Insect Conservation Biology

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Insect Conservation Biology

Proceedings of the Royal Entomological Society's 23rd Symposium

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Introduction

Insects have played a key role in the development of the science of conservation biology. Their abundance and diversity in most terrestrial and freshwater ecosystems, and the rapidity of their responses to environmental changes make them attractive model organisms for conservation research and monitoring, and as indicators or surrogates for wider biodiversity. At a time of unprecedented human impacts on natural environments, insect conservation biology has an important role to play in assessing and ameliorating the impacts of anthropogenic habitat modification and climate change. Increasingly, insects are the targets of conservation action in their own right, guided by detailed autecological study.

The Royal Entomological Society's 23rd International Symposium was held at the University of Sussex, UK, from 12 to 14 September 2005 on the theme of 'Insect Conservation Biology'. In convening that symposium, we sought to build on the Society's previous symposium on this theme held in 1989 'The Conservation of Insects and Their Habitats' (Collins and Thomas, 1991) and, in particular, to explore how the discipline has matured and diversified in the intervening 16 years. Many of the world's leading workers in insect conservation accepted our invitation to participate, and we adopted three major themes to be treated in sequence, as reflected in this volume.

The first of three half-day sessions set up the broad themes in insect conservation. The session commenced with two contrasting 'scene-setting' papers to examine the state of insect conservation in major regions of the world and what the major avenues for progress, and hindrances, have been. The temperate regions (Stewart and New, Chapter 1) have benefited from the close attention paid to well-documented fauna by a relatively large number of resident entomologists, particularly in the northern hemisphere. This has allowed species-level conservation programmes to become a major focus of conservation need and advocacy, leading to well-defined protocols and approaches for insect conservation management. Many tropical insect faunas are much less tractable in that a large proportion of species remain as yet undescribed (Lewis and Basset, Chapter 2), with the consequence that approaches to conservation necessarily emphasize broader approaches, largely based on habitat. The next four chapters deal with these contrasting approaches to insect conservation. Pearce-Kelly and an international team of collaborators (Chapter 3) illustrate the increasing importance of *ex situ* conservation for insects – both in practical conservation and for advocacy – using examples from many different insect groups and from various parts of the world. Warren *et al.* (Chapter 4) examine the benefits gained from listing species for conservation priority, with particular reference to butterflies as the most thoroughly appraised insect group. Dennis *et al.* (Chapter 5) emphasize the central importance of habitats, assessed as both place and coincidence of critical resources, as a wider level of focus. Samways (Chapter 6) takes us to the landscape level and the features of landscape architecture and change so vital for wider-scale insect conservation in all parts of the world.

The theme of our second session was examination of insects as 'model organisms' in conservation biology, to show how they have been used not only to enhance their own well-being, but also to illustrate or facilitate progress on wider conservation agendas. McGeoch (Chapter 7) discusses the diverse and important roles of insects as 'indicators' of environmental condition and change, and the transition of theory into ever-diversifying practice. Hanski and Pöyry's (Chapter 8) pioneering work on understanding metapopulation structures and the effects of landscape fragmentation on insect populations emphasizes the importance of scale in considering the accessibility of isolated habitat patches, with important implications for wider conservation management. The central importance of monitoring insect population sizes and species distributions is discussed by Conrad *et al.* (Chapter 9) with long-term studies and monitoring sequences enabling sound assessments of recent and possible future changes. The central roles of insects in ecological interactions (Memmott *et al.*, Chapter 10) as 'ecosystem engineers' and providers of ecosystem services emphasize their importance in the maintenance of ecosystem dynamics and processes, as well as the wider importance of their conservation. While most of the threats to insects receiving attention in the past involved tangible factors such as habitat loss or the spread of alien species, future threats consequent upon global climate changes are universal, not readily predictable and will have wide impacts (Wilson *et al.*, Chapter 11). Although the details of different future climate scenarios are hotly debated, climate change is increasingly accepted as the most serious global threat to insects and indeed the whole of biodiversity. The final chapter in this session (Thompson *et al.*, Chapter 12) explores the emerging science of insect conservation genetics, and its roles and applications in effective conservation practice.

Our third session, entitled 'Future Directions in Insect Conservation Biology', looked to the future – how might the lessons learned so far be fostered and developed for the greater benefit of insect conservation, and what should our priorities be? New (Chapter 13) suggests ways in which insects might be elevated to being considered as core components in wider conservation programmes. Cheesman and Key (Chapter 14) then explore ways in which entomological expertise can be conserved, to assure continuity of the requisite knowledge, interest and commitment. The final three chapters focus more specifically on arenas of current interest and debate. Kremen and Chaplin-Kramer (Chapter 15) explore further the role of insects in ecosystem processes, using pollination as an example of one such process which people can see readily as being of major economic and functional importance in crop production. Tscharntke *et al*. (Chapter 16) affirm the central importance of managing agricultural systems and landscapes (accounting for ~36% of global land area) in ways that encourage insect conservation. Woiwod and Schuler (Chapter 17) summarize the complex issues arising from the increasing use of genetically modified crops, how patterns of usage may change in the future and the likely implications for beneficial and other non-target insects. Finally, we review just how far insect conservation has come in recent years and make some suggestions as to what the future might hold for this fast-moving field (Lewis *et al*., Chapter 18).

As convenors of the Symposium and editors of this volume, we are well aware of the complexities of organizing such a meeting and bringing the proceedings to fruition. There are many people to thank for their contribution to a successful meeting. The participants – both speakers and attendees who contributed to the discussions – ensured that the Symposium was a scientific success. Each of the chapters was read by two reviewers, whose perceptive comments helped to ensure the integrity of the final volume. The president of the Society, Dr Hugh Loxdale, opened the Symposium and the vice-chancellor of the University of Sussex, Professor Alasdair Smith, co-hosted a wine reception on the first evening to welcome delegates. The Society's staff, Bill Blakemore (Registrar), June Beeson and Elena Lazarra, and a local team of postgraduates at the University of Sussex helped to ensure that the meeting ran smoothly. John Badmin and Dr Archie Murchie organized the concurrent Annual National Meeting of the Society, the afternoon sessions of which complemented the morning symposia. We are very grateful to them all.

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Reference

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1 Insect Conservation in Temperate Biomes: Issues, Progress and Prospects

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1 Introduction

Insects present conservationists with a very different set of challenges in comparison with more popular groups such as vertebrate animals and vascular plants. These are a consequence of several aspects of their life histories that make them especially vulnerable to the types of environmental changes currently being experienced across many temperate regions (McLean, 1990; Kirby, 1992; UK Biodiversity Group, 1999). Many insects have highly specialized habitat (and often microhabitat) requirements that are further complicated by the fact that the discrete stages in the life cycle often require radically different resources. Most insects have comparatively short life cycles (often annual or more frequent) with no dormant stage in which they can escape adverse conditions, so that these habitat requirements have to be met without interruption. Finally, many species are incapable of dispersing more than trivial distances, or are behaviourally reluctant to do so, resulting in their complex habitat requirements having to be met within relatively small areas and an increased sensitivity to habitat fragmentation. Thus, maintenance of habitat quality, continuity, heterogeneity and connectedness are recurrent themes in insect conservation biology.

The field of insect conservation has undergone rapid development in the last 30 years or so, with particular acceleration of pace since the Royal Entomological Society last met to review this topic some 16 years ago (Collins and Thomas, 1991). Reasons are multifaceted but include a wider realization that: (i) for the reasons stated above, conservation of insect species and assemblages requires a different approach to that traditionally adopted by conservationists more concerned with plants and vertebrates, with the consequence that insects are often poorly served by the protective 'umbrella' of these more conspicuous and charismatic groups (McLean, 1990; Kirby, 1992; Hambler and Speight, 1995); (ii) insects are highly sensitive and useful indicators of habitat and environmental change (Woiwod, 1991; Harrington and Stork, 1995; Wright *et al.*, 2000; Thomas, 2005); (iii) many insects have already undergone serious declines that exceed those of other high-profile groups such as birds and plants (Thomas *et al.*, 2004; but see Hambler and Speight, 1996, 2004, and Shaw, 2005 for contrary views, and the convincing response to them by Thomas and Clarke, 2004); and (iv) insects arguably deserve to be conserved in their own right, for their intrinsic qualities, their utility to people, as providers of important ecosystem services and as part of overall biodiversity (Samways, 2005).

The major principles of insect conservation have been derived very largely from concerns for individual species and wider habitats in the northern temperate region, predominantly from northern and western Europe and parts of North America. Much of the effort elsewhere has drawn heavily on these experiences, sometimes uncritically, for both procedures and practices; progress has arisen from testing on other faunas the conservation lessons and paradigms learned in this part of the world. By contrast, the field of insect conservation has developed along a rather different path in tropical environments, where the sheer magnitude of species richness and a range of logistical constraints have forced a somewhat different approach (Lewis and Basset, Chapter 2, this volume). In this chapter, we examine the importance and relevance of these lessons, and their wider applications. We do this with the considerable benefit of hindsight, and largely through comparing and contrasting the interests and priorities for insect conservation in the better-documented and generally less species-rich northern temperate regions with the more poorly understood, but richer, biota of the southern temperate regions. Most examples are from the UK and Australia, the areas with which we are most familiar. Tracing the rapid recent development of the field of insect conservation, the ideas that motivate and underpin it, and its geographical distribution, allows us to place it in the wider context of the expanding modern science of conservation biology.

1.1 Temperate regions: the arena of concern

The northern and southern temperate regions (Fig. 1.1) show one immediate and important contrast: their extent. In the north, two large continental landmasses collectively occupy approximately 250° of longitude, whilst in the south three highly disjunct regions together span only 105° of longitude. The northern region is thus considerably the larger, and includes much of the Holarctic geographical zone, together with parts of northern Africa. The southern zones are southern Africa, southern South America, and Australia and New Zealand, with associated islands. Australia is the only designated megadiverse country spanning tropical to cool temperate regions under the same federal government and with a sufficient resident cohort of concerned biologists to address conservation across this variety of environments. The first two of these zones are linked trans-tropically with the northern regions by land, but no current land bridges occur between Australia and the Asian

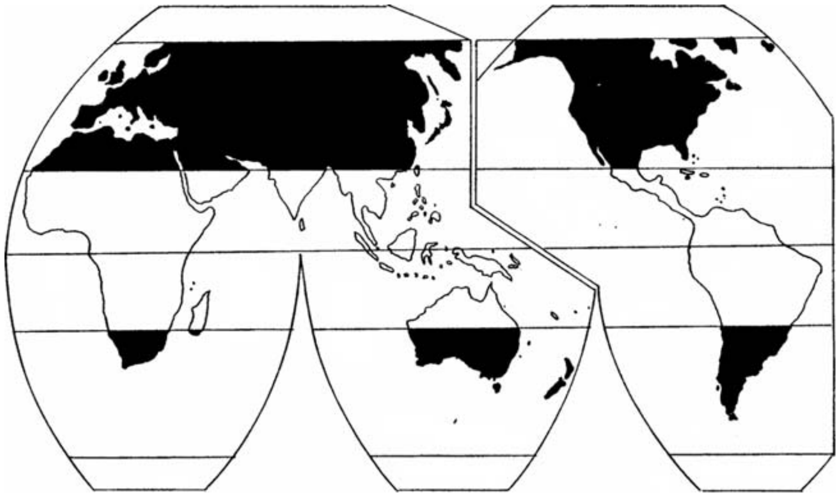

Fig. 1.1. The geographical extent of the temperate region (depicted in black), illustrating the contrast in total land area between the northern and southern hemisphere.

mainland. As Samways (1995) noted, the greater part of southern temperate land occurs north of about 40° S latitude, in marked contrast to the northern region, in which about half the land area occurs at latitudes higher than 40° N. For the most part, the northern and southern temperate regions are faunistically distinct. The least-documented southern area is that part of South America between the Tropic of Capricorn and about 40° S, mainly because the far south has attracted the interests of numerous visiting entomologists seeking to clarify Gondwanan relationships, particularly with New Zealand and southern Australia. Most biologists in South America have worked either in the tropics or the most southerly areas.

Patterns of local endemism are common, and many insect groups show southern concentrations of endemism or richness that are often coincident with the 'hotspots' of endemism and threat identified by Myers *et al.* (2000). The disproportionately elevated richness of southern Africa and Australia noted by Platnick (1991) reflects, in part, the extraordinarily rich floristic regions of the south-western Cape (the 'fynbos', for which the ecological importance of insects was evaluated by Wright, 1994) and south-west Western Australia, together with the wide variety of topography and habitats present. In contrast, the biota of far southern South America appear to be genuinely depauperate, but nevertheless important in supporting ancient and endemic lineages of insects, including significant Gondwanan taxa. The faunas of all southern areas need considerable further investigation, the recent discovery of the new insect order Mantophasmatodea in southern Africa (Klass *et al.*, 2002) attesting to the possibility of further novelty with considerable scientific interest.

Early developments in the field of insect conservation in some temperate regions were summarized by contributors to the earlier Royal Entomological

Society symposium (Collins and Thomas, 1991). Thus, Opler (1991) and Greenslade and New (1991) outlined the perspectives for North America and Australia, respectively; Mikkola (1991) and Balletto and Casale (1991) dealt with northern and Mediterranean Europe. With respect to the UK, McLean (1990) outlined broad themes, while Fry and Lonsdale (1991) and Kirby (1992) focused on habitat management principles. In a later symposium, Samways (1995) gave a broader perspective of southern hemisphere insect diversity, focusing mainly on southern Africa and Australia. Relevant topics for Australia are also discussed by Greenslade (1994, steppe-type landscapes), Rentz (1994, Orthoptera), New (1994, exotic species impacts), and for South Africa by Scholtz and Chown (1994, savannah) and Wright (1994, fynbos). These accounts refer to many of the early pioneering studies on British and other fauna, which remain highly pertinent in considering the emerging patterns of insect conservation. Some recent essays (such as those of McGeoch, 2002 on South Africa, and New and Sands, 2004 on Australia) demonstrate advances over the last decade or so. Symposia on invertebrate biodiversity and conservation both in South Africa (McGeoch and Samways, 2002) and the Australian region (Ingram *et al.*, 1994; Yen and New, 1997; Ponder and Lunney, 1999; Austin *et al.*, 2003) attest to the increasing interest and concerns in southern temperate regions. We are unaware of any parallel focus for southern South America, where there are few resident entomologists to appraise such problems and needs, but some recent surveys in Argentina (ants: Badano *et al.*, 2005; grasshoppers: Torrusio *et al.*, 2002) are important pointers to conservation focus.

1.2 Perspective: the tradition of conservation

Important regional differences in the levels of understanding of the insect fauna occur between the northern and southern zones. Perhaps the greatest geographical influence stems from a point discussed by Pyle (1995), namely that Britain, together with some parts of continental western Europe and North America, has long accepted natural history (including insect collecting and study) as a respectable activity. This tradition has led to the accumulation and documentation by professional and non-professional interests of vast amounts of information on insects based on well over a century of concerted endeavour. Thus, the diversity, specific biological and life history details, distribution patterns and their changes over a substantial period are reasonably well known for certain well-studied insect groups. Compendia such as the *Millennium Butterfly Atlas* (Asher *et al.*, 2001) and the analyses that continue to flow from it (e.g. Thomas *et al.*, 2004; Wilson *et al.*, 2004) demonstrate how detailed data on historical changes in species distribution patterns can inform conservation. Similarly detailed data-sets on the British insect fauna are steadily accumulating both for charismatic groups such as Odonata (Merritt *et al.*, 1996) and Orthoptera (Haes and Harding, 1997) and for groups, such as Carabidae (Luff, 1998) and Syrphidae (Ball and Morris, 2000), that have a more specialist following. The UK Biological Records

Centre has a long and venerable tradition of compiling and analysing distributional data for a wide range of insect groups, including those which have to rely on ad hoc accumulation of data rather than systematic surveys. These compilations represent the knowledge base for assessing the rarity status of individual species, even when based on only partial data coverage, and are critical in setting priorities for conservation on the most deserving targets. Such assessments are possible only for taxa for which information is reasonably adequate; Shaw and Hochberg (2001) make the point that around half the British parasitic Hymenoptera fauna cannot yet be identified reliably, if at all, other than by a handful of specialists, resulting in the almost complete neglect of this group in conservation assessments. Even in well-studied Britain, ecological knowledge of most insect species outside the popular groups is very fragmentary; precise habitat requirements are often unclear, so that appropriate management prescriptions are difficult or impossible to define for non-entomologist conservation practitioners who are charged with managing sites.

Major points of contrast between the northern and southern temperate zones relate to: (i) the much better documentation of many insect groups, particularly in parts of western Europe, than anywhere in the south; (ii) the longer history of conservation interests and concerns based on sound natural history; (iii) a larger population of resident concerned entomologists and other people, with wider support for conservation endeavours within (iv) a broader framework of ecological understanding and history of threats and their impacts on native species, communities and habitats. The less rich northern insect faunas have thus received far more attention, over a considerably longer period, than their southern counterparts. The fine-detail approach of species-focusing that has been possible for European butterflies, some beetles, dragonflies and others has led to these being 'global drivers' of insect conservation. The detailed and rigorous approach adopted by many of these studies has also been important in catalysing the wider development of insect conservation as a responsible and disciplined science (New *et al.*, 1995). Evidence for declines and losses of species (butterflies in particular) in the northern temperate zones has been provided because of the tradition of recording and monitoring species incidence and relative abundance. For example, both the Butterfly Monitoring Scheme (Pollard and Yates, 1993) and the Rothamsted Insect Survey of macro-moths (Woiwod, 1991) have drawn attention to dramatic recent declines in many species across Britain (see Conrad *et al.*, 2004). However, it is important to emphasize that this better information base for the north often relates to highly altered landscapes changed by many centuries of human impacts. By contrast, the major documented impacts in the southern zones are mostly more recent and can be compared more readily with conditions in relatively pristine environments in which human impacts have been minimal by comparison.

Levels of public sympathy and support for insect conservation, at least for the charismatic taxa, are much greater in Europe and North America than elsewhere; the Xerces Society in North America is a leading example. The recent establishment and growth of charities in Britain devoted to the conservation of specialist groups (e.g. Butterfly Conservation for the Lepidoptera; Buglife for invertebrates in general, British Dragonfly Society for the Odonata) is testament to this. Where there is a need to gather information on habitat needs or critical resources to guide management, interested people, support and expertise are often available or can be mustered relatively easily. Some species can command considerable resources over a long period to prevent their extinction. Campaigns to reintroduce the large copper *Lycaena dispar* to Britain, for example, extend over much of the 20th century, and continue (Pullin *et al.*, 1995), while the successful reintroduction to Britain of the large blue *Maculinea arion* after extinction in the 1980s (Thomas, 1999) has become a textbook example of how the fortunes of a single species can be turned around once its detailed ecological requirements are fully understood.

The level of this type of interest and commitment, and the information base which is necessary to inform conservation, can be considerably less elsewhere. Interest in conserving butterflies, or other insects, is still viewed in Australia as somewhat eccentric (New, 1984), although gaining impetus rapidly. Several state-based groups, mostly with few members, now focus on butterfly conservation in Australia, and some species have benefited from community involvement and the activities of local 'friends groups'. In much of the southern temperate region, insect conservation (together with many wider environmental issues) is viewed as low priority in relation to more pressing problems of human welfare, within social environments not intuitively sympathetic to such endeavours. This is not surprising in view of the pressures to establish, develop and sustain agriculture and other human-support systems and industries. Establishment and protection of agricultural or forestry crops and improved pastures (the latter often based on exotic pasture grasses, as in Australia) have traditionally taken priority over assuring sustainability of native biota, with insects ranked well below more charismatic and conspicuous wildlife in any conservation debates. Important exceptions include certain insects used as economic commodities such as human foods (e.g. caterpillars of *Imbrasia* [Saturniidae]; McGeoch, 2002) or for silk production (*Gonometa* spp. [Lasiocampidae]; Veldtman *et al.*, 2002), both in South Africa.

2 Limits to Species Focusing

The traditional single-species approach to insect conservation aims to set objective conservation priorities based on sound knowledge of the distribution and comparative status of all species in a group. Although elegantly demonstrated for certain well-studied insect groups in the northern temperate zone, this approach has not proved immediately transferable to all other temperate regions and taxonomic groups for a number of reasons. First, the number of formally described species is often only a fraction of the total number of species estimated to exist in a particular taxonomic group. Thus, a recent evaluation of the Australian insect fauna (Yeates *et al.*, 2003, building on the approach pioneered by Taylor, 1983) estimated the total insect fauna at 204,743 species, of which 58,491 (28.6%) are described, the authors noting that the fauna is likely to be far larger even than the highest figures cited. Austin *et al.* (2004) suggest that the conservative count for richness of Australian Hymenoptera (44,000 species) probably vastly underestimates the true size of the fauna which is 'difficult if not impossible to estimate with any accuracy given the current state of knowledge'. Comparative estimates are not always available for other temperate regions and often have high degrees of uncertainty attached to them. Scholtz and Chown (1994) suggest that 'between 5 and 50% of southern African insects are estimated to have been described'. Redak (2000) reports the North American insect fauna to comprise approximately 163,487 species of which about 72,500 (44%) remain undiscovered or inadequately described. Although not all species have been formally named even in the best-documented faunas, a stark contrast in this respect exists between the relatively well-documented northern faunas and the markedly less-studied southern temperate ones. It is sobering to contrast the relative excitement generated by the recent detection of a new butterfly *species* in Ireland (Nelson *et al.*, 2001), a comparatively unusual event in Europe for this well-studied insect group, with the equally recent discovery of a whole new insect *order* in southern Africa: the Mantophasmatodea (Klass *et al.*, 2002). Within southern temperate faunas, some insect groups are much better documented than others, with butterflies, some moths, some beetles, Odonata and some Orthoptera amongst the better-known. These, and some other groups differing between the continents, have high proportions of species described.

The inevitable consequence of these discrepancies in levels of knowledge between taxonomic groups is that they impact upon setting conservation priorities. Species richness increases the magnitude of the need, but also the difficulty of making such assessments reliable. For this reason, most insect species nominated or adopted for inclusion on protected species lists or national 'red lists' in southern temperate regions belong to the better-known groups, although other isolated species are sometimes present. In South Africa, by far the most advanced of the three southern zones in such compilations, databases have been compiled, and priority areas (such as centres of endemism) distinguished, for butterflies, termites, scarab and buprestid beetles, and Myrmeleontidae (references in McGeoch, 2002). A first *Red Data Book* exists for South African butterflies (Henning and Henning, 1989). Such works are important in helping to indicate some of the needs for species conservation, but for the southern zones can rarely be even reasonably representative of the real needs, because knowledge is generally insufficient to render such lists comprehensive for any taxonomic group other than butterflies. For this reason, butterflies are the best-represented group of protected insects in South Africa, with provincial lists of endangered insects for some areas consisting almost entirely of butterflies (Scholtz and Chown, 1994). Within the southern temperate zone, only in New Zealand has a reasonably comprehensive attempt been made to compile a preliminary listing of insects of conservation interest across a variety of orders (McGuinness, 2001), although less critical preliminary syntheses for Australia (Hill and Michaelis, 1988; Yen and Butcher, 1997) are also invaluable leads. McGuinness (2001) provided conservation profiles of 104 beetles and 13 moths, both groups assessed only by a small number of families, as well as other orders. Closer focus may be available for lower-level taxonomic categories: thus, again for New Zealand, Patrick and Dugdale (2000) profiled 114 species of Lepidoptera of conservation interest; a recovery plan for carabid beetles (McGuinness, 2002) dealt with 55 species; and a recovery plan for the most charismatic of all New Zealand insect groups, weta (Orthoptera), covered 15 species in some detail. Such formal action plans are rare for the southern temperate zones; an action plan for Australian butterflies (Sands and New, 2002) seems unlikely to be paralleled for other insect groups in the foreseeable future, although profiles for individual insects in isolation are appearing under various State Acts and more widely (Clarke and Spier, 2003).

Taxonomic bias in species listing is thus perhaps inevitable, even amongst the relatively well-studied European fauna, if we are to treat the process responsibly. For example, the British *Red Data Book* for insects (Shirt, 1987) lists representatives of only eight orders, and listings are dominated by Coleoptera (546 species, or 14% of the total fauna) and Lepidoptera. The latter are divided into three categories, which reflect relative popularity and knowledge: butterflies (12, 21%), 'macromoths' (99, 11%) and 'micromoths' (11, 0.7%), again emphasizing dependence on the more charismatic 'flagship groups' for conservation advocacy and advance, coupled with the relationship between good knowledge and improved ability to determine conservation status and management.

For most workers in temperate regions outside northern Europe, the challenge of dealing with the high proportion of undescribed species is exacerbated by the historical legacy that most taxonomic expertise and a high proportion of type material are housed in northern hemisphere museums. As Naskrecki (2004) noted 'access to those types is vital when studying these new faunas'. Fortunately, this discrepancy is now being countered by increasing deposition of type material in local (national or state) institutions. Furthermore, progressive development of the World Wide Web as a taxonomic tool is revolutionizing the ways in which information on such specimens can be communicated.

The main practical need is for consistent and replicable recognition of species or other taxonomic units, rather than necessarily for formal scientific binomials, so that the entities can be studied effectively to appraise conservation need and management. Although named species might appear more tangible, southern hemisphere workers have harnessed the concept of the 'morphospecies' (denoting a consistently recognizable entity without a formal binomial name) to address the challenge of incorporating numerous undescribed species into conservation assessment at both individual species and assemblage levels. This approach has given considerable power to analysing and appraising patterns of insect diversity and distribution in southern temperate regions. This approach to overcoming the 'taxonomic impediment' was pioneered in part through studies on Australian Orthoptera (see Taylor, 1983 for a discussion and the potential developments of the approach as then envisaged). Ecologists have been quick to adopt it as a short cut to studying assemblages or communities that are rich in species which are unnamed or difficult to identify. However, if this approach is to achieve its maximum value, vouchers of all designated entities need to be deposited in accessible reference collections so that future studies can be fully cross-referenced across different surveys and geographic regions. Whilst the progressive accumulation of specimens may eventually provide the basis for a more formal taxonomic appraisal of the group, it is invaluable for providing information on species distributions, diversity and ecology which is of massive importance for insect conservation.

3 Sailing on Flagships

The pioneering *Invertebrate Red Data Book* (Wells *et al.*, 1983) included representatives of 13 insect orders from the temperate regions. Northern zones were represented by 40 species (9 orders) but southern zones by only 13 species (7 orders), all of which were from Australia (9 species) or New Zealand (4 species, all weta). These initial suites raised awareness of insect conservation for many local scientists, largely as isolated cases deserving attention and advocacy. A number of these and other insects have achieved very high conservation profiles, sometimes elevated to the status of local or national emblems, and have thereby contributed enormously to wider understanding and awareness of insect conservation. Butterflies are amongst the most potent of these flagship taxa and have been instrumental in setting the paradigms of invertebrate species conservation. Thus, studies of the Bay checkerspot (*Euphydryas editha bayensis*) in North America (Ehrlich and Murphy, 1987; Opler, 1991; Ehrlich and Hanski, 2004) and the large blues (*Maculinea* spp.) in Europe (see summary in Wynhoff, 1998) have elucidated our understanding of butterfly ecology and conservation as well as more general ecological principles. *Maculinea* species, for example, captured public imagination not only because of their vulnerability, but also in drawing attention to the subtleties of interactions between butterflies, food plants and mutualistic ants and how these are affected by habitat change and management. This helped to emphasize the fact that conservation will be effective only if it is underpinned by sound science, and that successful rescue measures, such as the reintroduction of *M. arion* to Britain following its national extinction there, rely upon a detailed understanding of how to restore the right habitat conditions for a species. The North American Xerces blue (*Glaucopsyche xerces*), although extinct, has become an important flagship for wider invertebrate conservation interests, both as a reminder of what can happen if protective measures are not taken in time and in the name of a major invertebrate conservation pressure group (The Xerces Society) in North America.

Such prominent species are now some of the best understood of any non-pest insect species, and have become significant as models for ecological understanding and management procedures. Many of the papers in Boggs *et al.* (2003) are enviable examples for such wider emulation. These lessons from the north have been important drivers for conservation progress at the species level elsewhere. Although parallel levels of understanding are generally lacking for the southern hemisphere biota, a similar conservation focus on flagship species in South Africa and the Australian region has benefited from this prior knowledge, in spite of some major ecological differences. The Brenton blue butterfly *Orachrysops niobe* (Trimen) was rediscovered in 1977 for the first time after it was described 119 years earlier, and has become a national celebrity butterfly in South Africa (Steencamp and Stein, 1999), not only for its intrinsic worth but also as a political tool for emphasizing and countering the effects of building development on wildlife. Conservation recommendations were based on a detailed, although necessarily short-term, study of *O. niobe* at the single site where the butterfly is known to occur (Silberbauer and Britton, 1999), involving evaluation of site quality, population size, individual butterfly movements and an investigation of early stages.

Somewhat parallel roles have been promoted for two congeneric species of *Paralucia* (also Lycaenidae) in south-eastern Australia. *P. p. lucida* Crosby (the Eltham copper) and *P. spinifera* Edwards and Common (the Bathhurst copper) have become important flagships for insect conservation in Victoria and New South Wales, respectively. The former is important because it occurs on small isolated remnant urban sites within the greater Melbourne area (Yen *et al*., 1990; New and Sands, 2003), whereas *P. spinifera* has been instrumental also in encouraging community involvement in practical butterfly conservation (Nally, 2003).

One further flagship Australian butterfly merits comment for helping to bridge conservation understanding in tropical and temperate regions, as possibly a unique example of this kind. The Richmond birdwing (*Ornithoptera richmondia*) has been the focus of a large community conservation effort in south-eastern Queensland and northern coastal New South Wales, where it is an outlier of a charismatic group of tropical butterflies in the Australian region. It has been used to introduce numerous young people and community groups to the subtleties of insect ecology, thereby helping to increase awareness that conservation is indeed possible through careful management of critical resources (Sands *et al*., 1997; Sands and Scott, 2003). In addition, the lessons learned from *O. richmondia* have considerable relevance to other birdwings in northern Australia and New Guinea.

Flagship species have not been recruited solely from butterflies; species from other groups have helped to highlight particular issues. Thus, stag beetles (*Lucanus cervus*), which are quite numerous in suburban areas around London and south-east England, have drawn attention to the importance of the deadwood habitat and of retaining relatively unmanaged habitats in domestic gardens as well as forests for saproxylic invertebrates (Speight, 1989). The very rare, endemic, flightless *Colophon* stag beetles that are restricted to certain mountain peaks in South Africa have helped to raise awareness of the problem of illegal trade in specimens of endangered species (Geertsema, 2004). The hornet robberfly, *Asilus crabroniformis*, the largest Diptera species in the UK, has been used to focus attention on the rich insect community associated with dung (Holloway *et al.*, 2003). Finally, the giant New Zealand weta, some species of which are now reduced to single populations, have highlighted the problems that native species face when confronted with introduced predators, in this case rats, against which the local fauna has no innate defence.

All these examples demonstrate that certain charismatic species can be excellent instruments for raising public awareness of insect conservation issues in general, drawing attention to the fact that insects often have both complex and subtle requirements that can be met only through careful and scientifically based management. The intrinsic appeal of many of these species can also be used to engender public support and interest which can then be broadened to encompass other less charismatic species. It is likely that the spectrum of flagship insect species will continue to diversify.

4 Sheltering under Umbrellas, and Other Surrogate Measures

Insect conservation biologists have both the privilege and the challenge of investigating how to conserve a bewildering range of species. In order not to be overwhelmed completely by the task, entomologists have sought short cuts in the form of individual species or groups of species that can act as surrogates for a much wider set of species. In conservation biology, the principle of striving to conserve so-called umbrella species (often large conspicuous species with a requirement for large areas of habitat) on the assumption that a range of other taxa will also be automatically protected because they have similar habitat requirements has intrinsic appeal but has not been well supported by the evidence (Simberloff, 1998; Andelman and Fagan, 2000). Certainly, few convincing examples exist for insects and the evidence is contradictory. Ehrlich (2003) has suggested that 'not only do butterflies serve as a model system for research and function as individuals, but they can also serve as "umbrella groups" – ones whose preservation is likely, by protecting certain areas, to conserve many less charismatic organisms as well'. Thomas (2005) presents a carefully reasoned and convincing case for butterflies being imperfect but adequate indicators of change in many terrestrial insect groups, although this conclusion is not without its critics (see Hambler and Speight, 1995, 2004). Previously, Brown (1991) had suggested that, at least in the tropical context, the list of appropriate indicator groups could be extended from butterflies to include ants and certain Odonata and beetle groups. However, Ricketts *et al.* (2002) found that butterflies were poor predictors of diversity in a closely related but less well-studied group – moths – at least at the local scale, in Colorado, USA.

The principle of surrogacy covers a wide range of questions that have received much attention over the last 10 years or so. Conservation effort could be more efficiently focused geographically if species richness hotspots for different taxonomic groups: (i) coincided with each other; and (ii) encompassed foci of rare or endemic species. Perhaps not surprisingly, analysis of the UK fauna showed poor congruence between hotspots for butterflies and dragonflies (Prendergast *et al*., 1993) while some studies have actually shown distributional complementarity rather than coincidence between groups. Furthermore, protection of butterfly richness hotspots in the UK and in Oregon, USA, did little to encompass sites with rare or threatened species (Prendergast *et al*., 1993; Fagan and Kareiva, 1997). Even at the local scale, community-based rankings of sub-sites often do not run parallel for different insect groups. Painter (1999) found no correlation between species quality rankings of freshwater ditches based on beetles, snails and Odonata. This presents site managers with strategic dilemmas because it means that the habitat features and management options that are appropriate for one insect group may well be detrimental for another group.

Similar scepticism surrounds the issue of whether invertebrate conservation interest is coincident with, and predictable from, the composition of vegetation. The traditional conservationist's view that safeguarding the botanical interest of sites will ensure the protection of associated insect populations has long since been challenged and usually dismissed by entomologists (McLean, 1990; Kirby, 1992). Even exclusively phytophagous insects are reliant on more than the simple presence of their food plants, in many cases being equally dependent upon the physical structure of the habitat and how this is impacted by management. Thus, different grassland butterfly species have rather narrow preferences for particular vegetation heights (BUTT, 1986; Thomas, 1991) and they and other invertebrates respond rapidly to the seasonality, duration and intensity of grazing or cutting (Gibson *et al*., 1992; Morris, 2000). Similarly, traditional woodland management practices in Britain such as coppicing, used by conservationists to promote a diverse ground flora, have profound effects on the associated fauna: whilst some butterflies associated with woodland clearings cue into the early stages of the coppice regeneration cycle, other invertebrates associated with shaded or deadwood habitats are adversely affected (Fuller and Warren, 1991; Hambler and Speight, 1995). Indeed, the creation and maintenance of bare patches within certain habitats such as heathland and grasslands, often regarded by botanists as unproductive ground or the result of mismanagement, is now recognized as crucial for certain thermophilous ground-nesting and predatory insect groups (Key, 2000). Thus, whilst vegetation composition may substitute for information on insects in certain narrowly defined habitats and taxonomic groups (Panzer and Schwartz, 1998), this 'coarse-filter' approach to site selection and monitoring is unlikely to be widely applicable except in very crude terms.

A related development has been to designate 'functional groups' of insects to aid ecological interpretation, sometimes accompanied by some form of taxonomic surrogacy, so that genera may be used in analysis instead of species and thus remove the need for the most labour-intensive level of taxonomic determination. This approach thus reduces the need for taxonomist input, other than for specialist advice, with the major advantage that interpretation may be achieved adequately for much reduced cost, and for insect groups which include numerous undescribed species. Ants in Australia are an important example of this approach. Following initial interpretation by

Greenslade (1978) and Andersen (1990, 1995) for Australia and subsequently developed for application in North America (Andersen, 1997) and South Africa (Andersen, 2003) (see background in Majer *et al.*, 2004), ant functional groups are designated at the genus or species level, and changes in the relative representation of those groups are used to indicate habitat condition, as a monitoring tool. Ants are used widely in this way in monitoring human impacts and subsequent habitat restoration in Australia.

Interestingly, one of the first of such approaches, and certainly now the most extensively developed, uses freshwater invertebrates for ecological evaluation of lotic systems and water quality assessment. Freshwater invertebrates have long been known to be sensitive to water quality. Originally developed in the UK to provide a simple monitoring system based on family-level identification of invertebrates that can be achieved without specialist knowledge (the Biological Monitoring Working Party score), the approach has since been extended to produce a standard method for assessing water quality for human consumption. The River Invertebrate Prediction and Classification System (RIVPACS) established a robust system for predicting freshwater invertebrate communities based on physical and chemical parameters of pristine UK watercourses; departures of communities in other rivers from these predictions are then used as an index of water quality (Wright *et al.*, 2000). Analogous systems have been implemented across several temperate countries (papers in Wright *et al.*, 2000). A substantial infrastructure has been developed in the UK to provide this annual monitoring service, but the disadvantage from a conservation standpoint is that identification rarely proceeds beyond family level. However, as Wright *et al.* (1993) point out, a species-level modification of the general approach could be developed to identify sites of potential conservation significance.

5 Rarity and Vulnerability

The various connotations of 'rarity' (Rabinowitz, 1981) have considerable importance in assessing conservation status, but can be interpreted only from sound and relatively comprehensive documentation. Thus, butterfly records from Britain and western Europe convey a reasonably, sometimes highly, accurate picture of distributions and patterns of local endemism. This is often supported by data on actual abundance and trends over time, together with detailed ecological information, all of which is helpful in assessing vulnerability of species or populations. This kind of detailed information is absent for most southern temperate insects, with the consequence that rarity is much more difficult to appraise. Many species are known from only single sites or localities and appear to be point or local endemics, but there is often considerable doubt over such interpretations, because substantial areas of apparently similar habitat have not been surveyed effectively. In such cases, 'rarity' may simply equate to 'under-recorded'.

Rarity and endemism are often incorporated uncritically as components of conservation status, but do not necessarily equate to vulnerability or threat of extinction, as Dennis (1997) noted for European butterflies. Simply because a species occurs (or appears to occur) over a very limited range does not render it threatened. Rare species attract attention, much of it emotional, not least because (paralleling Diamond's (1987) comment on birds) many people make special efforts to find rare or putatively extinct species: that effort is simply not available for surveying insects in southern temperate regions. Most insect groups have very few devotees in Australia or South Africa, particularly if Macrolepidoptera are excluded. Even for butterflies in Australia (approximating the land area of western Europe or the continental USA), only a few tens of people collect or study them with any view of contributing to scientific knowledge.

Caughley (1994) distinguished two different mechanisms by which species become vulnerable: the 'small population paradigm' that encapsulates the range of genetic and stochastic problems experienced by small populations by virtue of their restricted size, and the 'declining population paradigm' that includes all the factors that can drive population numbers down in the first place. There is still much uncertainty about the effective population numbers at which these processes become important. Soulé's (1987) 50:500 rule for minimum viable population sizes, proposed as population thresholds to avoid the effects of inbreeding depression and genetic drift respectively in vertebrates, probably has little application to insects although empirical tests are lacking. After an initial emphasis on rarity, the UK Biodiversity Action Planning and the conservation priority setting processes, prompted by the recently revised IUCN criteria, are now focusing more on species for which there is evidence of threat due to recent decline rather than rarity per se (e.g. Warren *et al.*, 1997; see also Warren *et al.*, Chapter 4, this volume). In Australia, there is increasing advocacy to focus on 'declining populations', not least because resources available for conservation are grossly insufficient to deal with all species that are regarded simply as 'rare' but without apparent threats to their well-being, and definition of threat provides a sound base for focused management. In contrast, the numerous 'rare' insects exhibiting small populations without apparent threat may not need active management other than to prevent them declining, such as by enhanced site buffering. It is difficult or impossible to formulate management to counter stochastic events, and the genetic consequences of existing in small populations (although potentially severe; Frankham *et al.*, 2002) are also difficult to predict confidently. In large and poorly documented faunas (such as Australia), so many insect species are regarded as rare (however the term is interpreted) that more tangible criteria are needed to help designate conservation priority, particularly as expertise and resources are grossly insufficient to treat all species in need of conservation attention individually.

6 Threats to Temperate Insects

Many action plans for insects throughout the temperate region necessarily include a substantial component of surveying to determine current status and distribution, and of research to define management needs more effectively. This reflects the paucity of information on many insects of conservation concern. A recent call in Australia for systematic inventory surveys of selected insect groups in national parks (Sands and New, 2003) to help address possibilities for species management in such areas is starting to be heeded, particularly in Queensland. In addition, threat evaluation is intrinsic to appraising vulnerability and chances of extinction. This process is central to the formulation of recovery or management plans, which must include clear objectives and periods for review and any necessary revision. However, statements about perceived threats, even in well-studied fauna such as in the UK, are often little more than very general pointers towards changes that would be detrimental. Although comparative details of threats in the northern and southern temperate regions are perhaps not constructive to investigate in detail, because of the enormous variety in both areas, some broad generalizations may be informative in helping to inform conservation strategy.

Vulnerable and threatened insect species are not evenly distributed across habitats. Thomas and Morris (1994) provided an illuminating analysis of 232 species listed in the British *Red Data Book* (Shirt, 1987). A striking pattern emerged in that the majority of endangered species are associated with either the very early or very late stages of succession. The early successional stages included bare ground, pioneer heathland, the early stages of the woodland coppice cycle and grassland that develops within 2 years of major disturbance, whilst the opposite end of the sequence was represented by deadwood habitats and their associated saproxylic fauna. As would be expected, the pattern is not universal across all taxonomic groups, being especially pronounced for Coleoptera and Diptera but less so for the Lepidoptera, Orthoptera and Hemiptera. Some of the emphasis on early succession habitats is undoubtedly because many of the associated species are at the northern edge of their range in Britain and are dependent upon the warm microclimates that these open habitats provide. Nevertheless, the general pattern highlights the fact that many entomologists attach high priority to habitats that are very different from those highly prized by conservationists who are concerned with other taxa. We know of no comparable analyses that have been carried out for other temperate countries, but similar studies elsewhere would be instructive.

Although not originally coined with invertebrates in mind, Diamond's (1989) 'evil quartet' – of habitat destruction, degradation and fragmentation, overexploitation, invasive alien species and chains of extinction – has plenty of relevance to insects. A fifth threat, climate change, has since gained equal potential significance, and has the potential to override more localized threats.

6.1 Habitat change

The topic of how habitat change impacts upon insect conservation encompasses change consequent upon natural processes such as succession, but also human-engendered degradation, fragmentation and wholesale destruction of habitats. Although the topic will not be dealt with in detail here because it is covered fully elsewhere (e.g. Thomas *et al.*, 2001; Warren *et al.*, 2001; Tscharntke *et al.*, 2002), it is worth drawing attention to two points. First, it is axiomatic that any change to a species' preferred or optimal habitat will have serious consequences. Since most insects are best envisioned as inhabiting microhabitats and their associated microclimates, even minor changes in the overall habitat, whether brought about by natural processes such as succession or by active management, may have far-reaching consequences for insects. Thus, even minor adjustments to the grazing pressure in grasslands can bring about substantial structural changes to the vegetation, which in turn have important effects on the microclimatic regime for temperature-sensitive insects. Second, it is worth highlighting the fact that many insects in the northern temperate region inhabit only remnant or restored habitats, or those altered substantially by people. Conservation attention is focused on minimizing loss of the remaining natural and semi-natural habitat, but may already be dealing with substantially impoverished biota, even though the extent of this impoverishment can only be speculative. Clearing of native vegetation in Australia and southern Africa has been imposed relatively recently on large areas of previously relatively undisturbed ecosystems, so that species losses can be more conspicuous and appear more dramatic because the near-natural remnant habitats that support higher proportions of the pre-disturbance taxa still remain for comparative study and evaluation.

6.2 Impact of introduced species

Although most introduced species fail to become established and spread, invasive species can have far-reaching consequences for communities and habitats. Inadvertent introductions, or cases of unexpectedly invasive spread by deliberately introduced insects, have occurred in most parts of the temperate region. Invasive ants are regarded as particularly severe threats to native species in Australia, South Africa and North America. The Argentine ant, *Lipepithema humile*, is native to South America but has been introduced to Mediterranean climates around the world. Sanders *et al*. (2003) showed how invasion by the Argentine ant caused a complete breakdown in the structure of the native ant community in California within 1 year, while Human and Gordon (1997) demonstrated strong effects on overall invertebrate diversity and the population sizes of many non-ant species and groups. Non-native *Vespula* wasps in New Zealand *Nothofagus* beech forests compete with native insects and birds that exploit the honeydew produced by endemic scale insects; additionally, predation by the wasps reduces and possibly eradicates populations of many native invertebrate species (Beggs, 2001).

Introduced plants, including weeds, exotic pasture grasses and crops, are important in displacing native vegetation and the specialized insects that depend upon it. Even non-herbivorous insects may be influenced by consequent changes in habitat. The impacts of exotic or invasive flora are of greatest concern when affecting restricted habitat types. McGeoch (2002) cited high-altitude montane grassland in South Africa as one such vulnerable environment supporting numerous endemic insect species. Invasive plants may significantly alter native insect diversity through changes in plant community composition. Himalayan Balsam, *Impatiens glandulifera*, is highly invasive along northern European watercourses where it outcompetes native riparian plant species that are hosts for an important and rich assemblage of insect herbivores, although the flowers are an important nectar source for pollinator species.

The deliberate planting of exotic forestry crops, often in very extensive stands, is widely regarded as detrimental to insect diversity. Certainly, *Pinus radiata* plantations in Victoria, Australia (Sinclair and New, 2004), and South Africa (Samways *et al*., 1996) support very few native ant species in relation to the native forests they have replaced. The same is likely to be true where southern hemisphere trees have recently been introduced into northern temperate regions, for example, the widespread adoption of *Eucalyptus* spp. for plantation forestry in Iberia (Fernandez-Delgado, 1997). However, surveys in non-native conifer plantation forests in Britain have uncovered some unexpectedly diverse communities in which stand age, vertical structure and edge effects are important determinants of diversity (Humphrey *et al*., 1999; Ozanne *et al*., 2000; Jukes *et al*., 2001).

Deliberate introduction of insects (e.g. as biological control agents or pollinators) to southern temperate regions has sometimes not been undertaken with due care, although increasing concerns in recent years are helping to overcome this through development of effective screening processes or other controls. For example, a current application has been presented to introduce bumblebees, *Bombus terrestris*, to the Australian mainland for pollination of greenhouse tomatoes. *B. terrestris* has been present in Tasmania since the early 1990s, and has spread over much of the state, including remote areas far from cropping systems and may be causing ecological harm through competing with native pollinators and damaging specialized native flora (Buttermore, 1997). Similar effects could possibly occur on the mainland, and such invasive species are regarded widely as important threats to native insects in the region, but capability to investigate these is limited. As an example of the contrasting attitude shown when an invading insect poses a direct threat to human interests, discovery of the red imported fire ant, *Solenopsis invicta*, in Queensland has led to 'perhaps the most ambitious and important effort ever undertaken to eradicate an invertebrate pest in Australia' (Vanderwoude *et al*., 2003), with a funding commitment of AUS$120 million over 5 years.

6.3 Impacts of biological control agents on non-target species

Although the introduction of exotic predators and parasitoids in biocontrol programmes is often portrayed as an attempt to restore a balance between a pest and its natural enemies (e.g. Hoddle, 2004), impacts on other non-target species are often impossible to predict (Louda and Stiling, 2004) and are rarely adequately documented. Boettner *et al*. (2000) examined the effects of a generalist parasitoid fly that had been introduced into North America throughout most of the last century to control gypsy moth, *Lymantria dispar*. They reported 80% larval infestation rates by the parasitoid in a range of native saturniid moths, substantially explaining recent declines in these species, especially in the north-eastern USA. The Harlequin ladybird, *Harmonia axyridis*, is native to Asia but has been widely introduced into Europe and North America as a biological control agent of aphids and scale insects. As a very effective but also generalist predator, it is known to feed on the larvae of other Coccinellids as well; consequently, it has been implicated in the decline of certain native ladybird species in North America through both predation and competition for food resources (Koch, 2003). Its recent introduction into the UK has been taken sufficiently seriously to launch a government-funded national project to monitor both its spread and its impact on native ladybird species (Roy *et al*., 2005). Alarmingly, screening for impacts of biocontrol agents on non-target species is not a requirement in many countries, including the USA. Thus, for example, no restrictions were placed on the recent importation and release of a dryinid parasitoid from North America into four separate provinces of Italy to control the flatid planthopper, *Metcalfa pruinosa*, even though no assessment had been made of whether it might impact on other native non-pest flatid species (Sala and Foschi, 2000).

6.4 Extinction cascades

Dunn (2005) has drawn attention to the threat of 'coextinction' of parasites (*sensu lato*) and mutualists as a consequence of the extinction of their hosts. Host-specific species are clearly more vulnerable in this respect than generalists. Such knock-on effects through ecological webs are likely to be common but may often go unnoticed. Perhaps the best example of an extinction cascade that led ultimately to the extinction of an insect (albeit only the local extinction of a subspecies) concerns the large blue butterfly, *M. arion*, in Britain. Ultimately, the loss of this species in Britain can be traced back to the successful biological control of rabbits, *Oryctolagus cuniculus*, using the *Myxoma* virus in the 1950s. The widespread collapse of the rabbit population caused open closely grazed grassland swards to be replaced by taller vegetation with consequent cooling of the soil surface layers. This, in turn, removed the hot microclimatic conditions required by the thermophilous host ant, *Myrmica sabuleti*, on which the butterfly larvae were dependent for food and protection (Elmes and Thomas, 1992). This is perhaps one of the best-documented cases of extinction of an insect, in which the links in the chain of extinction are well understood. However, it is unlikely to be an isolated case.

6.5 Insidious threats

Other more subtle, but possibly no less potent, threats also face insects in temperate zones. One that impacts particularly on temperate compared to tropical zones because it is directly associated with human population density is 'light pollution': artificial night lighting that interferes with the natural diurnal light cycle in ecosystems. The most obvious group in which effects might be expected is night-active moths, but many other insects respond to night illumination. Light pollution has been implicated in the decline of moth populations in the USA (Frank, 1988) and UK (Parsons *et al.*, 2005), but evidence is mostly anecdotal at present. A variety of reactions by insects (attraction/repulsion, orientation/disorientation) could be expected but very few have been investigated experimentally (Longcore and Rich, 2004). Long-term impacts on species distributions and population densities are unknown but could be profound and urgently need investigation.

The widespread prophylactic use of avermectins to treat intestinal parasitic infestations in grazing livestock means that the dung produced by such animals has a depauperate invertebrate fauna (Wall and Strong, 1987). This change, plus a general decline in low-intensity or 'extensive' livestock grazing as a traditional agricultural practice in many modern landscapes, has led to a general decline in the associated invertebrate specialist dung fauna, of which the hornet robberfly, *A. crabroniformis*, is a particularly vulnerable example.

7 Political Outliers

In the past, much conservation activity has been dictated by limited political jurisdictions, rather than by more global need. Insects common over much of Europe, or in some states of Australia, may receive considerable attention resulting from their rarity on the fringes of natural ranges, or in particular sites where they are deemed vulnerable, simply through the vagaries of their geography. The attention paid to such 'political outlier' insect taxa has been regarded by some as unduly parochial and misplaced in relation to more urgent needs, especially where taxa are relatively secure elsewhere (e.g. Hambler and Speight, 1995). The counterargument emphasizes that many such projects, in the process of unravelling the detailed ecology of individual species, have additionally been invaluable in developing general principles and methodology and in fostering local conservation interest, involvement and 'ownership'. In highly modified landscapes such as in Britain, there is also the consideration that often such species are not in decline solely as a result of natural edge-of-range processes but instead as a consequence of large-scale land use changes. As such, they may be indicative of declines across a wide range of unstudied taxa.

High-profile conservation reintroduction projects, often commanding considerable resources but not always delivering successful outcomes, have also sometimes been criticized for being too parochial. However, recent discussions and guidelines on the topic, both in general terms (Hodder and Bullock, 1997) and specifically in relation to insects (JCCBI, 1986; Oates and Warren, 1990), have encouraged greater scientific scrutiny of such projects, especially in relation to the global conservation status of the focal species. Thus, the reintroduction of the large blue butterfly to Britain was amply justified on the grounds that it is part of a group of globally threatened *Maculinea* spp. Additionally, evidence is accumulating that habitat restoration for the large blue is also benefiting other scarce butterflies, plants and even birds (Thomas, 1999). On the other hand, a long-established attempt to reintroduce the large copper *L. dispar* to Britain (Duffey, 1977) has been suspended following detailed autecological research (Pullin *et al.*, 1995) and the realization that its requirement for extensive fenland habitat is not currently met in the UK. Likewise, further investment in assessing the feasibility of reintroducing the chequered skipper *Carterocephalus palaemon* to England is being withdrawn (N. Bourn, 2006, *in litt.*) given its requirement for large areas of habitat (Ravenscroft, 1995) and the fact that it is both widespread and not threatened elsewhere.

Disproportionate attention to range edge butterfly species in Australia has caused concern over use of very restricted resources and has emphasized the need to differentiate between simple 'range edge' populations extending narrowly across political (State) boundaries, and so falling under different state legislations, and truly isolated populations separated from others by considerable distances. Sands and New (2002) attempted to distinguish these categories for butterflies, with the latter accorded higher conservation priority. Similarly, early tendencies in the UK to allocate resources to species which were on the northern edge of their range but widespread and unthreatened in nearby continental Europe have since given way to more global selection criteria that include consideration of the level of threat throughout the species' entire range. Of course, the latter approach is dependent upon good quality information on the distribution and status of species throughout their range, against which to assess the global significance of particular local populations, which has not always been available.

8 The Collecting Paradox

Collecting of butterflies and certain other insects is now prohibited or strongly discouraged in much of Europe, formally so in the case of protected species but also more widely. In large part this attitude reflects increasing conservation concern, but excessive zeal from the anti-collecting lobby can have undesirable consequences. The European protective legislations for insects, as reviewed by Collins (1987), included some extreme cases, extending far beyond the possible impacts of overcollecting on selected sensitive species or populations. All insect collecting is banned in Germany except with appropriate licences. Perhaps the most extreme case is for Laggintal, Switzerland, where (with the stated purpose of protecting the endemic satyrine butterfly *Erebia christi*) collection of all species of Lepidoptera and the carrying of butterfly nets are prohibited. Consequent acts of public ire over apparently innocuous and legal collecting activities elsewhere have perhaps deterred people from entering entomology as a hobby or lifelong interest. Fortunately, the attitude that collecting is incompatible with conservation, once particularly prevalent amongst less-well-informed site managers and nature reserve wardens, is now giving way to a realization that such activities are essential in order to build the biodiversity information base on which to make rational conservation decisions. Codes of conduct for collecting are now available in many temperate countries (e.g. in the UK; Invertebrate Link, 2002) and widely respected as pragmatic and responsible guidelines.

One argument commonly advanced is that for well-known insect groups (predominantly butterflies) in well-studied faunas further collecting is not needed for documentation, cannot be justified except in particular responsible scientific contexts and should be replaced by activities such as photography. This is not the case in the south, but regulatory approaches (and public opinion) in Australia and elsewhere have inherited the sentiment that collecting is a threatening process and should be curtailed. With relatively rare exceptions (including high-profile collectable species in demand by overseas dealers – such as *Colophon* stag beetles in South Africa; Geertsema, 2004), collecting is, at most, a subsidiary threat to habitat changes. Particularly for narrow-range endemic species, very small populations or populations with clear threats, any additional mortality may be undesirable and could provide an argument for prohibiting collecting. However, such cases are relatively unusual, and the common nexus of protecting a species by regulation or listing and banning collecting of butterflies in Australia has, in fact, retarded conservation progress:

1. Most knowledge of Australian butterfly biology and distribution has come from the activities of highly competent and enthusiastic hobbyists.
2. Collecting bans, or complex needs for permits, have deterred many such activities, eroding the badly needed goodwill of hobbyists to inform conservation, and driving much of the knowledge essentially 'underground' rather than being publicized freely, so that published information may be misleading and outdated.
3. Even when permits are granted, activities may be very restricted. For example, in Queensland until recently, permits applied only to particular places and dates, as well as to species. It was thus illegal to capture voucher specimens of possibly threatened species from other sites for verification of identity; many small lycaenids (such as *Hypochrysops piceatus* in southern Queensland; Sands and New, 2002) and hesperiids cannot be identified reliably from sight records alone.
4. More generally, such additional collecting is crucial in establishing the distribution and conservation status as well as the needs of insects, helping to overcome the under-recording so prevalent over the large areas involved. Any impediments to this endeavour are undesirable, particularly in the great majority of cases in which overcollecting cannot be considered credibly as a realistic threat.

In summary, the major need is to determine the cases in which collecting is indeed a threat and to ensure that appropriate safeguards are then implemented.

9 Species and Ecology

The best-studied insects in conservation, predominantly northern hemisphere butterflies as noted earlier, have highlighted the importance of understanding autecology when planning species-level conservation. This knowledge has indicated some valuable ways forward, and possible 'short cuts', as models for pursuing similar conservation measures in the southern zones. Parallel studies are indeed starting to occur; Kitching *et al.* (1999) summarized much earlier information on Australian butterfly biology, but relatively little information on population structure and dynamics of most species of conservation priority was then available. A full review of the importance of insect ecology in conservation is beyond the scope of this work, but one topic deserves particular mention in demonstrating the differing levels of information between north and south.

Perhaps the most significant of these ecological advances for conservation has been the development of the 'metapopulation concept' (Hanski and Gilpin, 1997). A number of rare insect species exist in small and substantially closed populations with minimal exchange of individuals with other local populations (Thomas and Harrison, 1992; Kindvall, 1996; Piper and Compton, 2003; see also Thompson *et al.*, Chapter 12, this volume). The metapopulation concept has revolutionized the ways in which extinctions of such local populations may need to be interpreted. Population or other extirpations were earlier interpreted largely as permanent loss of closed populations, but many such instances in Europe are now considered loss of metapopulation units, as part of a less unusual cycle of extinctions and colonizations that characterize the true spatial population structure of the species involved and so are less calamitous than 'true' extinction. Such considerations have had important influences on developing conservation management for butterflies, particularly in the northern hemisphere, and in helping to understand the aspects of landscape ecology that may be important to preserve or enhance in order to reduce the chance of more permanent losses (Ehrlich and Hanski, 2004). Unfortunately, the metapopulation concept has sometimes been applied too readily and uncritically to any species with spatial population structure; Harrison (1994) reviewed the evidence for metapopulation and related population spatial structures and their relevance to conservation. However, the metapopulation concept has been especially valuable in understanding and predicting the persistence of habitat specialists in modern fragmented landscapes (e.g. Thomas and Harrison, 1992) and how species can recover after range contraction (Davies *et al.*, 2005). Recent debates on the relative importance for overall persistence of metapopulation structure (the number and connectivity of suitable habitat patches) compared to habitat quality within sites (Thomas *et al.*, 2001; Bourn *et al.*, 2002) are of direct practical relevance to conservation managers. The same is true for the debate about the dimensions of habitat corridors and whether they function simply as dispersal conduits between local populations or represent usable habitat (Sutcliffe and Thomas, 1995; Pryke and Samways, 2001). These lessons have considerable potential for emulation as management models elsewhere, but the population structure of most butterflies in the south is not yet understood in comparable detail. Such studies would be significant in helping to confirm or contradict the general inferences from the north.

10 Extending Insect Conservation from Species

In regions with relatively small and well-known insect faunas and a relatively large number of concerned entomologists and conservationists, focus on individual species can play a leading role in insect conservation strategy. In the converse case of more insect species but fewer entomologists, this balance changes, and reliance on attention to individual species to drive conservation practice almost inevitably becomes less tenable. In this respect, the southern temperate regions are intermediate between the northern temperate regions and the tropics. Thus, in southern temperate regions, the predominating influence in conservation strategy has essentially switched from the species to the habitat or community level, with insects being conferred with roles as assessment tools as well as targets for individual attention, so that greater collective benefits accrue. Under Australia's federal legislation 'threatened communities' can be listed for protection in the same manner as for endangered species. Thus, 'Butterfly Community No. 1' is listed under state legislation in Victoria, although this entity has been defined solely in terms of a list of species (including several threatened Lycaenidae) occurring at one site (Jelinek *et al*., 1994), and the extent to which this species list may need to differ from that at another site for that to be included in the same entity has not been defined. Many threatened vegetation types in Australia, some of them quite widespread, are important for insects, either notable species or wider diversity. For butterflies, Sands and New (2002) listed a number of vegetation-based communities that constitute important habitats to which notable species (some of them local endemics) are restricted. Sands and New also drew attention to the importance of 'topographical assemblages', to recognize the importance for butterfly conservation of features such as isolated hilltops in the landscape, utilized for hilltopping behaviour (see Britton *et al*., 1995). Clearing of hilltops is now listed formally as a threatening process under New South Wales legislation.

In the UK, formal Species Action Plans have been prepared for some 219 insect species. Perhaps inevitably, these are unevenly distributed with respect to ordinal diversity: 4 Orthoptera, 64 Lepidoptera, 90 Coleoptera and 4 Hemiptera species, representing approximately 12.1%, 2.6%, 2.3% and 0.2% respectively of the total fauna in each order. Likewise, although the plans are somewhat formulaic (UK Biodiversity Group, 1999), varying amounts of resource have been devoted to the different species; some have not required or received much more than focused surveys to establish current status, whilst others have prompted major research projects (Piper and Compton, 2003; Purse *et al*., 2003) and reintroduction programmes (Pearce-Kelly *et al*., Chapter 3, this volume). In addition to addressing the conservation needs of individual species, the action plans collectively have served the useful purpose of drawing attention to gaps in knowledge (regarding status, threats, management, etc.) and the requirement for further research and monitoring.

Although the traditional emphasis on insect conservation at the species level remains strong in Britain, there is a growing realization that resources are grossly insufficient to deal adequately with all the deserving species. Greater emphasis is now turning to the identification and monitoring of ecologically based insect assemblages, including both common and rare species, that can be used for site assessment and for monitoring to assess habitat condition (Alexander *et al*., 2004; Webb and Lott, 2006). This is a promising alternative to the traditional vegetation-based approach, since the UK National Vegetation Classification (NVC), now used almost universally as the template for much conservation assessment and monitoring, does not necessarily provide an appropriate classification for insect assemblages (Blake *et al*., 2003; Maczey *et al*., 2005).

Conservation strategies are often categorized as being either fine-filter or coarse-filter, reflecting respectively a focus on species or habitats (Samways, 2005). An extension to this dichotomy has recently been proposed which has some resonance with approaches now being adopted in Britain. Hunter (2005) adopted the term 'mesofilter' approach based upon identifying and prioritizing what he calls 'critical ecosystem elements': relatively small-scale habitat features that may be very important to individual species, including insects, but which are likely to be overlooked by more conventional habitat-based approaches to conservation focusing on higher-profile taxa such as plants and birds. This ties in with increasing focus in Britain on the conservation significance of specialized habitats and microhabitats harbouring important insect species. These include vegetated coastal shingle, soft-rock cliffs, quarries and 'brownfield' or post-industrial sites as habitat types that have conventionally received less attention for most taxa, although there is a growing realization of their importance for bryophytes, lichens, herpetofauna and invertebrates. Similarly, deadwood, bare ground, seepage, rot holes, temporary pools and river shingle banks are resources that have particular significance for insects in many other habitats. The challenge for conservation entomologists is to establish how best to create and maintain these habitat features sustainably and how to integrate them with the sometimes competing interests of other taxa.

11 Conclusions

Generally applicable patterns are elusive when faced with the very diverse canvas of insects and their habitats across temperate regions. However, some tentative conclusions are appropriate for developing future conservation strategies:

1. The past, present and future of insect conservation in temperate regions differ markedly between the northern compared to the southern hemisphere. In comparison to their southern hemisphere counterparts, northern temperate countries, especially in Europe, tend to have smaller and better-documented insect faunas, of which a higher proportion across many orders is formally described. Information is available for many groups in a non-specialist form, type material is largely accessible, a strong ecological and biological framework is available to support observations of species, and there are a relatively large number of entomologists sympathetic to a culture of conservation; the converse conditions pertain to much of the southern temperate region.

2. The single-species (fine-filter) approach that has been developed very successfully in northern regions, especially the UK, is normally impractical in southern temperate regions where the significantly larger number of species, a high proportion of which are undescribed, and the smaller number of workers have forced a more general, habitat- and community-based (coarse-filter) approach to sit alongside the species approach. This mirrors assemblage-based approaches that are now being actively developed in the UK. An intermediate (mesofilter) approach, which emphasizes the critical ecosystem elements that insects require, is helping to draw attention to habitat types and specialist habitat features that tend to be overlooked by conservationists focused on other taxa.

3. The single-species approach still has a role to play, especially where individual species can be presented as flagships for the general cause of insect conservation. Autecological studies have also done much to promote understanding of the unique requirements of insects and how these can be met in modern landscapes.

4. The sheer number of species of conservation concern precludes individual attention, so strategies will need to be developed for grouping species together in assemblages, communities or habitats that can be readily identified and conserved as higher groupings. Continuing emphasis will be needed on identifying, assessing and promoting indicator species and groups that can be used for routine monitoring of environmental change and human impacts.

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