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FORUM

Translating research into action; bumblebee conservation as a case study

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Introduction

Bumblebees belong to the genus *Bombus*, which comprises about 250 species, largely confined to the temperate Northern Hemisphere. They are wholly dependent on flowers for their energetic and developmental requirements. Most are social species, with nest sizes varying from 50 to 400 workers. As such, they have attracted considerable attention regarding their role as pollinators. There is a growing body of evidence that bumblebees have declined in Europe, North America and Asia in recent decades because of multiple causes probably including habitat loss, impacts of pesticides, competition from non-native species and the introduction of non-native diseases (Goulson, Lye & Darvill 2008a; Williams & Osborne 2009). Recent health problems affecting honeybees and a perception that other pollinators may be declining has led to serious concern that we might be facing a global 'pollination crisis' affecting pollination of crops and wildflowers (e.g. Aizen & Harder 2009).

The global value of crop pollination by bumblebees is unknown; Gallai *et al*. (2009) estimate that for the EU25 countries in 2005, the value of insect pollination of agricultural crops was €14·2 billion, with a large (but unquantified) proportion of this coming from bumblebees. Most crop pollination delivered by bumblebees is because of a handful of common species, so that from an economic viewpoint there may be no need to conserve a diversity of bumblebee species. However, bumblebees also provide pollination services to natural ecosystems, with numerous wild plant species largely or entirely dependent on bumblebees for pollination. As bumblebee species each occupy distinct (albeit often overlapping) niches with regard to their patterns of floral visitation (e.g. Goulson, Lye & Darvill 2008b), it is probable that many bumblebee species are needed to maintain functionality of natural ecosystems (Williams & Osborne 2009). Bumblebee nests also support a diversity of parasitic and commensal organisms. For these reasons, it can be argued that bumblebees are 'keystone species', upon which the survival of many other organisms depend (Goulson, Lye & Darvill 2008a).

Perhaps as a result of perceived declines, academic interest in bumblebees has risen markedly in recent decades. This can be simply illustrated by plotting the number of papers in Thomson's ISI Web of Knowledge which have *Bombus* in the abstract or key words (Fig. 1). Over the last 20 years the number of papers published per year has grown steadily from 12 to 144, a 12-fold increase (for comparison, studies concerning two other pollinator groups, Lepidoptera or Syrphidae, have each increased by a factors of *c*. 2·5 over the same period, Fig. 1). The studies of bumblebees encompass diverse topics from 'pure' research of, for example, social structure, foraging behaviour, population genetics, pheromones and navigation, to applied studies addressing how particular land management methods influence bumblebee numbers. There is no doubt that we understand far more about the biology of bumblebees than we once did, although there remains much more to learn (for example mating behaviour of many species has rarely been seen, and because natural nests are hard to find we know little about the factors affecting their survival and success).

Recent papers on bumblebees (and many grant applications) often start by summarizing evidence for bumblebee declines, the implication being that the research may contribute to our understanding of the causes of decline and so help us to reverse them. However, publishing a paper, no matter how good the science may be, does not in itself improve the fortunes of a single bumblebee. It is only when the research reaches the right audiences and is translated into practical action that it makes any difference. Very few farmers, gardeners, politicians or nature reserve wardens sit down of an evening to read a scientific journal, nor should we expect them to. If they did, they might struggle to make sense of most of it. Academics must take some of the blame for this situation; many researchers make little effort to communicate their work beyond the traditional use of scientific journals, publications which are all but incomprehensible to the layman. This in turn is largely because the traditional criteria used for judging academic success (publications and grant income) pay little attention to the

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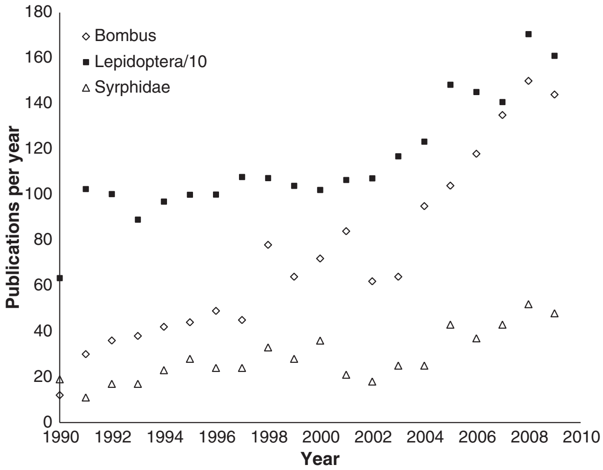

Fig. 1. The number of publications in Thomson's ISI Web of Knowledge which have *Bombus*, Lepidoptera or Syrphidae in the abstract, key words or title, plotted against year of publication. Numbers for Lepidoptera are divided by 10 for ease of comparison.

impact of the research. In some areas of science the breakdown of communication between scientists and the public may not be too disastrous, but in conservation this matters profoundly, because if conservation research is not communicated to those who might implement it, then the research effort (and funds) were wasted. Yet there remains a yawning gulf between the research consensus and practical on-the-ground habitat management, and it is not clear whose job it is to bridge this gap. This applies both at the level of rare species conservation (arguably the territory of conservation NGOs) and at the more basic level of maintaining healthy pollinator populations.

The Bumblebee Conservation Trust (BBCT, http://www.bumblebeeconservation.org) was founded in the UK in 2006 by academics (Goulson & Darvill), with the specific aim of linking science and practice by translating our growing understanding of bumblebee ecology into well-informed practical conservation measures, which would halt and hopefully reverse declines in bumblebee populations. It provides an example of one possible route by which conservation research can usefully feed directly into on-the-ground conservation. We discuss, in turn: What recent research has revealed about the conservation needs of bumblebees; how this has fed into the strategy of BBCT; current knowledge gaps with regard to bumblebee ecology of relevance to conservation; and barriers facing the more widespread implementation of research in conservation.

What recent research has revealed about the conservation needs of bumblebees?

Six key points have emerged in recent years:

1. *Population size*. Recent studies have demonstrated that the social nature of bumblebees renders them particularly sensitive to habitat fragmentation. Their effective population size is *c*. 1·5 times the number of successful nests, for each nest contains just one breeding female and the sperm she has stored from a (single) haploid male. Although some species remain widespread and hence have large populations, others thrive only in areas containing high densities of their favourite forage plants. Because of habitat loss, mainly attributable to agricultural intensification, these flower-rich areas are now often small and fragmented. Most nature reserves in the UK might only support a handful of nests of a rare bumblebee species, and are thus far too small to support viable populations. For example, Ellis *et al*. (2006) estimated that surviving UK populations of the rare *Bombus sylvarum* contained between 26 and 48 nests, and that the remaining populations are isolated from one another. Such tiny populations are unlikely to be viable in the long term, and it seems likely that a breakdown of metapopulation structure has already led to the UK extinction of *B. subterraneus* (Goulson, Lye & Darvill 2008a). Genetic studies have demonstrated that the rarer species such as *B. sylvarum, B. muscorum* and *B. distinguendus* are genetically depauperate compared to more common species (e.g. Ellis *et al*. 2006). There is a real risk that surviving populations of rare species will disappear in the near future because of stochastic effects, inbreeding, or both.

2. *Dispersal abilities*. Recent research has revealed marked differences in the dispersal ranges of the sexual stages of bumblebees, suggesting that some bumblebee groups such as the subgenus *Pyrobombus* (which includes *B. pratorum, B. jonellus, B. hypnorum* and *B. monticola*) may have relatively high dispersal abilities. In contrast the *Thoracobombus* group seem to be relatively sedentary (e.g. Darvill *et al*. 2010); this group includes *B. pascuorum*, *B. sylvarum*, *B. humilis*, *B. rudararius* and *B. muscorum*, of which all but *B. pascuorum* have undergone marked declines. Differences in dispersal ability dictate the scale of habitat fragmentation which an individual species can withstand.

3. *Foraging range*. The foraging range of worker bees determines the area which a nest can exploit. It is hard to quantify, and there have been many attempts, but it seems highly likely that there are important differences between species, with foraging ranges varying from *c*. 400 m to 1·5 km (e.g. Osborne *et al*. 2008a). Species with long foraging ranges such as *B. terrestris* will be able to cope with more patchy availability of floral resources than those with shorter foraging ranges (thought to include *B. pascuorum*, *B. muscorum* and *B. sylvarum*). Bumblebees do not store large quantities of nectar or pollen which means temporal and spatial patchiness in local forage availability is more difficult for species with short foraging ranges to withstand.

4. *Forage use*. Studies suggest that bumblebees do not require a high floral diversity to survive (e.g. Carvell *et al*. 2007). There is high dietary overlap between species, but most bumblebee species could be catered for throughout most of the season by providing a plentiful supply of 10 or fewer suitable plants. *Fabaceae* appear to be very important in providing protein-rich pollen for bumblebees, and it is likely that the large scale loss of species-rich grasslands and clover leys (habitats characterized by high densities of Fabaceae) are primary drivers of bumblebee declines in Europe (Goulson, Lye & Darvill 2008a). *Trifolium pratense* and its close relatives appear to be particularly important sources of both nectar and pollen for many long-tongued bumblebee species such as *B. distinguendus*, the UK's rarest species and a UK Biodiversity Action Plan priority species. Nevertheless, where available, bumblebees are known to forage from (and pollinate) a great diversity of flowering plants. Hence, bumblebees benefit from a diverse flora, and vice versa.

5. *The value of agri-environment schemes*. Simple agri-environment scheme options are available in many EU countries and the USA; for example pollen and nectar strips in field margins can be very effective in providing forage for bumblebees in the UK (Carvell *et al*. 2007). Schemes promoting the restoration and creation of species-rich grasslands also have the potential to greatly benefit bumblebees. There is now a wealth of information on how best to establish and manage both short and long-term pollen and nectar strips or species-rich grasslands (e.g. Pywell *et al*. 2002; Carvell *et al*. 2007). However, even in non-competitive, entry-level schemes uptake of these options can be poor. In total only 6000 ha of pollen and nectar mix has been sown in England, which has a total area of over 13 million ha (0·05%). Farmland areas under agri-environment schemes but not incorporating these targeted options are often no better for bumblebees than conventional farmland (e.g. Lye *et al*. 2009), indicating the need for interventionist measures where these are not currently available. If food prices rise in the future, as seems probable, agri-environment schemes may become less attractive to farmers, and in Europe, future Rural Development Programme funding could have a significant impact on the menu of fundable measures.

6. *Urban areas*. It has become clear that both gardens and brownfield sites in urban areas support higher densities of bumblebees and bumblebee nests than do typical farmed areas (Osborne *et al*. 2008b). In some cases these urban areas can also support rare and declining species (e.g. *B. sylvarum* and *B. humilis* in the Thames Estuary). Brownfield sites are often under threat as legislation prioritizes them for development.

How this research has fed into the strategy of BBCT

A number of practical messages have emerged from bumblebee research. From our growing knowledge of bumblebee population structure, it is clear that conservation measures need to focus on enhancing the size and connectivity of extant populations of the rare species, which otherwise are likely to go extinct one by one. Nature reserves are too small to support viable populations, so conservation measures need to target the wider countryside, i.e. farmland. Stepping-stone habitat is needed to link existing populations, and this is likely to be particularly critical for the more sedentary species.

Studies of foraging range suggest that some species forage much further afield than others. For the species with shorter foraging ranges, nests will only survive if there are patches of suitable flowers available through the season within a *c*. 400 m radius of the nest. However, even for the less mobile species, patches of floral resources clearly need not be contiguous and could readily be incorporated into most farming systems as patches of flowers interspersed among much larger areas of crops.

Suitable conservation measures include: (i) maintenance of flower-rich sites; (ii) restoration of species-rich grasslands; (iii) sowing pollen and nectar mixes; (iv) encouraging clover ley crops and a return to crop rotations as an alternative to the use of fertilizers; (v) promoting wildlife-friendly gardening. As bumblebees are found throughout the UK, these activities have some value wherever they take place; as a minimum they will help to boost populations of the common species. However, to conserve rare species and prevent further bumblebee extinctions, activities need to be targeted at appropriate sites close to or within areas where rare species persist.

It is clearly not possible for a small NGO to buy and manage sufficient land to make any significant impact on bumblebee populations at a national scale, so the challenge is to persuade land owners and managers to change their practices. The key stakeholders here are farmers, local councils, gardeners, and those involved in the management of nature reserves, national parks and other protected areas. Land management can also be improved indirectly by influencing government policy. To reach this diverse and substantial group of people is a considerable task for a small organization. The Trust has adopted a range of strategies to achieve its aims:

1. *Raising awareness*. Where stakeholders are numerous and diverse the simplest way to reach them is through popular media. The Trust seeks to engage with and educate the general public as to the importance of bumblebees and how they can be helped. If even a small proportion of farmers, gardeners, and other land managers can be influenced then diffuse effects might be achieved across large areas. Awareness-raising has been achieved so far through: articles in numerous popular media, including national newspapers, radio and television; development of a primary-school education pack; dissemination of information through our newsletter which goes to the 7000 trust members; and setting up 'citizen science' recording schemes which encourage members of the public to photograph or identify the bees in their local area and send in records.

2. *Targeted habitat management to support species recovery*. The Trust has dedicated conservation officers for the UK's two most threatened bumblebee species, *B. sylvarum* and *B. distinguendus*. Their role is to promote favourable management and habitat restoration in areas within a 10 km radius of populations of these species. This ranges from fundraising for specific grassland restoration projects, to encouraging farmers to enter appropriate agri-environment schemes. An important component of their work is carried out in partnership with other NGOs.

3. *A reintroduction programme for the extinct* B. subterraneus. This species was last recorded in the UK in 1988, but stock of UK origin persists in New Zealand, to which they were introduced over 120 years ago. Reintroduction attempts are often rightly criticized as requiring substantial resources with limited likelihood of success and rather narrow biodiversity benefits, when the organism to be reintroduced could often be conserved much more cheaply in the places where it survives. However, in this instance the species is a non-native alien in New Zealand so it will not receive aid by conservationists. More importantly, the habitat creation and restoration work being carried out in South East England in preparation for the reintroduction is benefitting several other endangered bumblebee species which still persist in the area, and much else besides. In a collaborative project with other stakeholders and numerous local landowners and farmers, several hundred hectares of species-rich grassland have been created and managed for biodiversity.

4. *Collaboration*. Many other organizations are involved in conservation of bumblebees and their habitats, and it makes sense wherever possible to work together and avoid duplication of effort. For example in the UK a number of organizations have overlapping remits: in addition to BBCT, there is Buglife (a charity devoted to invertebrate conservation with an extensive record of successful policy level engagement, http://www.buglife.org.uk), Hymettus Ltd (an organization providing advice and expertise relating to the conservation of bees, wasps and ants, http://www.hymettus.org.uk), and the Bees, Wasps & Ants Recording Society (who monitoring the changing distributions of species, http://www.bwars.com). A key driver of bumblebee declines is loss of species-rich grasslands, and creation and restoration of this habitat are clear mechanisms for reversing declines. Species-rich grasslands are important habitats for numerous other organisms, so this aspect of bumblebee conservation is eminently suitable for collaborative projects with other conservation NGOs. It is notable that, at present, most conservation NGOs work primarily at a national level, and there is scope for more collaboration between similar organizations in different countries [for example between the Xerces Society in the United States (a not-for-profit organization devoted to the conservation of invertebrates, http://www.xerces.org) and invertebrate conservation organizations in Europe]. It seems probable that these organizations could learn much from one another's successes and failures.

5. *Promoting wildlife gardening*. Gardens cover *c*. 1 million ha in the UK. Members of the public can get directly involved in bumblebee conservation by planting appropriate flowers in their garden. Thus far the Trust has distributed >20 000 packets of wildflower seeds, has produced and sold 8000 copies of a booklet *Gardening for Bumblebees*, has run stands at various national flower shows, and is currently collaborating with a large garden centre chain to develop and promote a range of bumblebee-friendly plants for the garden.

It must be noted that the approaches described here for conserving bumblebees would not be possible with many less endearing organisms. Bumblebees are large, colourful, and furry; they have media appeal. In contrast, most invertebrates and lower plants would be much harder to sell to the general public. Even in the UK where interest in natural history is high, and there appears to be an expert for any taxon, however humble, it would probably be impossible to attract sufficient members to provide adequate core income for a charity for the conservation of, say, nematodes or true bugs. However, as bumblebee conservation requires conservation of highly biodiverse habitats such as species-rich grasslands, they can usefully act as umbrella species for large numbers of less charismatic organisms, including a diversity of other pollinators and economically beneficial species.

Current knowledge gaps with regard to bumblebee ecology of relevance to conservation

Some aspects of the ecology and conservation of bumblebees remain poorly understood, and urgently require research. In particular, we need information on the following areas if we are to design appropriate mitigation/conservation strategies:

1. We currently have no data on population trajectories of either common or rare bumblebee species. BBCT are in the process of setting up a UK-wide transect recording scheme, 'Beewalks', modelled along the lines of the very successful butterfly monitoring scheme, which will begin to address this problem for the UK, but similar schemes are needed elsewhere.

2. At present there is little knowledge as to the impacts of pesticides on bumblebees, although among the non-scientific community this is a topic of great interest and much speculation. In particular, the possible role of neonicotinoids in causing bee mortality has received considerable media attention but few hard data are available. Sublethal effects of pesticides, such as impairment of learning ability which might lead to drastic effects at the colony level, have rarely been investigated.

3. The possible impacts of the global trade in commercial bumblebee nests include competition with native species, hybridization with native species, and accidental spread of pathogens, but these subjects remain poorly researched (reviewed by Goulson 2003; see also Ings, Ward & Chittka 2006). Non-native bumblebees are now established in the wild in many parts of the world (e.g. Chile, Japan, Tasmania) but their likely long-term impacts are not yet known. The relative importance of pathogens as causes of mortality in wild bumblebee populations, and the role of commercial bumblebees in spreading pathogens is poorly understood, although there is evidence that the accidental introduction of a non-native pathogen to North America with commercial bees may have caused catastrophic declines in some native bumblebee species (Winter *et al*. 2006). We know very little about which viruses infect bumblebees, although evidence suggests that honeybees and bumblebees share some viruses.

4. There is growing concern amongst practitioners that entry-level agri-environment schemes offer little concrete benefit to biodiversity, even where a diverse menu of measures is available. Because of limited funding, farmers have to compete for entry into higher level schemes, so uptake of these schemes is inevitably low. In addition, there is often inadequate targeting with respect to the biodiversity which might be present in a particular locality. Also, measures are not always successfully implemented. Some schemes might benefit a small number of species or particular taxonomic groups but not others. There is a clear need to establish which of the existing schemes/options are effective and for what, to establish why implementation is often poor and to balance the conservation requirements of different organisms (Kleijn *et al.* 2006). Given the substantial level of public subsidy for agriculture in Europe, there is an urgent need, but limited capacity, to achieve progress towards effective, balanced delivery of public goods from a productive agricultural sector, before the next 7-year funding programme of rural development in the EU is finalized.

5. We do not as yet know if wildflowers or crops routinely suffer from pollination shortages, or conversely whether pollinator populations remain largely adequate. This remains a fundamental question of huge ecological and economic significance. Recent and high profile health problems with honeybees highlight the danger inherent in relying heavily on a single species for pollination of many crops, and suggest that a less risky approach would be to maintain a diverse natural pollinator population in addition to domesticated bees. If clear evidence could be found that pollinator populations were now so low in agricultural landscapes that crop yields were beginning to be depressed then this would provide a powerful lever to gain funding for pollinator conservation. It would likewise provide an important indicator that conservation of biodiversity requires implementation of measures to support pollinators.

6. Bumblebees are comparatively well-studied in the UK, Western Europe, Japan and to some extent North America but little is known about the distribution, ecology or conservation status of the majority of species which live elsewhere. Citizen Science schemes, such as those operated by BBCT in the UK and the 'Beespotter' programme run by the University of Illinois can provide effective means of gathering these data.

Barriers facing the more widespread implementation of research in conservation

For bumblebees, considerable progress has been made in transferring scientific knowledge into practical conservation, but the gulf between evidence and practice remains in some areas, particularly with regard to policy. A major problem in the UK and elsewhere is that no clear mechanism exists for translating scientific evidence into governmental policy. There is little discourse between governmental organizations responsible for conservation and academics carrying out conservation-related research. Decision-making with regard to policies affecting conservation (including agri-environment schemes) is not transparent. Any academic wishing to have an input into conservation policy would be hard put to identify a mechanism by which to do so. Similarly, small conservation bodies such as BBCT struggle to have their voice heard. Conservation policy tends to reflect the popularity of the respective taxa and the resultant lobbying power of attendant NGOs, but also those taxa that are relatively simple to monitor, such as plants, birds and butterflies, because these provide indicators of long-term change that offer powerful reporting and lobbying tools. That policy decisions are weighted towards certain taxonomic groups, such as birds, is therefore no surprise given their popular appeal and the capacity for dedicated, research, policy, advocacy and advisory skills of associated individual NGOs and the BirdLife partner network. Bees, and other pollinators, have yet to make a similar impact, although that remains a clear aspiration, given their significant economic and ecological importance. It is our view that national governments should do much more to ensure not only that that conservation policy is based on scientific evidence, but that policy is not unduly biased towards conservation of a small number of vertebrate species and instead reflects a balanced approach to conservation of biodiversity and ecosystem function.

There are also issues with the targeting of conservation action. Particular agri-environment schemes such as pollen and nectar strips might be highly beneficial for boosting populations of rare bumblebee species, but only if they are implemented in locations where these rare species are likely to occur. Many farmers have no idea whether they have rare bumblebee species in their locality. Of course this applies to all taxonomic groups. There is considerable scope for improving the value obtained from agri-environment schemes by better targeting of schemes to appropriate areas according to the rare species present, but this requires coordination of knowledge of species distributions, decisions over which species or taxonomic groups to prioritize in each area, and then communication of this information to farmers.

At present, large sums of taxpayers' money are spent in the EU on both ecological research and on conservation (through agri-environment schemes and funds for governmental agencies), yet biodiversity continues to decline according to most measures and our environment is in a parlous state. Signatories to the International Convention on Biodiversity pledged 'to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level'. It is notable that very few of the specific targets agreed in this convention have been met. One might reasonably argue that taxpayers are getting poor value for money at present, and that this could be greatly improved by involving researchers in discussions over environmental priorities and policy (e.g. see Sutherland *et al.* 2010). With a little more joined-up thinking and appropriate use of existing scientific evidence when designing conservation strategies, public money could be spent more wisely and result in much greater benefits to biodiversity and the environment.

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Biosketch

Dave Goulson is an academic specializing in studies of insect ecology and conservation, with a particular focus on bumblebees. Ben Darvill did his PhD with Goulson on the population genetics of rare bumblebees, followed by a postdoc on the factors affecting populations of common bumblebees in arable ecosystems. Together, Goulson and Darvill founded the Bumblebee Conservation Trust in 2006 at the University of Stirling, where its Head Office remains. Darvill now works for the BBCT as Development Manager and Ecologist. Bob Dawson is Conservation Officer for Scotland for BBCT. His previous research concerned bird systematics and genetics before working on a captive breeding project in Morocco. He then worked for RSPB, carrying out ecological research and co-ordinating the Volunteer and Farmer Alliance in South & West Scotland. Pippa Rayner is Conservation Officer for England & Wales with the Bumblebee Conservation Trust. She did her PhD on creation and management of species-rich grasslands and then worked on restoring upland hay meadows in the Yorkshire Dales before bringing her expertise to BBCT in 2009.