Insect Conservation: A Synthetic Management Approach

Michael J. Samways

Department of Conservation Ecology and Entomology, and Center for Agricultural Biodiversity, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa; email: samways@sun.ac.za

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Abstract

Threats to insect diversity range from habitat loss and invasive alien organisms to environmental contamination and biological control. Many of the threats are synergistic, with the joint impact of habitat loss and global climate change being highly adversely synergistic. Recent research on insect conservation has elucidated some basic principles for conservation management. There are six basic principles that are interrelated and together provide guidelines for synthetic conservation management of insects. They are maintain reserves (principle 1), maintain as much quality landscape heterogeneity as possible (principle 2), reduce contrast between remnant patches and neighboring disturbed patches (principle 3), outside reserves, introduce land sparing (principle 4), simulate natural conditions and disturbance (principle 5), and connect similar patches of quality habitat (principle 6). These six principles constitute a coarse-filter, landscape approach. Permeating all six is the principle of maintaining healthy population levels, which require the combined support of the metapopulation trio of large patch (habitat) size, good patch quality, and reduced patch isolation. In addition to these six coarse-filter principles is an overlay of the fine-filter, species approach, in which particular species are given focused attention and management.

HISTORICAL BACKGROUND: WHY WE NEED TO CONSERVE INSECTS

Insects are enormously successful organisms, both in terms of numbers of species and abundance (164). Their diversity at the family level has been increasing over the last 400 million years, with about 600 families living today (106). At the species level there has not been such a steady increase, with many species lost at the end of the Cretaceous. Most of extinct species were specialists (105).

During the past few hundreds of thousands of years, with the advance and retreat of glaciers, there have been few insect species extinctions (34, 145). Insect populations in the Northern Hemisphere have responded to these chills and thaws by moving southward during the glacials. They have also moved up and down mountains, which has generated new species (78). These movements were unimpeded by the human-fragmented landscape.

During the Pleistocene and early Holocene, mammalian herbivores probably played a significant role in opening up the landscape (2), as they do today on the African savanna (155, 166). This vertebrate impact has been highly significant for many insect species because it leads to a myriad of microhabitat types. Beginning ~6000 years ago, this began to change as humans suddenly, in geological and evolutionary time, altered the landscape. Trees were felled and indigenous game were replaced by domestic livestock. Britain alone lost 20 of its log-inhabiting beetle species (68).

Since then there has been an acceleration of anthropogenic impact on insect populations, with an estimated 11,200 species having gone extinct since the year 1600 (120). Some estimates are that half a million insects may go extinct in the next three hundred years, while some projections suggest that perhaps a quarter of all insect species are under threat of imminent extinction (122). In Britain, butterflies are becoming locally extinct faster than plants or birds (195). Furthermore, some parasitic insects are becoming extinct with their vertebrate hosts (50), making a coextinction crisis.

CHALLENGES FOR INSECT CONSERVATION

Only about 10% of all insects have scientific names, with many taxonomic revisions still required, and many species, even common ones, are multispecies complexes with the determination of their DNA (76). Describing all unknown species before they become extinct is the taxonomic challenge. Still, there are likely to be many extinctions, even of species that have never and will never be described

Addressing this taxonomic challenge is not an easy task, although several approaches are making this possible. These include undertaking full inventories of small but important and tractable geographical areas, such as the Seychelles with its high number of endemics (67), or undertaking a global assessment of a particular taxonomic group as is being done for dragonflies. These approaches are supplemented with user-friendly keys for nonspecialists engaged in conservation planning and with the deployment of computer recognition of specimens.

Another great challenge for insect conservation is the perception challenge. Even among some general conservation practitioners, insects are often considered insignificant or given scant attention. This lack of appreciation of insects can reach major proportions among some sectors of human society, who may only recognize the dirty cockroach and the nuisance fly. Yet there is a growing awareness and even fondness for some insects. The British society Butterfly Conservation currently has about 14,000 members, roughly 200 members per national species!

THREATS TO INSECTS

Insidious Impacts of Environmental Contamination

A combination of rising human population and more consumption of resources and energy has, as measured by gross domestic product, increased by 460% over the last century, with estimates that there will be a further rise of 240% by the year 2050 (129). Among the concerns is that this human pressure will have cascading effects on ecosystems, with loss of plant species leading to loss of insect species. Hawaii has lost five moth species because of plant extinctions (63). Simulations suggest that loss of just 5% to 10% of keystone members of food webs can radically alter ecosystem function. Many effects of environmental contamination are sublethal and not easily detected. The insecticide deltamethrin can reduce fitness of larval and adult butterflies when applied at only 1/640 of the field dose (25).

Despite the apparent importance of environmental contamination, little is known about its impact on insect species. Species respond differently to any particular contaminant and concentration. Furthermore, there can be adverse interactive effects between impacts of contamination and other forms of stress, such as habitat fragmentation.

Differences in the responses of species in the same feeding guild are seen on Mayotte Island in the Indian Ocean, where some dragonflies are much more susceptible to stream contaminants such as detergent than are others (163). Some insects are little affected by some pollutants, with some herbivorous insects even benefiting from low levels of sulfur dioxide and nitrous oxide (16). In contrast, although the larvae of the butterfly *Parnassius apollo* can excrete metals, it cannot tolerate high levels on its host plant. Relaxation of heavy metal pollution has enabled it to widen its geographical range once again (134).

Loss of Natural Habitat: Prime Cause of Insect Extinctions

Tilman et al. (196) estimate that by 2050 another 10^9 ha of natural ecosystems will be converted to agriculture, with a 2.5-fold increase in nitrogen- and phosphorus-driven eutrophication. These changes will be synergistic with pollution, habitat fragmentation, impact of invasive alien organisms, and global warming. These impacts will not affect all species equally, with specialists likely to decline the most (99), although some common species may also decline dramatically (108), as did the Rocky Mountain locust, *Melanoplus spretus*. It was so abundant in the Midwest of North America in the late 1800s that it caused the wheels of locomotives to slip, yet by 1906 it was extinct (111). Some species even benefit from increased edge effects, such as aggressive ants at the interface between natural habitat and the agricultural matrix, where they heavily affect soil-dwelling arthropods of the transition zone (38).

Threats: anthropogenic factors that reduce population viability and can lead to extinction of a species

Land transformation leads to a mosaic of landscape patches, which is highly isolating for many species. Less mobile species may be tolerant of such isolation, which may be the confined spatial environment in which they evolved (165). At the other end of the spectrum, highly mobile species may move across transformed patches, but for those with intermediate mobilities, the anthropogenic landscape mosaic may pose a major threat (191).

Not all aspects of human disturbance are harmful. For example, limestone quarries in the Czech Republic are beneficial for some species that enjoy locally warm and disturbed conditions, which simulate early successional habitats (9). Indeed, some rare insect species require disturbed conditions, such as slipping cliff faces (213).

Urban impact includes traffic, which can be particularly devastating for many Lepidoptera species (121). Furthermore, the materials used to build roads affect not only the immediate area but also many tens of meters into the surrounding area. As with many other types of disturbance to natural systems, some specialist species are lost but some generalists, such as tramp ants, benefit (167). Similarly, canalization of rivers can encourage populations of certain resourceful species of black fly (*Simulium* spp.) (42).

Of greatest concern is the loss of tropical forests, where probably more than half of all insects live. Currently, 130,000 km^2 are lost annually, and in Southeast Asia it is estimated that by 2010 three quarters of the forests will be gone (175). Evidence is accumulating that forest-to-farmland conversion has a major effect on insect assemblages, particularly the primary forest specialists (39, 45, 51, 58, 80, 83, 92). As in some other ecosystems, it is the opportunist generalists, such as dung beetles and ants, that survive the transition (8, 41). Nevertheless, ecosystem function changes with the altered vegetational canopy (23, 109).

Other natural ecosystems are also losing species, with grassland insects (21, 137, 169, 189) and insects of Mediterranean-type ecosystems (73, 161) affected. The Satyr butterfly *Cercyonis sthenele sthenele* of San Francisco was the first recorded insect extinction in the United States, and the appropriately named katydid *Neduba extincta*, also formerly of San Francisco, was lost in 1937, and only scientifically named after it went extinct.

Of further concern is the loss of cave faunas (36, 86, 173) and island insects (67, 88, 91). Islands appear particularly prone to having their food webs altered, especially by invasive alien organisms (29), environmental changes, and, to some extent, lack of genetic variation (52).

Pervasive Effects of Invasive Alien Organisms

Invasive alien organisms are a major threat to many indigenous and endemic species (28). Invasive alien plants can displace indigenous ones and overrun ecosystems, even affecting local hydrology. Such impacts inevitably reduce local insect diversity (170), which can return when the alien plants are removed (171). Invasive insects are also posing a threat. In the United States, a new insect species is discovered on average every 54 inspections of maritime cargo (216).

Interestingly, the impacts of invasive alien plants are not always negative. Alien plants sometimes provide shelter when there otherwise might not be (22), and alien water weeds can provide increased habitat for some dragonflies, but only for already geographically widespread and generalist species (182).

Invasive alien vertebrates can have both direct and indirect effects on insects. On sub-Antarctic Marion Island, alien mice eat up to 194 g ha^{-1} of invertebrate biomass (174), and alien rats have been implicated in local extinction of several insects including the Lord Howe Island stick insect, *Dryocelus australis*, on that island (148). The cane toad, *Bufo marinus*, was introduced into Australia to control certain beetle pests and is now having a major impact on many nontarget native insects, as are mosquitofish *Gambusia* spp. introduced into Hawaii to control mosquitoes but have since affected indigenous *Megalagrion* spp. damselflies (54).

Of the invasive species, ants have been the most resourceful. The bigheaded ant, *Pheidole megacephala*, and the Argentine ant, *Linepithema humile*, have affected ecosystems in many countries, including Hawaii, which originally had no ants (84). These ants outcompete local ants and can devastate local insect faunas, as has the fire ant *Solenopsis geminata* in the United States (33). On Christmas Island, the yellow crazy ant, *Anoplolepis gracilipes*, is changing the local ecosystem as it kills large numbers of crabs that take refuge on the island. Other hymenopterans can also have a major impact; for example, the common wasp, *Vespula vulgaris*, is having a major affect on New Zealand insects and spiders and is thus changing ecosystem processes (198).

Side Effects of Classical Biological Control

Although the introduction of foreign biological control agents to control foreign pests has had economic and environmental benefits, inevitably it does carry some risks for nontarget organisms (87, 112, 132, 160). While adverse impact is likely species or genus specific, the main concerns are twofold: The activity of classical biological control is deliberate, and once control agents have been introduced and established, they cannot be recalled and are therefore a new and permanent feature of the host landscape, thus violating a sense of place (112). While the adverse impacts of classical biological control are often difficult to prove, there is nevertheless evidence that some facets of it are detrimental to indigenous biotas. For example, the tachinid fly *Compsilura concinnata*, which was introduced into the United States several times to control various pests, has been implicated in the decline of some local saturniid moths (14).

While the control of alien weeds with insect herbivores has in many cases been successful and has had economic and ecological benefits, there have also been some side effects. Indigenous prickly pear cacti (*Opuntia* spp.) in the United States and Mexico are currently threatened by the cactus moth, *Cactoblastis cactorum*, which is spreading in North America (79).

Even insect pathogens carry risks. The bacterium *Bacillus thuringiensis israelensis*, which is used to control mosquitoes, causes mortality in various aquatic insect larvae. Another form of *B. thuringiensis* used for controlling pest Lepidoptera has an impact on indigenous North American moths (123).

The Pernicious Side of Genetic Engineering

Genetically modified organisms (GMOs), particularly transgenic plants, are increasingly used in integrated pest management programs. The use of GMOs can pose risks to some indigenous insects (113), although it has been argued that these risks are considerably reduced at the large, regional spatial scale (135). Furthermore, GM plants are not a general answer for pest control, as there are transgenic plants with *B. thuringiensis* insecticidal toxins resistant to the diamondback moth, *Plutella xylostella* (216a). For insect conservation, the real risk of GM crops is what Woiwod (214) has called the "pernicious side": An area the size of Wales is cleared annually in Amazonian Brazil to grow GM-free soya for the European market, thus devastating Amazonian insect diversity.

Impacts of Global Climate Change

The phenology of British butterflies changed considerably between 1980 and 2000, with the first appearance of 13 species significantly advanced (157). Climate change is also affecting trophic interactions, with all components of food webs from pathogens and mycorrhizae to predators and parasitoids affected directly and indirectly (6, 66, 74). Insect herbivores in elevated carbon dioxide grew more slowly, consumed more plant material, took longer to develop, and suffered higher mortality compared with controls (210). Competitive interactions are also likely to be affected, as seen in *Drosophila* assemblages in which different species were favored by particular temperatures (40). Nevertheless, some interactions have remained in step with climate change, with the winter moth, *Operophtera brumata*, larvae tracking changed budburst (19) and the orange tip butterfly, *Anthocharis cardamines*, keeping pace with food plant phenology (176).

As insects typically migrate faster than trees, many temperate plant species are likely to have new encounters with particular herbivores shifting their geographical ranges from warmer areas. As each species responds to climate change in its specific way, there is likely to be a reshuffling of communities (37). This cautions the use of simple climatic models to predict future geographic range changes, as empirical evidence from ladybird range

Synergisms: the interaction between factors where the outcome is a multiple of these factors

Prioritizing: the regional scale activity of selecting reserves and landscapes of conservation value

extensions (through biocontrol activities) shows that many features of an insect's biology affect where and how it establishes more than simple thermal considerations (168).

Nevertheless, there is a salient warning from Kuchlein & Ellis's (103) study of microlepidoptera in the Netherlands, which suggests little point in monitoring individual species to assess the conservation status of specific ecosystems. This indicates that spatially fixed reserves of today may not necessarily be home to the same species in the future, with specialists ill-adapted to move through the fragmented landscape likely the first to suffer. This event is illustrated by British butterflies, in which 30 of 35 species have not tracked recent climate change owing to lack of suitable habitat (81). Indeed, for these butterflies the extensive alteration and destruction of natural habitats means that newly available, climatically suitable areas are too isolated to be colonized or do not contain some specific key elements for survival (209). Evidence suggests that it is only the more mobile generalist butterflies (43, 143, 142) and dragonflies (3) that are tracking climatic suitability.

It is conceivable that some species will adapt locally rather than move to geographically new and more suitable areas, the phenomenon of contemporary evolution. The brown argus butterfly, *Aricia agestis*, is now using an alternative host plant, enabling it to inhabit new localities (192). Nevertheless, there have been some dramatic geographical range changes, with the chequered skipper, *Carterocephalus palaemon*, having disappeared from England and now restricted to Scotland (81). This finding is also in agreement with some butterflies having shifted their northern range margins more than their southern margins (142).

The greatest concern is that climate change will be interactive and synergistic with other adverse factors, leading to multiple impacts on species. Indeed, Travis (199) has called the synergism between climate change and habitat loss a "deadly anthropogenic cocktail" for biodiversity. This is borne out by British butterflies, of which 89% of the habitat specialists, compared with only 50% of the mobile generalists, have declined in geographical distribution (209). Similarly, since the 1950s there has been a 70% decline in the larger British moths, probably due to agricultural intensification and widespread and intensive use of insecticides coupled with climate change (31). Similar fate has befallen moths in the Netherlands, especially those of marshlands (70).

INSECT CONSERVATION PLANNING AT THE REGIONAL SCALE

Systematic Reserve Selection

Planning at the global scale has identified at least 25 areas that are hotspots of world biodiversity and that are also threatened (128). These are likely to be major areas for insect diversity but this still has to be demonstrated, with the proviso that there is likely little distributional concordance (i.e., their habitat preferences and geographical ranges do not coincide) between some taxa in some areas (107, 146).

At the regional scale, insects have a role in systematic conservation planning, which aims to identify locations and landscapes that are a priority for conservation action (i.e., prioritizing) (147). There are many ways to combine targeted sites or reserve areas, and the outcome must be flexible enough for practical conservation management, including making allowances for climate change. As some sites may be common and others rare or even unique, it is essential to include irreplaceability, which is a concept that embodies the potential contribution of a site to a particular conservation goal, combined with determining the extent to which the options for meaningful conservation are lost if the site is lost. While the focus may be primarily on endemic hotspots, it is essential to include areas that are typical, areas that are zones of ecological transition (4), and areas that have evolutionary potential (177).

These reserve selection procedures are a coarse-filter or landscape approach. These should ideally be complemented with a fine-filter or species approach, in which particular, usually threatened, species of special conservation status are also built into the planning process. A shortcoming of systematic conservation planning for insect conservation is that when insect data are included, there are often taxonomic errors, poor distributional data, and a bias toward certain species. When actual intensive on-the-ground studies are made as part of the ground-truthing of the modeled reserve network, the insect fauna usually is richer than originally thought, much more so than for vertebrates or plants.

Surrogates in Conservation Planning

In the case of insects, the reserve selection procedure has to operate on crude or incomplete data. This shortcoming can be addressed by using surrogates of insect species diversity. Such surrogates may be alternatives or complements, such as higher taxa, species richness, rarity, endemism, threat status, and/or alternative taxa. Other types of surrogates include vegetation types, land systems or classes, and environmental domains. However, none of these surrogates is perfect, and the risk of using them is that important or even critical aspects of regional insect diversity may be overlooked. For example, although British butterfly family richness may be a good indicator of species richness, rare and threatened species will go unrecorded. When different types of taxa are compared, there may not be concordance, leading to biases depending on which taxa are used (146), making it essential to use a broad selection of taxa (101). While use of environmental surrogates can embrace a range of taxonomic diversity, this broad-scale approach can overlook critical small-scale habitats and special features (such as large logs for certain saproxylic species, hills for hilltopping behavior, mud for mud-puddling, and sunbasking sites) essential to small animals such as insects.

The consensus being reached is that it is best to combine both environmental and species surrogates for systematic conservation planning. The first studies in this field suggest that insects and plants are often, but not always, concordant and are represented by many environmental surrogates (159, 217), with due caution that there will not always be a perfect match (140). Where species and environmental surrogates have been combined, the alarming conclusion is that perhaps half the land surface needs to be conserved to maintain biodiversity at current levels (153).

This conclusion emphasizes that some creative approaches are needed for future insect conservation, and these may be divided into three broad categories: reserve selection, conservancies, and land sparing. Conservancies are areas of land, often adjacent to reserves, where there is reduced or minimal impact on the land surface. For certain species this means that there is some physical area outside a formal reserve which is their habitat, thus increasing their chances of long-term survival, which then become greater than if they were confined just to a reserve. In other words, the landscape contrast, which otherwise would have been great between the reserve area and the surrounding highly disturbed matrix, is dramatically reduced. Land sparing (119) is set-aside land that may not be a formal reserve. Usually it is strips (corridors, or linkages or greenways) and nodes of land that may be too small on their own for many species' long-term survival but nevertheless complement high-quality reserve areas. Such spared land may also have been disturbed land that has undergone restoration toward a more suitable state.

Coarse-filter: The landscape or community approach to conservation

Fine-filter: the species approach to conservation, in which the focus is on a particular species or small number of species

Corridor: a linear strip of land connecting one high-value conservation patch with another (also known as a linkage or greenway)

INSECT CONSERVATION MANAGEMENT AT THE LANDSCAPE SCALE

In a recent overview of insect diversity conservation (164), it became apparent that some principles for insect conservation were beginning to emerge. These six basic principles are further developed here, bearing in mind the need for conservation managers to have guidelines for practical insect conservation (62, 98). They are interrelated and together provide guidelines for synthetic conservation management of insects, and also have broader applicability to biodiversity than just insects, emphasizing just how integral insect conservation is to biodiversity conservation. They also build on the threats listed above and their mitigation.

Synthetic management: an overarching management approach which involves six principles of biodiversity management

Metapopulation trio: the combination of three landscape features that encourage metapopulation dynamics and hence optimal survival of populations and thus of species

The six principles are maintain reserves as source habitats, particularly for specialists (principle 1); maintain as much quality landscape heterogeneity as possible (principle 2); reduce contrast between remnant natural patches and neighboring disturbed areas (principle 3); outside reserves, maintain as much undisturbed or minimally disturbed habitat as possible (land sparing) (principle 4); in transformed landscapes, simulate natural conditions and disturbance as much as possible (principle 5); and connect like patches of quality habitat as much as possible (principle 6) (**Supplemental Figure 1**, follow the Supplemental Material link from the Annual Reviews home page at **http://www.annualreviews.org**). These principles are discussed below. All six are coarse-filter, landscape approaches. Running throughout all six is the necessity for healthy population levels, bearing in mind that the extinction process is about loss of populations and declining population levels until a point is reached when the last individual has died. Healthy populations usually require the combined support of the metapopulation trio of large patch (habitat) size, good patch quality, and reduced patch isolation. As fragmentation and loss of habitat quality are felt most critically in the case of principle 4, the importance of maintaining this metapopulation trio is discussed below. Furthermore, in addition to the six coarse-filter principles, there is an overlay of the fine-filter, species approach, in which particular species in specific areas require focused attention.

Maintain Reserves

Wildlife reserves are critical for many specialist organisms that cannot survive in transformed landscapes (27, 58, 110, 116, 179). A cautionary note is that reserves must be large enough to retain these species in the long-term and not lose them to ecological relaxation (114, 197) and global warming (103). Among such specialists are the birdwing butterflies (30) and Malaysian ants, which need over 40 km^2 (17). Size of reserve, however, is not necessarily a fixed entity, because in times of environmental adversity, larger areas may be required. This contributes to principle 3.

Such reserves are not necessarily simply ring-fenced and left as is. They may require some management to maintain natural processes, such as trampling and foraging by megaherbivores or fire, to simulate the natural precedent, at least since the last glacial in the Northern Hemisphere and perhaps deeper in time in the Southern Hemisphere. This principle thus sits closely with principle 6.

Maintain as Much Quality Landscape Heterogeneity as Possible

Maintenance of a naturally heterogeneous landscape is essential for conserving a wide range of insects, from bumble bees (95) to dragonflies (183). British bumble bees need a variety of field and forest boundaries, while South African dragonflies need a variety of structural vegetational types. Such vegetation heterogeneity is three-dimensional and includes the vertical dimension. For Sulawesi butterflies, it is essential that the vertical structural layers of primary forest remain intact (59). Even on the ground it may be necessary to maintain a healthy, thick layer of deciduous leaf litter for insect and other arthropod diversity (118). Management for heterogeneity for insects in Britain (69) and Ireland (127) may involve letting in sunlight to encourage both plant and invertebrate diversity through a variety of microhabitats. At the larger spatial scale of landscape elements, heterogeneity also encourages a variety of insect species on Swedish farms (212).

Temporal considerations overlay the spatial ones. While butterfly richness did not change with vegetation succession over time, species composition changed substantially (181). There have been similar findings for soil microarthropods (141). However, there must be adequate migration between like seral stages to avoid local extinction (20, 136). Such migration may not necessarily involve continuous habitat, so long as there are stepping-stone opportunities from one reasonably suitable habitat patch to another for individuals to reach an ideal patch (5, 32, 100, 151). Whether continuous habitat or stepping stone, it is essential in management terms to cater not simply for average environmental conditions but rather for adverse ones (96).

Reduce Contrast Between Remnant Patches and Neighboring Disturbed Ones

As insects are small and plants are larger, insect populations are generally affected by the boundaries at distances beyond what humans perceive as the vegetation boundary (166a). The boundary between landscape elements then becomes an important feature in management planning. This emphasizes that management activities must focus on the wider landscape and not simply on individual patches. Nevertheless, as reserves are important source habitats (85, 133, 138, 202), the ideal situation is to reduce contrast between these source areas and their surroundings to encourage movement through the differential landscape filter (89). Results from heathland (211), forest (117), and agricultural patches (48) point to reducing the contrast between patches. This is underscored by Ricklefs' (154) appeal that ecologists should abandon circumscribed concepts of local communities where they are simply considered spatially explicit entities.

Outside Reserves, Introduce Land Sparing

As small patches have a greater proportion of edge to interior than do larger patches, the quality of the patch generally decreases the smaller its size. This small patch size can lead to loss of populations of butterflies (82), katydids (97), and froghoppers (13). Conversely, large patches can be proportionately richer in species than small patches (49, 94) and suffer less emigration (207). Nevertheless, some small patches may still have important conservation value for certain species of butterfly (172, 200) and may also act as stepping-stone habitats for some species (1, 186, 187, 208). Outside reserves or outside large, good-quality patches in general, the transformed matrix may not necessarily be unsuitable for all species (132). Both metapopulation dynamics and island effects may be taking place (26, 194). The area surrounding a good patch can be viewed as a differential filter, favoring some species but not others, and even a certain sex, age, or ecotype (89), with specialists usually the most affected. Yet in the Southern Hemisphere, where there have been no glaciations for well over 200 million years, many species live in discrete, small populations that are virtually preadapted to fragmentation as long as the footprint of any severe impact does not land squarely on their total population (165). In the Northern Hemisphere, there is sometimes a related phenomenon in which an unsuitable matrix may encourage conservation of certain species that prefer to stay in a good patch rather than venture across a hostile matrix (104).

Habitat patches are usually variable in quality, with large patches sometimes acting as metapopulation units in their own right and small patches functioning only as temporary or semipermanent habitats (186), which are subject to changing environmental conditions and making them only differentially suitable for the suite of focal species (187).

For certain butterflies, habitat quality is more significant than patch isolation (193).

Adaptive management: an approach in which there is not regimented rotational management, but rather there is spontaneous, irregular or variable management to simulate natural impacts

This emphasizes that patch quality is the third parameter in metapopulation dynamics (in addition to habitat or patch area, and isolation). Indeed, these three factors (patch quality, patch size, and isolation) were by far the most important multiple driver for maintenance of populations of the large heath butterfly, *Coenonympha tullia* (44).

In the final analysis, large, good-quality, close-together remnants of natural habitat can play an important role as habitats (139) or as patches facilitating movement. Thus, set-aside land and the activity of land sparing (119) become an important feature of landscape management (203). However, land sparing is in need of much more development, as results from the disturbed British landscape illustrate that it is more complicated than just leaving parcels of land (57, 60). Thus, land sparing does not necessarily equate with no simulation of natural disturbance, the topic of principle 5.

Simulate Natural Conditions and Disturbance

Any simulation of natural conditions has a temporal component as well as a spatial component. Management and restoration targets require knowledge of the character of the focal ecosystem at different times in the past and aim to simulate some time bracket. For the postglacial Northern Hemisphere, this is arguably the landscape immediately prior to the Neolithic clearances, at least in Europe. Elsewhere, where biotas were not eliminated by ice sheets, deeper time considerations may be necessary. Such simulations may not always be possible because of the current extensive and intensive landscape fragmentation and loss of certain ecological drivers such as megaherbivores. The remaining natural fragments may not be large enough to sustain the natural disturbance factors, such as herds of ungulates, or, in the case of fire, may present too much of a risk to real estate (131). This means that each reserve or set-aside piece of land generally requires a customized management strategy that has clear conservation goals and is realistic and feasible. As not all options may be available, some sort of triage may be necessary, in which priority is given to the conservation goal rather than emulating what the ecosystem should look like (162), while remembering that no single management activity will suit all species (125) or all processes.

The conservation goal may be to maintain a range of ecological conditions (35, 126), ecological processes and trophic interactions (180), endemic species, or even typical species or landscapes (201). Accumulating evidence is suggesting that to address these conservation goals we need to employ adaptive management. This is illustrated by prairie butterflies (188, 190), in which most specialists increase with less frequent and/or less intrusive management. However, leaving habitat entirely unmanaged is rarely optimal, with the occasional wildfire generally more favorable for specialists than regimented rotational management. This approach also appears to suit grasshoppers in Africa, a range of North American arthropods in mixed forest (178), and butterflies in Borneo (72) and Britain (93). This adaptive management approach is an answer to the risks of applying a single management type, which would otherwise not benefit all the specialists. Swengel (188) concludes that both consistency of management type within site yet deliberate differences in management type between sites of like habitat is the best way forward. Indeed, patchy burns have the advantage that the resultant refugia become source habitats for dispersal (138), an important issue in general for insect conservation in various ecosystems (59, 152, 158).

Thus, the evidence points to retaining considerable spatiotemporal variation (which contributes to principle 2) among sites of the same ecosystem type, both in terms of megaherbivore grazing [for various taxa in various countries (7, 46, 53, 64, 65, 75, 102, 205, 219)] and fire (188, 204), as well as various special disturbance features such as tropical forest tree fall (15). In turn, domestic livestock may, in certain circumstances, be good disturbance surrogates in the absence of indigenous megaherbivores (155, 166, 218). A corollary is that we must never be too hasty in deciding what is appropriate for a species. After 18 years of work, it was found that fire was not necessary, as formerly thought, for the British rosy marsh moth, *Coenophila subrosea* (61), and that for some New Zealand tussock grass moths grazing is detrimental (144).

Connect Like Patches of Quality Habitat

Corridors, or linkages, are continuous linear strips of habitat that connect and therefore improve the chance of survival of otherwise isolated populations (10). As insects are small and speciose, a landscape feature that is beneficial for a large mammal will not necessarily be beneficial for a particular insect species or even a particular individual.

Corridors have multiple roles depending on the focal organism(s) at any particular time. These roles include conduit (movement corridor), habitat, filter, barrier, source, and sink (77). Various studies (71, 149, 185, 206) have illustrated how insects move along corridors of remnant indigenous vegetation. Where these corridors are large, they may also be habitats where certain species can fulfill all their life functions (150) and where normal ecological interactions between plants and insects take place (18). Yet not all species or all individuals can move along these corridors with equal ease [or, conversely, move across the corridor (115)], making these corridors differential filters (156, 215). When dispersal along these corridors is effective, they can have an important function for population persistence (124), although such movement may not be in a straight line (11, 24, 184) nor necessarily down the middle (12). Furthermore, sensitively managed field margins (47, 56) can also encourage movement of insect species across the wider countryside (56).

Instigation and development of corridors involve not only the short-term, ecological scale of movement but also the long-term, evolutionary scale of movement (90), which emphasizes the importance of developing ecological networks of corridors (and nodes) for conservation of both individual species (130) and biodiversity as a whole. For this function to take place, the network of corridors needs to be a source habitat. In turn, it is only acceptable as a link between habitats when it is a movement corridor or stepping stone to a new patch or habitat.

As reserves are unlikely to be enough to maintain insect species in a climatically dynamic era (103), a regional network of corridors (55) is likely to mitigate the effects of climate change. This also links with principles 3 and 4, in which reducing contrast between disturbed areas and adjacent natural areas along with land sparing all contribute to ameliorating the effects of landscape fragmentation. Although improving the landscape for population dispersal goes a long way to facing the "deadly anthropogenic cocktail" (199), it can also encourage other threatening factors such as invasive organisms, biocontrol agents pathogens, and GMOs. This means that a management program must consider all these factors as one holistic strategy while being sensitive to the nuances of individual species.

SYNTHESIS

Threats to the world's insect fauna are often synergistic and repercussionary. Deforestation encourages weedy species, invasive aliens, and pathogens, which in turn further fragment populations, lessening their chances of moving across the landscape to survive climate change. Some principles are emerging from recent research on how we might manage the landscape for insect conservation. These principles similarly are positively synergistic and interrelated. An ideal management strategy is to maintain reserves and habitat heterogeneity while reducing the adverse impacts of the transformed matrix, setting aside quality stepping-stone habitats across that matrix, and introducing ecological and evolutionary corridors. The outcome of this landscape management package cannot be left to its own devices, but must be adaptively managed to simulate a particular set of conditions that match the ecological conditions at some particular time in the past. This coarse-filter, landscape approach can then be overlaid with the fine-filter, species approach in spot locations to cater for individually threatened species. Such an approach always takes into consideration the importance of the combined positive effects of large patch size, good patch quality, and reduced patch isolation. Not all species will survive the current huge anthropogenic impact, and some difficult triage decisions are likely a part of future management planning for insect conservation.

SUMMARY POINTS

1. Threats to insect diversity are rapidly increasing, and many of these threats are synergistic.
2. Six, interrelated principles are emerging from recent research on how we might manage the landscape for insect and other biodiversity conservation.
3. An ideal management strategy is to maintain reserves (principle 1) and promote habitat heterogeneity (principle 2) while softening the disturbed matrix immediately surrounding the reserve (principle 3).
4. Outside reserves, set aside land for biodiversity (principle 4), and simulate natural conditions and disturbance (principle 5).
5. Link good-quality habitats with corridors (principle 6), which has both short-term ecological value and long-term evolutionary value and can be a buffer in the face of global climate change.
6. Permeating these six landscape principles is a population-level approach, involving the metapopulation trio, which are large patch (habitat) size, good patch quality, and reduced patch isolation.
7. Overlying these coarse-filter, landscape principles is the fine-filter, species approach, which recognizes the needs of particular species under threat.

LITERATURE CITED

1. Abensperg-Traun M, Smith GT. 2000. How small is too small for small animals? Four terrestrial arthropod species in different-sized remnant woodlands in agricultural Western Australia. *Biodivers. Conserv*. 8:709–26
2. Alexander K. 2005. Wood decay, insects, palaeoecology, and woodland conservation policy and practice: breaking the halter. *Antenna* 29:171–78
3. Aoki T. 1997. Northward expansion of *Ictinogomphus pertinax* (Selys) in eastern Shikoku and western Kinki districts, Japan (Anioptera: Gomphidae). *Odonatologica* 26:121–33
4. Araújo MB. 2002. Biodiversity hotspots and zones of ecological transition. *Conserv. Biol*. 16:1662–63
5. Arellano L, Favila ME, Huerta C. 2005. Diversity of dung and carrion beetles in a disturbed Mexican tropical montane cloud forest and on shade coffee plantations. *Biodivers. Conserv*. 14:601–15

6. Ayres MP, Lombardero MJ. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. *Sci. Total Environ.* 262:263–86
7. Barbero E, Palestrini C, Rolando A. 1999. Dung beetle conservation: effects of habitat and resource selection (Coleoptera: Scarabaeoidea). *J. Insect Conserv.* 3:75–84
8. Belshaw R, Bolton B. 1993. The effect of forest disturbance on the leaf litter ant fauna in Ghana. *Biodivers. Conserv.* 2:656–66
9. Beneš V, Kepka P, Konvička M. 2003. Limestone quarries as refuges for European xerophilous butterflies. *Conserv. Biol.* 17:1058–69
10. Bennett AF. 1999. *Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation*. Gland, Switz./Cambridge, UK: IUCN
11. Berggren Å, Birath B, Kindvall O. 2002. Effect of corridors and habitat edges on dispersal behavior, movement rates, and movement angles in Roesel's bush-cricket (*Metrioptera roeseli*). *Conserv. Biol.* 16:1562–69
12. Betzholtz PE. 2002. Population structure and movement patterns within an isolated and endangered population of the moth *Dysauxes ancilla* L. (Lepidoptera: Ctenuchidae): implications for conservation. *J. Insect Conserv.* 6:57–66
13. Biedermann R. 2000. Metapopulation dynamics of the froghopper *Neopilaenus albipennis* (F., 1798) (Homoptera, Cercopidae)—What is the minimum viable population size? *J. Insect Conserv.* 4:99–107
14. Boettner GH, Elkinton JS, Boettner CJ. 2000. Effects of a biological control introduction on three nontarget native species of saturniid moth. *Conserv. Biol.* 14:1798–806
15. Braker E. 1991. Natural history of a neotropical gap-inhabiting grasshopper. *Biotropica* 23:41–50
16. Brändle M, Amarell U, Auge H, Klotz S, Brandl R. 2001. Plant and insect diversity along a pollution gradient: understanding species richness across trophic levels. *Biodivers. Conserv.* 10:1497–511
17. Brühl CA, Eltz T, Linsenmair EK. 2003. Effect of tropical rainforest fragmentation on the leaf litter ant community in Sabah, Malaysia. *Biodivers. Conserv.* 12:1371–89
18. Bullock WL, Samways MJ. 2005. Conservation of flower-arthropod associations in remnant African grassland corridors in an afforested pine mosaic. *Biodivers. Conserv.* 14:3093–103
19. Buse A, Good JE. 1996. Synchronization of larvae emergence in winter moth (*Operophtera brumata* L.) and budburst in pedunculate oak (*Quercus robur* L.) under simulated climate change. *Ecol. Entomol.* 21:335–43
20. Butterfield J. 1997. Carabid community succession during the forestry cycle in conifer plantations. *Ecography* 20:614–25
21. Cagnolo L, Molina SI, Valladares GR. 2002. Diversity and guild structure of insect assemblages under grazing and exclusion regimes in a montane grassland from central Argentina. *Biodivers. Conserv.* 11:407–20
22. Cartagena MC, Galante E. 2002. Loss of Iberian tenebrionid beetles and conservation management recommendations. *J. Insect Conserv.* 6:73–81
23. Castaño-Meneses G, Palacios-Vargas JG. 2003. Effects of fire and agricultural practices on neotropical ant communities. *Biodivers. Conserv.* 12:1913–19
24. Chardon JP, Adriaensen F, Matthysen E. 2003. Incorporating landscape elements into a connectivity measure: a case study for the speckled wood butterfly (*Parange aegeria* L.). *Landsc. Ecol.* 18:561–73
25. Cilgi T, Jepson P. 1995. Pesticide spray drift into field boundaries and hedgerows: toxicity to nontarget Lepidoptera. *J. Environ. Pollut.* 87:1–9

26. Clarke RT, Thomas JA, Elmes GW, Hochberg ME. 1997. The effects of spatial patterns in habitat quality on community dynamics within a site. *Proc. R. Soc. London B* 264:347–54
27. Clausnitzer V. 2003. Dragonfly communities in coastal habitats of Kenya: indication of biotope quality and the need for conservation measures. *Biodivers. Conserv*. 12:333–56
28. Clavero M, García-Berthou E. 2005. Invasive species are a leading cause of animal extinctions. *Trends Ecol. Evol*. 20:110
29. Clout MN. 1999. Biodiversity conservation and the management of invasive animals in New Zealand. In *Invasive Species and Biodiversity Management*, ed. OT Sandlund, PJ Schei, Å Viken, pp. 349–61. Dordrecht: Kluwer
30. Collins NM, Smith HM. 1995. Threats and priorities concerning swallowtail butterflies. In *Swallowtail Butterflies: Their Ecology and Evolutionary Biology*, ed. JM Scriber, Y Tsubaki, RC Lederhouse, pp. 345–57. Gainesville, FL: Scientific Publ.
31. Conrad KF, Woiwod IP, Parsons M, Fox R, Warren MS. 2004. Long-term population trends in widespread British moths. *J. Insect Conserv*. 8:119–36
32. Conradt L, Bodsworth EJ, Roper TJ, Thomas C. 2000. Nonrandom dispersal in the butterfly *Maniola jurtina*: implications for metapopulation model. *Proc. R. Soc. London B* 267:1505–10
33. Cook JL. 2003. Conservation of biodiversity in an area impacted by the red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae). *Biodivers. Conserv*. 12:187–95
34. Coope GR. 1995. Insect faunas in ice age environments: Why so little extinction? In *Extinction Rates*, ed. JH Lawton, RM May, pp. 55–74. Oxford, UK: Oxford Univ. Press
35. Cremene C, Groza G, Rakosy L, Schileyko AA, Baur A, et al. 2005. Alterations of steppe-like grasslands in eastern Europe: a threat to regional biodiversity hotspots. *Conserv. Biol*. 19:1606–18
36. Culver DC, Christman MC, Elliott WR, Hobbs HH III, Reddell JR. 2003. The North American obligate cave fauna: regional patterns. *Biodivers. Conserv*. 12:411–22
37. Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, et al. 2001. Climate change and forest disturbances. *BioScience* 51:723–34
38. Dauber J, Wolters V. 2004. Edge effects on ant community structure and species richness in an agricultural landscape. *Biodivers. Conserv*. 13:901–15
39. Davies KF, Melbourne BA, Margules CR. 2001. Effects of within- and between-patch processes on beetle-community dynamics in experimentally fragmented forest. *Ecology* 82:1830–46
40. Davis AJ, Jenkinson LS, Lawton JH, Shorrocks B, Wood S. 1995. Global warming, population dynamics and community structure in a model insect assemblage. In *Insects in a Changing Environment*, ed. R Harrington, NE Stork, pp. 431–39. London: Academic
41. Davis AJ, Sutton SL. 1998. The effects of rainforest canopy loss on arboreal dung beetles in Borneo: implications for the measurement of biodiversity in derived tropical ecosystems. *Divers. Distrib*. 4:167–73
42. De Moor FC. 1994. Aspects of the life history of *Simulium chutteri* and *S. bovis* (Diptera; Simuliidae) in relation to changing environmental conditions in South African rivers. *Verhand. Int. Verein. Theor. Ang. Limn*. 25:1817–21
43. Dennis R. 1993. *Butterflies and Climate Change*. Manchester, UK: Manchester Univ. Press
44. Dennis RHL, Eales HT. 1997. Patch occupancy in *Coenonympha tullia* (Müller, 1764) (Lepidoptera: Satyridae): Habitat quality matters as much as patch size. *J. Insect Conserv*. 1:167–76

45. Didham RK, Lawton JH, Hammond PM, Eggleton P. 1989. Trophic structure stability and extinction dynamics of beetles (Coleoptera) in tropical forest fragments. *Philos. Trans. R. Soc. London B* 353:437–51
46. Dolek M, Geyer A. 1997. Influence of management on butterflies or rare grassland ecosystems in Germany. *J. Insect Conserv.* 1:125–30
47. Dover JW. 1997. Conservation headlands: effects on butterfly distribution and behavior. *Agric. Ecosyst. Environ.* 63:31–49
48. Dover JW, Sparks TH, Greatorex-Davis JN. 1997. The importance of shelter for butterflies in open landscapes. *J. Insect Conserv.* 1:89–97
49. Driscoll DA, Weir T. 2005. Beetle responses to habitat fragmentation depend on ecological traits, habitat condition, and remnant size. *Conserv. Biol.* 19:182–94
50. Dunn RR. 2005. Modern insect extinctions, the neglected majority. *Conserv. Biol.* 19:1030–36
51. Eggleton P, Bignell DE, Sands WA, Mawdsley NA, Lawton JH, et al. 1996. The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. *Philos. Trans. R. Soc. London B* 351:51–68
52. Elgar MA, Clode D. 2001. Inbreeding and extinction in island populations: a cautionary note. *Conserv. Biol.* 15:284–86
53. Elligsen H, Beinlich B, Plachter H. 1997. Effects of large-scale cattle grazing on populations of *Coenonympha glycerion* and *Lesiommata megera* (Lepidoptera: Satyridae). *J. Insect Conserv.* 1:13–23
54. Englund RA. 1999. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on Oahu island, Hawaii. *J. Insect Conserv.* 3:225–43
55. **Erwin TL. 1991. An evolutionary basis for conservation strategies. *Science* 253:750–52**
56. Feber RE, Smith M. 1995. Butterfly conservation on arable farmland. In *Ecology and Conservation of Butterflies*, ed. AS Pullin, pp. 84–97. London: Chapman & Hall
57. Feber RE, Smith M, Macdonald DW. 1996. The effects on butterfly abundance of the management of uncropped edges of arable fields. *J. Appl. Ecol.* 33:1191–205
58. Fermon H, Waltert M, Larsen TB, Dall'Asta U, Mühlenber M. 2000. Effects of forest management on diversity and abundance of fruit-feeding nymphalid butterflies in south-eastern Côte d'Ivoire. *J. Insect Conserv.* 4:173–89
59. Fermon H, Waltert M, Vane-Wright RI, Mühlenberg M. 2005. Forest use and vertical stratification in fruit-feeding butterflies of Sulawesi, Indonesia: impacts for conservation. *Biodivers. Conserv.* 14:333–50
60. Field RG, Gardiner T, Mason CF, Hill J. 2005. Agri-environment schemes and butterflies: the utilization of 6 m grass margins. *Biodivers. Conserv.* 14:1969–76
61. Fowles AP, Bailey MP, Hale AD. 2004. Trends in the recovery of a rosy marsh moth *Coenophila subrosea* (Lepidoptera, Noctuidae) population in response to fire and conservation management on a lowland raised mire. *J. Insect Conserv.* 8:149–58
62. Fry R, Lonsdale D. 1991. *Habitat Conservation for Insects: A Neglected Green Issue*. Middlesex, UK: Amateur Entomol. Soc.
63. Gagné WC, Howarth FG. 1985. Conservation status of endemic Hawaiian Lepidoptera. *Proc. Third Congr. Eur. Lepidop. Cambridge 1982*, pp. 74–84
64. Gebeyehu S, Samways MJ. 2002. Grasshopper response to a restored national park (Mountain Zebra National Park, South Africa). *Biodivers. Conserv.* 11:283–304
65. Gebeyehu S, Samways MJ. 2003. Responses of grasshopper assemblages to long-term grazing management in a semiarid African savanna. *Agric. Ecosyst. Environ.* 95:613–22

55. A significant paper emphasizing that we need to consider long-term, evolutionary conservation as well as short-term, ecological goals.

66. Gehring CA, Cobb NS, Whitham TG. 1997. Three-way interactions among ectomycorrhizal mutualists, scale insects and resistant and susceptible pinyon pines. *Am. Nat.* 149:824–41
67. Gerlach J, Matyot P, Samways MJ. 2005. Developing strategies for invertebrate conservation: the case for the Seychelles. *Phelsuma* 13:9–24
68. Girling MA. 1982. Fossil insect faunas from forest sites. In *Archaeological Aspects of Woodland Ecology: Symposia of the Association for Environmental Archaeology*, ed. M Bell, S Limbrey, No. 2, BAR Int. Ser. 146, pp. 129–46. Oxford, UK: John and Erica Hedges Ltd.
69. Greatorex-Davis JN, Sparks TH, Hall ML. 1994. The response of Heteroptera and Coleoptera species to shade and aspect in rides of coniferied lowland. *Biol. Conserv.* 12:1099–111
70. Groenendijk D, Van der Meulen J. 2004. Conservation of moths in the Netherlands: population trends, distribution patterns and monitoring techniques of day-flying moths *J. Insect Conserv.* 8:109–18
71. Haddad N. 1999. Corridor and distance effects on interpatch movements: a landscape experiment with butterflies. *Ecol. Appl.* 9:612–22
72. Hamer KC, Hill JK, Benedick S, Mustaffa N, Sherratt TN, et al. 2003. Ecology of butterflies in natural and selectively logged forests of northern Borneo: the importance of habitat heterogeneity. *J. Appl. Ecol.* 40:150–62
73. Hannah L, Carr JL, Lankerani A. 1995. Human disturbance and natural habitat: a biome level analysis of a global data set. *Biodivers. Conserv.* 4:128–55
74. Harrington R, Bale JS, Tatchell GM. 1995. Aphids in a changing climate. In *Insects in a Changing Climate*, ed. R Harrington, NE Stork, pp. 125–55. London: Academic
75. Hartley SE, Gardner SM, Mitchell RJ. 2003. Indirect effects of grazing and nutrient addition on the hemipteran community of heather moorlands. *J. Appl. Ecol.* 40:793–803
76. Herbert PDN, Penton EH, Burns JM, Janzen DH, Hallwachs W. 2004. Ten species in one: DNA barcoding reveals cryptic species in the neotropical skipper butterfly *Astraptes fulgerator*. *Proc. Natl. Acad. Sci. USA* 101:14812–17
77. Hess GR, Fischer RA. 2001. Communicating clearly about conservation corridors. *Landsc. Urban Plan.* 55:195–208
78. Hewitt G. 2000. The genetic legacy of the Quaternary ice ages. *Nature* 405:907–13
79. Hight SD, Carpenter JE, Bloem S, Pemberton RW, Stiling P. 2002. Expanding geographical range of *Cactoblastis cactorum* (Lepidoptera: Pyralidae) in North America. *Fla. Entomol.* 85:527–29
80. Hill JK, Hamer KC, Lace LA, Banham WMT. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. *J. Appl. Ecol.* 32:754–60
81. Hill JK, Thomas CD, Fox R, Telfer MG, Willis SG, et al. 2002. Responses of butterflies to twentieth century climate warming: implications for future ranges. *Proc. R. Soc. London B* 269:2163–71
82. Hill JK, Thomas CD, Lewis OT. 1996. Effects of habitat patch size and isolation on dispersal by *Hesperia comma* butterflies: implications for metapopulation structure. *J. Anim. Ecol.* 65:725–35
83. Holloway JD, Kirk-Spriggs AH, Khen CV. 1992. The response of some rain forest insect groups to logging and conversion to plantation. *Philos. Trans. R. Soc. London B* 335:425–36
84. Holway DA, Lach L, Suarez AV, Tsutsui ND, Case TJ. 2002. The causes and consequences of ant invasions. *Annu. Rev. Ecol. Syst.* 33:181–233
85. Horner-Divine MC, Daily GC, Ehrlich PR, Boggs CL. 2003. Countryside biogeography of tropical butterflies. *Conserv. Biol.* 17:168–77

86. Howarth FG. 1987. The evaluation of nonrelictual tropical troglobites. *Int. J. Speleol.* 16:1–16
87. Howarth FG. 1991. Environmental impact of classical biological control. *Annu. Rev. Entomol.* 36:485–509
88. Howarth FG, Ramsay GW. 1991. The conservation of island insects and their habitats. In *The Conservation of Insects and Their Habitats*, ed. NM Collins, JA Thomas, pp. 71–107. London: Academic
89. Ingham DS, Samways MJ. 1996. Application of fragmentation and variegation models to epigaeic invertebrates in South Africa. *Conserv. Biol.* 10:1353–58
90. Johannesen J, Samietz J, Wallaschek M, Seitz A, Veith M. 1999. Patch connectivity and genetic variation in two congeneric grasshopper species with different habitat preferences. *J. Insect Conserv.* 3:201–9
91. Jones AG, Chown SL, Gaston KJ. 2002. Terrestrial invertebrates of Gough Island: an assemblage under threat? *Afr. Entomol.* 10:83–91
92. Jones DT, Susilo FX, Bignell DE, Hardiwinoto S, Gillison AN, Eggleton P. 2003. Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *J. Appl. Ecol.* 40:380–91
93. Joy J. 1997. *Bracken management for fritillary butterflies in the West Midlands and Gloucestershire region*. *Occas. Pap. No. 8*. Colchester, UK: Butterfly Conserv.
94. Julião GR, Amaral MEC, Fernandes GW, Oliveira EG. 2004. Edge effect and species-area relationship in the gall-forming insect fauna of natural forest patches in the Brazilian Pantanal. *Biodivers. Conserv.* 13:2055–66
95. Kells AR, Goulson D. 2003. Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. *Biol. Conserv.* 109:165–74
96. Kindvall O. 1995. The impact of extreme weather on habitat preference and survival in a metapopulation of the bush cricket *Metrioptera bicolor* in Sweden. *Biol. Conserv.* 73:51–58
97. Kindvall O, Ahlén I. 1992. Geometrical factors and metapopulation dynamics of the bush cricket, *Metrioptera bicolor* Philippi (Orthoptera: Tettigoniidae). *Conserv. Biol.* 6:520–29
98. Kirby P. 1992. *Habitat Management for Invertebrates: A Practical Handbook*. Sandy, Bedfordshire, UK: R. Soc. Prot. Birds

98. An inspiring handbook on how to take positive steps for insect conservation.

99. Koh LP, Sodhi NS, Brook BW. 2004. Ecological correlates of extinction proneness in tropical butterflies. *Conserv. Biol.* 18:1571–78
100. Koivula M, Kukkanen J, Niemelä J. 2002. Boreal carabid-beetle (Coleoptera, Carabidae) assemblages along clear-cut originated succession gradient. *Biodivers. Conserv.* 11:1269–88
101. Kotze DJ, Samways MJ. 1999. Support for the multi-taxa approach in biodiversity assessment, as was shown by epigaeic invertebrate assemblages in an Afromontane forest archipelago. *J. Insect Conserv.* 3:125–43
102. Kruess A, Tscharntke T. 2002. Grazing intensity and the diversity of grasshoppers, butterflies and trap-nesting bees and wasps. *Conserv. Biol.* 16:1570–80
103. Kuchlein JH, Ellis WN. 1997. Climate-induced changes in microlepidoptera fauna of the Netherlands and implications for nature conservation. *J. Insect. Conserv.* 1:73–80

103. A significant paper that emphasizes the risks of spatially fixed reserves and of Red Listing under a dynamic situation of climate change.

104. Kuussaari M, Nieminen M, Hanski I. 1996. An experimental study of migration in the Glanville fritillary butterfly *Melitea cinxia*. *J. Anim. Ecol.* 65:791–801
105. Labandeira CC, Johnson KR, Wilf P. 2002. Impact of the terminal Cretaceous event on plant-insect associations. *Proc. Natl. Acad. Sci. USA* 99:2061–66
106. Labandeira CC, Sepkoski JJ Jr. 1993. Insect diversity and the fossil record. *Science* 261:310–15

107. Lawton JH, Bignell DE, Bolton B, Bloemers GF, Eggleton P, et al. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in a tropical forest. *Nature* 391:72–76
108. Léon-Cortes JL, Cowley MJR, Thomas CD. 2000. The distribution and decline of a widespread butterfly *Lycaena phlaeas* in a pastoral landscape. *Ecol. Entomol*. 25:285–94
109. Lewinsohn TM, Freitas AVL, Prado PI. 2005. Conservation of terrestrial invertebrates and their habitats in Brazil. *Conserv. Biol*. 19:640–45
110. Lien VV, Yuan D. 2003. The differences of butterfly (Lepidoptera, Papilionidae) communities in habitats with various degrees of disturbance and altitudes in tropical forests of Vietnam. *Biodivers. Conserv*. 12:1099–111
111. Lockwood JA, DeBrey LD. 1990. A solution for the sudden and unexplained extinction of the Rocky Mountain grasshopper (Orthoptera: Acrididae). *Environ. Entomol*. 19:1194–205
112. Lockwood JA, Howarth FG, Purcell MF, eds. 2001. *Balancing Nature: Assessing the Impact of Importing Non-Native Biological Control Agents (An International Perspective)*. Lanham, MD: ESA
113. Losey JE, Rayor LS, Carter ME. 1999. Transgenic pollen harms monarch larvae. *Nature* 399:214
114. Lövei GL, Cartellieri M. 2000. Ground beetles (Coleoptera, Carabidae) in forest fragments of the Manawatu, New Zealand: collapsed assemblages? *J. Insect Conserv*. 4:239–44
115. Mader HJ. 1984. Animal habitat isolation by roads and agricultural fields. *Biol. Conserv*. 29:81–96
116. Maeto K, Sato S, Miyata H. 2002. Species diversity of longicorn beetles in humid warm-temperate forests: the impact of forest management practices on old-growth forest species in southwest Japan. *Biodivers. Conserv*. 11:1919–37
117. Magura T, Ködöböcz V, Tóthmérész B. 2001. Effects of habitat fragmentation on carabids in forest patches. *J. Biogeogr*. 28:129–38
118. Magura T, Tóthmérész B, Elek Z. 2005. Impacts of leaf-litter addition on carabids in a conifer plantation. *Biodivers. Conserv*. 14:475–91
119. Mattison EHA, Norris K. 2005. Bridging the gaps between agricultural policy, land-use and biodiversity. *Trends Ecol. Evol*. 20:610–16
120. Mawdsley NA, Stork NE. 1995. Species extinctions in insects: ecological and biogeographical considerations. In *Insects in a Changing Environment*, ed. R Harrington, NE Stork, pp. 321–69. London: Academic
121. McKenna DD, McKenna KM, Malcolm SB, Berenbaum MR. 2001. Mortality of Lepidoptera along roadways in central Illinois. *J. Lepidop. Soc*. 55:63–68
122. McKinney ML. 1999. High rates of extinction and threat in poorly studied taxa. *Conserv. Biol*. 13:1273–81
123. Miller JC. 1990. Field assessment of the effects of a microbial pest control agent on nontarget Lepidoptera. *Am. Entomol*. 36:135–39
124. Mönkkönen M, Mutanen M. 2003. Occurrence of moths in boreal forest corridors. *Conserv. Biol*. 17:468–75
125. Morris MG. 1981. Responses of grassland invertebrates to management by cutting. IV. Positive responses of Auchenorrhyncha. *J. Appl. Ecol*. 18:763–71
126. Morris MG. 1991. The management of reserves and protected areas. In *The Scientific Management of Temperate Communities for Conservation*, ed. IF Spellerberg, FB Goldsmith, MG Morris, pp. 323–47. Oxford, UK: Blackwell Sci.
127. Mullen K, Fahy O, Gormally M. 2003. Ground flora and associated arthropod communities of forest road edges in Connemara, Ireland. *Biodivers. Conserv.* 12:87–101

128. Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403:853–58
129. National Research Council. 1999. *Our Common Journey: A Transition Toward Sustainability*. Washington, DC: Natl. Acad. Press
130. Néve G, Barascud B, Hughes R, Aubert J, Descimon H, et al. 1996. Dispersal, colonization power and metapopulation structure in a vulnerable butterfly *Proclossiana eunomia* (Lepidoptera: Nymphalidae). *J. Appl. Ecol.* 33:14–22
131. New TR. 1997. *Butterfly Conservation*. Melbourne: Oxford Univ. Press. 2nd ed.
132. New TR. 2005. *Invertebrate Conservation and Agricultural Systems*. Cambridge, UK: Cambridge Univ. Press
133. Niemelä J. 1997. Invertebrates and boreal forest management. *Conserv. Biol.* 11:601–10
134. Nieminen M, Nuorteva P, Tulisalo E. 2001. The effect of metals on the mortality of *Parnassius apollo* larvae (Lepidoptera: Papilionidae). *J. Insect Conserv.* 5:1–7
135. Ortman EE, Barry BD, Bushman LL, Calvin DD, Carpenter J, et al. 2001. Transgenic insecticidal corn: the agronomic and economic rationale for its use. *BioScience* 51:900–3
136. Pagel M, Payne RJH. 1996. How migration affects estimation of the extinction threshold. *Oikos* 76:323–29
137. Panzer R. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conserv. Biol.* 16:1296–307
138. Panzer R. 2003. Importance of in situ survival, recolonization, and habitat gaps in the postfire recovery of fire-sensitive prairie insect species. *Nat. Areas J.* 23:14–21
139. Panzer R, Gnaedinger R, Derkovitz G, Stillwaugh D. 1995. Prevalence of remnant-dependence among the prairie and savanna-inhabiting insects of the Chicago region. *Nat. Areas J.* 15:101–16
140. Panzer R, Schwartz MW. 1998. Effectiveness of a vegetation-based approach to insect conservation. *Conserv. Biol.* 12:693–702
141. Paquin P, Coderre D. 1997. Changes in soil macroarthropod communities in relation to forest maturation through three successional stages in the Canadian boreal forest. *Oecologia* 112:104–11
142. Parmesan C. 1996. Climate and species' range. *Nature* 382:765–66
143. Parmesan C, Ryrholm N, Stefanescy C, Hill JK, Thomas CD, et al. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature* 399:579–83
144. Patrick BH. 2004. Conservation of New Zealand's tussock grassland moth fauna. *J. Insect Conserv.* 8:199–208
145. Ponel P, Orgeas J, Samways MJ, Andrieu-Ponel V, Beaulieu LD, et al. 2003. 110,000 years of Quaternary beetle diversity change. *Biodivers. Conserv.* 12:2077–89
146. Prendergast JR, Quinn RM, Lawton JH, Eversham BC, Gibbons DW. 1993. Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* 365:335–37
147. Pressey RL, Humphries CJ, Margules CR, Vane-Wright RI, Williams PH. 1993. Beyond opportunism: key principles for systematic reserve selection. *Trends Ecol. Evol.* 8:124–28
148. Priddel D, Carlile N, Humphrey M, Fellenberg S, Hiscox D. 2003. Rediscovery of the 'extinct' Lord Howe Island stick insect (*Dryocoelus australis* Montrouzier) (Phasmatodea) and recommendations for its conservation. *Biodivers. Conserv.* 12:1391–403
149. Pryke SR, Samways MJ. 2001. Width of grassland linkages for the conservation of butterflies in South African afforested areas. *Biol. Conserv.* 101:85–96

128. Insects were not included in this significant study on global biodiversity hotspots, challenging insect conservation biologists.

132. A recent synthesis of the conservation of insects and some other organisms in the agricultural context.

150. Pryke SR, Samways MJ. 2003. Quality of remnant indigenous grassland linkages for adult butterflies (Lepidoptera) in an afforested African landscape. *Biodivers. Conserv*. 12:1985–2004
151. Purse BV, Hopkins GW, Day KJ, Thompson DJ. 2003. Dispersal characteristics and management of a rare damselfly. *J. Appl. Ecol*. 40:716–28
152. Reemer M. 2005. Saproxylic hoverflies benefit by modern forest management (Diptera: Syrphidae). *J. Insect Conserv*. 9:49–59
153. Reyers B, Wessels KJ, Van Jaarsveld AS. 2002. An assessment of biodiversity surrogacy options in the Limpopo Province of South Africa. *Afr. Zool*. 37:185–95
154. Ricklefs RE. 2004. A comprehensive framework for global patterns in diversity. *Ecol. Lett*. 7:1–15
155. Rivers-Moore NA, Samways MJ. 1996. Game and cattle trampling, and impacts of human dwellings on arthropods at a game park boundary. *Biodivers. Conserv*. 5:1545–56
156. Rosenberg DK, Noon BR, Meslow EC. 1997. Biological corridors: form, function, and efficacy. *BioScience* 47:677–87
157. Roy DB, Sparks TH. 2000. Phenology of British butterflies and climate change. *Glob. Chang. Biol*. 6:407–16
158. Ryder C, Moran J, McDonnell R, Gormally M. 2005. Conservation implications of grazing practices on the plant and dipteran communities of a turlough in Co. Mayo, Ireland. *Biodivers. Conserv*. 14:187–204
159. Sahlén G, Ekestubbe K. 2001. Identification of dragonflies (Odonata) as indicators of general species richness in boreal forest lakes. *Biodivers. Conserv*. 10:673–90
160. Samways MJ. 1997. Classical biological control and biodiversity: What risks are we prepared to accept? *Biodivers. Conserv*. 6:1309–16
161. Samways MJ. 1998. Insect population changes and conservation in the disturbed landscapes of Mediterranean-type ecosystems. In *Landscape Disturbance and Biodiversity in Mediterranean-Type Ecosystems*, ed. PW Rundel, G Montenegro, FM Jaksic, pp. 313–31. Berlin: Springer
162. Samways MJ. 2000. A conceptual model of ecosystem restoration triage based on experiences from three remote oceanic islands. *Biodivers. Conserv*. 9:1073–83
163. Samways MJ. 2003. Threats to the tropical island dragonfly fauna (Odonata) of Mayotte, Comoro archipelago. *Biodivers. Conserv*. 12:1785–92
164. Samways MJ. 2005. *Insect Diversity Conservation*. Cambridge, UK: Cambridge Univ. Press

164. A recent synthesis of the field of insect conservation biology.

165. Samways MJ. 2006. Insect extinctions and insect survival. *Conserv. Biol*. 20:245–46
166. Samways MJ, Kreuzinger K. 2001. Vegetation, ungulate and grasshopper interactions inside vs outside an African savanna game park. *Biodivers. Conserv*. 10:1963–81
166a. Samways MJ, Moore SD. 1991. Influence of exotic conifer patches on grasshopper (Orthoptera) assemblages in a grassland matrix at a recreational resort, Natal, South Africa. *Biol. Conserv*. 57:205–19
167. Samways MJ, Osborn R, Carliel F. 1997. Effect of a highway on ant (Hymenoptera: Formicidae) species composition and abundance, with special recommendation for roadside verge width. *Biodivers. Conserv*. 6:903–13
168. Samways MJ, Osborn R, Hastings H, Hattingh V. 1999. Global climate change and accuracy of prediction of species geographical ranges: establishment success of ladybirds (Coccinellidae, *Chilocorus* spp.) worldwide. *J. Biogeogr*. 26:795–812
169. Samways MJ, Sergeev MG. 1997. Orthoptera and landscape change. In *The Bionomics of Grasshoppers, Katydis and Their Kin*, ed. SK Gangwere, MC Muralirangan, M Muralirangan, pp. 147–62. Wallingford, UK: CABI

170. Samways MJ, Taylor S. 2004. Impacts of invasive alien plants on red-listed South African dragonflies (Odonata). *S. Afr. J. Sci.* 100:78–80
171. Samways MJ, Taylor S, Tarboton W. 2005. Extinction reprieve following alien removal. *Conserv. Biol.* 19:1329–30
172. Schultz CB, Crone EE. 2005. Patch size and connectivity thresholds for butterfly habitat restoration. *Conserv. Biol.* 19:887–96
173. Sharratt N, Picker MD, Samways MJ. 2000. The invertebrate fauna of the sandstone caves of the Cape Peninsula (South Africa): patterns of endemism and conservation priorities. *Biodivers. Conserv.* 9:107–43
174. Smith VR, Avenant NL, Chown SL. 2002. The diet and impact of house mice on a sub-Antarctic island. *Polar Biol.* 25:703–15
175. Sodhi NS, Koh LP, Brook BW, Ng PKL. 2004. Southeast Asia biodiversity: an impending disaster. *Trends Ecol. Evol.* 19:654–60
176. Sparks TH, Yates TJ. 1997. The effect of spring temperature on the appearance dates of British butterflies 1883–1993. *Ecography* 20:368–74
177. Spector S. 2002. Biogeographic crossroads as priority areas for biodiversity conservation. *Conserv. Biol.* 16:1480–87
178. Spence JR, Langor DW, Hammond HEJ, Pohl GR. 1997. Beetle abundance and diversity in a boreal mixed-wood forest. In *Forests and Insects*, ed. AD Watt, NE Stork, MD Hunter, pp. 287–301. London: Chapman & Hall
179. Spitzer K, Jaros J, Havelka J, Leps J. 1997. Effect of small-scale disturbance on butterfly communities of an Indo-Chinese montane rainforest. *Biol. Conserv.* 80:9–15
180. Steffan-Dewenter I, Leschke K. 2003. Effects of habitat management on vegetation and above-ground nesting bees and wasps of orchard meadow in Central Europe. *Biodivers. Conserv.* 12:1953–68
181. Steffan-Dewenter I, Tscharntke T. 1997. Early succession of butterfly and plant communities on set-aside fields. *Oecologia* 109:294–302
182. Stewart DAB, Samways MJ. 1998. Conserving dragonfly (Odonata) assemblages relative to river dynamics in a major African savanna game reserve. *Conserv. Biol.* 12:683–92
183. Steytler NS, Samways MJ. 1995. Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. *Biol. Conserv.* 72:381–86
184. Sutcliffe OT, Bakkestuen V, Fry G, Stabbetorp OE. 2003. Modeling the benefits of farmland restoration: methodology and application to butterfly movement. *Landsc. Urban Plan.* 63:15–31
185. Sutcliffe OL, Thomas CD. 1996. Open corridors appear to facilitate dispersal of ringlet butterflies (*Aphantopus hyperantus*) between woodland clearings. *Conserv. Biol.* 10:1359–65
186. Sutcliffe OL, Thomas CD, Peggie D. 1997. Area-dependent migration by ringlet butterflies generate a mixture of patchy population and metapopulation attributes. *Oecologia* 109:229–34
187. Sutcliffe OL, Thomas CD, Yates TJ, Greatorex-Davis JN. 1997. Correlated extinctions, colonization and population fluctuation in a highly connected ringlet butterfly metapopulation. *Oecologia* 109:235–41
188. Swengel AB. 1998. Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biol. Conserv.* 83:77–89
189. Swengel AB. 2001. Effects of prairie and barrens management on butterfly faunal composition. *Biodivers. Conserv.* 10:1757–85

190. Swengel AB, Swengel SR. 1997. Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. *J. Insect Conserv.* 1:131–44
191. Thomas CD. 2000. Dispersal and extinction in fragmented landscapes. *Proc. R. Soc. London B* 267:139–45
192. Thomas CD, Bodsworth EJ, Wilson RJ, Simmons AD, Davies ZG, et al. 2001. Ecological and evolutionary processes at expanding range margins. *Nature* 411:577–81
193. Thomas JA, Bourn NAD, Clarke RT, Whitfield KE, Simcox DJ, et al. 2001. The quality and isolation of habitat patches both determine where butterflies persist in fragmented landscapes. *Proc. R. Soc. London B* 268:1791–96
194. Thomas JA, Clarke RT, Elmes GW, Hochberg ME. 1998. Population dynamics in the genus *Maculinea*. In *Insect Population Dynamics: In Theory and Practice*, ed. JP Dempster, IFG McLean, pp. 261–90. London: Chapman & Hall
195. Thomas JA, Telfer MG, Roy DB, Preston CD, Greenwood JJD, et al. 2004. Comparative losses of British butterflies, birds and plants and the global extinction crisis. *Science* 303:1879–81
196. Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, et al. 2001. Forecasting agriculturally driven global environmental change. *Science* 292:281–84
197. Tilman D, May RM, Lehman CL, Nowak MA. 1994. Habitat destruction and the extinction debt. *Nature* 371:65–66
198. Toft RJ, Rees JS. 1998. Reducing predation of orb-web spiders by controlling common wasps (*Vespula vulgaris*) in a New Zealand beech forest. *Ecol. Entomol.* 23:90–95
199. Travis JMJ. 2003. Climate change and habitat destruction: a deadly anthropogenic cocktail. *Proc. R. Soc. London B* 270:467–73
200. Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C. 2002. Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. *Ecol. Appl.* 12:354–63
201. Usher MB. 1986. Wildlife conservation evaluation: attributes, criteria and values. In *Wildlife Conservation Evaluation*, ed. MB Usher, pp. 3–44. London: Chapman & Hall
202. Usher MB, Keiller SWJ. 1998. The macrolepidoptera of farm woodlands: determinants of diversity and community structure. *Biodivers. Conserv.* 7:725–48
203. Van Buskirk J, Willi Y. 2004. Enhancement of farmland biodiversity within set-aside land. *Conserv. Biol.* 18:987–94
204. Vanderwoude C, Andersen AN, House APN. 1997. Community organization, biogeography and seasonality of ants in an open forest of south-eastern Queensland. *Aust. J. Zool.* 45:523–37
205. Verdú JR, Crespo MB, Galante E. 2000. Conservation strategy of a nature reserve in Mediterranean ecosystems: the effects of protection from grazing on biodiversity. *Biodivers. Conserv.* 9:1707–21
206. Vermeulen HJW. 1994. Corridor function of a road verge for dispersal of stenotopic heathland ground beetles Carabidae. *Biol. Conserv.* 69:339–49
207. Wahlberg N, Klemetti T, Selonen V, Hanski I. 2002. Metapopulation structure and movements in five species of checkerspot butterflies. *Oecologia* 130:33–43
208. Wallis de Vries MF. 2004. A quantitative conservation for the endangered butterfly *Maculinea alcon*. *Conserv. Biol.* 18:489–99
209. Warren MS, Hill JK, Thomas JA, Asher J, Fox R, et al. 2001. Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature* 414:65–69

195. A biodiversity appraisal illustrating that insects are possibly under more threat than many other organisms.

197. A salient warning that current set-aside land alone, while in the short-term may have conservation value, may be insufficient to maintain biodiversity at current levels.

199. An important message on the severely adverse effects of synergistic impacts, particularly global climate change and habitat destruction.

209. A significant paper illustrating the devastating effect of combined impacts such as habitat loss and climate change.

210. Watt AD, Whittaker JB, Docherty M, Brooks G, Lindsay E, Salt DT. 1995. The impact of elevated atmospheric CO_2 on insect herbivores. In *Insects in a Changing Environment*, ed. R Harrington, NE Stork, pp.197–217. London: Academic
211. Webb NR. 1989. Studies on the invertebrate fauna of fragmented heathland in Dorset, UK, and the implications for conservation. *Biol. Conserv*. 47:153–65
212. Weibull AC, Östman Ö, Granqvist Å. 2003. Species richness in agroecosystems: the effect of landscape, habitat and farm management. *Biodivers. Conserv*. 12:1335–55
213. Whitehouse A. 2005. Living on the edge: the importance of maritime soft cliffs and slopes for insect conservation. *Antenna* 29:179–85
214. Woiwod IP. 2004. Butterflies and GM doom. *Butterfly* 85:34
215. Wood PA, Samways MJ. 1991. Landscape element pattern and continuity of butterfly flight paths in an ecologically landscaped botanic garden. *Biol. Conserv*. 58:149–66
216. Work TT, McCullough DG, Cavey JF, Komsa R. 2005. Arrival rate of non-indigenous insect species into the United States through foreign trade. *Biol. Invas*. 7:323–32
216a. Wright DJ. 2002. Transgenic crops expressing Bt toxins: status, prospects and resistance. *Antenna* 26:93–94
217. Yen AL. 1987. A preliminary assessment of the correlation between plant, vertebrate and Coleoptera communities in the Victorian mallee. In *The Role of Invertebrates in Conservation and Biological Survey*, ed. JD Majer, pp. 73–88. Perth: Western Aust. Dep. Conserv. Land Manag.
218. Young MR, Barbour DA. 2004. Conserving the new forest burnet moth (*Zygaena viciae* (Denis and Schiffermueller)) in Scotland; responses to grazing reduction and consequent vegetation changes. *J. Insect Conserv*. 8:137–48
219. Zulka KP, Milasowszky N, Lethmayer C. 1997. Spider diversity potential of an ungrazed and a grazed inland salt meadow in the National Park 'Neusiedler See-Seewinkel' (Austria): implications for management (Arachnida: Araneae). *Biodivers. Conserv*. 6:75–88