Beetles in conservation

T.R. New

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Beetles in conservation

Beetles in conservation

T.R. New

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered office: John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell

Library of Congress Cataloguing-in-Publication Data

New, T. R.
Beetles in conservation / T.R. New.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4443-3259-9 (alk. paper) 1. Beetles–Conservation. 2. Beetles–Ecology.
I. Title.
QL573.N49 2010
595.76–dc22
2009038743

ISBN: 978-1-4443-3259-9

A catalogue record for this book is available from the British Library.

Set in 10.5/12pt Classical Garamond by Graphicraft Limited, Hong Kong
Printed and bound in Singapore

1 2010

Contents

Preface

Some years ago I discussed my tentative ideas for a book on beetle conservation with several experienced coleopterists. Eminent coleopterist number 1 gave his initial reaction that 'no one in his right mind would try it'. This encouragement was echoed by eminent coleopterist number 2 in suggesting that the subject was just too vast for anyone to tackle properly, so that any author's credibility might be placed seriously at stake. As Zimmerman (1994) put it, at the commencement to volume I of *Australian Weevils*, 'Those who know most about this subject know best how little they know'. As a non-coleopterist, I recognize very clearly the dangers of a little knowledge, but during several decades of interest in insect conservation I have gained some general appreciation of the importance of beetles in the natural world, and of conserving them and the systems they help to sustain. I have become aware of some of the many ways in which knowledge of beetle ecology and population management has contributed significantly to wider conservation progress and interest. However, with a lifetime passed among the 'little folks' of entomology, I do not aspire to join the men of Oliver Wendell Holmes' essay[1], although I recall thinking the comparison a little unfair when I came across it first (in Walsh & Dibb 1954) as a young teenager. However, from this vantage point, and *mens sana* or no, such a synthesis or overview appears worthwhile, if for no other reasons than to challenge conservation-oriented coleopterists to refine, correct and expand on the perspective presented here, and to acknowledge and emphasize the important place of Coleoptera in the wider scenarios of insect conservation as this science matures.

Interest in beetles extends for well over two centuries, and has spawned a vast and daunting literature on these insects, collectively addressing many aspects of their identification and biology. In recent years, printed material has

[1] 'These Lepidoptera are for children to play with, pretty to look at, so some think. Give me the Coleoptera, and the kings of the Coleoptera are the beetles! Lepidoptera and Neuroptera for little folks; Coleoptera for men, sir!' Oliver Wendell Holmes (1872) *The Poet at the Breakfast Table*. Walter Scott: London.

been augmented enormously by web-based information and comment, so that entering the name of any major beetle group into a recognized search engine is likely to generate hundreds to hundreds of thousands of responses. Refinement of search terms yields much of conservation interest, not least through facilitating access to unpublished reports and other forms of ‘grey’ literature. Devotees of any particular beetle group are likely to be served by specialist newsletters and, in some cases, journals as important foci for their interests. A number of more generalized Coleoptera journals occur, some as organs for society or specialist groups. The literature on pest Coleoptera is also enormous, with their management commonly a major economic need. The collector interests so important in fostering conservation awareness for insects are increasingly catered for by series of handbooks (such as Cooter & Barclay 2006, for Britain) or identification guides to more popular families, particularly of larger beetles. The increasing availability and use of colour to illustrate many of these is evident in many publishers’ and dealers’ catalogues of modern books, with a correspondingly deep pocket needed to purchase many of these volumes. Many, indeed, seem priced to ensure that their distribution is restricted to wealthier institutional libraries but, significantly, also that they are unlikely to reach important potential user groups in less-developed parts of the world. However, whilst books on beetles abound, few focus specifically on beetle conservation or their importance in natural ecosystems. Many accounts allude to scarcity or rarity of particular species or more generally mention threats to beetles, but a very high proportion of major works expressing concern about the well-being of beetles do this simply as an apparent afterthought rather than a primary message or purpose. Likewise, the journal literature on beetle conservation is very widely dispersed. A recent special issue of *Journal of Insect Conservation* (2007) focused on beetles and conservation.

Nevertheless, over the last few decades in particular, a considerable variety of beetle species have appeared on conservation agendas, for a wide array of reasons. Some are listed formally among endangered or threatened species compilations, with such concerns arising from habitat changes, implications of over-exploitation by collectors or traders, and numerous other manifestations of human activity that render them increasingly vulnerable. Understanding conservation need draws on the massive amount of knowledge on how beetles work, much of this emanating from studies on pest species or beneficial species, such as predators of crop pests. In this book, I have tried to bring together some of the information on relationships between beetles and their environments, and to exemplify the roles of beetles as individual targets for conservation, and as broad ecological tools of massive value in helping to assess environmental quality and change.

I cannot claim to have read more than a small fraction of the voluminous literature on beetles, to which I allude above, but have tried to digest a reasonable selection of the papers and essays (published up to late 2008) in which appraisal and management for conservation has been discussed. The first chapter is a broad introduction to beetle conservation, diversity and ecology, illustrating many of the major advantages and disadvantages in employing such a vast and varied group, and how beetles may be incorporated constructively into conservation theory and practice. Chapter 2 outlines some of the main approaches, and how beetles may be studied and appraised for conservation. Threat evaluation is a paramount theme, whether to individual species, assemblages or wider habitats, and the most universal of these devolves on changes to places and resources, broadly ‘habitats’, and understanding how those changes affect the occupants or users. Studies of the responses of beetles to environmental changes have contributed substantially to this understanding, in ways that can be extrapolated easily to concerns for many other invertebrates. Background to the suite of themes involved is included in Chapter 3. The later chapters are shorter. Chapters 4–6 exemplify the variety of other threats, one or more of which may become important, predictably or unexpectedly, and perhaps exacerbate effects of habitat change on other species. One major threat with severe implications, climate change, is both inevitable and at this stage largely imponderable in detail, but emphasizes the need for a long-term view in insect conservation programmes. The tactics available for conservation management include establishment of new populations, through a variety of *ex situ* techniques which are discussed in Chapter 7. Parameters of habitat and resource management are numerous but, as indicated in Chapter 8, there may be a very fine line between benefits from constructive manipulations and enhancing threats through well-intentioned changes but ignorance of the wider ramifications of these. Chapter 9 includes further general background to several of the families of beetles that have contributed most constructively to advancing knowledge of beetle conservation and, in the final chapter (Chapter 10) I discuss some possible ways in which the future of this predominant insect group may be rendered more secure.

T.R. New
Department of Zoology
La Trobe University
Melbourne

Acknowledgements

The following are thanked for permission to use or modify previously published material in this book: CAB International, Wallingford, UK; Cambridge University Press, Cambridge; Ecological Society of America; Entomological Society of America; Elsevier Science, Oxford; Finnish Zoological and Botanical Publishing Board, Helsinki; National Academy of Sciences, USA; Oxford University Press, Oxford; Princeton University Press, Princeton, New Jersey; Springer Science and Business Media, Dordrecht; Surrey Beatty and Sons Pty Ltd, Baulkham Hills, New South Wales, Australia; Wiley-Blackwell, Oxford. Every effort has been made to obtain permission for such use. The publisher apologises for any inadvertent errors or omissions and would welcome news of any corrections that should be incorporated in future reprints or editions of this book.

This book was initiated through Ward Cooper at Wiley-Blackwell. I greatly appreciate his continuing support, together with the help given by Delia Sandford, Camille Poire, Kathy Auger and Kelvin Matthews during early production stages. Copy-editing by Jo Phillips is gratefully acknowledged.

The cover illustration is from an original embroidery sewn by Zanela Buthelezi Matsetsa, whom I thank for allowing me to use it here. Thanks are due also to Kathy Ducasse, Brigid Turner and Shirley Hanrahan for their help in facilitating this.

1

Introduction

Beetles and conservation

Beetles, the members of the insect order Coleoptera, are widely believed to be the most species-rich animal group that exists on Earth and, perhaps, that has ever shared our world. Comprising around one-quarter of all animal species, their richness and ubiquity led Evans and Bellamy (1996) to comment 'We live in the Age of Beetles'. That Age is a long one. Modern beetles, the outcomes of some 250 million years of evolution since the earliest beetle fossils found in the Permian period, are difficult to ignore. Collectively, they are immensely diverse in their lifestyles and ecology, and intrude on human consciousness and well-being in many ways. Our perceptions of beetles cover a huge range of human experience: as creatures of cultural importance and symbolism (such as scarabs in ancient Egypt), as objects of desire and fascination to naturalists and collectors, and as severe pests and our major competitors for crops and other commodities. Their countering positive values are as predators and biological control agents of other pests, as valued tools in environmental assessments of terrestrial and freshwater ecosystems, as study tools to help elucidate ecological functions, and as key components aiding the working and sustainability of the natural world. Much of the above emphasizes their ecological variety, with more than half the order in some way phytophagous. Plant-feeding apparently arose early in beetle evolution, with the ancestors of the current major radiations of angiosperm-feeding beetles (namely the weevils, Curculionoidea, and leaf beetles, Chrysomeloidea) existing in the Triassic, some 230 million years ago, and arising most likely from conifer- and cycad-feeding lineages (Farrell 1998). The massive radiations of beetles in the Cretaceous period paralleled the development and spread of flowering plants, and over about 100 million years

Beetles in Conservation, 1st edition. By T.R. New. Published 2010 by Blackwell Publishing.

they developed a broad array of feeding guilds and occupied virtually all available biotopes (see Erwin & Geraci 2009). However, numerous beetles are predators, fungus-feeders or other, and the collective variety of feeding habits encompasses exploitation of the variety of accessible foodstuffs in natural and anthropogenic environments.

Thus, unlike butterflies, whose wide general appeal renders them invaluable ambassadors in promoting the values of insect conservation and which contain few pest or otherwise damaging or undesirable species, the public image of beetles is decidedly mixed and more complex. Indeed, the same species may be regarded as a pest or conservation target in different places and its status change over time, so that local and wider perceptions of its role (and sympathy for its conservation) may differ substantially across its range. One example is the oak pinhole borer beetle *Platypus cylindrus* (Platypodidae). This species is a serious forestry pest in parts of continental Europe, but was listed as rare and associated with veteran oaks in Britain (Shirt 1987). Since then, and following severe gales in Britain in 1987, it has become a serious pest of stressed and dead oak trees. Yet, whatever the practical perceptions of particular beetles may be, the group's richness and diversity renders them of immense importance in understanding the natural world and leads to human interests encompassing the extremes of conservation on the one hand to suppression or eradication on the other. The latter attitude may broaden from confirmed pest species to others, just in case they cause damage. And the various components of 'beetlephilia' (a term advanced by Evans & Bellamy 1996, drawing on E.O. Wilson's famous 'biophilia') ensure continued attention to some groups of beetles by hobbyists and others not concerned directly with either their welfare or slaughter. Perhaps tiger beetles (treated variously as Carabidae: Cicindelinae, or the full family Cicindelidae), many of which are brightly coloured and active by day, promote such attitudes particularly well, so that Pearson *et al.* (2006) introduced their book with a chapter entitled 'The magic of tiger beetles', and included comments such as 'Hundreds of otherwise normal people are passionate about an intriguing group of insects called tiger beetles' and 'tiger beetles elicit something more than a routine response to the necessities of employment'.

The appearance of many beetles can be dramatic, even bizarre; for example, the enlarged mandibles or pronotal horns of some Lucanidae or Scarabaeidae have long been objects of curiosity and appeal. Arrow's (1951) sentiment at the start of his book on these insects ('all who see . . . one of the great horned beetles for the first time cannot fail to experience feelings of astonishment') remains entirely suitable, whilst many smaller beetles may impress just as much by some feature of colour or morphological extravagance.

In short, such liking and sympathy is an important positive component of insect conservation. Perhaps particularly for beetles embedded in national or regional culture, public interest in conservation can be garnered readily. Thus, the Genji firefly (*Luciola cruciata*, Lampyridae) in Japanese traditional agricultural environments has always attracted exceptional public interest (Takeda *et al.* 2006) and is an important flagship species for conservation. The earliest literature records of these fireflies are reportedly in Japan's oldest collection of poetry in the late eighth century (Masayasu 2005), and their flight season (in early summer:

June, July) attracts tourists through events such as the annual Yokoyama Firefly Village festival that can promote interest in conservation. Larvae of *L. cruciata* are aquatic, and the species has suffered greatly from habitat loss and degradation through pollution, following likely over-collecting for sale in the past.

It may indeed be feasible to promote beetles (and many other invertebrates) responsibly for greater interest in ecotourism itineraries. Buprestidae and Scarabaeidae were listed among the sample invertebrate groups suitable for inclusion in such activities in South Africa (Huntly *et al.* 2005), the former as conspicuous spectacular-looking beetles often seen on flowers, and the latter for their dung-rolling activities. The Addo elephant dung beetle (see p. 74) has received particular attention, but the suggested approach for invertebrates has been to highlight particular features as part of an educational process. In this example, Buprestidae were promoted by contrasting the habits of pollen-feeding adults with wood-boring larvae, and dung beetles for their important ecological role in breaking down wastes and their elaborate behaviour (Huntly *et al.* 2005). These families were selected as among those easily seen in one game reserve, with ease of observation an important aspect of promoting insects to visitors. Surveys of tourists in South Africa have suggested that many people will embrace chances to broaden their experience beyond the major current focus on large mammals (mainly the Big Five) and to learn about other taxa. An important requirement to facilitate this is to train tour guides more effectively, so they can comment on invertebrates as well as the larger animals. Conversely, epidemics of pest beetles may deter tourism. The massive outbreak of mountain pine beetle *Dendroctonus ponderosae* in western Canada (see p. 134) has the potential to affect both the ecology of some national parks and the experiences gained by visitors (McFarlane & Witson 2008). Likely consequences on visitors include lessening quality of scenery, hazards from dead and falling trees, and effects on local economics by reduced tourist numbers, with this effect extending well beyond park boundaries. However, the role of bark beetle epidemics in public perception can be more complex. Whilst they are massively damaging to commercial forests, in national parks the beetles may be regarded instead as natural regeneration agents, helping to sustain the area's ecosystems (Muller & Job 2009). Despite the reaction of visitors noted above for Canada, surveys in an affected park in Bavaria (Germany) showed that the infesting beetle (*Ips typographus*) was generally accepted by tourists. A prevailing opinion was that control measures should not be introduced in the park (Muller & Job 2009). Information provided about the beetle's function and importance countered initial negative attitudes, as an education process fostering wider appreciation.

However, and perhaps paradoxically, disliking economically damaging or other pest beetles may also be important in promoting interests in beetles, because it leads to accumulation of information with considerable relevance in conserving their close relatives or other species occurring in similar environments. Some pest beetles, in stored products, timber, or as pests of agricultural, orchard or forestry crops, are among the best-studied insects. Much of that knowledge, as well as that on beneficial species such as manipulable predatory ladybirds (Coccinellidae) used as biological control agents, and the techniques by which it is acquired and analysed merits careful appraisal by insect conservationists.

The juxtaposition between the applied entomology literature and the conservation ecology literature is perhaps nowhere closer than for Coleoptera, and the wealth of detail in the former can provide invaluable ideas and leads in management of beetle species and assemblages for conservation. The appraisal of Coccinellidae by Dixon (2000), for example, is a broad biological foundation of interest for studying any member of that family in a wider perspective.

As well as contributing enormously to evolutionary and ecological understanding in numerous different terrestrial and freshwater ecosystems, beetles are important considerations in practical conservation. Their value and their roles range from the high-profile focus on single notable species threatened with decline or loss to documentation of the vast regional assemblages reflecting dependence on restricted resources threatened by human activity. Regarded widely as an easily sampled taxon, beetles have become an important group in addressing many questions of wide conservation relevance, so contributing to disciplines such as landscape ecology, reserve design and placement, and restoration or rehabilitation of most terrestrial and freshwater biomes. The bulk of ecological studies on beetles have not been undertaken specifically to address conservation issues. However, the leads they give, the background information accumulated on more basic ecology and biological understanding of how beetles work, and the methods and analyses pursued collectively lay a very sound foundation for more conservation-focused endeavours. It is also increasingly common for the discussions in papers on beetle biology to allude to the conservation implications of the work presented. It is impossible to summarize the ecology of beetles briefly, but their ecological specializations and variety may be considered to lie along a continuum from strictly monophagous and highly specialized species (with obligately small niches and frequenting only one or two habitat types, sometimes highly circumscribed as local endemics) to extreme generalist species (with wide niche breadths and in a wide variety of habitats across a broad geographical range) (Dufrene & Legendre 1997). Any terrestrial or aquatic beetle assemblage in a restricted habitat will thus include the two major elements of (i) obligate specialist species restricted or largely restricted to it, and (ii) generalists that may either extend casually into that environment or, by actively selecting particular resources or other attributes, become more abundant there than elsewhere. Whereas conservation interest may gravitate predominantly towards the specialist species, which tend to become detectably threatened more easily than many generalists, the operating environment for such species includes the assemblage of which they are part, and with which they may interact. Slightly more broadly, it is useful to separate three major ecological categories that transcend any individual trophic category: (i) ubiquitous species, i.e. those that are geographically and ecologically wide-ranging; (ii) eurytopic species, i.e. those found in a variety of habitats but over a more restricted geographical range; and (iii) stenotopic species, i.e. those that are much more specific and found in one or few habitats, as specialists. The first group, ubiquitous species, are commonly also eurytopic, because they occur in a variety of habitats, so are then distinguished by the extent of their distribution.

Highly specialized ecological oddities abound among Coleoptera, so that many broad generalizations about their habits and biology are subject to increasing numbers of exceptions as biologically novel or unexpected traits are discovered. Some may augment conservation interest as informative evolutionary lineages, or by demonstrating unusual adaptations that render them resistant or vulnerable to environmental changes. One recently appraised oddity is the fairy shrimp hunting beetle (*Cicinis bruchi*), a highly unusual carabid (Erwin & Aschero 2004). Unlike most ground beetles, this species (formerly known from only two specimens and characterized, in an intriguing image, as 'the carabid equivalent of a crocodile') is aquatic and the nocturnal adults swim on the surface of alkaline water bodies, salt flats, in Argentina. The salt flats are very extensive, but Erwin and Aschero (2004) believe that the beetle's distribution there was restricted by that of 'tiled' soils providing refuges for the beetles during the day. The beetles feed solely on anostracan shrimps. At present, the extensive habitat area seems not to be threatened, but the future influence of global warming may pose a severe threat in this semi-desert environment.

Beetle extinctions and extirpations

In his magisterial *The Biology of Coleoptera*, Crowson (1981) commented (p. 650):

> The immense diversity of the recent beetle fauna of the earth is the product of extremely diversified ecosystems which have maintained considerable degrees of stability for very long periods of time. Both the diversity and the stability are now being destroyed, at an increasing rate, by human action. In the process large numbers of Coleoptera must inevitably become extinct . . .

and (p. 689) 'we fear . . . the early extinction of large and scientifically interesting parts of the present world fauna of Coleoptera'. Stability or stasis of many beetle species is inferred strongly from the record of Quaternary beetle fossils (or subfossils), which comprise fragments that resemble closely, and indeed are often identical to, the equivalent parts of modern beetles. Many of these, including elytra, pronota, heads and sclerotized male genitalia, enable fossils to be identified reliably as modern species. Many such fossils (which can occur in large numbers in sediments) retain structural and pigmented colours, together with setae and micro-ornamentation, and provide strong indication of the long periods for which some species have existed, notwithstanding the many gaps in the record. Crowson's sentiment has been echoed repeatedly, for example by Erwin (1997) in referring to the vulnerability of tropical forest beetles: 'current human activity and that of the immediate future will exterminate a large percentage of these species'. In general, fear of extinction of enormous numbers of species, including beetles, within the next few decades (Dunn 2005) is a vital rallying call for urgent conservation measures throughout the world. More specific contexts occur, with many general warnings of likely demise of particular beetle taxa. For example, surveys of the large montane bess beetles (Passalidae) roused the comment from Schuster *et al*. (2003, p. 302) that 'In general *Proculus*, as well as other montane species of passalids, is probably in danger of extinction throughout its range due to the elimination of most of the forest where it occurs'.

With few exceptions, however, specific knowledge of such extinctions does not exist, particularly over most of the tropics where beetle diversity can be extraordinarily high. Indeed, Mawdsley and Stork (1995) could enumerate only 10 recorded global species extinctions of beetles, all of them from isolated islands. Even in the Quaternary fossil record, beetle extinctions seem to be few, with stasis (accompanied by, sometimes dramatic, range changes; p. 135) more common, reflecting the sequences of glacial and interglacial periods over which vegetation may change through advance and retreat over several thousand kilometres. Coope (1995) and others have suggested that the perceived lack of extinctions may be partly due to this long-term series of changes, associated with a high degree of population mixing with resulting homogeneity of populations diminishing the chances of extinction by countering genetic impoverishment. Indeed, Ashworth (2001) could cite only two possible extinctions over that period, the dung beetles *Copris pristinus* and *Onthophagus everestae* from the La Brea asphalt deposits, but, following Miller (1997), suggested caution in declaring that even these Pleistocene species had really disappeared. The twin concepts of structural extinction and sampling extinction differentiated by Gaston and McArdle (1994) are important components of understanding, whereby the latter emphasizes the difficulties of evaluating small, elusive and perhaps cryptic taxa. This dichotomy was explored by Didham *et al.* (1998a,b) in their study of forest fragmentation effects on beetles in Amazonia, and in which they attempted to appraise the likelihood of extinction from changing abundance across sites of different sizes and conditions (see p. 96). Habitat fragment size was apparently a key predictor of extinction risk for some species. Some insect extinctions are indeed difficult to prove, and declarations of extinction may reflect periods where the species is not recorded, but often with little indication of the amount of targeted search effort for it. It is not particularly uncommon for beetles to be rediscovered decades after they were last seen. One such example is the New Zealand dytiscid water beetle *Rhantus plantaris*, described from a single specimen in 1882 and found again in 1986 (Balke *et al.* 2000). The site where it was then found was a small perennial pond with water diameter only about 5 m, so that its existence may still be regarded as rather tenuous, but at least in 1986 it was not extinct! Whilst McGuinness (2001) remarked that three beetle species had been reported to be extinct in New Zealand, his own inferences were more cautious. For the carabid *Mecodema punctellum*, not seen since 1931, McGuinness (2002) noted 'this species *may be* extinct' (my italics). However, sometimes repeated and specifically targeted surveys have not revealed the beetle sought. The large flightless ground weevil *Hybomorpus melanosomus*, endemic to Lord Howe Island, formerly occurred there under logs and in rotten wood. It is known from a few specimens in collections and has not been collected since the 19th century. Soon after, it was considered to be extremely rare or possibly extinct (Oliff 1889), even before the introduction of rats to Lord Howe Island early in the 20th century. Intensive invertebrate surveys over several recent decades have not yielded specimens, and the weevil is now listed as presumed extinct under New South Wales Government legislation.

Strong declines and more local disappearances of particular beetle species are documented more commonly and effectively for parts of the temperate regions, particularly in the UK (from where Hambler & Speight 1996 listed 12 species believed to have become extinct since 1900, and Hyman & Parsons 1992, 1994 noted a number of species that had not been seen for at least several decades, but did not categorize these as extinct in their rankings), parts of western continental Europe, and parts of North America. These declines and extirpations are the source of much modern conservation interest, with the species brought to attention in this way the usual candidates for conservation. Studies on islands have also led to documentation of many such extirpations: several Tenebrionidae have been lost from particular Iberian islands for example (Cartagena & Galante 2002). In contrast to full extinctions, local extirpations are frequent and many of the threats noted later for recent beetles have had influences well before people became concerned about them (Whitehouse 2006). The riparian beetle faunas in northern Europe include a number of Carabidae that have been lost through river regulation and canalization, changes to nearby vegetation and bank structure, and pollution, with some peculiar to areas with particular substrates such as stones or sand (Andersen & Hanssen 2005). As another example, the Californian tiger beetle *Cicindela tranquebarica joaquinensis* was historically found over much of the San Joaquin Valley, associated with alkaline habitats. However, most populations have been extirpated because of intensive agricultural development, such as cultivation and changes of water for irrigation supply, so that the specialized habitat has been largely lost. Only three populations, each on a patch of habitat less than 3 ha in area, were known to Knisley and Haines (2007). As another striking example, the historical distribution of the American burying beetle *Nicrophorus americanus* (p. 145) was formerly extensive across the eastern half of the USA, but has now been reduced to three small disjunct areas (Fig. 1.1) (Lomolino *et al*. 1995; Sikes & Raithel 2002). Collectively, most of the more reliably evaluated recent losses are within the areas for which beetle faunas have been described most completely, as a continuing legacy of collector interests spanning some 150–200 years and the progressive availability of series of identification guides and handbooks that render the fauna at least partially tractable to people taking up their study.

Beetle diversity

Elsewhere, our knowledge of modern beetle diversity and its distribution is highly uneven, although broad historical biogeographical patterns within the order can be traced with the aid of the substantial fossil legacy (Coope 1995), so that many of the better-studied regional faunas can be defined and, in many instances, alien species recognized reliably. Thus, Australian beetles are often recognizable as regional endemics, and their presence elsewhere in the world (be they pests, beneficial species or with more neutral impacts) definable. Conversely, beetles from elsewhere are commonly detectable in Australia. Very commonly, knowledge from studies on alien beetles, undertaken to clarify their impacts or management to suppress or foster them, comes to exceed that available from within their natural range, and may have direct applications in conservation. Likewise, searches for beneficial insects, such as biological control agents, can

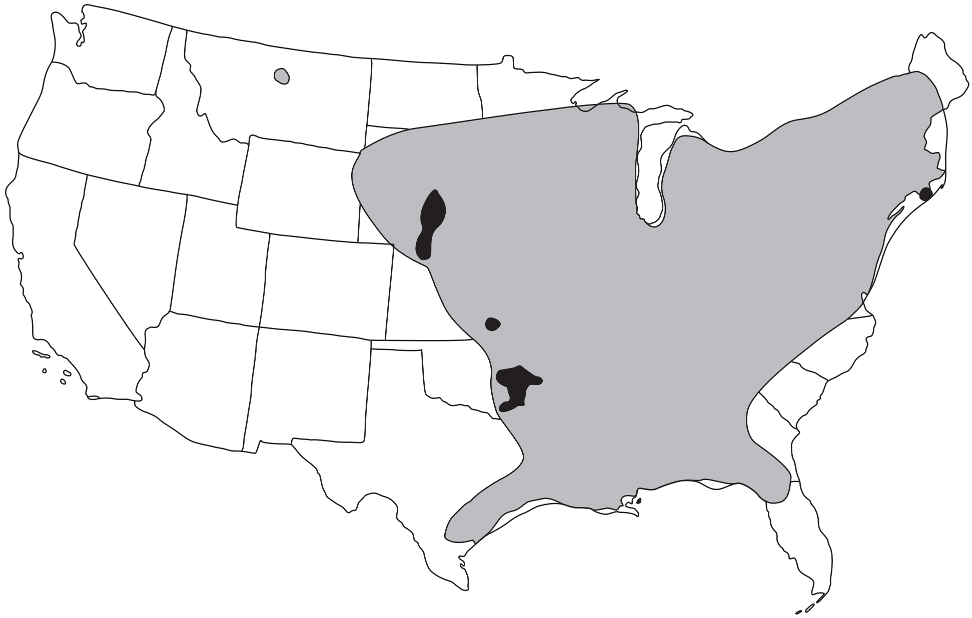

Fig. 1.1 The historical (shaded) and current (black) distribution range of the American burying beetle *Nicrophorus americanus* in North America. (After Lomolino *et al*. 1995 with permission.)

stimulate detailed investigation of possible source faunas: for example, Koch *et al.* (2000) noted the 'intensive, wide-ranging dung beetle collection programme' and resulting comprehensive reference collection of specimens from Australian exploration for South African dung beetles suitable for importation to Australia. However, in broad terms for much of the rest of the world, beetles are much less effectively documented than in Europe or North America; even though a strong systematic framework exists, many families have not been documented completely and a high proportion of species are unnamed and undiagnosed. We have little realistic idea about how many species of beetles occur on Earth; certainly several hundred thousand species have been described, but estimates of their total richness extend to several million species, and these figures continue to be debated. A tally of 358,000 described species (Bouchard *et al.* 2009) includes several earlier authoritative estimates, with the six largest families enumerated being Curculionidae (60,000 described species), Staphylinidae (47,744 species), Chrysomelidae (36,350 species), Carabidae (30,000 species), Scarabaeidae (27,800 species) and Cerambycidae (20,000 species). As Grove and Stork (2000, p. 735) commented 'In reality, and despite the best efforts of a number of researchers, we are still little nearer to determining the true extent of beetle diversity'. And, from Zimmerman (1994), 'Estimates of the numbers of described weevils are as variable as the opinions of those making the estimates'. However, several families are very large, whilst many others are small. The bulk of described beetles belong to only about eight families including those listed above, namely Carabidae, Staphylinidae, Scarabaeidae, Buprestidae, Tenebrionidae, Cerambycidae, Chrysomelidae and Curculionidae. An estimate by Gaston (1991) suggested that these together contained about two-thirds of beetles decribed at that time, and that high proportions of undescribed species would also be referable to these groups. Simply studying these families, whose members range over many trophic guilds and habitats, would alone provide a very strong practical framework for conservation.

However, considerably greater variety occurs. Thus, for Australia, around 23,000 beetle species have been described (in more than 120 of the global total of 166 families listed by Lawrence & Newton 1995 and, as an aside, a scarab beetle *Haploscapanes barbarossa* was the first formally named Australian endemic animal), but predictions of 80,000–100,000 species (or even more) have been made (Yeates *et al*. 2003). Such uncertainties are common, and render many aspects of evaluation based on fundamental documentation of biodiversity difficult and sometimes unconvincing, little more than 'guesstimates'. Within such large faunas, with their characteristic high levels of endemism, many beetles are ecologically specialized, and many are scarce or highly localized. Background knowledge and sampling effort is, in most cases, simply inadequate to detect their loss or continued presence in very low numbers, even if they are recognized as distinct entities. However, valuable information on assemblages can accrue relatively easily, because a high proportion of beetles can be allocated with reasonable confidence to feeding habit or guild, from knowledge of related taxa elsewhere. As an example from the tropics, in the poorly described beetle fauna of Sarawak, Malaysia, Chung *et al*. (2000) could confidently assess over 40% of the more than 1700 species they accumulated as predators, as well as determining that more than 15% were saprophages and fungivores and 10–13% herbivores, so that assemblage changes based on changing frequency of such guilds could be estimated and compared. Nevertheless, a high proportion of beetle species diagnosed or named from most of the tropical regions are known from few individuals, many of them from single specimens, and the biology of most of these is simply unknown, and can be inferred only in general terms by comparison with any better-known related taxa. Many beetles are known only from an inadequately documented, sometimes old, type specimen or description. The reality of studying beetles, and assessing their relevance to ecological sustainability and needs for conservation, involves acceptance of this vast uncertainty and learning how to treat it responsibly.

However, despite the taxonomic uncertainties which ensure that only low proportions of species in most general surveys of tropical beetles may be identifiable to species level (see below), studies of assemblage composition and the changes associated with disturbance or changing patterns of land use, made either along gradients (see p. 102) or more patchily, have commonly utilized beetles as signals or indicators of habitat condition. Many analyses of beetle assemblages have focused on particular families, so that differences or changes in richness and composition are correlated, sometimes tentatively, with habitat characteristics.

In any part of the world, and with information encompassing most continental and island areas, many beetles are regional or much more localized endemics, and most of the species signalled individually for conservation concern have highly restricted distributions. Additionally, Hammond (1994) recognized a category of near-endemics, illustrated by a number of intertidal/coastal beetles in Britain, but which are scarce or very restricted elsewhere in Europe. For example, some Staphylinidae in this category are known from very few sites outside Britain, and then only from Europe-facing Channel coasts or similar restricted ranges. For most parts of the world, patterns such as this cannot be defined with confidence, but there is no doubt that levels of narrow-range endemism among beetles can be very high. Two Australian examples illustrate the scenarios likely to be paralleled widely elsewhere.

1 Many flightless beetles in Australia's northern wet tropics (a World Heritage Area) are restricted to a single forest subregion (Yeates *et al.* 2002). The large number of such species with presumed low dispersal ability in several families (namely Carabidae 86 species, Scarabaeidae 32 species, Tenebrionidae 87 species) implies that many, together with a variety of other beetles and insects of other orders (particularly Hemiptera: Aradidae), may indeed be vulnerable there as highly localized taxa.
2 Many of the dytiscid water beetles from underground calcrete aquifers in Western Australia (see p. 115) are known only from single aquifers which, following results of mitochondrial DNA investigations on the beetles (Cooper *et al.* 2002), may represent a series of subterranean islands with independently evolved beetle taxa.

The bewilderingly high richness of tropical beetle faunas, although long suspected, was brought to wide attention through Erwin's (1982) classic study of sampling beetles from the tropical forest canopy in Panama. His analysis founded later debate on the magnitude of tropical insect species richness. For the first time, Erwin provided testable hypotheses by which richness could be estimated and, although his assumptions have been challenged in detail, they have formed the foundation for considerable later evaluation (see Stork 1997). In acknowledging the massive diversity of beetles in tropical forests (as 'biodiversity at its utmost'), Erwin (1997) noted that they had been little used in interpreting environmental disturbance, for environmental monitoring or for understanding how tropical communities are structured, and also emphasized their great potential for augmenting our understanding of evolutionary biology and conservation. The sheer amount of information potentially available from tropical beetle faunas would have unique and massive importance in these areas of endeavour. The problems remain over how to harness and employ that information from such hyperdiverse groups and to overcome the current impediments to doing so. Much information on diversity emanates from studies on single sites or small regions, and the reasons for varying distributions and high beta diversity may be difficult to assess. Again from the Neotropics, only about 2.6% of the beetles of seven selected families from fogging samples were common to surveys from near Manaus (Brazil) and Tambopata (Peru) (Erwin 1988). These sites are separated by about 1500 km but, in a wider discussion of species turnover with distance across sites, Bartlett *et al.* (1999) noted that interpretations of distributions based on such separated samples are 'fraught with intensive site-specific differences that confound distance effects'.

The central paradox and values of beetles in conservation flow from their vast abundance and taxonomic and biological diversity. On the one hand, they offer abundant opportunities for study and evaluation of environmental changes. Almost every terrestrial or freshwater biome supports a wide taxonomic array of beetles, many of them responsive to some or other environmental change, whether natural or imposed, and many of them commanding attention as declining, either alone or as an entire specialized assemblage. The long-term interest in beetles noted earlier has laid a solid foundation of taxonomic and biological knowledge that aids some such appraisals, as well as suitable (ecologically informed) study and sampling methods. On the other hand, the bewildering variety of beetles is sometimes a barrier to understanding: we may indeed find numerous species in a locality, occupying collectively all or most trophic roles in a biome, but the detailed ecology of most (even all) the species is likely to be fragmentary, and the mechanisms sustaining them may need to be projected from little background other than from related taxa, or from similar biomes undergoing apparently similar processes or change. For conservationists, beetles, whether directly as conservation targets or tools for wider applications, offer both severe impediments and massive opportunity for progress.

In common with other insects with complete metamorphosis, conservation of beetles must consider the biology and needs of two very different life forms, whose ways of life may demand very different resources and conditions. Larvae and adults of the same species may coexist, or be separated in space and time, utilize different foodstuffs and occupy different feeding guilds. As Dennis *et al.* (2006, 2007) have emphasized for butterflies, successful conservation must determine and ensure the needs for both these active stages in a wider milieu in which the entire life cycle can be supported.

In much practical insect conservation and faunal documentation, high species diversity is a very mixed blessing. Relatively low-diversity groups, perhaps with only a few thousand species (however formidable such numbers seem to people used to working with mammals or birds), are fundamentally more tractable to non-specialists in particular. Within the insects, butterflies comprise only around 20,000 species, with regional faunas typically much smaller, and many of the genera and species are recognizable through well-illustrated field guides. A framework for their biology is also likely to exist, perhaps by reference to close relatives in the area or elsewhere. In contrast, with tropical beetles we are dealing with much larger numbers of taxa, most of whose biology and distribution is almost entirely unknown, and many of which are undescribed and undiagnosed. Many beetles may not be identifiable easily much beyond family level, and some to that level only with considerable difficulty attendant on small size and complex or confusing morphological characters. As Erwin, and many others, have emphasized, the decline of the taxonomic workforce has ensured that most of these taxa will not receive such formal treatment in the foreseeable future. In the terminology of Yeates *et al.* (2003), many beetle groups are 'taxonomically orphaned' by the absence of any specialist able to evaluate them in a regional or the global fauna, and comment on their affinities and peculiarities. Beetles are by no means alone in this regard: the situation may be even worse for parasitoid Hymenoptera for example (even in the best-documented temperate-region faunas; Shaw & Hochberg 2001), and paralleled in many families of Diptera and other diverse insect groups. Perusal of taxonomic journals (such as *Zootaxa*) in which numerous descriptive papers on beetles are published may convey misleading impressions: whereas many taxa are indeed being described, and many groups progressively revised, the size of the demand and the task ahead remain daunting.

Beetle recognition and identification

The practical ramifications of this absence of data are important. Lack of formal species' names and lack of ability to obtain those names (the situation sometimes termed the 'taxonomic impediment'; see Taylor 1983 for background) is exacerbated by high diversity to the extent that need for formal taxonomy cannot be fulfilled as a prerequisite for basic documentation, and is viewed widely by non-scientists as equivalent to lack of importance or interest. However willing and interested they may be, lack of taxonomic resources ensures that the few specialists on any individual insect group are substantially overextended. Employer demands may effectively prevent such people participating in identification of ecological survey material for other people, and related activities. And, for groups such as beetles, the amount of material collected during such exercises can be formidable in both abundance and variety. It is one thing to ask a specialist to identify a single beetle or a few voucher specimens of particular interest or relevance to a study and within that person's sphere of interest (commonly a single beetle family or part thereof), but quite another to confront him or her with the entire outcome of a substantial survey, comprising perhaps hundreds of species across a wide array of families. Examining such collections is often a major research exercise in itself. However, lack of up-to-date guidebooks or other non-specialist publications renders such exercises almost impossible (and, at least, often unwise) to undertake without specialist direction and access to a major and well-curated institutional collection for comparison. Handbooks for many families are indeed available for many parts of the northern temperate zones in particular, and identification can then be undertaken with relative confidence, but it remains wise to attempt to have a series of voucher specimens checked by an experienced coleopterist, as recommended later for any survey in which the results may be used in recommendations for conservation management. The situation remarked by Crowson (1981), that few countries outside Europe have even reasonably comprehensive handbooks for beetle identification, although guides for particular families may exist, still pertains. Broad-based introductory illustrated handbooks to tropical beetles, such as those by Tung (1983) for Malaysia and Gressitt and Hornabrook (1977) for Papua New Guinea, are immensely valuable introductions to those faunas but can do little more than titillate for the wealth not included. Nevertheless, as Tung hoped, they can stimulate people to take up the study of beetles in such regions and lead to advances in knowledge. Clearly, the resources for the interested ecologist or conservation biologist to identify beetles easily and unambiguously beyond family level in much of the world simply do not exist, particularly locally. The practical dilemma is that for beetle faunas with high proportions of poorly documented species, non-specialist identifications are likely to often be erroneous, and specialists unlikely to be routinely available to help interpretation. Larochelle and Lariviere (2007), writing on New Zealand Carabidae, go further and state (p. 160): 'Species-based information should never be published or databased unless a carabid specialist has confirmed the validity of genera and species involved'. They noted also that isolated descriptions of new taxa, sometimes motivated by need to provide names for conservation targets, are misguided, and that beetle taxonomy should be pursued in the context of revisionary studies rather than piecemeal.

When, and if, a particular species of beetle is described formally is often serendipitous, and depends largely on the interest of a specialist examining that family or genus group at that time. Other factors also intervene: for the well-known British fauna, most larger beetles were described earlier than many small ones (Gaston 1991). The latter are commonly (i) more difficult to differentiate without close microscopical examination, or dissection of genitalic structures, and (ii) less attractive to many collectors and so less important unless with direct economic or other intrusive values. Gaston suggested that the smaller beetles may be simply less conspicuous, and harder to collect. This trend is by no means universal, as Allsopp (1997) found for the Australian scarabs, for which wide-ranging species were generally described earlier than many highly localized taxa, irrespective of their size. Many of the earlier-described species were those found closest to major human settlements (so that the south-eastern fauna was for long better documented than the fauna of the remote northern regions). However, importantly, all scarabs are at least moderately large beetles, and thereby reasonably conspicuous. Allsopp (1997) pointed out another possible anomaly relevant to conservation assessments – the probability that some of Australia's recently described scarabs currently have small defined ranges *because* they have been described recently, so that there has been little time to accumulate comprehensive information on their real distributions, which might be substantially underestimated from the material available. For Iberian Scarabaeidae, Lobo *et al.* (2007) also noted that mapping schemes (see p. 41) may show considerable bias, because initial records of species may be based on localities favoured by collectors seeking particular rare species and on more thorough exploration of places near to investigators' homes. Many hobbyists, seeking particular species but with limited recreational time available, will opt to visit traditional localities to seek their specimens rather than explore new areas that might not yield their targets.

Keys to beetle families are included in many general entomology texts, but regional bias may limit their usefulness. Most textbooks, for example, cater predominantly for one or other temperate-region fauna as their primary market and, at the least, the examples of beetles used to illustrate key characters may not occur widely elsewhere, or other faunas include additional families not treated in that text because of regional scarcity or absence.

Most information in texts, and most of the work referred to in this book, deals only or almost solely with adult beetles as the life stage most amenable to