that benefit the rural poor;
- insects provide 'ecosystem services', through pollination, pest control, soil aeration and others;
- insects have considerable potential as sources of protein;
- insect biodiversity is a sensitive indicator of the health of various types of habitat.

Although insects may contribute to poverty reduction in rural areas of the South, it is through the specific targeting and intensive manipulation of one or just a few insect species. For example, the production of silk from silkworms, honey from domesticated bees, or

Iranian 'gaz' from scale insects, all depend on one insect species which in many cases is heavily bred away from wild counterparts. However, such long-term domesticates do not benefit from the maintenance of diversity in the wild, just as macro-livestock colonise grasslands vacated by large mammals.

Ecosystem changes as described in the previous sections are probably unavoidable in the main. The losses of forest cover, increased fragmentation, and general conversion of primary forests to plantations and even farmland are due to economic pressures, which may be difficult to avoid. It is hard to imagine, for example, that though wild honey collected by local people from natural habitats plays significant roles in social, economic and cultural life (Costa, 1998) (see section 2.1.2), conversion of areas which support bees for forestry or agriculture is likely to have a higher priority on a national or international, rather than local, scale. It is only in the interest of communities to conserve insect biodiversity when they can profit directly from its maintenance. Only when the economic benefits of biodiversity maintenance are real and substantial may the maintenance of insect species, and their general biodiversity, be looked on favourably. One of the best examples of this is the trade in spectacular insects in New Guinea and Irian Jaya (see section 2.2.1). Assuming the harvest is sustainable, insects can provide a long-term income for local communities, but only if they also conserve the forest that provides a habitat for these insects. Clearly, modern practices are more desirable than the older, some might say, traditional, approaches of logging and 'be damned'. However, even now, such low-level, low-profit enterprises are frequently vulnerable to the enticements of the relatively large sums paid by loggers on a one-off basis. Such insect harvesting is very limited in its relevance; only tropical rainforest of a certain type is likely to yield adequate numbers of saleable insects.

High insect diversity may promote pest management in tropical crops, but a subsistence farmer who promotes high biodiversity, with lots of wild land, mixed crops and zero pesticides would rapidly find declining yields. Background biological control, sufficiently effective as to reduce tropical crop pests below economic thresholds (especially if the pest happens also to be a disease vector), is simply not to be to be relied upon at the moment. Many insect species in tropical ecosystems are basically 'redundant' in terms of essential ecosystem functionality – we simply do not need so many species.

The value of insect diversity in its ecological sense (i.e. a large number of distinct species and numerous individuals) to the developing world appears in general to be fairly low. Individual insect species can be extremely important, either as destructive pests or more beneficial life forms, but there seems little merit or advantage in a broad-scale enhancement of insect diversity, apart from in one or two specific scenarios, such as pollination and pest control. Pollination effects are fairly well known. There appears to be some redundancy in the system, whereby if one species declines or disappears from an area, others will carry on the job, except in very specialized circumstances, such as mixed natural forest, where commercial interest is limited. As for pest control, we simply do not know enough about natural regulation, except again to say that in intensive crop systems, the bias has got to be in favour of the pests by the very nature of the agricultural practice.

Key areas in which development programmes could promote the sustainable use of insects for livelihoods could be through indigenous production of the various products, such as honey, silk and shellac, since these can directly benefit local people. The benefits may only emerge in the long term, such that biodiversity losses are used as a lever to promote agricultural intensification. Two other areas, which do have merit, are pollination and pest regulation respectively.

Research priorities in the area of insect pollination and associated biodiversity have been summarized by Allen *et al.* (1998). These are:

- increased attention to insect systematics, monitoring and reintroduction as part of habitat management and restoration;
- large-range assessments of the lethal and sub-lethal effects of pesticides and habitat fragmentation on wild pollinators;
- restoration and management of habitats adjacent to crop land as alternative nectar sources and corridors to stabilize and improve crop yields.

Significantly, research into the last topic might also mesh well with similar habitat manipulation for the encouragement of natural biological pest control agents.

Of all potential benefits at a community level, pest regulation needs a great deal of background research to separate dogma and qualitative observations from hypothesis tested, experimental and large-scale manipulations in a variety of distinct but comparable tropical crop scenarios. Undoubtedly, subsistence farmers with little access to costly and potentially hazardous pesticides must rely more on cultural practices to enhance biological control, to reduce crop suitability to pests, or to increase its tolerance (Letourneau, 1995). Van Emden and Dabrowski (1994) note "the pest management implications of changes in biological diversity need to be considered at a smaller scale in the management of cropping systems, and on a larger scale in developmental programmes and national land use planning". Published results in this field are very variable. Box 3 identifies some key questions that might be answered with adequate funding and careful scientific hypothesis testing. Only when clear and predictable advantages for insect conservation and biodiversity can be demonstrated will there be any real interest from local people and governments alike.

Box 3 Key questions in insect diversity and pest management

- Does wild land around crops promote a quantifiable and dependable reduction in crop losses due to pests?
- Do mixtures of distinctly different crops suffer less impact from pests?
- If it is possible to grow crops in mixtures with non-crop (wild or managed) vegetation, does this lead to worthwhile reductions in damage by pests?
- Can reductions in pesticide usage be sustained by the provision of habitat (and thus insect) diversity in and around high-intensity crop production?
- Can changes in crops themselves (e.g. resistant varieties, transgenics) be accompanied by biodiversity?
- Maintenance or augmentation to promote natural pest management?

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Acronyms

AMNR	Arfak Mountain Nature Reserve
BCN	Biodiversity Conservation Network
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
IPM	Integrated pest management
IRDP	Integrated Rural Development Programme
NDVIs	Normalized difference vegetation indices
NTFP	Non-timber forest product
RIL	Reduced-impact logging
USAID	United States Agency for International Development
WWF	World Wide Fund for Nature