

I The need for insect diversity conservation

Never use the words higher and lower . . . Certainly, they are difficult words, not only descriptive but value laden . . . while bald eagles are an endangered species, so are 129 species of American freshwater mussels . . . Is it more important to save the eagle than ten dozen species of mussels? . . . Perhaps eagles and mussels are just there, and neither is higher or lower. Of the animal biomass on our planet, 90 percent is invertebrates, who account for 95 percent of all animal species.

Charles Darwin (a penned note)



The diversity of insect life today is, as far as we know, the richest it has ever been. The variety is so great that insects make up three-quarters of all species. Insects have radiated into so many diverse forms that we have been able only to describe a small fraction of them. They are a major component of all life we see around us. Out of simple beginnings, the earliest life forms continued to radiate through the process of variation/selection/retention to endow the earth with a fantastically rich tapestry of form and colour, of development and dispersal, that has enriched every corner of terrestrial systems with insect character of some sort. Humans are a latter-day arrival who hold in their palms the future of the insect mosaic. This insect variety is losing its spatial and compositional integrity as we enter the new era, the Homogenocene, which is a mere Blink of a geological eyelid.

1 Ethical foundation for insect conservation

We may notice . . . that the tree-hopper, called by the Greeks *Tettix*, by the latins *Cicada*, received also from the former the title of "Earth-born," - a title lofty in its lowliness, because it was an implied acknowledgment from men of Athens and of Arcady of a common origin with themselves - an admission that the insect was their brother, sprung (as they fabled) from the earth, their common parent, - whence, also, they wore golden tree-hoppers in their hair.

Acheta domestica (1851)

We feel our world in crisis.

David Rothenberg (1989)



1.1 Introduction

Conservation action must have a sound philosophical and ethical foundation. This gives the action meaning and direction. It is the 'why' we are doing it. At the most superficial level, that of utility, nature is at our service to be used, ideally sustainably. In this philosophy, humans have complete dominion over nature, and this is the language of most international agreements and conventions.

Deeper levels require more wrestling with thoughts and ideals. Among these is one philosophical approach where humans and nature are still separate, but nature is to be admired and enjoyed. An alternative view is that humans are part of the fabric of nature, and nature is used sustainably yet respected deeply.

In recent years, a more profound environmental philosophy has emerged, where organisms, including insects, have the right to exist without necessarily being of any service to humans. A powerful epithet to this deep ecology view has emerged: that we should appreciate and love other organisms without the expectation of anything in return.

Different world religions have recognized the environmental crisis and have made declarations that bridge their faith for the future well-being of the world. While philosophy is an essential foundation for how we approach conservation activities, religion is a spiritual complement, which in some countries such as India can play a significant role at the local scale.

Insect diversity conservation has received an enormous upsurge in recent years, principally with the recognition of the major role that insects play in maintaining terrestrial ecological processes. Yet there is recognition too, that insect individuals and species are being lost at an enormous rate. Stemming this loss of diversity is a vast task. A philosophical base helps decide on which value systems we should use to approach the challenge. Religion then provides spiritual recognition that what we are doing is a good thing. These lead to the scientific pursuit of insect diversity conservation, which is the subject of the following chapters.

1.2 Environmental philosophy and insect conservation

1.2.1 *Ethical foundations*

No conservation effort can meaningfully begin without a firm foundation of human value systems or ethics. Such ethics are the language of conservation strategies. Without some moral guidelines, it is difficult to define our goals and hence the expected outcomes of conservation activity.

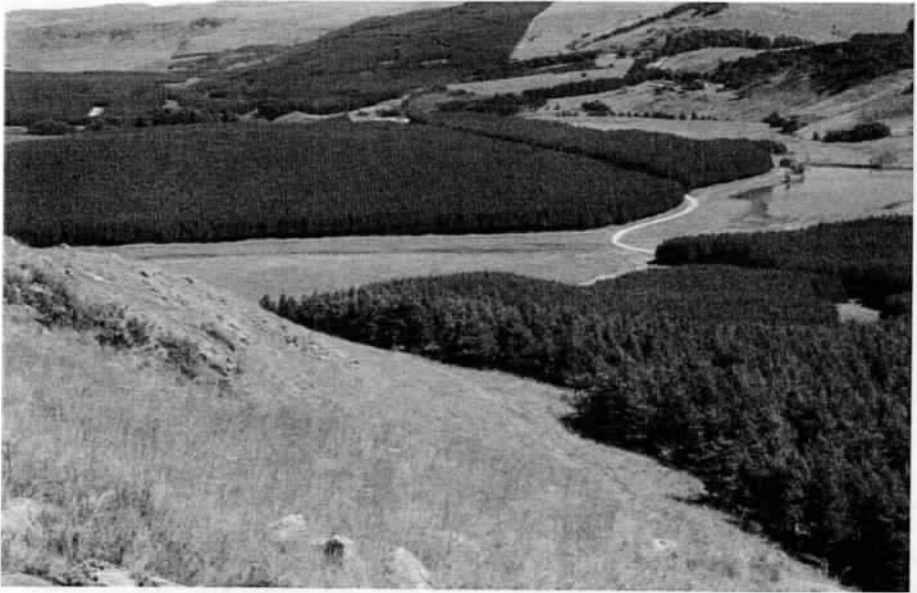
There is little to separate insects from other organismal aspects of biodiversity in environmental philosophy. A noteworthy exception is that not all insects are good for each other, or for us. Insects can be parasitoids or disease vectors. Indeed, we exploit parasitoids as biological control agents.



1.1 A ramification of the Resource Conservation Ethic. Mopane 'worms' (larvae of the emperor moth *Gonimbrasia belina*) are harvested and dried, and considered an important source of protein and fat to people in Africa.

At the arguably lowest level of ethical consideration, insects have utilitarian or instrumental value for us. This includes aesthetic, food, adornment, ornament, service, spiritual and cultural, heuristic, scientific, educational, conservation planning and ecological values. These utilitarian values have two facets. The first is that they are there for us to enjoy aesthetically and be left alone. This is the Romantic-Transcendental Preservation Ethic (Callicot, 1990). This goes beyond just the insects themselves. It considers all their interactions and ramifications with other aspects of nature. It is an ethic that we adopt when we visit a nature reserve. The second utilitarian facet is that insects are there for sustainable use (Figure 1.1). This is the Resource Conservation Ethic. The harvesting of honey from honeybees is an example. But this ethic may apply to a wider, indirect set of services that insects supply, such as pollination and natural biological control. Where insects do not fit snugly into this ethic is when many actually do a disservice to our resources by nibbling, piercing and burrowing into plants, transmitting disease and killing animals. To entertain this ethic may indeed involve some control of insects.

In both the Romantic-Transcendental Preservation Ethic and Resource Conservation Ethic, humans are essentially separate from the rest of nature and



- 1.2 Building an Evolutionary-Ecological Land Ethic at the smaller spatial scale into Resource Conservation Ethic at the larger spatial scale. Here remnant linkages of grass-land are maintaining ecological and evolutionary processes, while the landscape as a whole is also being utilized to produce timber for export (KwaZulu-Natal, South Africa).

organisms have positive, negative or neutral value. In contrast, Leopold (1949) articulates in a subtle and charming way that other species have come about through the same ecological and evolutionary means as humans, and as such, deserve equal consideration. Humans nevertheless, reserve the right to use and manage nature as well as there being recognition of the intrinsic value of other species and the integrity of ecosystems (Figure 1.2). This is the Evolutionary-Ecological Land Ethic. Rolston (1994) goes a step further, and points out that culture has now emerged out of nature, which brings with it a responsibility for humans to nurture other organisms. Samways (1996d) then illustrates that culture has now become an evolutionary path and the human self-manipulating genome the driving force. Ideally, we now need to build into our new genome an environmental ethic.

1.2.2 *World in crisis*

The sharp increase in consumerism and human population growth over the last few decades has stimulated an acute awareness of the adverse impacts on the natural environment. A feeling has developed that not all is well in the world, and that wild nature, unsullied by humans, may even have ended (McKibben, 1990). There is also a growing awareness and accumulating evidence that our world is in crisis – but not necessarily doomed (Cincotta and Engleman,

2000). Out of these changes has developed a strong movement, that of deep ecology, which provides a sense of wisdom combined with a course for action (Naess, 1989). Pessimism is not allowed to prevail, and a sense of joy is the spirit behind the philosophy.

Deep ecology is not something vague as some have claimed. It is an ontology, which posits humanity as inseparable from nature, and with an emphasis on simplicity of lifestyle and on communication with all critics. Naess (1989) termed this approach ecophilosophy (shortened to ecosophy). It is the utilization of basic concepts from the science of ecology, such as complexity, diversity and symbiosis, to clarify the place of our species within nature through the process of working out a total view (Rothenberg, 1989). This is especially relevant to insect conservation, as the insect world is indeed complex and diverse, and it is one where symbioses in the widest sense are widespread. Also, it is at the core of the landscape approach to conservation, where focusing on individual species and interactions is insufficient to conserve the vastness of insect diversity. This emerging arena of ecophilosophy, ecopsychology or transpersonal ecology is likely to play a role in future conservation (Fox, 1993). Indeed, Johnson (1991) advances a potent argument on behalf of the morally significant interests of animals, plants, species and ecosystems. He notes that in a moral world, all living things, insects included, have a right to survival (Figure 1.3).

1.2.3 *Overcoming the impasse between utility and deep ecology theories*

Although deep ecology and even some schools of thought in landscape ecology (Naveh and Lieberman, 1990) include humans in the global ecological equation, it is nevertheless this very human factor that is threatening the planetary processes that in the past have led to the current, rich world-ecology. Although deep ecology purports a human omnipotence, the risk here is that a sense of place, and, in turn, places of wild nature, are left out. To ignore ecological differentials across the globe and to homogenize all would simply be sad. After all, it is the essence of conservation biology to conserve diversity, which, quite literally, is all the differences within nature and across the globe.

Norton (2000) argues persuasively that utility (instrumental value) and deep ecology (intrinsic value) theories are confrontational, and he then asks whether there is perhaps an alternative, shared value that humans may place on nature. The instrumental and intrinsic value theories share four questionable assumptions and obstacles: (1) a mutual exclusion of each other, (2) an entity, not process, orientation, (3) moral monism, and (4) placeless evaluation. To overcome these impasses, Norton (2000) suggests an alternative value system, which recognizes a continuum of ways that humans value nature. Such a spectrum would value processes rather than simply entities, is pluralistic and values biodiversity in place. Such a universal earth ethic values nature for the creativity of its



- 1.3 A road sign at Ndumo Game Reserve which emphasizes the ecophilosophy approach where all creatures have the right to survival, no matter how small or ecologically significant.

processes (Norton, 2000). This ethic is vital when we consider not only the sustainability of nature, whether for itself or for humans, but arguably and more importantly, it is crucial for maintaining the evolutionary potential of biodiversity, especially in extensive wild places (Samways, 1994).

The value of wild places is high, and such places are often the seat of interesting, curious and irreplaceable biodiversity. The problem with placing great emphasis on wild places is that reserves constitute less than 4% of the Earth's land surface (World Resources Institute, 1996). This emphasizes that much of nature is now within a stone's throw of humans, and the degree of anthropogenic modification varies from very little to very much. This spectrum has various degrees of ecological integrity. As such, a major goal of conservation is to conserve as much as possible of this remaining integrity, with due respect

to the role of critical processes in maintaining that integrity (Hunter, 2000a). Indeed, even wild places are only likely to survive in the long run if recognized as wildland gardens that continue to be used with minimum of damage (Janzen, 1999).

Rolston (1994) has illustrated that there are various types or levels of values: natural and cultural, diversity and complexity, ecosystem integrity and health, wildlife, anthropocentric and natural intrinsic. All enter the essence of conservation biology, and all impinge on insect diversity conservation. It is this diversity of values, when maintained, that enrich the world, not just for us, but also for all the other organisms and all the processes that make this, as far as we know, a unique planet.

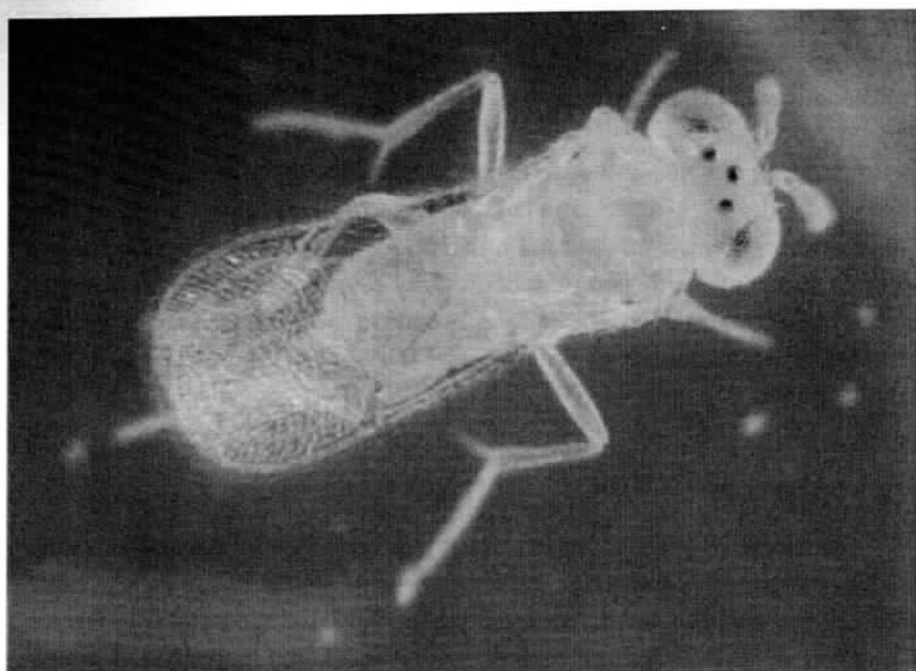
1.3 Insect utility

Although in practice insects are rarely harvested in the way of many other organisms, the principle of utility value still applies to them. The most significant feature of insects in terms of this utilitarian philosophy is to ensure continuance of their ecological services, so that ecological integrity and health are maintained (see Chapter 3). This is where we largely do not understand the consequences of our actions. To name one example, landscape fragmentation and attrition of landscape patches influence the insect assemblages such that the services they normally supply may no longer be possible (see Chapters 4 and 5).

In the agricultural context, it is not always possible to maintain ecological integrity, even though specific insects are being conserved and human intentions are good. Natural ecosystems adjacent to agricultural fields are often utilized for pools of natural enemies that invade the crop and control pests. On harvesting of the crop, the natural enemies then flood back to the surrounding natural ecosystem where they exert strong, albeit local, impact on natural hosts. This is a manifestation of the human demand for harnessing the interaction between host and parasitoid or predator. Biological control is one of the most sought-after services of insects, and one which is not without risks to ecological integrity (Figure 1.4).

Ecological services from insects include more than predation and parasitism. Technical details of these are addressed in Chapter 3. Among these is pollination of crops, both by wild insects and by captive honeybees. Encouragement of these pollinating insects can hardly be in excess, as the same insects can play a major role in maintaining indigenous plants, and hence in their conservation (Kwak *et al.*, 1996).

One area where insect overexploitation requires caution is in the case of colourful butterflies. Regulations need to be called into play, with many species on the *IUCN Red List of Threatened Species* (Hilton-Taylor, 2000). Local laws also



- 1.4 The parasitoid *Aphytis melinus* an important biological control agent against scale insects (Diaspididae). Biological control is one of the most sought after services from insects, but does carry risks (see Chapter 6). Although introduced specifically against Red scale (*Aonidiella aurantii*) in South Africa, *A. melinus* is now known to parasitize at least ten other species.

play a significant part, as does blanket protection of wild areas containing the habitats of these sought-after species. Insect farming can take pressure off the wild populations by providing reared specimens that are often in visibly better condition than wild-caught specimens.

Perhaps the utilitarian aspects of insects have been underexploited. While we are likely to see only limited progress in the direct harvesting of insects (simply because they are generally unpredictable, small and difficult to harvest) there may be some future for medical and novel silk products.

However, the heuristic value of insects in genetic research is undeniable, with *Drosophila melanogaster* virtually a household name. The future is likely to see particular insect genes, rather than the whole animal, having utilitarian value in many aspects of our lives.

Caring for the Earth (IUCN/UNEP/WWF, 1991), which is a world conservation strategy, implicitly addresses many facets of insect diversity conservation that underpin the well-being of humans. Insects and their activities are vital for conserving our life-support systems and for renewing our resources through services in addition to pollination, such as soil maintenance, population regulation, and

in the food webs of terrestrial invertebrates. The value of insect utility therefore, is about conservation of insect diversity. This is part of the wider concept of sustainable use of the world's resources which involves a challenge, among others, which will require learning how to recognize and resolve divergent problems, which is to say a higher level of spiritual awareness (Orr, 2002).

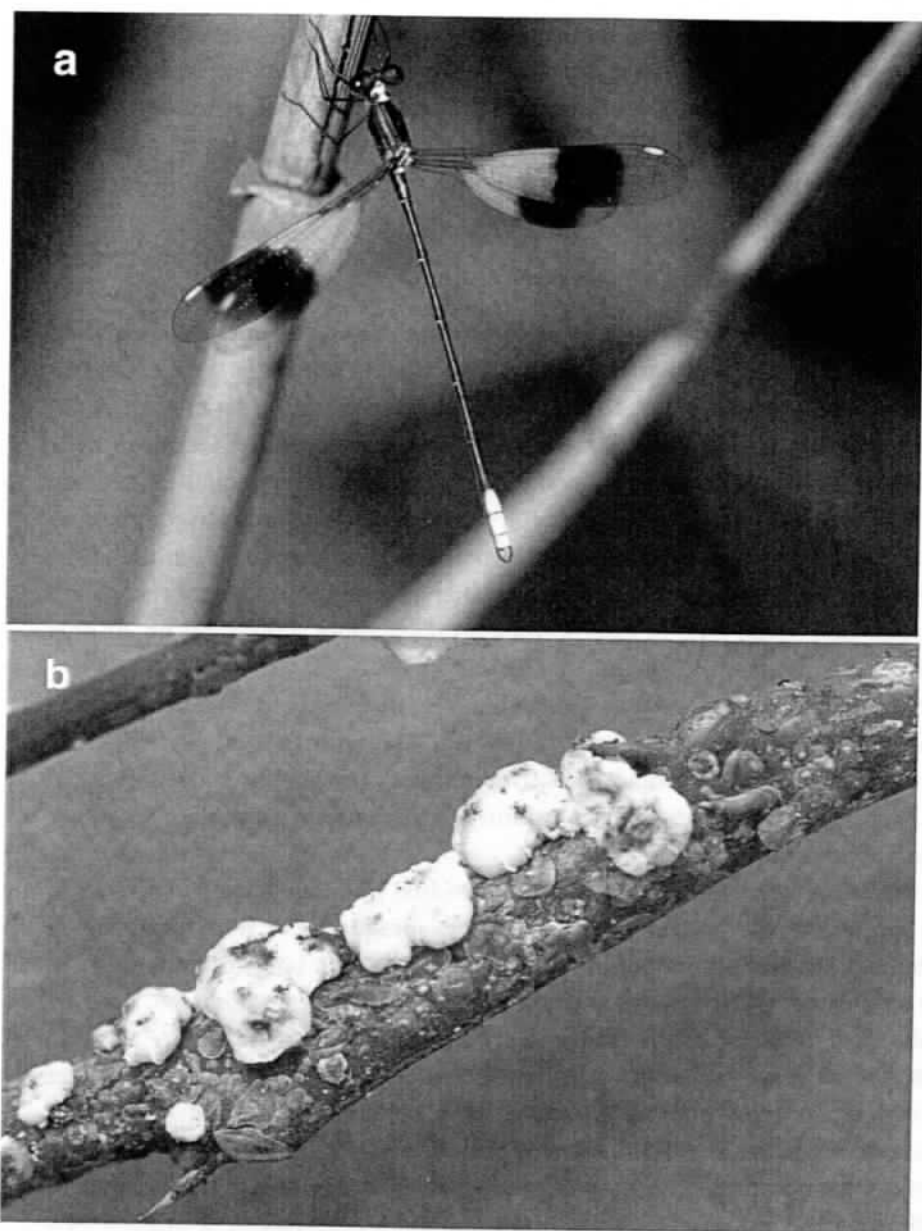
1.4 Insect rights and species conservation

Individuals have rights so as to maintain and even improve their lives, and then they die. So then, do insects have rights? As this is such a difficult question to answer, it is best to put it in a converse sense. Do we have the right to assume that insects do *not* have rights? Bearing in mind the weight of their collective individuality, best we adopt the precautionary principle of keeping all the parts. This includes the moral option that, in fact, individual insects do have rights. From this standpoint, Lockwood (1987) proposes a minimum ethic: 'We ought to refrain from actions which may be unreasonably expected to kill or cause non-trivial pain in insects when avoiding these actions has no, or only trivial, costs to our own welfare.'

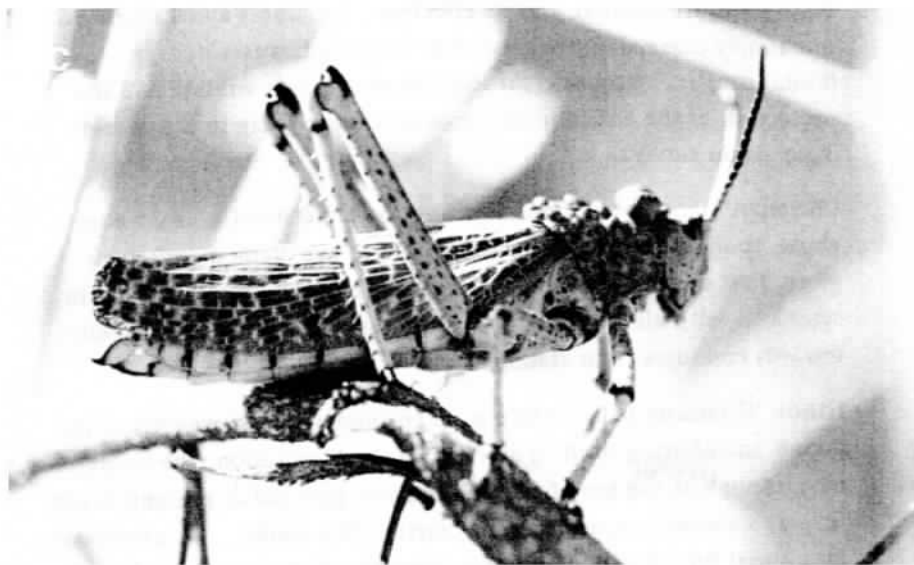
This may also be seen as a complement to species preservation, which is accentuated with increasing rarity of a species. The genotype and phenotype are naturally locked into a symbiosis. With great rarity and genetic bottlenecks, loss of individuals has the added responsibility of increasing risk to the species *per se* and its evolutionary potential.

It does not mean however, that the individual of an endangered species has any special rights over the individual of a widespread species. Both have nervous systems that demonstrate post-inhibitory rebound, both launch pheromones to attract a mate, and both will avoid a predator if they can. Both too, have an evolutionary offering to the future. Best we let individuals live (Figure 1.5).

But what of species? Is the fact that 99% of all species that have existed on earth are now extinct (Novacek and Wheeler, 1992) really a consideration? Perhaps not when we consider that many clades have evolutionarily advanced and that there is now more insect diversity on earth than ever before (Labandeira and Sepkoski, 1993). Yet no two species, or for that matter, subspecies or morphs (evolutionarily significant units, ESUs), are alike, and so all are special. This applies as much to the parasitoid as to the caterpillar host. Indeed, as polymorphisms are so rife in the insect world, it is essential to consider the caterpillar as well as its developmental polymorph, the butterfly. Reality has it, that we *have* to conserve both developmental morphs to preserve the species. The parasitoid and the butterfly polymorphism also remind us of the connectedness of all life, and that species value, in turn, is linked to the value of ecosystems and landscapes, the conservation of which are essential for maintaining all insect variety and interactions.



- 1.5 'The good, the bad and the ugly' - but there is not much between these three insects in terms of general biochemistry and physiology. All have a similar nervous system, but our perceptions of them vary considerably. (a) Basking malachite (*Chlorolestes apricans*), an attractive South African damselfly on the verge of extinction, (b) Citrus wax scale (*Ceroplastes brevicauda*), and other scale insect pests on a citrus twig that has been oversprayed with an insecticide (parathion), and (c) (see next page) the Leprous grasshopper (*Phymateus leprosus*), an African species that gives out an unpleasant protective foam when disturbed.



1.5 (cont.)

1.5 Spiritual conceptions

Jacobson (1990), with an educational perspective, has illustrated that conservation biology is an interdisciplinary science and activity. It involves the basic biological sciences as well as the applied management sciences, such as wildlife management, forestry, range and forage management and fisheries. Impinging on conservation biology, besides the physical environment, is the implementational environment (planning, education, law, communication, public health, engineering and veterinary science) and the social environment (economics, political science, sociology, anthropology and philosophy). What is missing from this model, at least in explicit terms, is the role of spiritual beliefs. Yet conservation concerns everyone, as well as every organism. A conviction through spiritual involvement can play a major role in sustaining conservation action over and above the activities of scientists, managers and policy workers. This is particularly relevant in the case of insects, which are among 'the world's many creatures' and do not have the charisma of the large animals with which the western media are so absorbed.

Spiritual outlooks were brought to the fore in a major interfaith conference in Assisi, Italy in 1986. Various faiths made 'Declarations on Nature', sections of which directly relate to insect diversity as well as to other aspects of biodiversity, and are (Anonymous, 1986/7), in alphabetical order:

Buddhist In the words of the Buddha himself: 'Because the cause was there, the consequences followed; because the cause is there, the effects will follow.' 'These few words present the inter-relationship

between cause (karma), and its effects . . . happiness and suffering do not simply come about by chance or irrelevant causes.' . . . it (Buddhism) . . . attaches great importance towards wildlife and the protection of the environment on which every being in this world depends on survival . . .'

Christian '. . . man's dominion cannot be understood as licence to abuse, spoil, squander or destroy what God has made manifest his glory. That dominion cannot be anything else than a stewardship in symbiosis with all creatures . . .' 'Every human act of irresponsibility towards creatures is an abomination.'

Hindu 'Hinduism believes in the all encompassing sovereignty of the divine, manifesting itself in a graded scale of evolution. The human race, though at the top of the evolutionary pyramid at present, is not seen as something apart from the earth.' 'This leads . . . to a reverence for animal life. The Yajurveda lays down that "no person should kill animals helpful to all. Rather, by serving them, one should attain happiness."'

Jewish 'In the Kabbalistic teaching, as Adam named all of God's creatures, he helped define their essence. Adam swore to live in harmony with those whom he had named. Thus, at the very beginning of time, man accepted responsibility, before God, for all of creation.' '. . . when the whole world is in peril, when the environment is in danger of being poisoned, and various species, both plant and animal, are becoming extinct, it is our Jewish responsibility to put the defence of the whole of nature at the very centre of concern.'

Muslim 'Allah makes the waters flow upon the earth, upholds the heavens, makes the rainfall and keeps the boundaries between day and night.' 'Unity, trusteeship and accountability . . . the three central concepts of Islam, are also the pillars of the environmental ethics of Islam . . . It is these values which led Mohamed . . . to say, "Whoever plants a tree and diligently looks after it until it matures and bears fruit is rewarded."'

Throughout these declarations there is the common denominator that all in the world, including humans, are connected, and that protection of biodiversity and the environment is essential for a sustainable future. There is greater or lesser specific mention of organisms, although their role is implicit in the debate on interconnectedness. Such spiritual bases are now a fundamental underpinning for some major conservation donor agencies, such as the World Bank (Palmer and Finlay, 2003).

Like the philosophical approach to conservation biology, the religious one is also based on the writings of the intellectual forerunners. There is, of course, no guarantee that all followers will be strong adherents of a particular philosophy or religion. While the conservation of biodiversity needs positive philosophical, spiritual and active participation by all humans, this simply is not always going to happen. As Garner (2003) puts it 'Religion is not part of the problem; people are the problem'.

Nevertheless, philosophy gives guidance and draws attention to why we are doing what we are, and for whom. Religion then provides the spiritual underpinning. In turn, research explores the technical way forward, which is framed by policy makers, and implemented by managers.

1.6 Summary

Conservation activities require a philosophical base so as to reflect on why and for whom these activities are being undertaken. Insects, as they are so speciose, so numerous and so important in terrestrial ecosystems, are an important subject for environmental philosophy. A notable corollary however, is that not all insects are good for each other or for us.

There are various philosophical approaches, and among these are the utilitarian approaches of, on the one hand, the preservationist ethic (insects are there for us to enjoy) and the resource conservation ethic (insects provide useful goods and services for us). These philosophies set us apart from the rest of nature, and this has stimulated philosophies where humans and wild nature are considered together. One approach, of deep ecology, considers a total view and that all in the world is interconnected. More recent philosophies have emphasized that all organisms, including insects, have the right to survival. These philosophies, which portray omnipotence in nature, are being addressed with the added view that joy for nature and a sense of place are important. Furthermore, it is important to value nature at all hierarchical levels. It can be argued that insect individuals do have rights, but this is linked through the genotype-phenotype symbiosis, to species conservation. Polymorphisms, which are so rich in the insect world, are an additional consideration in this debate.

Declarations from some of the world's major religious faiths have the common denominator that all in the world, including humans, is connected. It is vital that natural ecological processes, of which insects are pivotal, must be sustained. Insect diversity conservation needs a philosophical and moral base so as to give reason to why it is being done. Religion spiritually underpins this, while research investigates the technical avenues available. Policy makers then provide the frame for these avenues, and managers implement them.

2 The special case of insects in conservation biology

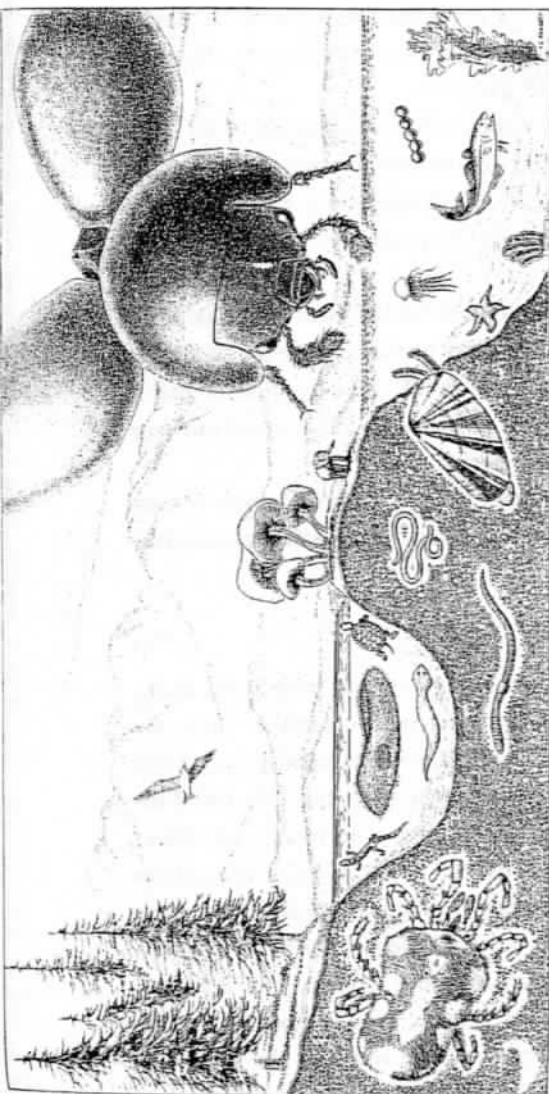
Thus, as this class (insects) is prolific beyond computation, so are its varieties multiplied beyond the power of description. The attempt to enumerate all species of a moth would be fruitless; but to give a history of all would be utterly impracticable: so various are the appetites, the manners, and the lives of this humble class of beings that every species requires its distinct history. An exact plan, therefore, of Nature's operations in this minute set of creatures, is not to be expected; and yet such a general picture may be given, as is sufficient to show the protection which 'Providence affords its smallest as well as largest productions . . .'

Oliver Goldsmith (1866).



2.1 Introduction

Insects have been hugely successful. There are possibly eight million species making up some four-fifths of all metazoans (Figure 2.1). The insect bauplan (their general design) has been a mouldable one, with flight being a hallmark.



Size of individual organisms represents number of described species in major taxon.
Unit Area: □ = approximately 1000 described species.

| Taxon | No. of Described Species | Taxon | No. of Described Species |
|--------------------------------------|--------------------------|------------------------------------|--------------------------|
| 1 Mosses (Bryozoa, Blue-green Algae) | 4,780 | 11 Melusina (Melusina) | 50,000 |
| 2 Fungi | 46,983 | 12 Echinodermata (Starfish etc.) | 6,100 |
| 3 Algae | 26,900 | 13 Insecta | 751,000 |
| 4 Plants (Multicellular Plants) | 248,428 | 14 Non-insect Arthropoda | 125,181 |
| 5 Protoczoa | 30,000 | (Mites, Spiders, Crustaceans etc.) | |
| 6 Ciliates (Sponges) | 5,000 | 15 Phlebotomina (Phlebotomina) | 4,184 |
| 7 Corals | 9,000 | 16 Arachnida (Arachnida) | 6,300 |
| 8 Jellyfish, Corals, Comb Jellies | 12,200 | 17 Reptalia (Reptalia) | 9,040 |
| 9 Phyllozoa (Phlebotomina) | 12,000 | 18 Aves (Birds) | 4,000 |
| 10 Nematoda (Roundworms) | 12,000 | 19 Mammalia (mammals) | 4,000 |

Illustration by FRANCIS L. FINECOTT From O.D. Wheeler: 1960. *Ann. Entomol. Soc. Am.* 83: 1031-1047

2.1 The 'species-scape' of Wheeler (1990) in which the size of the organism represents the size of the described species in the overall taxonomic group (principally at class level). The beetle, for example, represents the insects; the elephant the mammals; the mite the non-insect arthropods; the pine trees the multicellular plants, etc. As so many insects are yet to be described, compared with many of the other groups, in real terms the beetle in the illustration should be much larger (from Wheeler, 1990).

Nevertheless, insects are structurally limited in the size to which they can grow. Thus insects generally remain small, yet often highly mobile. It is the tensile strength of the cuticle that has been the raw attribute for evolutionary sculpturing of a wide array of morphological modifications so vivid in the insect world. To take just the mouthparts: they can pierce, sponge, rasp and chew. So it is that insects have been able to inhabit a wide range of nooks, crevices and tunnels throughout all but the very coldest and most marine parts of the planet. Flight between these retreats enables searching for distant resources, dispersal to more salubrious settings and dispersal of gametes.

Insect genetic versatility has also been notable. Polymorphisms of all sorts are common among insects. This includes developmental polymorphism, where, from functional and conservation viewpoints, the caterpillar is a different animal from the butterfly. So both forms and both their habitats, must be equally conserved.

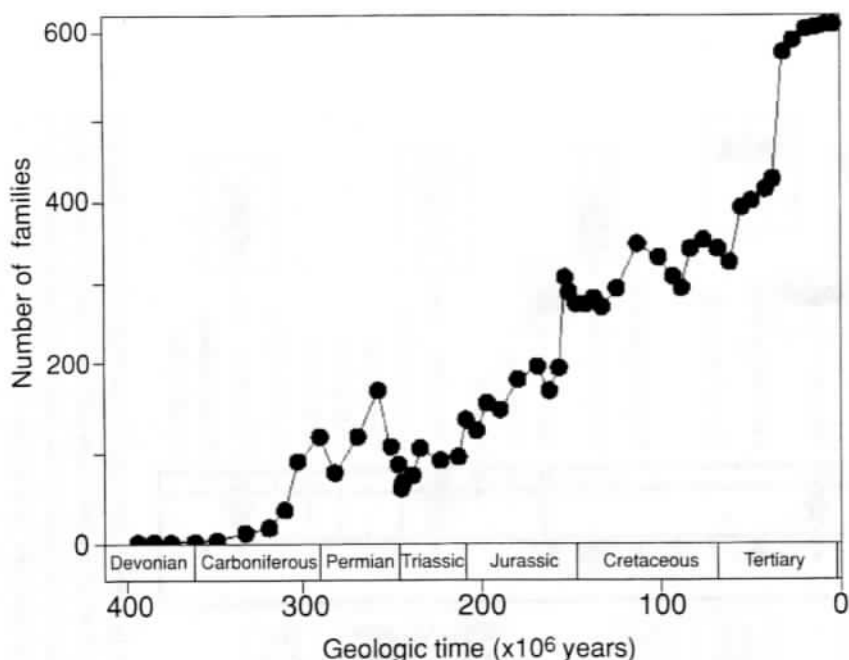
Although insects have been an immensely successful life-form that has taken so many diverse evolutionary paths, for many, their world is suddenly changing so much faster than possibly at any time before (with the exception of major meteor impacts). This is threatening for many of them, and they need our support and salvation, without which many will perish.

Let us now turn to these jewels of our planet, the insects, and review conservation of their diversity and how it might differ from that of other organisms.

2.2 Insect radiation

As the prow of the pirogue slices the water on its way to Nosy By, Madagascar, fast-moving sea skaters (*Halobates* sp.) skit across the surface. These are among the few insect mariners. The majority of insects are terrestrial, and/or aquatic. In both air and freshwater, they are among the most speciose and dominant of all organisms. This may not have always been the case, with insect families having steadily increased over the last 400 million years (Labandeira and Sepkoski, 1993) (Figure 2.2). Sometime during the Early Carboniferous, more than 325 million years ago, a massive insect radiation began, followed by peaks in fossil insect diversity during the Late Carboniferous and middle Permian. Labandeira and Sepkoski (1993) suspect a lower Triassic drop in insect diversity, reflecting the terminal Permian mass extinction, which was also the case with marine animals and terrestrial tetrapods. Indeed, eight out of the 27 orders of insects, making up 15 families, which were alive earlier, did not survive beyond the Permian.

About half of the orders that survived into the Recent underwent few to many diversifications through the Triassic and Jurassic. This shift in phylogenetic pattern of diversification is the most pronounced event during the history of

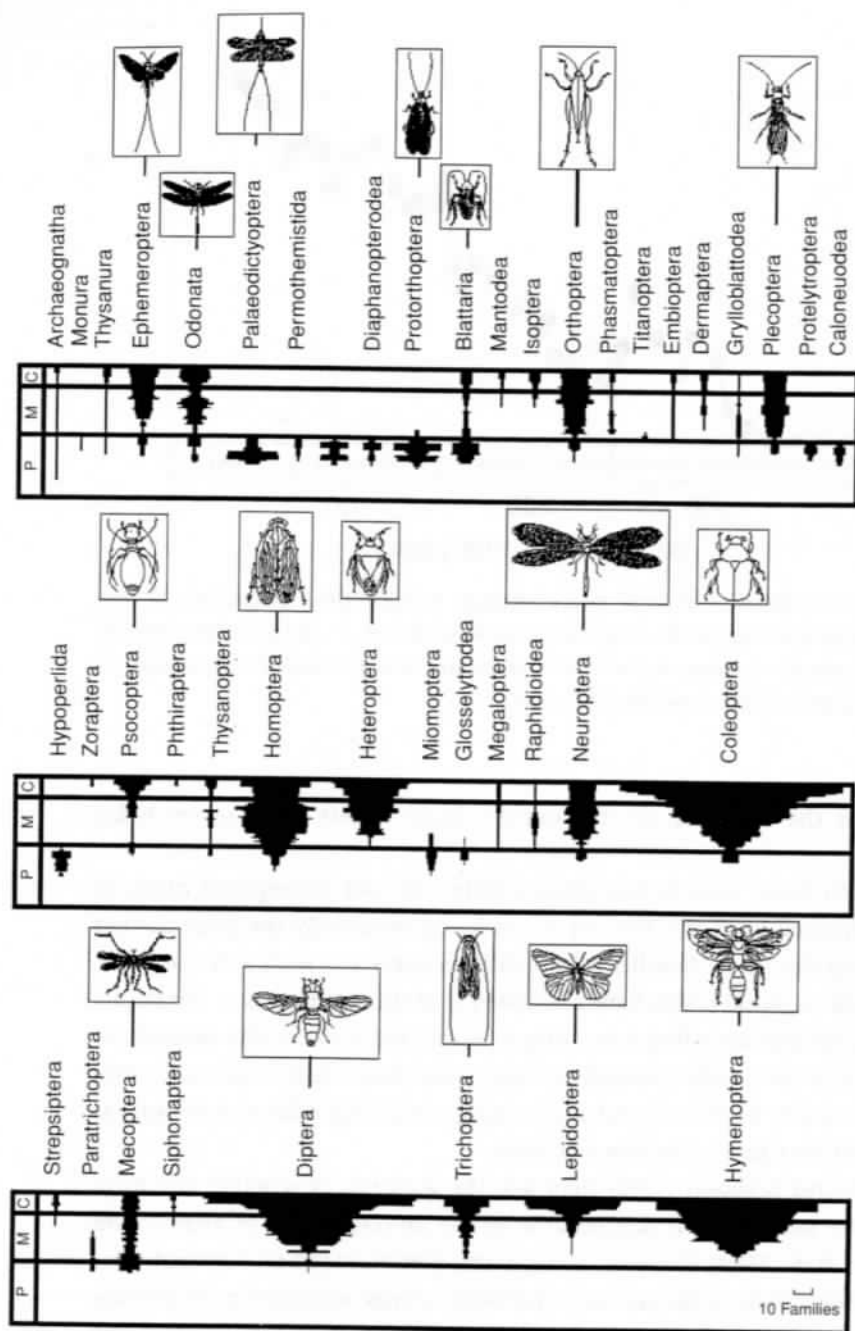


2.2 Family-level diversity of fossil insects through geologic time, plotted at the level of stratigraphic stages. D = Devonian, C = Carboniferous, P = Permian, Tr = Triassic, J = Jurassic, K = Cretaceous, T = Tertiary. (Reprinted with permission from Labandeira and Sepkoski (1993). Copyright 1993 AAAS.)

insects, and is the backdrop for the current huge variety that we see today (Figure 2.3).

At the family level, insects have shown little turnover throughout much of their recent history, with the Tertiary fauna being essentially the same as that today, and even the insect families of 100 million years ago were 84% the same. Labandeira and Sepkoski (1993) have cautioned that this analysis is at the family level, with insect families often consisting of many smaller taxa, the turnover of which, can carry the family through geologic time. Nevertheless, certain beetle (*Tetraphalerus*), crane fly (*Heliopsis*) and leaf-mining moth (*Stigmella*) species appear to have existed over tens of millions of years.

Labandeira and Sepkoski (1993) then ask the question of whether the huge insect diversity seen today is attributable to the diversification of angiosperm plants (Strong *et al.*, 1984). However, using extrapolation based on constant rates of diversification, there is no necessity to invoke a huge angiosperm diversification as the specific reason for current insect familial diversity. The extant 980 or so insect families possibly represent saturation. Also, the radiation of insect families began more than 100 million years before angiosperms appeared in the



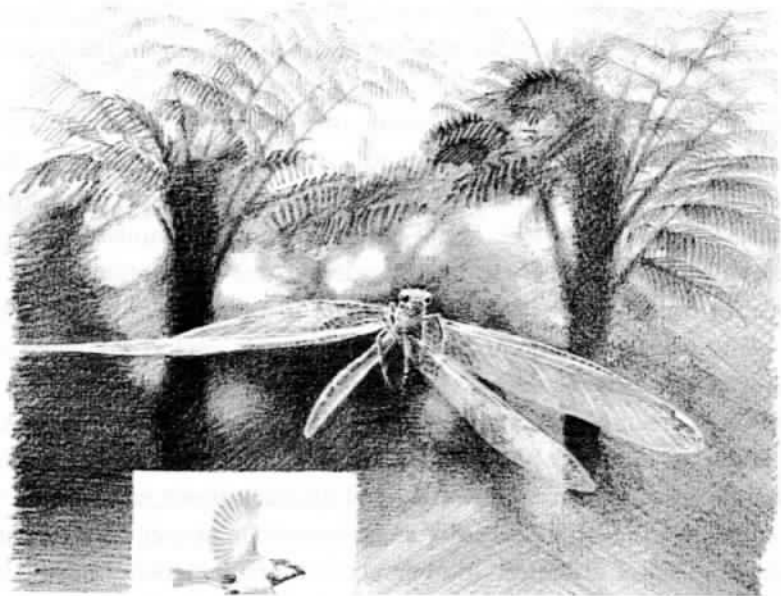
2.3 Spindle diagrams displaying diversities of fossil families within insect orders in stratigraphic stages of the Phanerozoic. P = Paleozoic, M = Mesozoic, C = Cenozoic. Boxed illustrations (not to scale) depict typical adult representatives of the more important orders. Angiosperm plants make their fossil appearance about two-thirds of the way up the band for the Mesozoic (that is, just above the 'M' in Mz). (Reprinted with permission from Labandeira and Sepkoski (1993). Copyright 1993 AAAS.)

fossil record. This is especially so for the highly speciose Coleoptera, Diptera and Hymenoptera, all of which apparently began their radiations in the Triassic and Jurassic, long before the ascendancy of the angiosperms.

A burning question however, is whether angiosperms have had a major effect on insect diversity below the level of family. This is a compelling point bearing in mind the close interrelationships between certain insect species and particular plants (Jolivet, 1998), which has become extremely fine tuned in the case of *Yuccas* and *Yucca* moths (Powell, 1992). An alternative explanation is that it was insects that triggered the radiation in plants in the mid-Cretaceous (Pellmyr, 1992). Only 10 out of the 30 extant orders of insects exploit the living tissues of higher plants. This relatively small proportion is surprising given the ready availability of green plant material. Life on plants therefore seems to have been a formidable evolutionary hurdle (Southwood, 1973), although once the hurdle was cleared, great opportunities existed and dramatic insect radiation occurred. The complexity of plant architecture and composition opened up opportunities for a range of insect exploiters. In turn, plant diversity increases in response to the pressures imposed by herbivores, especially insects (Strong *et al.*, 1984). Yet the flowers, in contrast to the vegetative parts, often provide a mutually beneficial interrelationship (Ehrlich and Raven, 1964), making plant diversification a process of adaptation to escape herbivorous insects and yet include pollinating ones. For many of the large holometabolous groups, especially the Lepidoptera, Diptera, Coleoptera and Hymenoptera, the developmental polymorphism of larva and adult often presents these two contrasting faces to plants.

In a comprehensive study of insect mouthparts, Labandeira and Sepkoski (1993) suggest that a number of insect feeding guilds diversified well before the appearance of angiosperms. By the Middle Jurassic, 65% (low estimate) to 88% (high estimate) of all modern insect mouthpart types were present, including those normally associated with flowering plants. This suggests, as does the radiation of insect families, that the special associations of specific insects with particular plant types and parts is a relatively modern phenomenon. It is a question of the taxonomic scale at which we are working as to whether insects and plants are to be considered as mutually evolutionary.

This effect of taxonomic scale has a major influence on our thinking relative to insect diversity conservation. Firstly, conservation prioritization and action based on higher-level taxonomic surrogates could be misleading as a means of conserving the huge species richness and all their subtle interactions. Secondly, the enormous number of insect-plant interrelations, as well as many other interrelations mediated by plants, is an evolutionarily finely tuned process, and, as Labandeira and Sepkoski (1993) point out, exploitative destruction of angiosperm communities could well reverse 245 million years of evolutionary success. This is underscored by the fact that it was the most specialized associations that were diverse and abundant during the latest Cretaceous and were the ones that



2.4 A giant dragonfly (*Meganeura* sp.) of the Carboniferous, with a modern-day sparrow for size comparison. (Illustration by courtesy of Valter Fogato.)

almost disappeared at the Cretaceous/Palaeogene boundary, while generalized associations regained their Cretaceous abundances (Labandeira *et al.*, 2002).

2.3 Bauplan, flight and insect conservation

The general design of insects has a profound influence on how we think about them in terms of their conservation. Flight is unquestionably one of their major features to consider. Indeed, giant dragonflies, such as *Meganeura monyi*, with a wingspan of 70 cm, were airborne some 300 million years ago (Figure 2.4). With airspace to themselves, and possibly elevated oxygen levels at the time (Dudley, 1998) (enabling highly efficient muscle action), these insects were the supreme flying predators. With pterodactyls and birds having not yet arisen, the Carboniferous airspace was dominated by flying insects.

Flight probably arose through a step by step improvement in wing form and action, as early stonefly-like insects continued to skim across the water's surface (Marden and Kramer, 1994). Insect diversification rate increased substantially with the origin of the Neoptera (insects with wing flexion) (Mayhew, 2002). Nevertheless, today, not all winged insects fly well. The threatened Apollo butterfly *Parnassius apollo*, although potentially a good flier (< 1840 m) is still constrained in its movement over host plant and nectar patches by segregation of adult and larval resources (Brommer and Fred, 1999). Nevertheless, flight enables some aquatic adult insects to reinhabit an optimal upstream habitat after the

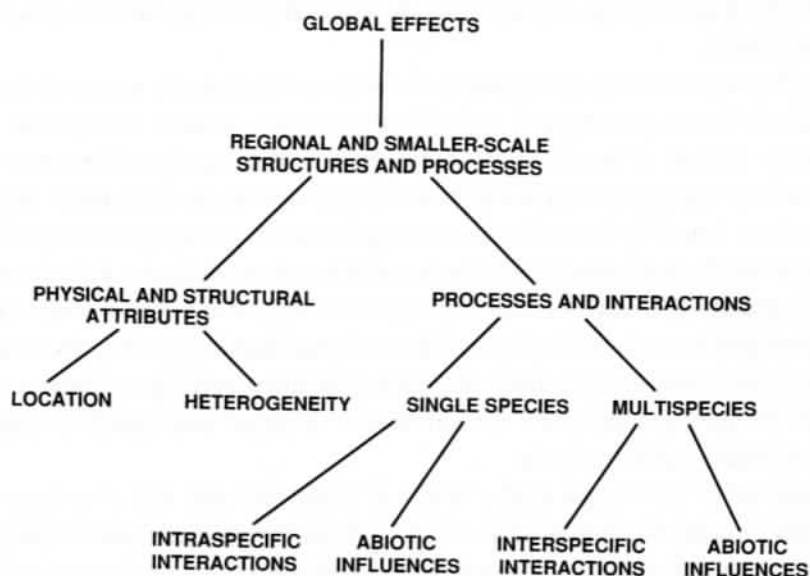
larvae have been swept downstream by unusually strong currents (Samways 1989a, 1996a).

Flight, besides being a mechanism to escape predators, is a means of exploiting food, shelter, mating and oviposition resources. Indeed, at any one time there are billions of insects on the wing, even at night and travelling over long distances (Riley *et al.*, 1995). Some of these movements are directional, and are migrations honed by natural selection (e.g. Monarch butterfly *Danaus plexippus* (Brower, 1977)). But many insect movements are short distance, but not necessarily random. The ladybird *Chilocorus nigritus* forages at the spatial level of habitat, prey patch and individual prey (Hattingh and Samways, 1995). Tree images attract the ladybirds first, then leaf shape; in turn, prey odour focuses their search on prey groups; then, a combination of visual and olfactory cues are used to detect individual prey.

Many other insects are at the mercy of wind currents, and they may even land on snowfields (Ashmole *et al.*, 1983), and colonize recently cooled lava flows (New and Thornton, 1988; Thornton, 1996). Some even travel on flotsam, arriving serendipitously on islands (Peck, 1994a,b). Small insects are known to regularly travel high up on wind currents (Berry and Taylor, 1968). Even first-instar moth larvae with silken threads can rise to 800 m on air turbulence and travel 19 km on wind currents (Taylor and Reling, 1986). On Anak Krakatau, Indonesia, around 20 arthropod individuals land per square metre per day (Thornton *et al.*, 1988), which equates to about 50 million individuals arriving each day on that volcanic speck.

2.4 Polymorphisms

Insects are well known for their great functional and morphological variation. This is the case within particular species, as well as between them. Indeed, ecomorphs are common in the insect world. Such morphs, or evolutionarily significant units (ESUs) (Ryder, 1986; Moritz, 1994; Vogler and De Salle, 1994) not only may have differing evolutionary potentials but also may have quite different conservation statuses. This is highlighted in the case of the Gypsy moth *Lymantria dispar*, which was extirpated from Britain around 1907 (Hamblen and Speight, 1996). Yet, in June 1995, Britain saw a pest outbreak of an Asian variety of this species (Nettleton, 1996). Genetically, there must be something quite disparate here, which, by some extraordinary coincidence, makes the name *dispar* very appropriate. Moths are known to have ESUs (Legg *et al.*, 1996), and clearly, through subtle change in genetics, such an insect *species* can be extinct on the one hand yet be a pest on the other. This is why it is critical to recognize ESUs in insect diversity conservation as one of the crucial units of conservation, as a tiny genetic difference can lead to quite different ecomorphs (Samways, 1997b). This calls also for regular revision of insect species' threat category and the



- 2.5 Global effects have a general overall effect upon regions and landscapes. These, in turn, may be divided into tangible, physical attributes such as geometry and architecture, and also into processes and interactions. Physical attributes can then be divided into location (where the physical structure is located) and heterogeneity (how the physical structures spatially change). Processes and interactions can then be viewed, and this is not the only way, under single-species situations ('fine-filter'), or, alternatively, under multispecies ones ('coarse-filter'). Further subdividing separates interactions between organisms on the one hand, and between organisms and their abiotic environment on the other. (From Samways, 1993a with kind permission of Intercept.)

clear need to emphasize what is regionally or nationally threatened as opposed to globally threatened. Hambler and Speight (1996) point out that the British ambrosia beetle *Platypus cylindrus* is classified as 'Rare' in the British *Red Data Book* yet it is a serious pest in parts of continental Europe and has become a pest of oaks even in Britain. Clearly, in insect conservation biology, we must recognize a dynamic and sometimes volatile genetic situation.

Other ecomorphs are those with alternative life-history attributes, such as apterous and alate aphids. Sexual morphism is also highly marked in insects, such as many scale insects and mealybugs. In addition to these are many other types of morphisms, some of which are listed in Samways (1993a). But above all, the most significant polymorphism feature that insect conservation biologists have to deal with, is developmental polymorphism. This is especially so for many species, where the larva is functionally a different animal from the adult. Any form of habitat conservation or management must consider survival of both these forms. Although this may seem intuitively obvious, there are few studies that really focus on restriction imposed on population survival through conditions having to be suitable for both larva and adult (including two types of

feeding, predator avoidance etc.) in the same place at more or less the same time.

A further factor is that the immature and mature morphs interact mostly in different food webs, with caterpillars being significant herbivores and butterflies significant pollinators. Also, the caterpillar's and butterfly's natural enemies are mostly different. Any one caterpillar may have five species of parasitoids that are able to attack it, making up a food web that functionally may only overlap with that of the butterfly through bird predation.

2.5 Insect diversity and the landscape

Knowing that insects are major components of most terrestrial and aquatic ecosystems, does not help us much in focusing on conservation priorities. It does, however, indicate that conservation of the Earth's landscape heterogeneity and, indeed, conservation of the whole biosphere is a foundation for insect diversity conservation. All the while we need to be acutely aware of all spatial scales, and of compositional (how things are made up), structural (how things are arranged in space) and functional (the processes involved) aspects of biodiversity (Noss, 1990) (Figure 2.5).

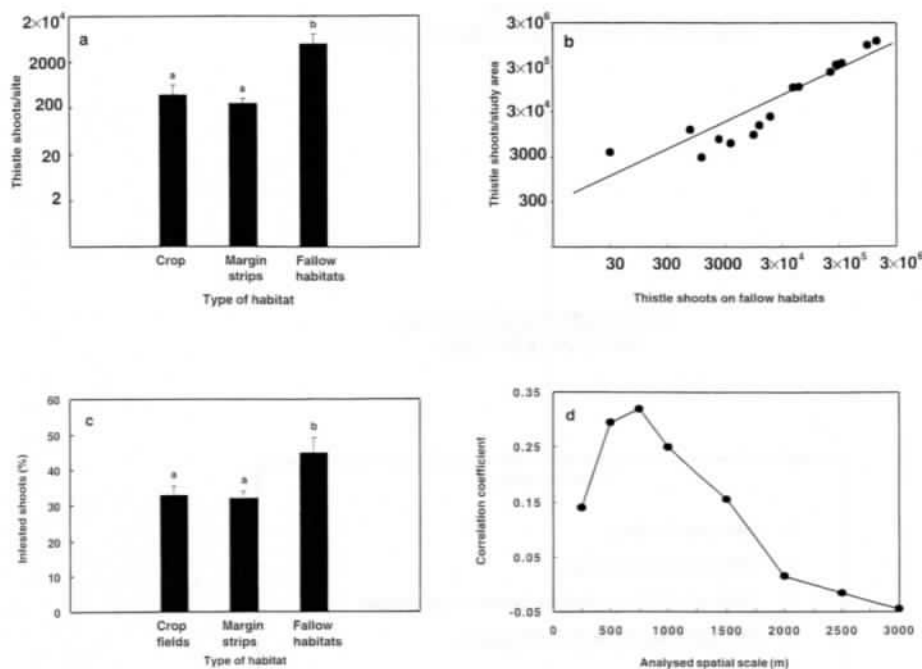
As insects are small, often highly polymorphic organisms with hugely varying ways of life, we need to take cognisance of the 'sense of place' and be aware of these spatial scales, the subregional ones of which are given in Table 2.1.

Within a region, landscapes have attributes that are compositional and structural, as well as involving interactions and processes (Figure 2.5). Spatial scale is important in insect conservation biology because different behaviours of different morphs and different species each require specific scales to carry out their life functions (Chust *et al.*, 2003). But within a landscape are great complexities of composition, structure and processes. This has been emphasized by Kruess (2003), who showed that biological diversity and ecological functions within a plant-insect community are not only affected by local habitat factors but also by large-scale landscape characteristics. Furthermore, insect herbivores suffered most from parasitism in landscapes that were structurally rich and with a high proportion of large and undisturbed habitats (Figure 2.6).

So vast are these landscape complexities that we have to view the higher spatial scale (i.e. landscape level) as sufficiently large to accommodate most insects' activities yet small enough for practical management. This may be considered the 'black box' approach i.e. a whole range of composition and structural units plus a whole range of interaction types and strengths, as well as ecological processes (Figure 2.7), all of which have dynamics often with unpredictable outcomes. This is so through the principle of chaos (Capra, 1996), which leads to various and varying outcomes of huge complexity. For insects, and much other biodiversity, this 'coarse filter' landscape approach is a critical approach

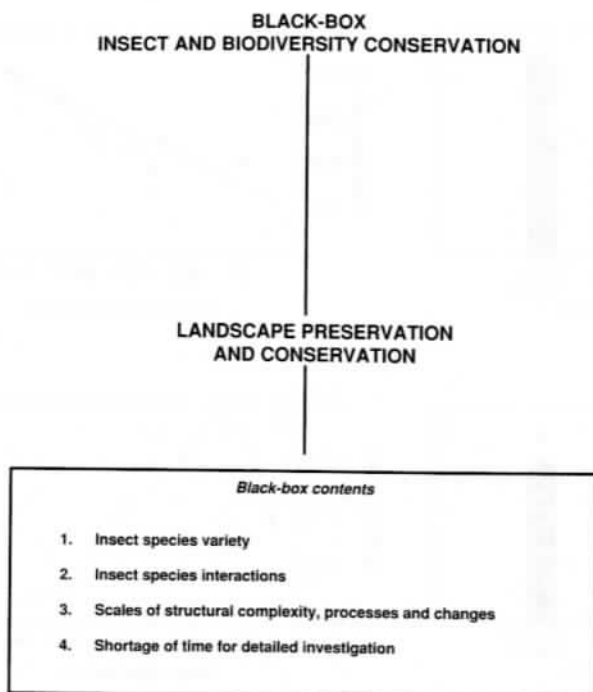
Table 2.1. *Subregional framework for insect and biodiversity conservation research and management*

| Scale and units of measurement | Physical attributes | | Biotic groupings, interactions and processes | |
|--------------------------------|--|---------------------------|---|---|
| | Location | Heterogeneity | Single-species (principally formational and involving size changes) | Multispecies (principally processes) |
| mm to cm (micro) | Microsite | Microscope | Intraspecific group, and their interactions/microhabitat | Intraspecific and intimate interspecific interactions/Guild/Community |
| cm to m (meso) | Biotope | Plantscape (Animalscape) | Subpopulation/Habitat | Community |
| m to km (meso) | (a) Landscape element (for fragmented landscape) (b) Ecotone (for variegated landscape) | Heteroscape Multiscape | Subpopulation/Population/ Metapopulation/Populations | Community/Communities/Ecosystem/ Ecosystems |
| km (macro) | Landscape | Landscape heterogeneity | Population/Metapopulation/ Populations | Ecosystem/Ecosystems |



2.6 Effects of local habitat and large-scale landscape factors on species diversity and species interactions illustrated using Creeping thistle (*Cirsium arvense*). Above: Mean thistle abundance in fallow habitats was significantly higher than in crop fields and field margin strips (left) (a). Thus, total thistle abundance on landscape scale was mostly determined by thistle abundance in fallow habitats (right) (b). Below: However, the infestation rate of thistle shoots caused by the herbivorous agromyzid fly, *Melanogromyza geneoventris*, was significantly higher in fallow habitats than the other two habitats (left) (c). However, at the landscape scale, the infestation rate increased from 30% in areas with a low percentage of non-crop habitats to > 40% in areas with a high percentage of non-crop habitats. Moreover, this effect was scale-dependent because significant correlations were found for per cent non-crop area on a landscape scale of 500 and 750 m, whereas the correlation declines with further increase of the study areas (right) (d). (Redrawn from Kruess, 2003, with kind permission of Blackwell Publishing.)

for biodiversity conservation. This is not to decry the role of behaviour and the need for special, single-species, 'fine-filter' studies in special circumstances, especially when compiling the Red List (Hilton-Taylor, 2000). Indeed, the coarse-filter and fine-filter approaches are complementary. The disadvantage of the 'coarse-filter' approach is that it is blind to actually what and in which way the immensely complex contents are being conserved (Haslett, 2001). Nevertheless, conserving black boxes (i.e. whole landscapes with high connectivity, high ecological integrity and minimal human disturbance) is one answer in view of the magnitude of the biodiversity crisis and the shortage of time to conserve it. But it also requires critical consideration, which is the subject of Chapter 8.



- 2.7 Black-box insect and biodiversity conservation. There are millions of insect species, of varied and varying abundances, and there are many times that number of interactions between insects and other biota. These interactions, in turn, are taking place at various spatial scales from centimeters to kilometers within the landscape. Within the time available for preservation of much of the world's biota, we cannot hope to define all the conservation parameters. Preservation (no management) and conservation (with management) of landscapes that are both unique or irreplaceable, and also typical, of regions are the only realistic approaches for maximal preservation of insect and other biota. Various approaches are being developed for doing this, and they are discussed in Chapter 8. (From Samways, 1993a, with kind permission of Intercept.)

2.6 Global insect species richness

The question of how many species there are on earth has fuelled some intense debates (Erwin 1982, 1988; May, 1990; Stork 1988, 1999; Gaston 1991; Hodkinson and Casson, 1991; Hammond, 1992; Ødegaard *et al.*, 2000). As the lexicographer Samuel Johnson pointed out we can argue only once we have defined what it is we are arguing. Here of course, it depends on what we define as species (Adis, 1990; May, 1990). The phylogenetic species concept of Nixon and Wheeler (1992), which is the smallest aggregation of populations (sexual) or linear (asexual) diagnosable by a unique combination of character states in comparable individuals (semaphoronts), is a useful starting point in insect diversity conservation. Nevertheless, there still are subspecies, evolutionarily significant units (ESUs) and polymorphisms, all of which also deserve conservation

status. Species concepts based on implications of ancestry, while valuable in certain cases and for specific conservation questions, especially irreplaceability, are limiting for much practical insect diversity conservation because of the taxonomic insight and technical sophistication required. Invoking genetic concepts also poses problems in view of the inferential findings of Houck *et al.* (1991) that the semiparasitic mite *Proctolaelaps regalis* can transfer genes from one *Drosophila* species to another.

So any estimate of species numbers will be crude, not just because we are not quite sure when one species ends and another starts (Mallet, 1997), but also because our taxonomic knowledge of the insect world, and indeed invertebrates in general, is very sparse. Nevertheless, it is a healthy exercise for knowing the magnitude of what we aim to conserve and to estimate just how many species with which we share the world.

Erwin's (1982, 1988) estimates of 30–50 million species on Earth may be overly large (Ødegaard *et al.*, 2000), with the revised average figure being about 10 million (May, 1989) to 12.25 million (Hammond, 1992) species. Of these, insects may constitute 1.84–2.57 million (Hodkinson and Casson, 1991), 2.75–8.75 million (Gaston, 1992) or 5–10 million (Gaston, 1991) species. Bartlett *et al.* (1999) point out that estimates of number of species on Earth depend on understanding beta diversity, the turnover of species composition with distance. This involves also knowing whether species have widespread or localized distributions. Such studies are fraught with methodological problems of bona fide comparisons of geographical sites. Nevertheless, Bartlett *et al.*'s (1999) study suggests wasps may not have such restricted geographical ranges as Erwin's (1988) herbivorous beetles, which would certainly downsize world estimates of species numbers. Similar conclusions were reached by Thomas (1990) using heliconiine butterflies. Future efforts to refine biodiversity and insect diversity estimates should focus on site-region or region-region comparisons rather than on site-site comparisons of species beta diversity (Bartlett *et al.*, 1999). All such comparisons are also illuminating for spatial insect heterogeneity, and hence for prioritizing conservation actions.

2.7 Survival in prehistorical times

2.7.1 Insect response to pre-agricultural impacts

With the advance and retreat of the Quaternary (last 2.4 million years) ice sheets, so have insect populations similarly pulsed. There is a clear suggestion that there were not the widespread extinctions among insects as there were among the mammals (Elias, 1994; Coope, 1995; Ashworth, 1996). Furthermore, there is no evidence of widespread evolutionary change during this period (Ashworth, 1996) and constancy of species, and even species assemblages, appears

to have been the norm for the last million years or so (Coope, 1995). This is a fascinating array of events that deserves closer scrutiny because it may indicate whether insects are equipped to survive the current, massive human impact.

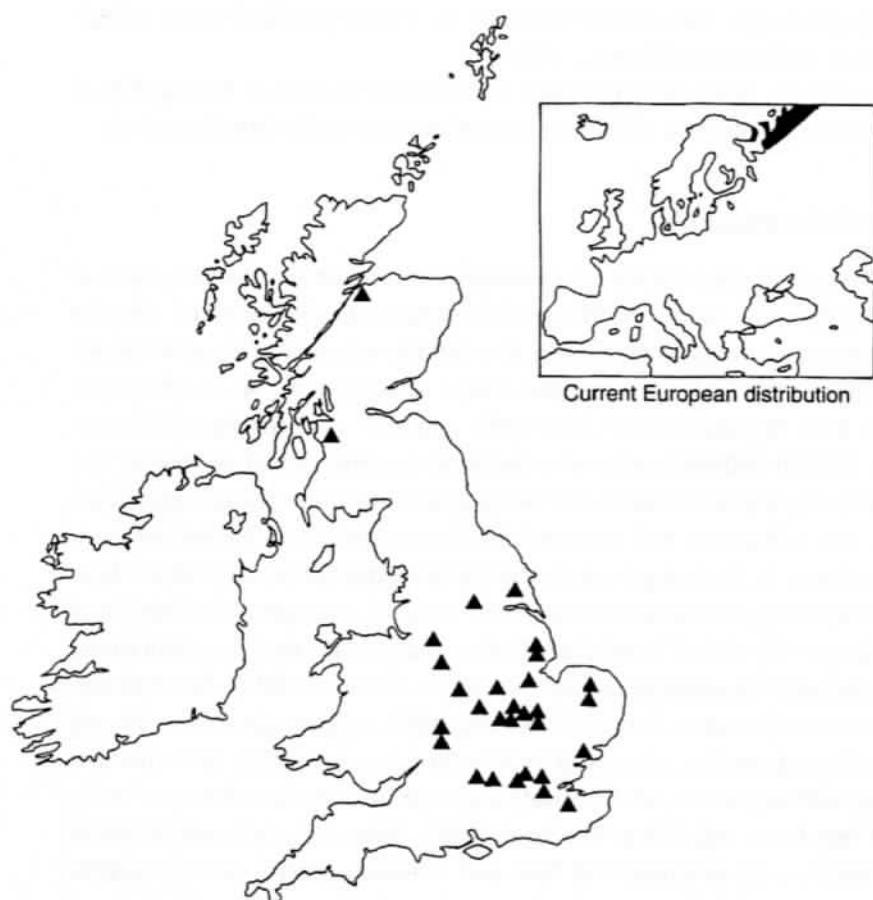
Shackleton (1977) has shown that during the last three-quarters of a million years the Earth has been glaciated to a much greater extent than it is today, and the current state of affairs is a rare, warm post- or interglacial period. Also, the transitions between glacial and interglacial times were very fast indeed, with change from glacial to interglacial at the end of the Last Glaciation taking only 50 years (Dansgaard *et al.*, 1989).

During the transition from the last glacial to the current interglacial period, the climate was highly unstable. In Britain, about 13 000 years ago, the July temperatures rose from about 10 °C to 17 °C in less than a century (Coope and Brophy, 1972). Just a few centuries after this warming, a chill set in again, with sporadic drops, until 11 000 years ago, when again, glacial conditions prevailed, with summer temperatures no more than 10 °C and winter temperatures about -15 °C. Then, about 10 000 years ago, there was a rapid thaw occurring over about a century. These climatic changes were global (Ashworth and Hoganson, 1993; Ponel, 1995) and during this time there were also global sea-level variations of more than 100 metres. Insect assemblages in Europe at a single location changed dramatically during these times, driven by vegetation changes in response to climatic ones (Ponel *et al.*, 2003).

Despite these huge climatic variations, some 2000 beetle species are known both from the Quaternary and today, with far less than 1% of the fossil beetles defying identification and possibly extinct. The fossil species, although formerly occurring in Britain, are today extant in more northerly latitudes (Figure 2.8). Coope (1995) points out that these species survived because they were sufficiently mobile, and space was available to receive them. But it must be remembered that there were late Tertiary extinctions, 2.47 million years ago, when the first major climatic oscillations began. This would have been a hurdle, with those species clearing it, capable of surviving the subsequent oscillations. The important point made by Coope (1995) is that the Quaternary survival strategy, at least in northern Europe, was to shift geographical ranges. This was coupled with the splitting and meeting of populations, with concurrent genetic mixing, and lack of speciation. This may not have been the case the world over. Eggleton *et al.* (1994) suggest that for termites in Africa, the particularly high level of Quaternary disturbance in this region has enabled high speciation.

2.7.2 Early human impacts

Although the prehistorical changes in plant and insect assemblages were driven primarily by climate, there is some evidence that humans have also played a role in changing the flora and insect fauna in these early times (Ponel



- 2.8 Fossil sites in the British Isles of the flightless beetle *Diacheila polita* which was common in Britain during the middle period of the Last Glaciation. It did not recolonize Britain at the close of the glacial period, and today is confined to much more northerly continental areas. Other, more mobile species that could fly, such as *D. arctica*, recolonized Britain during cold conditions. (From Coope, 1995. Reprinted by permission of Oxford University Press.)

et al., 1992). In Mediterranean France, the Neolithic human impact (4310 BP) has not only affected the local distribution of coleopteran fauna through a drastic change in hydrological regime, it has also induced major changes in the regional distribution of certain species through local extinctions (Andrieu-Ponel and Ponel, 1999). Neolithic landscape modification also impacted on insect faunas in Britain (Robinson, 1991; Dinnin, 1997), and in some cases, indirectly through increased sedimentation of rivers from soil erosion induced by forest clearance for agriculture (Osbourne, 1997). Girling (1982) lists 20 species of Neolithic saproxylic beetles that no longer occur in Britain. Not that the Neolithic forest clearances were all bad. With the cooling of the British climate

4500–3500 years, ago, the cleared landscape may have provided warm refugia for grassland Lepidoptera (Thomas, 1991).

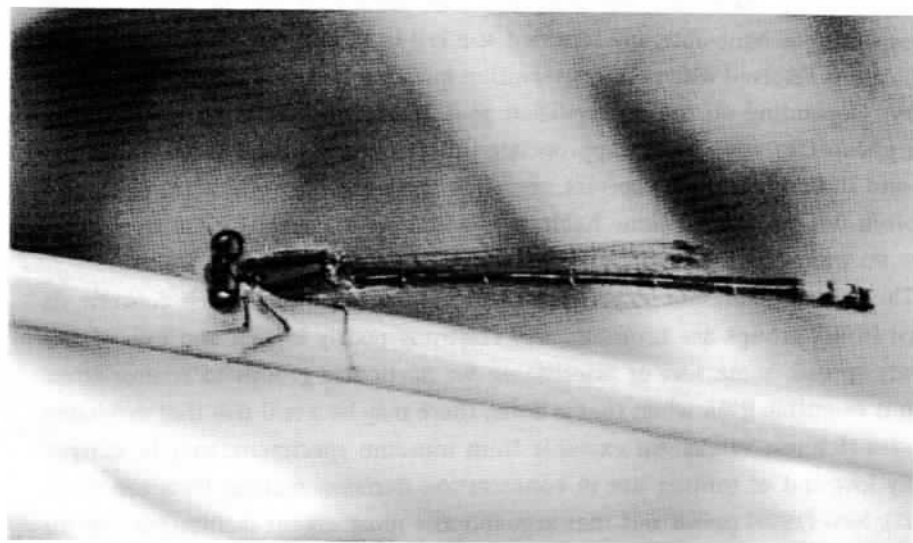
In recent years, however, it has been the intensity as well as the rapidity of landscape change (Forman, 1995) that is causing concern for insect survival.

2.8 Current extinctions

There is a discrepancy in assessments of current extinction rates of insects. The dilemma lies in the difference between what we know and what we suspect. We categorically know of very few definite extinctions in recent years, yet, with loss of tropical forest in particular, it is suspected that 11 200 species of insects have become extinct since 1600, and that over the next 300 years a further 100 000–500 000 species of insect may become extinct (Mawdsley and Stork, 1995). The problem lies in not being quite sure when the last individual has died, and as Harrison and Stiasny (1999) have pointed out for fish, we must not be too hasty in declaring a particular species extinct, only to find out later that it is surviving, and in some cases, even thriving. Premature declaration of extinction runs the risk of forestalling further searches of remnant populations. Also, 'crying wolf' on extinctions can lose conservation credibility. Nevertheless, there is cause for concern, because McKinney (1999) suggests that the estimated number of insect species extinctions may be far too conservative, by as much as three orders of magnitude, with possibly a quarter of all species of insects under threat of imminent extinction. The level of this threat is re-inforced by McKee *et al.*'s (2003) model of threatened bird and mammal species, which suggests that the average nation is expected to have an increase in number of threatened species of 7% by 2020, and 14% by 2050.

Insects are particularly risky animals on which to declare extinction. Firstly, they are small and easily overlooked. Often the time window for the most apparent stage, usually the adult, is narrow. Populations also can be highly variable and shifting, particularly in a metapopulation context. Furthermore, while species extinction is the final result of population extinctions, it is probably not unusual that populations of generally abundant species occasionally and perhaps even readily become extinct. Indeed, an average of 24% of the populations of the Common cinnabar moth *Tyria jacobaea* become extinct every year, only to reappear in subsequent years (Dempster, 1989). This is a manifestation of sink populations being resupplied by source populations (Pulliam, 1988).

As extinction is forever, the listing of suspected extinct species cannot be taken lightly. The IUCN (2001) category 'Extinct in the Wild' is a formidable category, and as very rare and threatened insects are generally not easy to rear, this category, at least for insects, is virtually equivalent to category 'Extinct'. Harrison and Stiasny (1999) provide a useful key, developed for fish. Although complex, it has much merit for listing extinct or possibly extinct insects. Such a



2.9 Feared extinct and red-listed as Critically Endangered, the minute and unusual-coloured (purple) Cape bluet damselfly *Proischnura polychromatica* is now known to be extant but highly localized.

key should be followed before an insect Red List categorization involving extinction is stipulated. The fundamental tenet is that a species should not be declared 'Extinct in the Wild' until a full and thorough search has been undertaken. This is particularly important for insects, which are cryptic, and outlier populations may exist in unexplored locations (Figure 2.9).

This critical categorization of 'Extinct in the Wild' could also be performed on regional populations, which in some countries such as Britain are indeed considered as 'extinctions'. But as Thomas and Morris (1995) point out, such national extinctions are a warning knell for global extinction.

2.9 The taxonomic challenge

Insect diversity is great, and little known. Perhaps only 10% of species have scientific names, and among those that do, many require taxonomic revision. The situation is compounded by cryptic species (the adults of the hymenopteran parasitoids *Aphytis africanus* and *A. melinus*, for example, cannot be distinguished on morphology), evolutionarily significant units and polymorphisms. Such barely understood taxonomic variety has been described as the taxonomic impediment (New, 1984), and, more recently, the taxonomic challenge (Samways, 2002a).

There has been considerable debate concerning the value of taxonomy and systematics in biodiversity conservation (Stork and Samways, 1995; New, 1999). Much of the debate has been at cross-purposes with proponents of the necessity

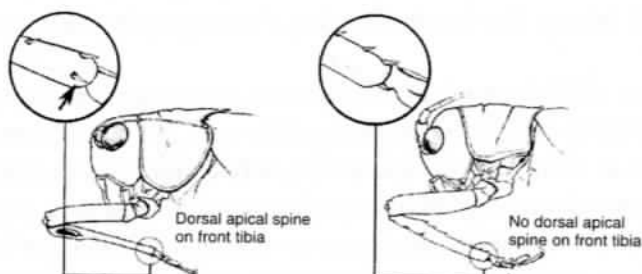
of overcoming the taxonomic challenge and those that see the value of morphospecies (recognizable, unidentified species) in biodiversity assessments. The problem is resolved when the conservation question is clearly posed (Oliver *et al.*, 1999). Depending on the conservation goal, identified species or, alternatively, morphospecies, may be the appropriate units of study. Much as we would like to, and should use named species, and their variation within (Austin, 1999), this is often not possible in some habitats in some areas, especially the tropics. So, how do we tackle the taxonomic challenge?

The loss of taxonomic expertise worldwide has generated much concern. As most insect groups are taxonomically relatively poorly known and expertise is thinly spread, some sort of prioritizing for particular groups to receive attention is essential. Even when that is done, there may be a real risk that estimated species richness values, for example from museum specimens, may be dangerously low and of limited use in conservation decision making (Petersen *et al.*, 2003). New (1999) points out that arguably the most urgent facilitating role for taxonomy in practical invertebrate conservation is to help increase the number of groups which can be appraised effectively. One way to achieve this would be to concentrate on lesser-known, but not poorly known, groups and make them into well-known groups. This is a choice process involving triage, where most attention is given to those taxonomic groups that would benefit most from the increased knowledge.

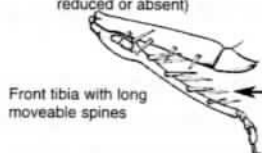
Interestingly, New (1999) emphasizes that facing the taxonomic challenge involves more than simply improving our descriptive knowledge of selected groups. It is also important to define, enumerate and describe the constituent elements of these groups in a way that is meaningful in practical conservation. This may involve, for example, the use of taxonomic keys that are readily comprehensible to non-specialists. McCafferty's (1981) *Aquatic Entomology: The Fishermen's and Ecologists' Illustrated Guide to Insects and their Relatives*, and Naskrecki's (2000) *Katydid of Costa Rica* (with CD) are superb examples (Figure 2.10). With the development of digital technology, the description process is being speeded up. *BioTrack*TM, which is a development of The Key Centre for Biodiversity and Bioresources at Macquarie University, Australia, is an innovative biodiversity data management system that makes rapid and accurate identifications of specimens from digital images with only a small amount of taxonomic training. This directly addresses New's (1999) concern that taxonomic data must be worthy in the context of conservation management. *BioTrack*TM does just this, harmonizing taxonomic and ecological approaches to biodiversity conservation and management (Oliver *et al.*, 2000).

A final consideration is that these user-friendly taxonomic keys are available for use by non-specialists, especially parataxonomists (i.e. insect, or other taxa, identifiers without formal taxonomic training). Parataxonomic sorting of insect material can generate a huge amount of data, and when combined with

Subfamily Phaneropterinae:
Approx. 40 genera and 100 species in
Costa Rica, mostly arboreal, green, leaf-
like insects

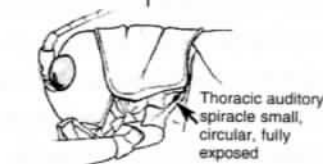


Eyes very large (if not
then wings greatly
reduced or absent)



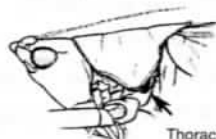
Front tibia with long
moveable spines

Subfamily Listroscelidinae
2 genera and 6-7 species in Costa Rica; small,
predaceous insects; fully winged (genus *Phlugis*)
or micropterous (genus *Arachnoscelis*)



Thoracic auditory
spiracle small,
circular, fully
exposed

Subfamily Pseudophyllinae
Approx. 40 genera and 115 species in
Costa Rica; extremely varied in general
appearance, mostly arboreal



Thoracic auditory
spiracle large, oval,
at least partially hidden
under pronotum

Subfamily Conocephalinae (See next page)

- 2.10 First-page extract from a user-friendly key that enables rapid keying out of taxa, in this case, of subfamilies of Costa Rican bush crickets (Tettigoniidae) (from Naskrecki, 2000).

supplementary activities such as caterpillar rearing, can produce a large amount of ecologically and conservation-useful information. There is however, a disadvantage to working with parataxonomists. According to Basset *et al.* (2000) 'the amount of field data amassed by them [parataxonomists] is forcing ecologists to become desk-bound, number-crunching writers of research papers instead of enjoying themselves in the forest'.

2.10 The perception challenge

It is the surroundings that make cockroaches dirty, and not cockroaches that make a situation unsanitary. In short, cockroaches are facultative carriers of bacterial pathogens, and the diversity of bacteria transported by them depends

on where they live. Rat fleas, however, are carriers of the plague bacterium and mosquitoes of the trypanosome that causes malaria. Not surprisingly, people in general see insects as enemies rather than worthy conservation subjects. Butterflies, by virtue of their bright colours, delicate form, large size and association with flowers, are among the few insects that charm peoples' hearts (Kellert, 1986).

Yen and Butcher (1997) have pointed out that we need to overcome adverse attitudes towards invertebrates. At the Queensland Museum Reference Centre there are always twice as many queries concerning vertebrates than invertebrates, with most of those concerning the spectacular and the dangerous, especially spiders (Czechura, 1994). Indeed, conservation of invertebrates faces the 'tyranny of numbers' (Kellert, 1993). How can invertebrates be in trouble if we have so many of them? Currently, the mainstay is conservation of the aesthetic, harmless flagships, such as the Richmond birdwing butterfly *Ornithoptera richmondia* (Horwitz *et al.*, 1999) and the Wart-biter bush cricket *Decticus verrucivorus* (Pearce-Kelly *et al.*, 1998). Indeed, it is these very flagship, iconic species that are under threat, sometimes because of specialist habitat requirements, but also because they are sought after by collectors. In the case of crickets in China, the demand for 'fighting crickets' for gambling is estimated to involve up to 100 000 specimens per day during the peak period (Jin and Yen, 1998).

Smith (1999) suggests that the road to raising awareness is as 'perfected by our vertebrate cousins: stealth, persistence and subterfuge'. He also points out that stressing 'environment' or 'invertebrate' in a proposal is more likely to doom it to the filing cabinet.

New (2000a) provides an interesting slant on the perception challenge. Although many invertebrates are clearly 'webmasters' (Coleman and Hendrix, 2000) in ecosystems, many more are not, or we do not know whether they are. These unknown or unknowable organisms are what New (2000a) calls the 'meek inheritors'. They are probably best conserved by admitting our ignorance and seeking to cover them using an umbrella taxon or group whose values can be quantified more convincingly. (We revisit this topic in Chapter 8.) New (2000a) then emphasizes that the alternative, of promoting the 'meek inheritors' by suggesting positive, even extravagant, ecological values which we cannot prove, must inevitably lead to loss of credibility that we can ill afford.

2.11 Pest insects and population crashes

Pests are organisms that impact on our lives when and where we do not want them to. They do not know that they are pests, only we do. In terms of overall physiology and biochemistry, a pest insect is little different from a threatened one, and killing an aphid is morally little different from killing an Apollo butterfly. But small differences in DNA can have huge implications. For

example, there is a large, brown, brachypterous variant (*ssp. monspeliensis*) of the familiar green European Wart-biter bush cricket *Decticus verrucivorus*, which was a pest in the late 1940s in southern France. The population then crashed and was thought extinct (Samways, 1989b) although there are reports that a small, remnant population might still exist. Such population surges and crashes do not seem to be a feature of the more familiar *D. v. verrucivorus*, which appears to remain at considerably more constant levels (Cherrill and Brown, 1990; Pearce-Kelly *et al.*, 1998).

Among higher taxa there are also huge differences in pest versus threatened status, especially among Orthoptera species (Samways and Lockwood, 1998). A first glance might suggest a 'typical threatened orthopteran species' to be a narrowly distributed, specialist-feeding, relatively local bush cricket or cave cricket. In contrast, a 'typical pest orthopteran species' might be a widely distributed, polyphagous, highly mobile grasshopper or locust. However, the Rocky Mountain grasshopper (*Melanoplus spretus*) was so abundant in the western United States and Canada prior to 1880, that it caused the wheels of locomotives to slip (Swinton, 1880). Yet by the early 1900s it was extinct (Lockwood and DeBrey, 1990). The population changes that occurred in this pest were not so much due to changes in genetics as changes in the landscape. A similar situation appears to be happening today in the Moroccan locust, *Dociostaurus maroccanus*, where deforestation and overgrazing stimulate its increase, whereas converting grasslands to croplands suppress it (Latchininsky 1998). The point here is that abundant, even pestiferous species, can be at risk, once their habitat has been modified. Abundance at one time, and notoriety as a pest, is not necessarily a guarantee against extirpation or even extinction. Insects can be passenger pigeons too.

2.12 Summary

Insects have been enormously successful in terms of species richness and abundance. The main platform for this success has been the evolution of flowering plants. Insect conservation, particularly of specialist species, therefore goes hand in hand with plant community conservation. Destruction of plant communities could therefore reverse, and is indeed reversing, the evolutionary success of insects. Nevertheless, many insects are superb dispersers, often turning up in remote places, surprisingly rapidly. This suggests that many non-specialists, at least, will survive the future.

Although we so often speak of insect 'species', we must at all times be acutely aware that many insect species are a complex of polymorphisms. Among these is developmental polymorphism, where the larva is a functionally different animal from the adult, and conservation of the habitat means conservation of conditions for long-term survival of both these forms. In turn, this means

conservation of compositional, structural and functional aspects of the landscape. Such a coarse filter approach (i.e. conservation of landscapes) is the only realistically all-embracing approach to future insect diversity conservation, especially bearing in mind that less than 1% of the 10 million or so species have scientific names. However, this does not preclude the fine-fitter, single-species, approach when resources are available for such fine focus.

Although in the past, many species shifted geographical ranges in response to climate change, the current anthropogenic impact on landscapes is causing mass extinctions. This mass extinction is mostly to unnamed, 'Centinela' species, which most humans do not know about, or perhaps even care about. Indeed, some pest insect species can be prone to extinction. With landscape transformation, an abundant species can become a rarity in a matter of a few years.