# What is the relative value for wildlife of native and non-native plants in our gardens?

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## 1. Introduction

Most gardeners choose their plants for practical or personal aesthetic reasons. It's not much use planting an azalea if you live on chalk for example, or you may have a real love of roses, or be a keen soft fruit grower. Then there are plants you could choose to be statuesque, or give a wild or jungle feel, or to fill dark areas, or hide eyesores. This is clearly your personal choice, but if you want to attract lots of wildlife into your garden, are there other factors you should consider before investing in plants?

The use of ordinary garden plants, most of which are not naturally found in Great Britain, is one of the few controversial aspects of wildlife gardening. Many earlier books on the subject, and some current advocates, state that wildlife gardens should be planted as much as possible with native species found naturally in this country. On the face of it this makes sense, since wild animals should be adapted to wild plants, but the more we learn, the clearer it becomes that the issue is not as simple as that.

It is important to take a pragmatic and evidence-based approach to non-native plants in gardens. If the facts suggest that gardens planted mainly with wild plants are much better for wildlife, this is what we should recommend. If however the evidence suggests that typical gardens containing a majority of non-natives can be good resources for wildlife - or even better in some respects, then our advice would reflect this too. If typical gardens are indeed valuable for wildlife, then all gardeners can aspire to bring a concern for wildlife within the various aspirations of their own gardening.

In this article we examine the nature and origins of our native plant species, how diverse they are compared with the rest of Europe, and the evidence for how pollinators and herbivores interact with native and non-native species.

## 2. What are "native species?"

A native species (plant or animal) is one that has arrived in an area (through dispersion or having evolved there) *without the involvement of people*. Human involvement could be quite deliberate, as in the introduction of food crops from another continent, or accidental, as in the introduction of black rats or the "American" cockroach, (which actually originated in Africa). As we will see below, this simple definition has been stretched recently to accommodate new categories of species that arrived with human help in the distant past.

## 3 How long have British native species been here?

British native species arrived here in a relatively short period after the last Ice Age, during which the British Isles were largely covered with thick ice sheets. The ice not only destroyed all vegetation, but much of the soil as well, leaving when it melted a blank canvas for recolonization.


**Extent of ice sheets during the last glaciation.**[1]

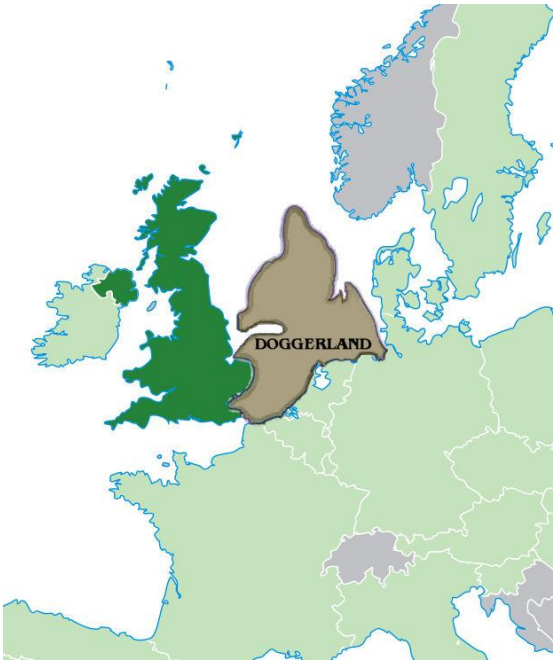
South of the ice were expanses of dry tree-less tundra vegetation on permafrost. Until recently it was assumed the vegetation was dominated by grasses, but recent work suggests it was mainly forbs (non-grass vascular plants), which supported ice-age megafauna such as the mammoth and woolly rhinoceros[2]. This whole cold-adapted ecosystem disappeared as the ice melted and the ground thawed, leaving the land vacant for new colonists from Europe.

Conditions began to warm about 20,000 BC, but there were two further cold spells, and the icy conditions finally ended only about 9,500 BC. It is unlikely that any permafrost plants survived the warming, but some, such as mountain avens (*Dryas octopetala*), were very early colonists marking the first (temporary) stages of warming. As glaciers retreated, sea level was initially very low at about 120m below present[3], and large areas of continental shelf were dry land, linking the UK to continental Europe. The early colonists, however, were highly cold-adapted species, and these became extinct or migrated north as temperatures rose.

As sea level rose rapidly, the lower shelf areas were soon flooded, but the shallow North Sea and Dogger Bank survived as low or marshy land for a long time. This area has been termed "Doggerland", and it formed a land-bridge across which the plants, animals and people that repopulated Britain migrated. Cold-tolerant, and fast-reproducing species were the first to arrive, and others followed steadily until the land-bridge finally disappeared about 5,800 BC[4] separating Britain from the continent of Europe. This event was preceded about 6150 BC by

a massive tsunami from an underwater landslide off south-western Norway, with a 20 m wave surge which must have devastated Doggerland and may have effectively ended migration[5].

**Doggerland 8,000 BC Wikimedia Commons**




This means the entire native fauna and flora of Great Britain had only about 3,700 years to become established, and the slower- dispersing and more warmth-dependent species would have been the last to arrive. Many potential recolonisers never made it.

## 4. How rich is the British native flora?

British plants are among the most highly documented in the world, but our total species list is remarkably small. The British Isles are part of the Western Palaearctic ecozone, which includes all Europe and countries east to the Urals, the near east and North Africa. We are a medium-sized island group towards the north of the region. Our island status gives a moderate climate relative to central northern Europe, and our fauna and flora should be similar to that of the adjacent mainland. Great Britain has 1,625 native plant species, compared with 2,656 for Germany and 4,395 for France[6]. The Netherlands have about 1,460 species[7], despite being one fifth the size of Britain, and lacking high-altitude or geologically varied habitats. Ireland, which was cut off from Great Britain about 14,000 BC[8], much earlier than the latter separated from Europe, has only 1,022 native species.

The poverty of British species is reflected in the animals too, for example the British butterfly list has only 59 species[9], while the Netherlands have 70 natives[10]. In Upper Normandy, the Seine-Maritime Department, with an area of less than a third that of Wales, has 89 butterfly species[11].

## 5. Endemic species found only in Britain

Long-established islands often have large numbers of “endemic” species which have evolved there in isolation, and are not found (naturally) anywhere else. As an example, over a quarter of the 1,992 vascular plants found on the Canary Islands are endemic to these islands and so

are some 44% of the arthropods[12]. Where endemic species occur, they are of particular importance for conservation, especially if they have not been introduced anywhere else. Chinese water deer, which were introduced to Britain in the early 1900s, are threatened in their native region, and the British population, despite being an alien species, is important since it accounts for 10% of the total world population[13].

Britain has not been isolated long enough to build any significant level of endemism at the level of non-interbreeding species. While forty seven species of plants are listed as endemic to Britain[14], most are in the very variable and taxonomically difficult genera *Euphrasia* (eyebright), *Limonium* (sea lavender) and *Sorbus* (rowan and whitebeam), where species status is very unclear. Many of these apparently endemic "species" are probably locally isolated populations of other species. Only 15 seem definitely accepted as species in their own right, and two of these arose very recently by hybridisation (Welsh ragwort *Senecio cambrensis* and common cordgrass *Spartina anglica*).

Endemism is even rarer in the more mobile animals. The Scottish crossbill (*Loxia scotica*) is probably the only vertebrate species endemic to Britain, where a tiny population lives in the Caledonian Forests of Scotland. There are several endemic sub-species of birds and mammals which have evolved small differences from the main species pool through isolation. Several whitefish (*Coregonus*) and char (*Salvelinus*) species have been named from various deep cold lakes in Scotland, Ireland, Cumbria and Snowdonia, where they are relicts of the first cold-adapted recolonisers after the Ice Age. The classification of these fish is very uncertain and they are probably best viewed as locally divergent varieties or subspecies. The only rivers where freshwater fish (other than those that arrived from salt water) are indigenous, are catchments bordering the eastern English Channel and the southern North Sea where they arrived through the land bridge to Europe. In all other rivers they are considered to be introduced[15].

The tineid moth *Eudarcia richardsoni* is known only from Portland in Dorset. The Lundy cabbage flea beetle *Psylliodes luridipennis* is restricted to the island of Lundy, and its food plant Lundy cabbage *Coincya wrightii* is also a genuine endemic species to Lundy.

We can conclude that Britain's native flora (and fauna) is impoverished and not at all unique. There are many European species which could flourish here, and in the context of climate warming, we should consider identifying and welcoming such "future natives"[16].

## 6. Origins of our non-native plants

The first plants introduced to Britain by humans arrived with Neolithic farmers bringing near-eastern crops and associated arable weeds. The list grew steadily through to the end of the Medieval period, and then accelerated prodigiously as trade brought garden and crop plants from the Far East and the New World. See our page on Garden History for more about this.

There are 1,798 non-native plant species naturalised (ie surviving in the wild) in England[17] , but there are tens of thousands growing in gardens, and in 1992, 55,000 varieties were listed[18] The RHS Horticultural Database, which includes many horticultural varieties as well as species, lists for example 6,413 entries for *Narcissus* (daffodil) and 2,012 for *Malus* (apple)[19]. Although most naturalised (and most invasive) plants are "ergasiophygophytes[20]" which

escaped from cultivation, the vast majority of garden plants stay where they are put, and do not thrive outside gardens.

Most of the introduced garden plants, especially the earlier arrivals, came to us from the Western Palaearctic region, and Jennifer Owen found that 91 of the 214 non-native plants in her garden were from this region. Another 59 originated in the Americas, and 28 were from Asia[21].

Many terms are used to describe non-native plants. Those arriving from Europe, (some of which one could argue would have been here already had the English channel been even shallower), can be termed near-natives, and most are in the same genera as existing native plants. Then there is the somewhat loaded term "alien", which implies "undesirable" to some ears, and "exotic", which is perhaps more appropriate for plants from different hemispheres or continents. Many exotic plants in common usage are spectacular tropical species that need indoor or greenhouse care.

## 7. Invasive non-native species

Ecologists have always been in a bit of a bind over non-native plants. They are automatically treated as suspicious because "They aren't proper British species", and a few (108 according to the RHS[22]) of the naturalised species cause problems in the countryside by outgrowing or interfering with native plant communities, or even damaging buildings. Twenty six of these are sufficient problem to be listed in Schedule 9 of the Wildlife and Countryside Act, and may not be planted in the wild. In Scotland, legislation has gone further by forbidding: "*Planting or otherwise causing to grow any plant in the wild outwith its native range*." However, even in Scotland, agricultural land, and private or public gardens are not generally considered to be 'in the wild'[23].

There is great concern, here and across the world, of the impact of non-native invasive species[24]. Importation of these seven species is already banned through the European Union through Annex B to Council Regulation (EC) No 338/97 (1966):

| | |
|---|---|
| *Callosciurus erythraeus* | Red-bellied tree squirrel, |
| *Sciurus carolinensis* | Grey squirrel |
| *Sciurus niger* | Fox squirrel |
| *Oxyura jamaicensis* | Ruddy duck |
| *Lithobates (Rana) catesbeianus* | American bullfrog |
| *Chrysemys picta* | Painted turtle |
| *Trachemys scripta elegans* | Red-eared terrapin |

The EU is currently proposing wide-reaching legislation to ban the establishment of species outside their native range[25], although how the native range is arrived at is not yet clear, and species migrating of their own accord will not be affected.

Invasive non-native species in Great Britain have been estimated to cost £1,678,434,000 per year[26]. This figure includes the cost of managing species, as well as other direct and indirect costs. The analysis does not include any positive economic impact of non-natives, which includes nearly all our crop species, and the huge chicken and egg industries.

An analysis of the positive economic benefits of non-natives would start with the table below, based on UK figures[27,28,29].

| | |
|---|---|
| Wheat | £1,200,000,000 |
| Barley | £525,200,000 |
| Rapeseed | £557,500,000 |
| Potatoes | £11,471,000 |
| Oats | £63,705,000 |
| Peas | £52,000,000 |
| Beans | £121,590,000 |
| Sheep | £465,900,000 |
| Poultry | £1,890,000,000 |
| Eggs | £559,000,000 |
| **Total** | **£5,446,366,000** |

The figures for eggs and poultry include a tiny component for domestic ducks and geese which could be viewed as derived from native species. It would appear that the economic benefits of non-native species easily exceed the costs three-fold, although many conservationists would probably see little merit in this argument.

The concern about *invasive* species has certainly coloured thinking about *all* non-natives, including those which are not invasive in habit. For some naturalists all such species are automatically suspect, in case, perhaps through climate change, they might break out and become a problem. We should not let this perception get in the way of an evidence-based assessment of the role of these species in domestic gardens. This is not the place to discuss the evidence behind some concerns of invasive species impacts, which are well analysed elsewhere[30]. Some native species are also a tremendous nuisance to conservationists (and gardeners), especially through encroachment onto managed habitats. These species include nettles, blackthorn, hawthorn, willow, birch and bracken. This important issue is discussed from the gardener's viewpoint in our web page Plants to avoid!

## 8. Shifting the goalposts - archaeophytes and crayfish.

Although non-natives are suspicious, and a few are a problem, conservationists *really like* some of them. In particular, arable weed plants like pheasant's eye or cornflower that were imported into Britain by Neolithic people are very attractive, and now very rare. These plants are actively conserved and some are designated Priority Species with their own action plans. These old invaders are tolerated, and now termed archaeophytes ("ancient plants") to distinguish them from neophytes or "new plants", and the cut-off is taken as 1500 AD. This feels very like special pleading so we don't have to tar these plants with the name "non-natives". Properly applying the cut-off means that species like sweet chestnut, asparagus, quinces, ground elder, sycamore and figs should be considered archaeophytes too.

A similar argument applies to some animal species. The "native" crayfish *Austropotamobius pallipes* is under massive threat of extinction in Britain as the result of the spread of the signal crayfish *Pacifastacus leniusculus* introduced here in the 1970s. Very considerable effort goes into conserving this species, although it is now quite clear it was a late introduction from Europe. If it arrived before 1500, it can be regarded as "indigenous" (subtly different from native) but if after 1500, it would be a new alien arrival, hence suspicious and

not of conservation significance. Fortunately, enough documentary evidence has been found[31] to suggest that it was introduced about 1460, *just* before 1500, so freshwater conservationists can heave a sigh of relief.

Finally, it is worth noting that some species not native in Britain today, were part of our wildlife in previous interglacial periods. A contentious example is *Rhododendron ponticum* which was native in the British Isles in the last interglacial[32]. The modern species (actually a hybrid *R. superponticum*) is a major problem in woodlands throughout Britain. Another is the common vole *Microtus arvensis* which was found here during the last interglacial[33] but failed to recolonize mainland Britain after the last Ice Age. Ironically, this species is abundant on Orkney, where it has evolved to a subspecies *Microtus arvensis orcadensis* , but because it is thought to have hitched a ride with the Vikings, it is described as non-native[34]. It is mind boggling to consider how an animal that evolved on an island cannot be native to it, but of course since the introduction was well before 1500, it is indigenous or an honorary native anyway.

It is fair to conclude that while the concept of native and non-native was once clear and simple, it is far from the case now.[35]

## 9. Role of non-native species in supporting garden wildlife

We have seen that the British flora and fauna is impoverished, and that the distinction between native and non-native species isn't as clear cut as it might seem. It is clear that there are some invasive non-natives we should keep out of our gardens just as we would control invasive natives like bramble. What does this mean for our wildlife-friendly planting?

### 9a. Ordinary gardens and wildlife: how do non-natives fit in?

There is no doubt that our native animal wildlife has depended primarily on native plants since the Ice Age. It is perfectly logical to start from the premise that this is what we should grow in our gardens if we really want to help wildlife. But first let's remember, that gardens have many roles, and that even for keen naturalists, sustaining wildlife is only one purpose for gardening. We all like to have bright, strongly flowering "garden worthy" plants, and a succession of them through the whole gardening year. It is therefore completely reasonable to plant non-native and even exotic species alongside natives if you wish, because it is *your* garden.

Secondly, there is a mass of evidence that non-native species are of value to wildlife in gardens. Ordinary gardens are overwhelmingly planted with non-native species. 70 % of the 1056 plant species recorded in urban gardens in five major UK cities were exotic in origin[36] and yet typical gardens are full of wildlife.

Jennifer Owen found evidence that up to 8,450 species of insects alone could be collected in her ordinary suburban garden[37]. See our page on Garden Biodiversity for more information on the diversity of garden life. The Sheffield-based BUGS project paid special attention to the role of native and non-native plants in relation to the richness and abundance of garden wildlife species. Surprisingly, little relationship was found between the number of native plant species (planted deliberately or weeds) in gardens and the number of animal species found in the corresponding gardens[38]. When the numbers of individual invertebrates in various groups were examined, there was again no correlation except in the case of

pollinating species of solitary bees and hoverflies where there was a strong link to the number of native plants present[39].

It is worth considering how plants and insects (the vast majority of garden wildlife) interact:

| Plant resource | Natives needed? | Comments |
|---|---|---|
| Shelter | Not likely | Plant structure is more important than species |
| Pollen and nectar | Evidence suggests not | Although some insects require particular flower shapes, these are found in non-natives as well as natives |
| Leaves for herbivores | Sometimes | Many insects eat a large variety of plant species, but some are specific to one or two native plants. |
| Dead material for detritus eaters and decomposers | Not likely | Palatability is more related to woodiness, and the amount of food available relates to plant size not native status |

Assuming it is correct that shelter and dead material resources are not greatly influenced by native or non-native status, it is worth looking in detail at pollinator and herbivore needs.

### 9b. Pollinators and non-native plant species

There is growing concern about global pressures on pollinating insects and the impact this could have on ecosystem services.[40] Much recent evidence suggests that gardens with their great variety of strongly flowering non-native plants giving a succession of forage through the year, are very beneficial for pollinators. Beekeepers now generally find some of the best yields of honey come from urban rather than rural areas, as the abundance of country wildflowers has declined. Countryside wild pollen and nectar sources are usually scarce in midsummer while gardens continue to produce.

The majority of studies have used bees, especially bumblebees, to assess the relative merits of native and non-native garden plants. Bumblebees are important pollinators, but declining in numbers. In a landscape-level study in Hertfordshire[41], Dave Goulson's team found that the area of gardens within a 750 and 1000m radius positively influenced nest survival in *Bombus lapidarius*. For *Bombus pascuorum*, the number of nests towards the end of the year was higher at those sites with more gardens within a 500 and 750-m radius. They concluded that gardens now provide a stronghold for bumblebees in an otherwise impoverished agricultural environment; and that the positive influence of gardens on bumblebee populations can spill over at least 1 km into surrounding farmland.

Another study by Goulson[42] placed nests of *Bombus terrestris* in conventional farmland, in farmland with flower-rich conservation measures and in suburban areas. Gardens provided a greater supply and diversity of bee resources than farmland, and probably support larger populations. Surprisingly, conservation planting designed to increase farmland biodiversity had little measurable impact on nest growth of this bumblebee species, probably because *B. terrestris* forage over a larger scale than that on which single farms are managed.

Gardens seem to be enabling the common bumblebee *B. terrestris* to adapt to all-year breeding in some urban contexts. An ingenious experiment in London used walked transects, micro-balances and radio tags to measure foraging success of worker bees in the winter of October 2007 to March 2008.[43] Queens and workers were found throughout the winter, suggesting a second generation of bee colonies active during the winter months. *Mahonia* and other mass-flowering shrubs were found to be important food resources. The foraging

experiments showed that bees active during the winter can attain nectar and pollen foraging rates that match, and even surpass, those recorded during summer. It is clear that *B. terrestris* in the UK are now able to utilise a rich winter foraging resource in urban parks and gardens.

The National Bumblebee Survey examined bumblebee nesting in gardens, short grassland, long grassland and woodland, and along linear habitats of woodland edge, hedgerows and fence lines[44]. Nest densities were high in gardens (36 nests $ha^{-1}$), and linear countryside habitats (20–37 nests $ha^{-1}$), and lower in non-linear countryside habitats (woodland and grassland: 11–15 nests $ha^{-1}$). Gardens provide an important nesting habitat for bumblebees in the UK, while installing more fences and hedges could help rural bumblebees.

Studies around Lyon in France[45] found 291 species of wild bee, one third of the French species list. Urban areas had high bee diversity, but the largest number of species was found in areas where the amount of concrete and other hard surface did not exceed about 50%, although there were more cavity-nesting bee species in urbanized areas than in more natural ones with less hard surface.

Research from the Laboratory of Apiculture & Social Insects at the University of Sussex has shown that although attractiveness of alien garden plants to bees varies enormously, those species and cultivars that proved best for pollinators are very good indeed[46].

In Southern Sweden a study in an intensive agricultural area found that both the abundance and number of species of wild bees, and the seed set of the native plant *Campanula persicifolia*, were higher in samples close to gardens (<15 m) than further away (>140 m). The study concluded that private gardens are an important landscape-wide resource for pollinators and that without gardens to boost pollinators, there is inadequate pollination of wild plants in modern agricultural landscapes[47]. A similar finding came from northern Germany[48] where gardens at the urban-rural interface had the highest diversity of wasps, and the largest numbers and diversity of bees, compared with inner city or purely rural sites, indicated that the presence of gardens (with their non-native flora) is a benefit for pollination in adjacent crops. A British experiment comparing tubs of two species of plants grown in gardens or adjacent to arable fields showed that seed set (and hence successful pollination) was generally best in garden settings[49].

Somewhat at variance to these studies, Adam Bates and his colleagues investigated bee and hoverfly diversity and abundance in urban, suburban and rural areas around Birmingham[50]. They used churchyards and cemeteries as their study sites, because these are fairly consistent in all landscape settings. While they found no difference in the pollinator diversity or abundance between urban and sub-urban sites, the rural sites had consistently larger numbers and more species than either urban set. It is not however clear whether the rural sites studied were within a kilometre of gardens as in the studies above.

Research in southern New Jersey found that bees collect pollen from both alien and native plants in proportion to a plant's abundance in the landscape[51]. In urban habitats therefore, bees make greater use of non-native plants because they are more commonly available, not because they are preferred. As Rachael Winfree, one author of the study said "I don't see why bees would know or care whether a plant was native or exotic."[52]

A study by Plymouth University scientists studied the use made by five bumblebee species of 119 plant species in gardens[53]. They distinguished British native plants, non-British but

Palaearctic species, non-Palearctic species where bumblebees occur naturally, and exotic species from the southern hemisphere where no bumblebees are naturally found. Looking at all plant species as a whole, bumblebees primarily selected from the pool of available plants according to the abundance of their flowers, in keeping with the New Jersey study findings.

When only the plants actually used by bees were separated out, there was some preference for British native plants over other Palearctic species, but only because of "weed" plants included in the native total. When only cultivated plants were considered this link disappeared. The relative value of native plants therefore depends on how you define "garden plants".
Bee species varied in their choices. Three species showed no preference for "local" origin plants, and *Bombus pratorum* and *B. terrestris*, preferred non-Palaearctic plant species, with the former never found foraging on British natives. Only *B. hortorum* and *B. pascuorum* showed a preference for biogeographically local plants, the latter devoting over 70 % of its visits to Palaearctic species even when weeds were excluded.

The authors concluded that "*it is not simply a question of growing species native to the particular biogeographic range in question… but that any showily flowered plant is likely to offer some forage reward.*" They did however point out that cultivated plants may not be enough for all bumblebee species: "*traditional garden plants alone may not fulfil all the dietary requirements of the urban pollinator community. Native weed species* (bramble, smooth hawks-beard and creeping buttercup) *attracted visits from all five bumblebee species."* The gardens studied contained typical levels of weeds, and these seemed to provide adequate resources for the more specialist bumblebees.

Studies on pollinators other than bees and hoverflies are more limited. A major citizen science project conducted throughout France[54] examined the flowers visited by a large number of butterfly species using submitted photographs for evidence. The scientists devised a simple "native preference index" calculated by counting the number of photos where a butterfly is feeding on native plant species and comparing it to the total number of pictures taken for this butterfly. The native preference index showed that specialist feeding butterflies, with long proboscises were seen more often on exotic flowers. This would lead one to suppose that such species might be more common in urban areas where gardens would contain more exotic species. However, this was not the case and generalist feeder species such as the speckled wood or the green-veined white occurred more frequently in urban habitats than specialist butterflies like the swallowtail and orange tip. In this case it is likely that other factors such as larval food plant availability limited specialist species form urban areas where their adult resources were widely available.

Rachael Winfree and her colleagues perhaps summed it up through a study on the response of pollinators to land-use change[55]. They concluded that the main determinant of response to land-use change across pollinator groups is dietary specialization, with pollen specialist bees, and fly and butterfly larval host specialists, being most sensitive.

All of these studies used real garden settings, with predominantly non-native species typical of gardens. Would planting more natives be of value? A telling experiment in New York[56] showed that adding 70 plants of 7 species of native flowering plants to urban gardens over two years did not increase the numbers of bees, butterflies and predatory wasps recorded. Instead, they noted that butterflies and leaf-cutter bees heavily utilised introduced ornamental and crop flowers in these gardens, even when native flowers were present. They suggested that much larger scale changes in garden planting may be needed for a discernible effect.

In general, the evidence suggests that most pollinators are fairly indiscriminate in their preferences for flowers, and that they favour prolifically flowering plants, regardless of native and non-native status. Most of the evidence however relates to bees, which are specialist pollen and nectar users. Bees rely on flowers for food through their whole lifecycle, so flower-rich gardens are likely to suit many species with fairly general needs. Other pollinators like butterflies and hoverflies are common in gardens, but have additional resource needs in their larval stages. The larvae of many hoverflies are predators of aphids and so are generally welcomed by enlightened gardeners. These hoverflies could maintain their whole lifecycle resource needs in gardens, so, like bees, gardens offer a favourable habitat for them. For butterflies, this is less clearly the case, since many are quite specialist in their larval food requirements, although the adults of these species may still forage for nectar in gardens.

### 9c. Herbivores and non-native plant species.

Much less work has been done on the response of herbivorous insects to non-native plants. Somewhat trivially, the huge array of pest control chemicals on sale in garden centres shows conclusively that non-native garden plants and crops are indeed eaten by insects. The studies that have been published are more equivocal than those on pollinators, and have come to some contrary conclusions.

Jennifer Owen's important studies already cited showed a great deal of use of non-native plants by herbivores in her garden. Of the 15 plants eaten by most moth species, the most popular foodplant was Buddleia with 18 moth species feeding on it. In order the plants were:

1. Buddleia (*Buddleja davidii*)
2. Shrubby potentilla (*Potentilla fruticosa*)
3. Cherry plum (*Prunus cerasifera*)
4. Roses (*Rosa* spp.)
5. Spotted dead nettle (*Lamium maculatum*)
6. Crack willow (*Salix fragilis*)
7. Flowering currant (*Ribes sanguineum*)
8. Hawthorn (*Crataegus monogyna*)
9. Shasta daisy (*Leucanthemum* × *superbum*)
10. Gooseberry (*Ribes uva-crispa*)
11. Sweet marjoram (*Origanum majorana*)
12. Michaelmas daisy (*Aster novi-belgii*)
13. Perennial candytuft (*Iberis sempervirens*)
14. Nettle (*Urtica dioica*)
15. Parsley (*Petroselinum crispum*)

At least 11 of those 15 are introduced, even if we give the benefit of the doubt to crack willow, which is only very doubtfully a British native, and to *Rosa* (a native genus, but few roses in gardens are native). In short, there's little sign that moths in British gardens are dependent on native plants. Of course, no-one would claim that that's true of the wider landscape, where – by definition – native moths eat native plants. In the UK and in the US,

the largest numbers of insect herbivores are supported by big, common trees, with oaks coming out top in both regions. But gardeners don't often grow oaks, and what is true for trees isn't necessarily true for shrubs and herbaceous species. Nor are the Lepidoptera that visit gardens a random draw from the native fauna; they are – inevitably – the most mobile, adaptable and polyphagous (able to eat many plants) species. And there isn't much sign that you can do much about that, *whatever* you choose to grow.

Jennifer Owen also noted that some plant families are much better than others as food for native insects. Rosaceae stood out, but Lamiaceae, Grossulariaceae, Salicaceae and Caprifoliaceae were also good, and it didn't seem to matter much whether the individual species was native or alien. Across the board, 68 species of moth larvae used 115 of the 360 plant species in Owen's garden. 46 moths used 40 native species (out of 146 available), and 38 species used 75 non-native species, out of 214 species available. This means that moths used 35% of the non-native, compared with 27% of the native species. This difference is not statistically significant, but it is clear that non-natives are definitely not disfavoured by the moths.

A large body of work, accumulated over many years by American ecologist Douglas Tallamy has provided evidence that non-native species in North America are poor food resources for herbivores. Six such studies are outlined below.

Burghardt, Tallamy and Shriver[57] compared 6 pairs of suburban properties in southeastern Pennsylvania where one property in each pair was planted only with native plants and the other exhibited a more conventional garden planting with a natives and non-natives. Native gardens supported significantly more caterpillars and caterpillar species and significantly greater bird abundance, diversity, species richness, biomass, and breeding pairs of native species. Of particular importance is that bird species of regional conservation concern were 8 times more abundant and significantly more diverse on native properties.

Using four experimental gardens specially planted with trees and large shrubs, another study[58] compared butterfly and moths using locally native plants, non-natives from the same genus as natives, and completely unrelated non-natives. They found non-native plants supported significantly fewer caterpillars of significantly fewer specialist and generalist species even when the non-natives were close relatives of native host plants, although the difference here was less.

A similarly planted garden experiment also using woody plants[59] found that native plants supported larger and more diverse herbivore communities, and this was more marked in insects with chewing mouthparts and herbivorous larvae than insects with piercing-sucking mouthparts and adult herbivorous adults. The reduction in herbivore populations on non-native plants was smaller, but still significant, if species had a close native relative.

Another approach looked at the experimental rearing of caterpillars of four large moth species (regarded as generalist feeders) on native and non-native tree foliage[60]. It found with only one exception that the caterpillars offered plant species with which they have had no evolutionary history either died or developed at extremely slow rates. On the basis of this very limited trial, the authors made the correct but surprisingly wide-reaching assertion that "We found no evidence that the alien plants pervasive in the mid-Atlantic region of North America can support a productive fauna of insect generalist herbivores".

Tallamy and Shropshire[61] used records from published papers on the feeding habits of North American butterflies and moths to rank all 1,385 plant genera by their ability to support numbers of these species. They found woody plants supported more species of moths and butterflies than herbaceous plants, and that native plants supported more species than introduced plant. These differences were highly significant.

In contrast, another study[62], looking at a single plot planted with native and non-native trees and shrubs in Delaware, failed to find significant differences between the number of species of herbivores on native, relatives of natives and alien species of herbivores, although overall biomass was greater on natives. The authors considered their sampling may have been biased to leaf eaters rather than internal feeders and that this may have explained their inability to show more diversity in native plants.

Some of this work needs to be approached with caution, at least as it applies to gardens. It is all based on study of herbivores on tree and woody shrub species, and gardens contain many herbaceous plants. Tallamy and Shropshire used published records of larval food plants of Lepidoptera, which are almost useless for plants in gardens, whether native or alien. Jennifer Owen found that rare UK native *Potentilla fruticosa* was one of the larval food plants most commonly used by moths in her garden, yet in the wild it does not register as a moth food plant at all. The online phytophagous insect database[63] reports nine moths eating it, but all these records are from Owen's garden. It's not clear whether this is because the plant is rarely encountered by entomologists in the wild, whether it acquires new herbivores in gardens that it would never meet in the wild, or perhaps both. Whatever the reason, published insect herbivore records are a poor guide to what goes on in gardens, and more studies would be very useful.

For much the same reason, it's also not clear how we should interpret the results from experiments conducted on farms or in other rural sites as in most of the other studies above. Burghardt, Tallamy and Shriver consciously selected pairs of suburban properties with high or low numbers of native plants and the abundance and richness of birds and of Lepidoptera larvae were greater on the properties with more native plants. Nevertheless, this study illustrates the difficulty of accounting for uncontrolled variables when using existing sites: plant diversity of the 'high-native' sites was almost twice that of the 'low-native' sites, and the authors note that "*Although these results suggest that the evolutionary origins of the plants is the source of differences in avian and lepidopteran abundance and diversity in our study, a field experiment rigidly controlling for plant richness and diversity would more clearly isolate these variables.*"

In complete contrast, Arthur Shapiro has spent a lifetime studying Californian butterflies and has come to some startling conclusions about the butterflies of his home town of Davis[64]. Davis is a medium-sized town and its butterfly fauna, intensely monitored since 1971, may be the best-known in the USA. Thirty-two species of butterfly live and breed in Davis, all of them Californian natives except the ubiquitous "cabbage white" *Pieris rapae*. Twenty-nine feed on alien plants at least some of the time, and 13 have no known native host plants in the town. Only three of Davis's butterflies have no known alien host plant in the town. The Anise Swallowtail, a spectacular and beautiful insect, depends almost entirely on fennel, a weed introduced from Europe. If fennel were eradicated, as is sometimes suggested, the citizens of Davis would lose their most iconic butterfly too.

The reason Davis's native butterflies are now so dependent on alien plants seems to come down to a combination of climate and history. Davis's butterfly fauna is now very different

from that of the surrounding countryside. The country around Davis, typically for a Mediterranean climate, is rather dry and supports butterflies that breed once annually, in the Spring, before the hot dry Summer. The urban butterflies breed all summer, and probably previously lived in local marshes (where that life-cycle is possible, owing to a continuous supply of water), before they were all drained for agriculture. In a Mediterranean climate, gardens are now their only refuge.

Studies in the Netherlands came to a similar conclusion[65]. About 10% of plant species in "natural" habitats there are non-native introductions. Sampling in forests, gardens and parks, the authors collected 99 species of herbivorous insects feeding on non-native trees, shrubs and herbaceous plants. The species fell into the following insect groups:

| **Insect Group** | **Species found** |
|---|---|
| Coleoptera (beetles) | 24 |
| Diptera (flies) | 9 |
| Hemiptera (bugs) | 19 |
| Hymenoptera (sawflies and gall wasp) | 7 |
| Lepidoptera (moths) | 39 |
| Thysanoptera (thrips) | 1 |

Most insects were chewers, sap feeders or leaf miners. Most were found on only one non-native plant, but some used up to 5. The leaf miners and gall formers were of particular significance, because once feeding on a plant, they are unable to move to another. This doesn't of course mean all non-native plants can sustain insects; no herbivores were found on *Rhododendron ponticum* for example, while 60 species used non-native black cherry *Prunus serotina*.

We don't yet have a good study of what plant sucking herbivores eat in gardens, but there is a recent study of bugs (insects with piercing mouthparts) on trees in Bracknell[66]. Some of these trees were in parks or on waste ground, but most were on roundabouts. There was huge variation between different species of trees; so that it quite overwhelmed any general distinction between natives and aliens. The best trees, in terms of numbers of species and individuals of bugs, were natives. The top five trees on both counts were native, with hawthorn, silver birch, ash, oak and goat willow all supporting lots of bugs of many different species. On the other hand, the *worst* trees also tended to be natives; in terms of numbers of species of bugs supported, four of the bottom five were natives. The very worst tree for both numbers and diversity of bugs was holly, and beech and lime weren't much better. So exotic trees weren't exactly bad, they were just kind of middling, with apple and Swedish whitebeam among the best.

We don't know if the few exotic trees that turn up on Bracknell roundabouts are representative of the huge diversity of trees in gardens, or even whether roundabouts behave like gardens. Nor do we know how well foreign congeners of outstanding natives like silver birch and hawthorn would perform, although an indication comes from a recent study in the Czech Republic which looked not at the herbivores, but at the level of herbivory[67]. In nine pairs of plant species (each in the same genus, but one a Czech native and the other an alien), the researchers measured visible damage to leaves, stems and seeds, usually caused by caterpillars or molluscs, and the presence of herbivores that are easy to spot: leaf miners,

stem borers and aphids. Interestingly, natives and aliens did not differ in the total amount of damage, or in the number of different *kinds* of damage (a very rough guide to the diversity of herbivores). So in this study at least, native plants are no better for native herbivores than closely-related aliens. Total damage is probably the best predictor of the quantity of caterpillars, bugs and beetles, which is what matters to the birds, wasps, spiders and other predators that depend on them.

The bottom line is that nativeness *alone* seems to be a poor guide to value for native wildlife. There are two good theoretical reasons why some insect herbivores will eat some non-native plants. First, herbivores' choice of food plants may be sufficiently plastic that they can move immediately onto related aliens. Second, over the longer term, native herbivores may evolve to exploit new food plants. In either case, the host shift is more likely if (a) the insect has a wide host range, and (b) the alien plant is closely related to its usual native host(s).

In Central Europe for example, the geometrid moths *Eupithecia virgaureata* and *E. absinthiata* eat (among other things) various native mugworts and ragworts (*Artemisia* and *Senecio* spp.). In recent decades, both have expanded their diets to include North American goldenrods (*Solidago canadensis* and *S. gigantea*). Similarly, the pine-lappet moth has moved onto the non-native Douglas fir. Using information like this, ecologists have been able to predict known host shifts of Central European Lepidoptera with surprising accuracy[68].

One conclusion to emerge from this work is that, unsurprisingly, and consistently with some of the American studies, non-native plants that have native host plants in the same family are more likely to be used as larval host plants by Central European butterflies and moths, compared to non-native plants that lack native hosts in the same family. What is perhaps more surprising is the relatively high level of use of plants in *both* groups. Around half of plants without native relatives in the same family are eaten by these Central European Lepidoptera; among plants that do have native relatives, that figure rises to 75 %. In other words, the results support Jennifer Owen's anecdotal observation that if a plant is in the right family, it doesn't matter a lot whether it's native or alien. This would explain the apparently bizarre adoption of exotic fuchsia as a food plant by the large elephant hawk moth *Deilephila elpenor*. Both *Fuschia* and willow herb, the "normal" choice of the caterpillars, are in the plant family Onagraceae. In this context, it's worth noting that the Sheffield BUGS project found that 93.2 % of species in the average individual private garden belonged to families with native relatives[69].

Note that the observations on which the Central European study were based came from the usual natural conditions, i.e. not from gardens, and we've already seen that such observations underestimate the ability of moths to use 'unusual' hosts in gardens. Finally, also note that the study was able only to use host records of alien plants that currently exist; both logic and previous experience suggest that natural selection will produce more of these in the future.

## 10. Conclusions

There is little evidence that would persuade the Wildlife Gardening Forum to advise gardeners in the UK and Ireland to use native-only planting in their gardens. It is clear that pollinators, especially bees, find plenty of excellent forage in ordinary gardens, and that gardens have a very positive effect on their diversity and populations. Likewise, allowing for some negative studies which limited the plants investigated to woody species, there is plenty of evidence that non-native garden plants species are greatly used by herbivores, and in some

cases more than natives. The one study that added extra native species to typical gardens found it made little difference. It may also be true that if all gardens grew only native species appropriate to their local conditions, we would lose the tremendous diversity of structure and habitat which we know supports biodiversity in typical gardens. We would certainly lose the continuous flowering from early spring to late autumn that makes our existing gardens so good for pollinators.

This does not imply that some native plant species aren't both garden-worthy in appearance and behaviour, and also capable of supporting some wildlife species not often found in gardens. Examples are given in our Plants and Planting website section. Likewise, for personal reasons, some gardeners take a special interest in native plants and enjoy growing them in their gardens, and this is to be supported, especially if this raises public awareness of their decline. See our page on Wildflowers for discussion of native species in gardens.

It must be noted however, that evidence remains thin in some areas. More studies in Britain of the role of native and non-native trees would be valuable, and of course better understanding of how different cultivars of garden plants differ in their values to pollinators. There is also a great need for more studies like Jennifer Owen's on the variety of moths and other herbivore species using non-native plants in a variety of gardens. We look forward to the results of the Plants for Bugs project which will give figures to test assertions of the impact of native and non-native planting in British gardens.

Gardens in general will never be host for extremely specialist species that, in the case of plants, require very tight ecological conditions, or in the case of animals are dependent on rare specialist plants, or cannot tolerate the levels of disturbance in gardens. Gardens are not a substitute for conserving the few remaining quality countryside sites where these species can survive. For the less choosy generalist species however, gardens, with their unique mosaic of mini-habitats, remain among the most biodiverse habitats we know, despite and because of the range of non-native species they support.

The British fauna and flora is depauperate compared with that of our continental neighbours, and we have little in the way of unique species or even sub-species to protect. There are many plant species in the western Palaearctic province that would do well in this country, had we not been cut off so quickly after the last ice age, and many of them are already present in our gardens. Almost all such species have arrived in our gardens or naturalised without causing harm, and many are supporting native animal species. It is undeniable that a small number of species have become problems as invasive aliens, but the concern for managing these should be balanced by some celebration of how the rest have enhanced our flora, and awareness that with climate change, more tolerance of new species in our plants lists would be logical form of adaptation.

## 11. References

[1] *www.bgs.ac.uk/discoveringGeology/ geologyOfBritain/iceAge/home.html?src=topNav*

[2] Willerslev, E. et al 2014 Fifty thousand years of Arctic vegetation and megafaunal diet. Nature **506**:47–51

[3] Kenneth G. Miller, K.G. 2009. Sea level change, last 250 million years pp 879-887 in Encyclopedia of Paleoclimatology and Ancient Environments
Vivien Gornitz ed. Springer

[4] W. I. Montgomery et al. 2014. Origin of British and Irish mammals: disparate post-glacial colonisation and species introductions Quaternary Science Reviews **98**: 144-165

[5] Weninger, B. et al 2008. The catastrophic final flooding of Doggerland by the Storegga Slide tsunami. Documenta Praehistorica **35:**1-24

[6] Winter, W. et al 2009. Plant extinctions and introductions lead to phylogenetic and taxonomic homogenization of the European flora. PNAS **106:** 21721–21725

[7] Derived from CBS, PBL, Wageningen UR (2008). Exoten in de Nederlandse flora (indicator 1398, versie 02, 29 april 2008). www.compendiumvoordeleefomgeving.nl. CBS, Den Haag; Planbureau voor de Leefomgeving, Den Haag/Bilthoven en Wageningen UR, Wageningen. The figure of 4,541 given in Winter et al appears to be an error

[8] Edwards, R.J., Brooks, A.J., The Island of Ireland: Drowning the Myth of an Irish Land-Bridge?, Mind the Gap: Postglacial Colonisation of Ireland. Special Supplement to The Irish Naturalists' Journal., 2008, 19 - 34

[9] http://butterfly-conservation.org/679/a-z-of-butterflies.html

[10] van Swaay, C.A.M., Plate, C.L. and van Strien, A., 2002, Monitoring butterflies in the Netherlands: how to get unbiased indices. Proceedings of the Section Experimental and Applied Entomology of The
Netherlands Entomological Society (N.E.V.), **13:** 21–27.

[11] http://www.lepinet.fr/especes/depart/liste_lat.php?e=l&a=rhop&dep=76

[12] Machado, A. 1998. Biodiversidad. Un paseo por el concepto y las Islas Canarias. Ed. Cabildo Insular de Tenerife.

[13] http://www.bds.org.uk/chinese_water_deer.html

[14] Hill, M.O.; Mountford, J.O.; Roy, D.B.; Bunce, R.G.H.. 1999 *Ellenberg's indicator values for British plants. ECOFACT Volume 2 Technical Annex.* Huntingdon, Institute of Terrestrial Ecology, 46pp. (ECOFACT, 2a).

[15] Wheeler, A. 1977. The origin and distribution of the freshwater fishes of the British Isles. Journal of Biogeography **4**:1-24

[16] See David Attenborough's address to the 2014 RSPB Conference for Nature. http://vimeo.com/105133745

[17] Hill, M. et al 2005 English Nature Research Reports Number 662 pp 81

[18] Philip, C. and Lord, A. 1992. The Plant Finder 6th ed. Whitbourn Headman

[19] http://apps.rhs.org.uk/horticulturaldatabase/

[20] Nelson, E. C. 1994. Ergasiophygophytes in the British Isles - plants that jumped the garden fence. pp. 17-31 in: The common ground of wild and cultivated plants: introductions, invasions, control and conservation. Proceedings of a conference held in Cardiff, UK, 10-15 July 1992 ed. Perry, A. R. and Ellis, R. G.

[21] Owen, J. 1991. The Ecology of a Garden, the first fifteen years. Cambridge University Press.

[22] https://www.rhs.org.uk/advice/profile?pid=530

[23] www.snh.gov.uk/docs/B1113471.pdf

[24] See for example http://www.nonnativespecies.org

[25] http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P7-TA-2014-0425+0+DOC+XML+V0//EN&language=EN#BKMD-43

[26] Williams, F. et al 2010. The Economic Cost of Invasive Non-Native Species on Great Britain. CABI Project No. VM10066

[27] http://www.ukagriculture.com/crops/crops.cfm

[28] Crane, R., Davenport, R. and Vaughan, R. 2013. Farm Business Survey: Poultry Production in England 2011/12**.** School of Agriculture, Policy and Development University of Reading

[29] NSA and NFU 2014. A Vision for British lamb production. www.nationalsheep.org.uk/pdf_files/NSANFUVisionDocument28072014195406.pdf

[30] Thompson, K. 2014. Where do camels belong? The Story and Science of Invasive Species. Profile Books, London

[31] Holdich D.M., Palmer M. and Sibley P.J. 2009. The indigenous status of *Austropotamobius pallipes* (Lereboullet) in Britain. In: Brickland J., Holdich D.M. and Imhoff E.M. (eds.) (eds), Crayfish Conservation in the British Isles, Proceedings of conference held in Leeds, pp. 1-11. Leeds.

[32] Godwin, H. 1956. History of the British Flora: A Factual Basis for Phytogeography. Cambridge University Press

[33] Kurten, B. 1968 Pleistocene mammals of Europe Weidenfeld and Nicolson London

[34] Wembridge, D. and Bowen, C.P. 2010 Britain's Mammals: a concise guide. People Trust for endangered species, Whittet Books

[35] Thompson, K. 2014. Where do camels belong? The Story and Science of Invasive Species. Profile Books, London

36 Loram A, Thompson K, Warren PH, and Gaston KJ. 2008 Urban domestic gardens (XII): the richness and composition of the flora in five UK cities. Journal of Vegetation Science **19**:321-330.

[37] Owen, J. (1991) *The Ecology of a Garden: The First Fifteen Years*. Cambridge University Press, Cambridge

[38] Smith, R.M., Warren, P.H., Thompson, K. & Gaston, K.J. 2006. Urban domestic gardens (VI): environmental correlates of invertebrate species richness. *Biodiversity and Conservation* 15, 2415-2438

[39] Smith R.M., Gaston K.J., Warren P.H. & Thompson, K. 2006. Urban domestic gardens (VIII): environmental correlates of invertebrate abundance. *Biodiversity and Conservation* 15, 2515-2545.

[40] Adam J Vanbergen and the Insect Pollinators Initiative 2013. Threats to an ecosystem service:pressures on pollinators. Front Ecol Environ; doi:10.1890/120126

[41] Goulson, D et al 2010 Effects of land use at a landscape scale on bumblebee nest density and survival. Journal of Applied Ecology, **47:** 1207–1215

[42] Goulson, D. , Hughes, W.O.H., Derwent , L.C. and Stout, J.C. 2002 Colony growth of the bumblebee, Bombus terrestris, in improved and conventional agricultural and suburban habitats Oecologia **130**:267–273

[43] Stelzer RJ, Chittka L, Carlton M, Ings TC (2010) Winter Active Bumblebees (Bombus terrestris) Achieve High Foraging Rates in Urban Britain. PLoS ONE 5(3): e9559. doi:10.1371/journal.pone.0009559

[44] Osborne, J.L. et al 2008 Quantifying and comparing bumblebee nest densities in gardens and countryside habitats Journal of Applied Ecology **45:**784–792

[45] Fortel L, et al 2014. Decreasing Abundance, Increasing Diversity and Changing Structure of the Wild Bee Community (Hymenoptera: Anthophila) along an Urbanization Gradient. PLoS ONE 9(8): e104679. doi:10.1371/journal.pone.0104679

[46] Garbuzov, M and Ratnieks, F.L.W. 2013 Quantifying variation among garden plants in attractiveness to bees and other flower-visiting insects Functional Ecology **28**: 364–374

[47] Samnegård, U. Persson, A.S. and Smith, H.G. 2011 Gardens benefit bees and enhance pollination in intensively managed farmland. Biological Conservation **144**: 2602–2606

[48] Pereira-Peixoto, M.H., Pufal, G., Martins, C.F. and Klein, A.M. 2014 Spillover of trap-nesting bees and wasps in an urban–rural interface. Journal of Insect Conservation **18:**815-826

[49] Cussans J, Goulson D, Sanderson R, Goffe L, Darvill B, et al. (2010) Two Bee-Pollinated Plant Species Show Higher Seed Production when Grown in Gardens Compared to Arable Farmland. PLoS ONE 5(7): e11753.

[50] Bates AJ, Sadler JP, Fairbrass AJ, Falk SJ, Hale JD, et al. (2011) Changing Bee and Hoverfly Pollinator Assemblages along an Urban-Rural Gradient. PLoSONE 6(8): e23459. doi:10.1371/journal.pone.0023459

[51] Williams, NM, D Cariveau, R Winfree, and C Kremen 2011 Bees in disturbed habitats use, but do not prefer, alien plants. Basic and Applied Ecology 12: 332-341

[52] Levy, S. 2011. The pollinator crisis: What's best for bees? www.nature.com/news/2011/111109/full/479164a.html

[53] Hanley, M.E., Awbi, A.J. and Franco M. 2014 Going native? Flower use by bumblebees in English urban gardens. Annals of Botany 03/2014; DOI: 10.1093/aob/mcu006

[54] Bergerot, B. , Fontaine, B., Renard, M., Cadi, A. and Julliard, R. 2010 Preferences for exotic flowers do not promote urban life in butterflies. Landscape and Urban Planning **96**: 98–107

[55] Winfree, R., Bartomeus, I. and Cariveau, D.P. 2011. Native Pollinators in Anthropogenic Habitats. Ann. Rev. Ecol. Evol. Syst. **42**:1–22

[56] Matteson, K. C. and Langellotto, G. A. (2011), Small scale additions of native plants fail to increase beneficial insect richness in urban gardens. Insect Conservation and Diversity, 4: 89–98. doi: 10.1111/j.1752-4598.2010.00103.x

[57] Burghardt, K.T., D.W. Tallamy, and W.G. Shriver (2009) Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, **23**, 219-224.

[58] Burghardt, K. T., D. W. Tallamy, C. Philips, and K. J. Shropshire. 2010. Non-native plants reduce abundance, richness, and host specialization in lepidopteran communities. Ecosphere 1(5):art11. doi:10.1890/ES10-00032.1

[59] Burghardt, K.T. and D.W. Tallamy (2013) Plant origin asymmetrically impacts feeding guilds and life stages driving community structure of herbivorous arthropods. *Diversity and Distributions*, **19**, 1553-1565.

[60] Tallamy, D.W., M. Ballard, and V. D'Amico (2010) Can alien plants support generalist insect herbivores? *Biological Invasions*, **12**, 2285-2292.

[61] Tallamy, D.W. and K.J. Shropshire (2009) Ranking Lepidopteran use of native versus introduced plants. *Conservation Biology*, **23**, 941-947.

[62] Zuefle, M.E., W.P. Brown, and D.W. Tallamy (2008) Effects of non-native plants on the native insect community of Delaware. *Biological Invasions*, **10**, 1159-1169.

[63] http://www.brc.ac.uk/dbif/homepage.aspx

[64] Shapiro, A.M. (2002) The Californian urban butterfly fauna is dependent on alien plants. *Diversity and Distributions*, **8**, 31-40.

[65] Meijer, K., Smit, C., Beukeboom, L.W**.** & Schilthuizen, M. (2012) Native insects on non-native plants in the Netherlands: curiosities or common practice? *Entomologische Berichten* **72:**288-293.

[66] Helden, A.J., G.C. Stamp, and S.R. Leather (2012) Urban biodiversity: comparison of insect assemblages on native and non-native trees. *Urban Ecosystems*, **15**, 611-624.

[67] Dost, P. et al. 2013. Enemy damage of exotic plant species is similar to that of natives and increases with productivity. Journal of Ecology **101**:388–399

[68] Pearse, I.S. and F. Altermatt (2013) Predicting novel trophic interactions in a non-native world. *Ecology Letters*, **16**, 1088-1094.

[69] Smith, R.M., et al. (2006) Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity. *Biological Conservation*, **129**, 312-322