# THE SOLITARY WASPS AND BEES (HYMENOPTERA: ACULEATA) OF A SUBURBAN GARDEN IN LEICESTER, ENGLAND, OVER 27 YEARS

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ABSTRACT

The solitary aculeate wasp and bee species collected in a Malaise trap during 27 years in a Leicester suburban garden, England, are surveyed, species indices of quality, parasitic (mainly cleptoparasitic) behaviour and nesting habits are calculated, species trends and seasonal distributions are analysed, and the numerical relationship between the solitary aculeate species and honey bees assessed. From 1975 until 2001, a hundred solitary wasp and bee species represented by 10,332 individuals were trapped. There was an increasing yearly trend for the number of species due to the number of solitary wasp and spring bee species. There was no yearly trend for the number of individuals because the number of individuals of new species trapped during the last ten years was very small. Species could be divided into two equal groups of less and more frequent species based on the number of years in which trapped. The more frequent bees included a relative lack of cleptoparasites, while the wasps and more frequent bees included a relative excess of aerial nesters. One nationally rare and eight nationally scarce species were trapped giving a Species Quality Score of 2.2, which was lower than for relevant semi-natural sites. The 23 species, represented by 100 or more individuals, showed increasing, decreasing or no yearly trends. All the species showed stationarity, and periodicity was shown by ten species. Such population dynamic characteristics indicate the operation of endogenous factors, which for some species seem to indicate a two-year cycle with damping to the carrying capacity of the environment. Higher mean temperatures and sunshine with less rainfall generally could be related to the yearly abundances of non-periodic species. The yearly species accumulation curve showed an increase in the number of species from 1992, which could be related to increases in mean temperature. The yearly numbers of solitary and honey bees were not correlated.

Keywords: Hymenoptera, Aculeata, 27-year survey, suburban garden, Western Palaearctic

## INTRODUCTION

There is a growing awareness of the importance of urban gardens for biological conservation (Good, 2000; Tucker, Ash & Plant, 2005; Gaston, 2010). In England, 7% of the land area is covered by cities and towns of more than 10,000 people and with 80% of the human population living in such urban areas, gardens are important in bringing people into contact with wildlife (Loram *et al.*, 2007). Owen (1991) estimated that about 27.6% of urban and suburban Leicester consisted of gardens. This estimate is supported by the finding that from 21.8% to 26.8% of five cities in England, Wales and Scotland consisted of gardens, with Leicester gardens slightly reduced to 26.8% (Loram *et al.*, 2007). It has been estimated that urban and suburban households have access to about 432,964ha across the UK which is equivalent to about 9.2% of the 4.7 million hectares of statuary protected areas (Davies *et al.*, 2009).

Few authors have reported on the aculeate wasps and bees to be found in gardens in the British Isles. Guichard & Yarrow (1948) summarised data on aculeates found in six gardens in or near Hampstead, London.

More recently, Harvey (2001) reported on the aculeates found in Buckingham Palace Gardens, London, and Archer (2004a) on the aculeate wasps and bees of York Victorian Cemetery, which can be considered as a large garden. Baldock (2010) gives some information from five gardens in Surrey. The solitary wasps and bees from 81 gardens of urban Sheffield, mainly from the BUGS (Biodiversity in Urban Gardens in Sheffield) survey (Smith *et al.*, 2005, 2006), are summarised, with analysis, by Archer (2009).

Gardens are often very heterogeneous (e.g. flower beds, shrubs and trees, lawns, vegetable and herb areas, rockery, ponds, compost heaps, paths, dead wood and old walls) and so provide many microhabitats capable of supporting a rich biodiversity. It is important that biological surveys of gardens are made to record their microhabitats and species with their resource needs. The following report deals with the solitary wasps and bees of a suburban garden in Leicester, England, over 27 years as a contribution to providing such information. An earlier paper (Archer, 1990b) dealt with the data for twelve years from 1975 until 1986.

As an example of a garden with diverse microhabitats, the Leicester garden, situated at the corner of a busy road 3.8km from the centre of the City of Leicester, covers an area of 741m$^2$ and has remained essentially unchanged for the last 60 years. A continuous soil cover with trees, shrubs, cultivated plants and weeds is maintained; flowering plants are grown that are known to be attractive to insects; no insecticides or other poisons are used (the garden is organic); and vegetables and flowers are inter-planted. A lawn, rockery and compost heap are also present. The garden is about 800m from open fields; a small stream flanked by tall trees is within 125m and there are two parks with mature trees within 450m. The area has relatively cool summers and mild winters with the temperature rarely falling below 0$^o$C or exceeding 25$^o$C. The mean annual rainfall is about 650mm distributed throughout the year. However, there is much day-to-day variation in sunshine, temperature and rainfall besides differences between years. Further information is given by Owen (1991, 2010).

The main requirements of solitary wasps and bees are food sources and nesting sites besides overwintering, sunning and mating sites and, sometimes, building materials to make their nests. Suitable nesting sites generally need to be in sunny situations. Aerial nesters use old beetle burrows in dead wood, central stem cavities (e.g. bramble), old snail shells, or crevices in cob walls, old mortar, or nests exposed on the surface of rock or other hard material. Subterranean nesters nest in the soil, usually in burrows dug by them, but sometimes existing holes and crevices are used after being altered. Solitary bees require flower-rich areas with pollen sources, and solitary wasps require hunting areas for specific prey species which are needed as food resources for their larvae. Suitable hunting areas are found in a range of habitats from grasslands, scrubs and woodlands. Some solitary wasps are cleptoparasites or parasitoids and some bees are cleptoparasites on other, often specific, solitary wasps and bees. All species need nectar as a food source so again there is a need for flower-rich areas. Further information is given by Grissell (2010).

The aim of this paper is to survey the solitary aculeate wasp and bee species, with their trends and seasonal distribution, collected in a Malaise trap during 27 years in a Leicester suburban garden in England. Analysis will include the use of the species indices of quality, parasitic (mainly cleptoparasitic) behaviour and nesting habits, the importance of weather and the numerical relationship between honey bees and solitary bees.

## METHODS

A Townes trap (Townes, 1972), better known as a Malaise trap, is a passive sampling method, and traps by intercepting flying insects. A Malaise trap was operated in the same position in the study garden from 1 April until 31 October during the period 1975–2001: a period of 27 years. The trap-catch was collected each month (189 samples) and the aculeate solitary wasps and bees (and honey bees *Apis mellifera* Linnaeus, 1758, from 1983) were sorted by J. Owen and sent to MEA for mounting and identification. Orientation and siting in a habitat can greatly affect a Malaise trap catch (Disney *et al*., 1982) so the position and orientation of the trap was the same each year. Malaise traps are known to readily take aculeate species (Archer, 1988; Pauly, 1989; Baños-Picón, 2007). The Malaise trap will take species from the garden and from the surrounding gardens and area (Archer, 1990b).

Visits were made to the garden on 19 April 1982 and 12 July 1983 to observe the activities of the solitary wasps and bees and to determine if any species was nesting in, or outside, the garden. Individuals were followed to determine if they were flying into or out of the garden (Archer, 1990b). The seasonal activity of the adults was investigated, with the monthly adult activity of the 23 species trapped on 100 or more occasions enabling the bees to be divided into three groups. These were the spring (adults mainly active from April until June), summer (mainly active from May to August) and spring/summer (mainly active from April to August) species groups (see Appendix 1 & Table 6). The Provisional Atlases of Britain and Ireland (1997–2009) and Else (*in prep*.) were used to categorise the species (Appendix 1). *Andrena nigroaenea* and *A. scotica* are probably bivoltine (Else, *in prep*.), but they were treated as spring species since this is when they were active in the Leicester garden. The wasps were all summer species with the adults active from May to September (see Fig. 5).

Weather data were supplied by a meteorological station at Newton Linford, Leicestershire, which is about 11.5km northwest of the garden (Owen, 2010). The rainfall (mm), sunshine (hrs) and mean temperature (°C) for each month in each year was summed as required.

To investigate the yearly variations and trends of species, one was added to the yearly data to eliminate any zero readings and then transformed to $\log_{10}$ to normalise the data. The autocorrelation function (ACF) provided by MINITAB statistical software was used to analyse the yearly data for each species, and to account for any effects of autocorrelation [the measure of strength of association between pairs of values of a time series as a function of the time interval that separates them] that could mask or spuriously enhance the effects of other factors. The ACF is estimated by calculating the correlation coefficients between years separated by an increasing number of years or yearly lags. A plot of ACF is called a correlogram and it shows 0.05 critical bands. The ACF was computed for each data set. The shape of the estimated ACF provides insight regarding two aspects of population dynamics: stationarity and periodicity. The stationary dynamic indicates the population fluctuates around a constant mean level (i.e. carrying capacity of the environment); and when the population is perturbed it returns to a constant mean level (Turchin & Taylor, 1992). If the plot falls outside the 0.05 critical bands, the ACF shows periodicity. Periodic dynamics arise from an endogenous process when the correlogram shows a return to a constant mean level either by a monotonic or oscillatory process (Turchin & Taylor, 1992). Such numerical changes of a population typically affect and are in turn affected by population abundance of resources, natural enemies and competitors.

To investigate the relationship to the yearly number of individuals of a species it is necessary to consider the effect of the number of records in the current year with the number of records in the previous year. This was achieved by using the method of Pollard & Moss (1995) with the following equation:

$$\boldsymbol{R_i = a + b_1 R_{i-1} + b_2 W + error}$$

Where, $\boldsymbol{R_i} = \log_{10}(n+1)$ the number of species or individuals, $_i$ = the current year, $\boldsymbol{W}$ = the weather variable being considered, $\boldsymbol{a}$ = regression constant, and $\boldsymbol{b_1}$, $\boldsymbol{b_2}$ the partial regression coefficients.

## RESULTS

*Number of species and individuals*

A total of 100 solitary wasp and bee species represented by 10,332 individuals was collected by the Malaise trap from 1975 until 2001 (Table 1, Appendix 1 with species list, authority and date). The dominant solitary wasp group was the Crabronidae, both in numbers of species and individuals. For the solitary bee groups, the Andrenidae, Halictidae and Megachilidae were the dominant groups in terms of species, and the Colletidae and Andrenidae in terms of individuals. There were more species of solitary wasps (55%) than solitary bees (45%) although nearly twice as many individuals of solitary bees (65%) than solitary wasps

TABLE 1. — NUMBER OF SPECIES AND INDIVIDUALS OF SOLITARY WASP AND BEE FAMILIES TRAPPED FROM 1975 UNTIL 2001 IN A LEICESTER SUBURBAN GARDEN

| | No. species | No. individuals |
|---|---|---|
| Solitary wasps | | |
| Chrysididae | 7 | 378 |
| Tiphiidae | 1 | 5 |
| Sapygidae | 2 | 16 |
| Pompilidae | 1 | 6 |
| Vespidae - Eumeninae | 5 | 105 |
| Crabronidae | 39 | 3110 |
| Total solitary wasps | 55 | 3620 |
| Solitary bees | | |
| Colletidae | 3 | 2126 |
| Andrenidae | 10 | 2314 |
| Halictidae | 13 | 456 |
| Megachilidae | 12 | 764 |
| Apidae | 7 | 1052 |
| Total solitary bees | 45 | 6712 |
| Total solitary species | 100 | 10332 |

(35%) (Table 1). Five species (*Passaloecus singularis*, *Colletes daviesanus*, *Hylaeus communis*, *Andrena fulva* and *Anthophora plumipes*) were particularly noticeable in representing 49.1% of all individuals trapped. Each of these five species was represented by 799–1338 individuals. These are clearly separated numerically from the remaining species that were represented: at most by 385 individuals (*Pemphredon lugubris* and *Andrena scotica*, Appendix 1).

The number of species trapped each year, except for 1976, showed a decreasing trend between 1975 and 1991 before generally reaching a higher value from 1992 onwards (Fig. 1). The species accumulation curve showed a rapid increase during the early years, as would be expected, followed by a slow increase and then a more noticeable increase starting from 1992 and particularly from 1996 (Fig 2). The number of new species trapped during five year periods, except for the first two years, showed an increase from 1992 (Fig. 3).

The number of individuals trapped each year, although rather variable (Fig. 4), showed a slight decreasing trend with years. The number of individuals of new species trapped during the last five (30) or ten (103) years represented a very small percentage (0.3% and 1.0%, respectively) of the total number of individuals trapped during the 27 years.

In terms of number of species, the spring/summer group was the most numerous (40.0%) followed by the spring (31.1%) and summer (28.9%) species. In terms of numbers of individuals, the order of abundance was reversed with spring bees being more numerous (51.6%) followed by the

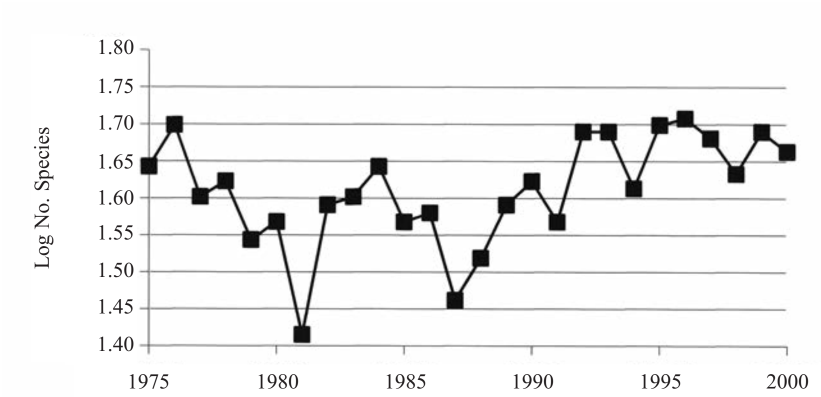



Fig. 1. — The number of species of solitary wasps and bees trapped each year in a Leicester suburban garden.

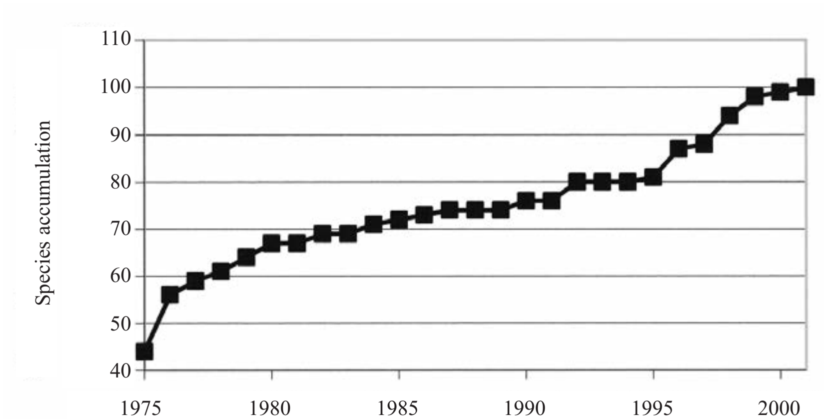



Fig. 2. — Species yearly accumulation of solitary wasps and bees trapped in a Leicester suburban garden.

summer species (37.2%) and the spring/summer species (11.2%) (Table 2).

For the four species groups (summer wasps, spring, summer and spring/summer bees; Appendix 1, Fig. 5), the number of species versus years is shown in Fig. 6 and the number of individuals versus years in Fig. 7. The number of wasp and spring bee species showed an increasing yearly trend. The number of species of the summer and spring/summer bees showed no yearly trend except for the absence of spring/summer bees

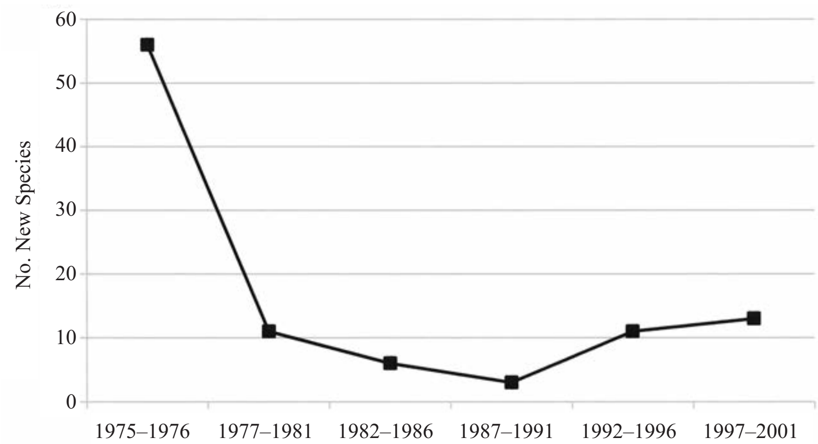



Fig. 3. — The number of new species of solitary wasps and bees trapped during five years periods (except for the first two years) in a Leicester suburban garden.

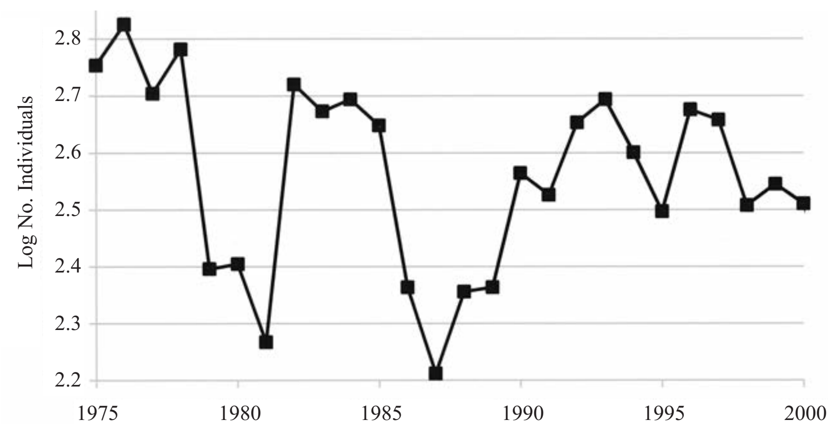



Fig. 4. — The number of individual solitary wasps and bees trapped each year in a Leicester suburban garden.

during 1987. The number of individuals of summer bees showed a decreasing yearly trend with the other three groups showing no trend.

*Species Frequency*

The solitary species can be divided into two equal frequency groups of those recorded during 1–7 years (50 less frequent species: 29 wasp, 21 bees) and those recorded during 8–27 years (50 more frequent species: 26

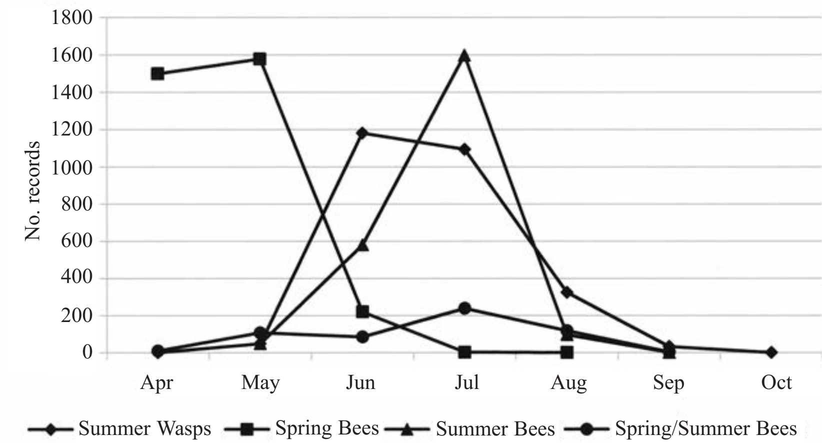



Fig. 5. — The monthly distribution of adult activity of four seasonal groups (SuW=Wasps, SpB=Spring Bees, SuB=Summer bees, SpSuB=Spring/Summer Bees) of the 23 aculeate species represented by 100 or more individuals.

TABLE 2. — THE NUMBER OF SPECIES AND INDIVIDUALS OF THE THREE SOLITARY BEE GROUPS TRAPPED FROM 1975 UNTIL 2001 IN A LEICESTER SUBURBAN GARDEN

| | No. species | No. individuals |
|---|---|---|
| Spring Bees | 14 | 3463 |
| Summer Bees | 13 | 2498 |
| Spring/Summer Bees | 18 | 751 |
| Total | 45 | 6712 |

TABLE 3. — THE RELATIVE FREQUENCY OF THE PARASITIC (CLEPTO-PARASITES OR PARASITOIDS) SPECIES OF THE LESS AND MORE FREQUENT SPECIES AMONG THE SOLITARY SPECIES TRAPPED IN A LEICESTER SUBURBAN GARDEN (see text for explanation; *Cleptes semiauratus* and *Tiphia minuta* excluded as they are not parasites of aculeates)

| | No. parasites (C) | | No. nest-builders (H) | | Cleptoparasitic Load CL = 100 × C/(H + C) | |
|---|---|---|---|---|---|---|
| | Less frequent | More frequent | Less frequent | More frequent | Less frequent | More frequent |
| Solitary wasps | 3 | 5 | 24 | 21 | 11.1% | 19.2% |
| Solitary bees | 7 | 4 | 14 | 20 | 33.3% | 16.7% |

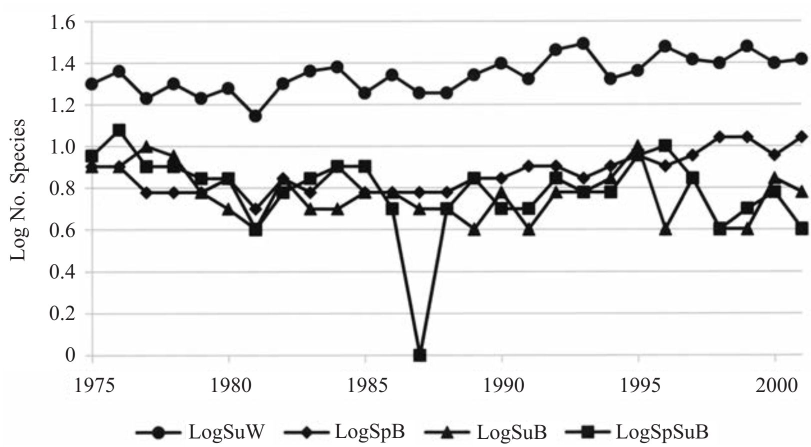



Fig. 6. — The log number of aculeate species (SuW=Wasps, SpB=Spring Bees, SuB=Summer bees, SpSuB=Spring/Summer Bees) versus years.

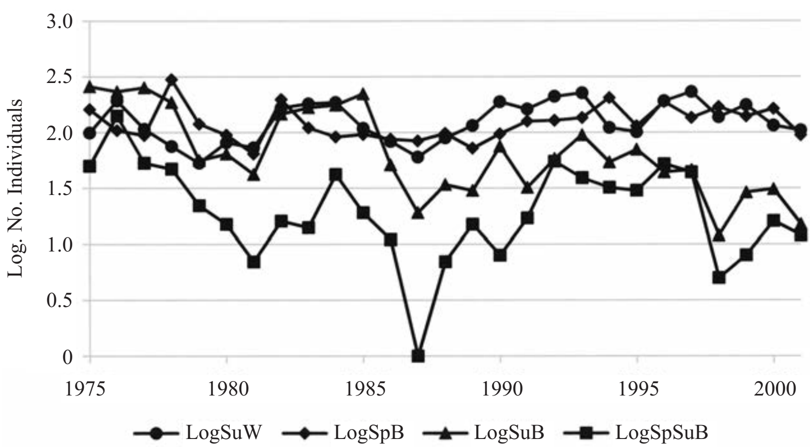



Fig. 7. — The log number of individual aculeates (SuW=Wasps, SpB=Spring Bees, SuB=Summer bees, SpSuB=Spring/Summer Bees) versus years.

wasps, 24 bees). These two frequency groups can be used to investigate the indices of cleptoparasitic load and aerial nester frequency.

The cleptoparasitic load (CL) is the percentage of aculeate species that are cleptoparasitic (or parasitoids) on nest-building species (Appendix 1) (Table 3). Normally the CL varies between 10–25% for solitary wasps and

TABLE 4. — THE NESTING HABITS OF THE LESS AND MORE FREQUENT SPECIES AMONG THE SOLITARY SPECIES TRAPPED IN A LEICESTER SUBURBAN GARDEN (see text for explanation)

| | Aerial nesters (A) | | Subterranean nester (S) | | Aerial-nester frequency AF = 100 × A/(A + S) | |
|---|---|---|---|---|---|---|
| | Less frequent | More frequent | Less frequent | More frequent | Less frequent | More frequent |
| Solitary wasps | 18 | 20 | 6 | 1 | 75.0% | 95.2% |
| Solitary bees | 3 | 9 | 11 | 11 | 21.4% | 45.0% |

TABLE 5. — ARCHER NATIONAL QUALITY SCORES OF SOLITARY WASPS AND BEES TRAPPED FROM A LEICESTER SUBURBAN GARDEN

| National Status | Status Value (A) | No. Species (B) | Quality Scores (A × B) |
|---|---|---|---|
| Universal | 1 | 45 | 45 |
| Widespread | 2 | 46 | 92 |
| Scarce | 8 | 8 | 64 |
| Rare | 16 | 1 | 16 |
| Total | | 100 | 217 |

Species Quality Score (SQS) 217/100 = 2.2

between 25–40% for solitary bees (Archer, 2011). The solitary wasps and the less frequent solitary bees fall within these ranges with the more frequent solitary bees falling below this range.

The aerial-nester frequency (AF) is the percentage of aculeate species that have aerial nest sites. For some species, in Britain, division into subterranean and aerial nesters creates a problem, e.g. *Anthidium manicatum*, *Osmia rufa, Megachile* spp. and *Anthophora plumipes.* For these species, with the help of Else (*in prep.*), their major nesting habit was used to define their characteristic nesting habit (Appendix 1). The AF for the solitary species is given in Table 4. The AF for all the British species of solitary wasps is 46.2% and solitary bees is 17.9%. The AF for the less and more frequent solitary wasps and bees groups is higher than the British data.

*Species Conservation Status*

From Shirt (1987), four species (*Crossocerus distinguendus*, *Ectemnius ruficornis*, *Pemphredon morio*, *Philanthus triangulum*) are listed as Red Data Book (RDB) species in Britain. Falk (1991) accepted the RDB status of *P. triangulum* but downgraded the other species to National Scarce Status (NSS), and added a further five species (*Cleptes semiauratus*, *Pseudomalus violaceus*, *Sapyga clavicornis*, *Crossocerus binotatus*, *Ectemnius sexcinctus*) to NSS. More recent work carried by the Bees, Wasps and Ants Recording Society (BWARS) indicates that all Shirt's (1987) RDB species should lose their RDB status and *E. sexcinctus* and *P. triangulum* should lose their NSS.

To take account of these changes and to keep the national statuses up to date, Archer (1999, 2002) gave one of six statuses to all solitary species. The Archer national statuses are divided into High Quality Species (Very rare, Rare, Scarce) and Low Quality Species (Restricted, Widespread, Universal). The definitions of the statuses are given in Appendix 2 and Archer (2005). The statuses of the Leicester garden species are given in Appendix 1. According to this system the Leicester garden has one rare (*Crossocerus walkeri*) and eight scarce (*Cleptes semiauratus*, *Pseudomalus violaceus*, *Sapyga clavicornis*, *Crossocerus binotatus*, *Spilomena beata*, *Pemphredon morio*, *Diodontus tristis*, *Coelioxys inermis*) species. By allocating each of 100 species a Status Score, a Quality Score of 217 and a Species Quality Score (SQS) of 2.2 are given by addition (Table 5). The SQS has no units but can be used to compare sites for conservation purposes.

*Trends and correlograms of some species*

The trends of the 23 species represented by 100 or more individuals are given in Table 6. Increasing trends were shown for five species and decreasing trends for six species. Of these 23 species, the ten wasp species were all predators of aphids, hemipterans and flies (with the exception of *Pseudomalus auratus*, which is a parasite of stem-nesting wasps). These wasps are usually aerial nesters (often in dead stems), with only *Crossocerus elongatulus* a subterranean nester. The bees are all polylectic for pollen resources except for *Colletes daviesanus*, which is probably oligolectic on Asteraceae. The *Andrena* species are all subterranean nesters and their cleptoparasitic *Nomada* species were recorded. The cleptoparasite, *Epeolus variegatus* (Linnaeus), of the subterranean nesting species *Colletes daviesanus* was not recorded. The other bees are crevice nesters usually in aerial situations. The cleptoparasites of the *Megachile* spp., *Coelioxys*, *Osmia* spp., *Sapyga*, and *Lasioglossum smeathmanellum* (a small *Sphecodes*) were recorded. The *Melecta* cleptoparasite of *Anthophora plumipes* was not recorded and *Hylaeus communis* has no known cleptoparasitic species.

All 23 species showed stationarity either with increasing (e.g. Fig 8ai, 9ai), decreasing (e.g. 8bi, 9bi) or no (e.g. Figs 8ci, 9ci) yearly trends. Periodicity was not shown by 13 species (e.g. Figs 8aii, 8bii, 8cii), but was shown by ten species (e.g. Figs 9aii, 9bii, 9cii). The periodicity was usually indicated by a negative one-year lag, but with a negative two-year lag for *Ectemnius cavifrons* and a negative four-year lag for *Colletes daviesanus*.

*Weather relationships*

Table 7 shows the significant associations between weather characteristics and those species showing non-periodic stationarity. Mean

TABLE 6. — THE NUMBER OF INDIVIDUALS AND YEARS TRAPPED WITH YEARLY TRENDS AND OCCURANCE OF SIGNIFICANT PERIODICITY OF THE 23 SOLITARY WASPS AND BEES REPRESENTED BY 100 OR MORE INDIVIDUALS FROM A LEICESTER SUBUBAN GARDEN

| | No. individuals | No. years trapped | Trend | Periodic |
|---|---|---|---|---|
| Solitary wasps | | | | |
| *Passaloecus singularis* | 917 | 27 | Increasing | Not shown |
| *Pemphredon lugubris* | 385 | 27 | Decreasing | Not shown |
| *Passaloecus gracilis* | 276 | 26 | Increasing | Shown |
| *Pseudomalus auratus* | 229 | 26 | No trend | Not shown |
| *Crossocerus annulipes* | 214 | 27 | Increasing | Shown |
| *Pemphredon lethifer* | 211 | 22 | Decreasing | Not shown |
| *Ectemnius cavifrons* | 126 | 25 | No trend | Shown |
| *Crossocerus elongatulus* | 125 | 26 | No trend | Shown |
| *Psenulus pallipes* | 102 | 25 | No trend | Not shown |
| *Psenulus concolor* | 100 | 24 | No trend | Shown |
| Solitary bees | | | | |
| *Andrena fulva* | 1338 | 27 | Decreasing | Shown |
| *Colletes daviesanus* | 1286 | 23 | Decreasing | Shown |
| *Hylaeus communis* | 817 | 27 | No trend | Shown |
| *Anthophora plumipes* | 799 | 27 | Increasing | Not shown |
| *Andrena scotica* | 385 | 26 | No trend | Shown |
| *Osmia rufa* | 333 | 27 | No trend | Not shown |
| *Lasioglossum smeathmanellum* | 299 | 23 | Decreasing | Not shown |
| *Andrena haemorrhoa* | 295 | 25 | Increasing | Shown |
| *Andrena nigroaenea* | 151 | 25 | No trend | Not shown |
| *Osmia caerulescens* | 136 | 23 | No trend | Not shown |
| *Andrena bicolor* | 130 | 20 | No trend | Not shown |
| *Megachile willughbiella* | 114 | 22 | Decreasing | Not shown |
| *Megachile centuncularis* | 109 | 25 | No trend | Not shown |

temperature and total sunshine generally had a positive effect, and total rainfall a negative effect on species of summer wasps, spring, summer and spring/summer bees.

*Honey and solitary bee abundance*

The correlation between the number of honey and solitary bees was not significant (Correlation coefficient = 0.414, $p = 0.078$) although a plot of the number of honey and solitary bees (Fig. 10) seems to indicate that they generally increase and decrease together.

## DISCUSSION

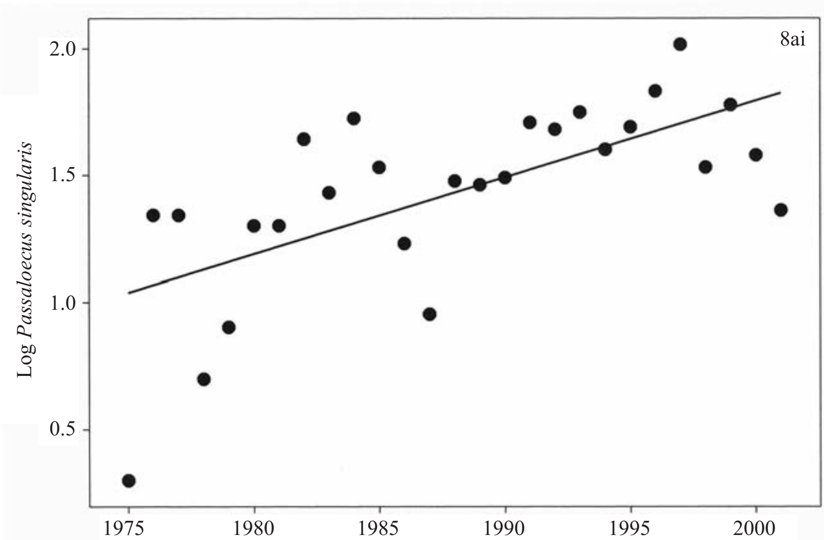
The recorded number of species was similar to, or more, than recorded in other English garden sites (Table 8), except for the semi-natural or rural site of Milford, Surrey. Frankie & Ehler (1978) comment on high diversity found in urban areas. McIntyre (2000) found gardens, in particular, to be an important refuge for insects. Frankie & Ehler (1978) related this high

TABLE 7. — THE SIGNIFICANT POSITIVE AND NEGATIVE ASSOCIATIONS (PROBABILITIES) OF WEATHER WITH THE YEARLY NUMBER OF SPECIES SHOWING NON-PERIODIC STATIONARITY

| | Mean Temperature (°C) | Total Rainfall (mm) | Total Sunshine (h) |
|---|---|---|---|
| Summer wasps (May to September) | | | |
| *Passaloecus singularis* | + (0.001) | – (0.009) | + (0.016) |
| *Pemphredon lugubris* | + (0.002) | – (<0.001) | + (0.002) |
| *Pseudomalus auratus* | + (0.020) | – (0.011) | + (0.023) |
| *Pemphredon lethifer* | + (0.002) | – (<0.001) | + (0.005) |
| *Psenulus pallipes* | | | |
| Spring bees (April to June) | | | |
| *Anthophora plumipes* | + (0.049) | + (0.009) | + (0.048) |
| *Osmia rufa* | | | |
| *Andrena nigroaenea* | + (0.032) | – (0.013) | + (0.005) |
| Summer bees (May to August) | | | |
| *Osmia caerulescens* | + (0.001) | – (<0.001) | + (0.001) |
| *Megachile willughbiella* | | | |
| *Megachile centuncularis* | | – (0.023) | |
| Spring/Summer bees (April to August) | | | |
| *Andrena bicolor* | – (0.005) | | |
| *Lasioglossum smeathmanellum* | + (0.001) | – (0.001) | – (0.001) |

TABLE 8. — THE NUMBER OF SOLITARY WASP AND BEE SPECIES (ALL WASPS AND BEES, INCLUDING SOCIAL SPECIES IN BRACKETS) WHERE KNOWN FROM ENGLISH GARDEN SITES

| | Type | No. species | Area (ha) | Authority | Length of study (years) |
|---|---|---|---|---|---|
| Leicester | Suburban | 100 (121) | 0.08 | This paper | 27 |
| South Croydon | Suburban | (129) | 0.5 | Baldock, 2010 | 1 month |
| Buckingham Palace | Urban | 72 (85) | 16 | Harvey, 2001 | 4 |
| York Victorian | Cemetery | 55 (70) | 10 | Archer, 2004 | 8 |
| RHS Wisley | Botanic | (124) | 100 | Baldock, 2010 | Several |
| Milford | Semi-natural | (257) | 2 | Baldock, 2010 | 7 |
| Hampstead, London (six gardens) | Suburban | (70) | Unknown | Guichard & Yarrow, 1948 | Unknown |
| Sheffield (81 gardens) | Suburban | 67 | Unknown | Archer, 2009 | 1 |



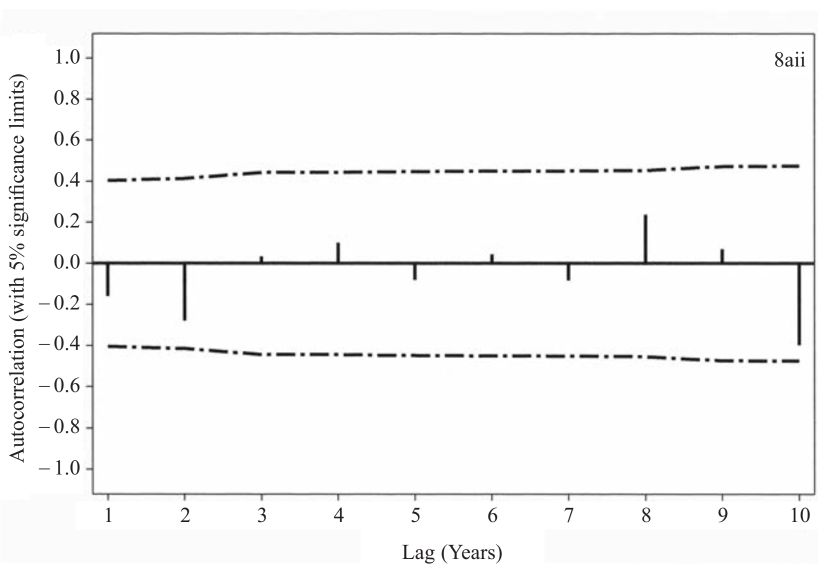
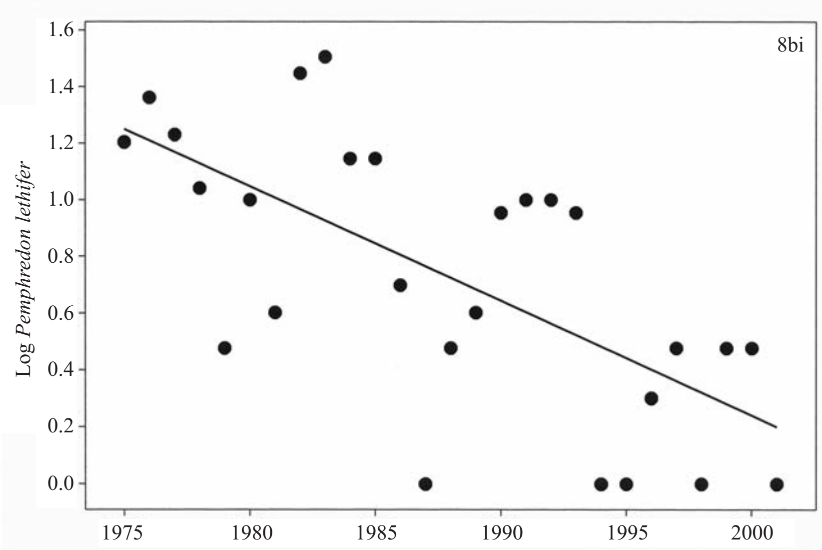




Fig. 8a — The log number of species versus years with regression lines (i) and correlograms (ii) of *Passaloecus singularis* (see text for explanation).



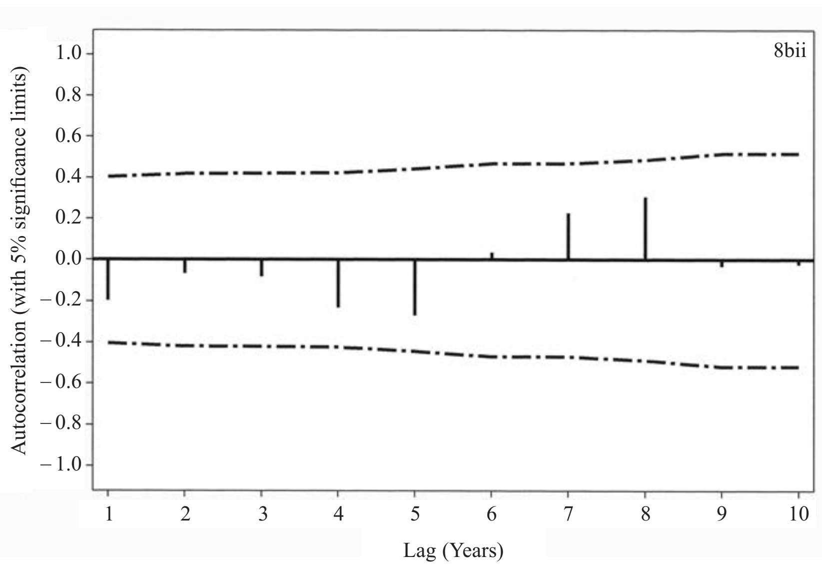




Fig. 8b — The log number of species versus years with regression lines (i) and correlograms (ii) of *Pemphredon lethifer* (see text for explanation).

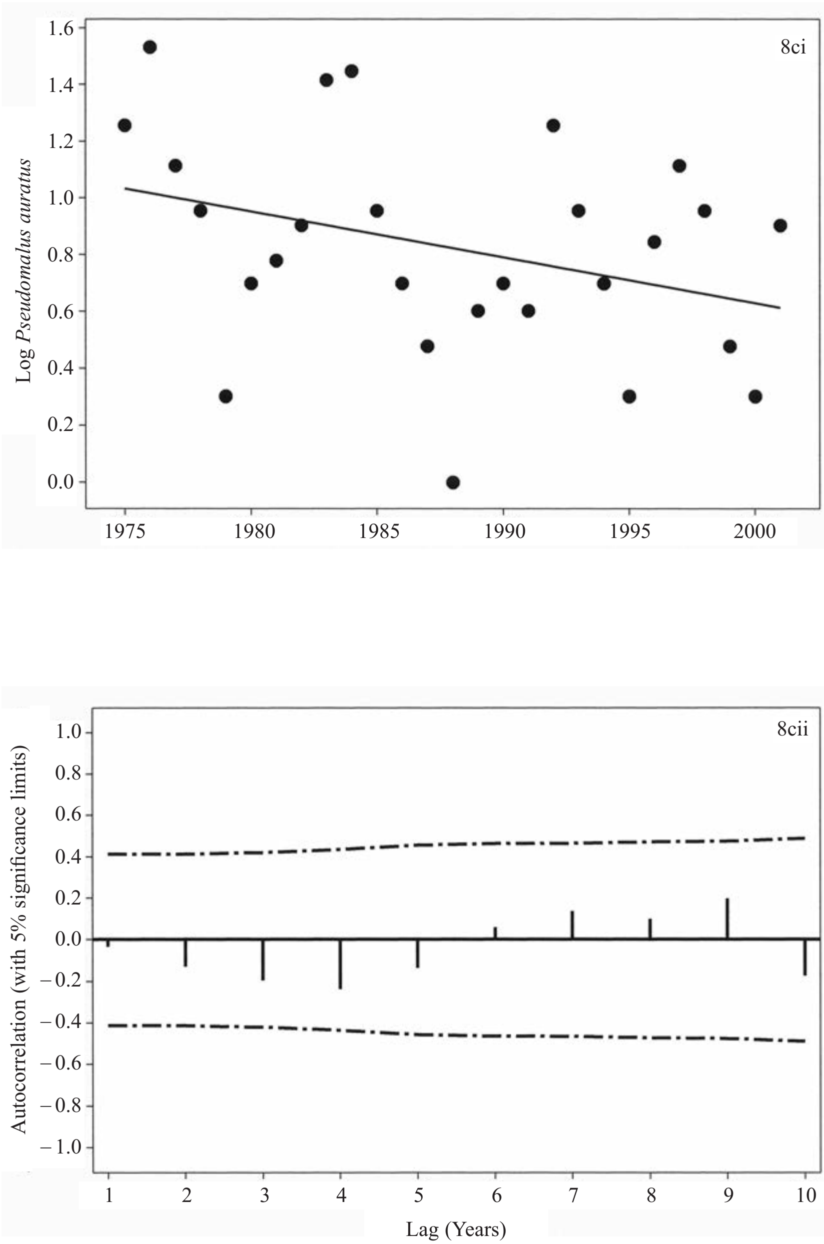
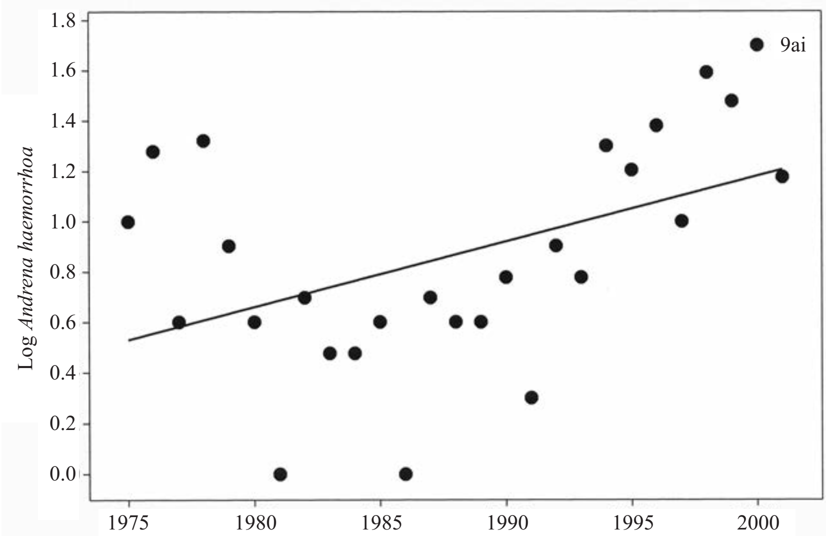



Fig. 8c — The log number of species versus years with regression lines (i) and correlograms (ii) of *Pseudomalus auratus* (see text for explanation).



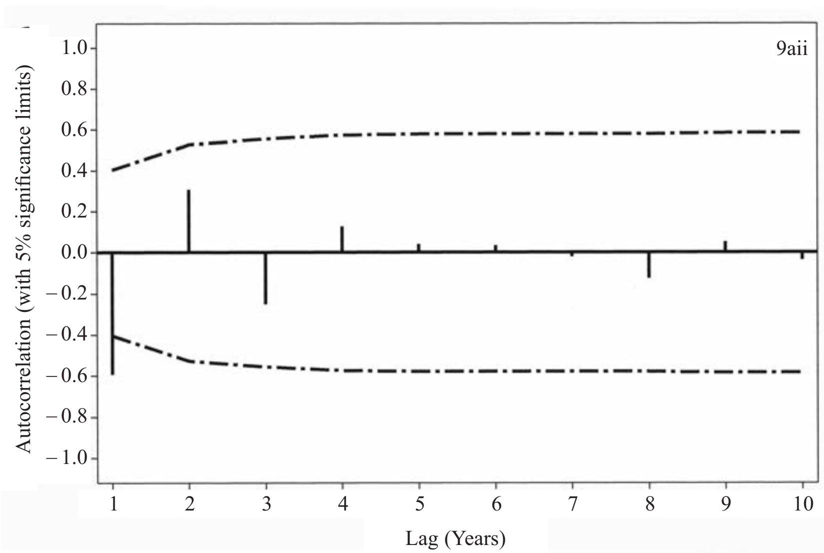




Fig. 9a. — The log number of species versus years with regression lines (i) and correlograms (ii) of *Andrena haemorrhoa* (see text for explanation).

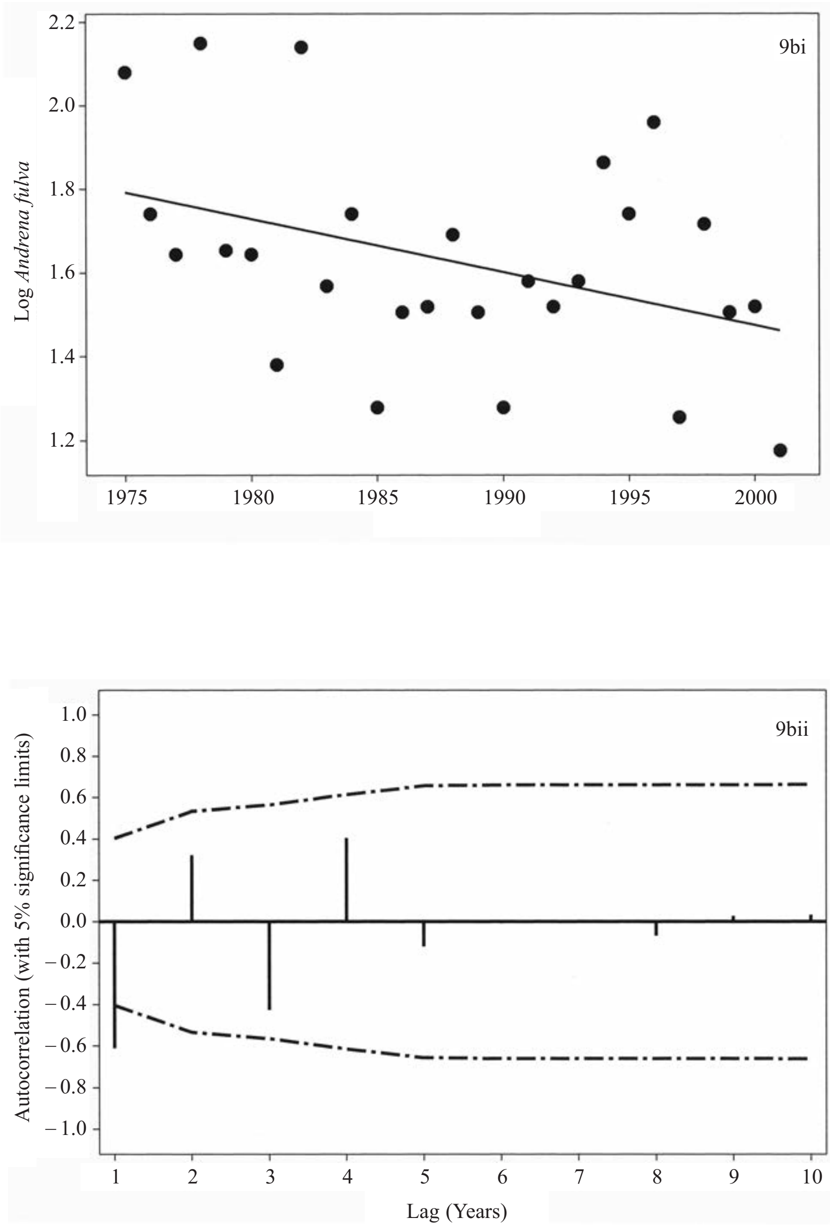
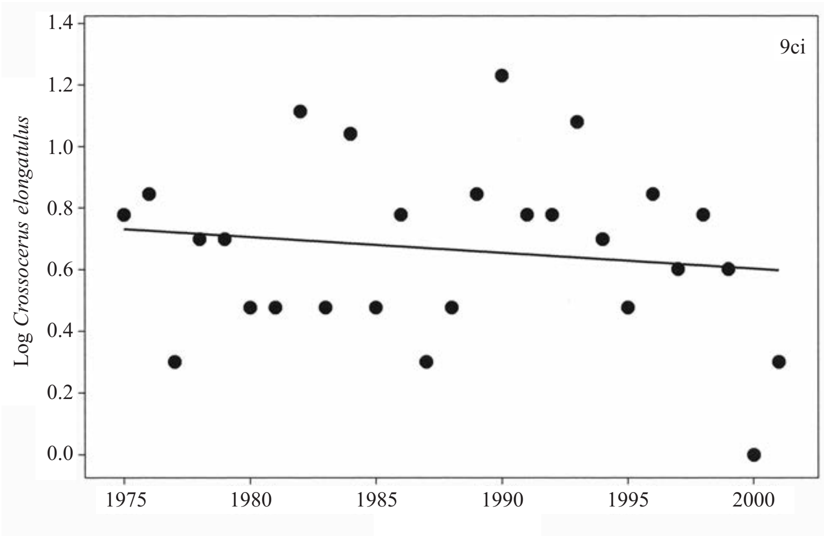



Fig. 9b. — The log number of species versus years with regression lines (i) and correlograms (ii) of *Andrena fulva* (see text for explanation).



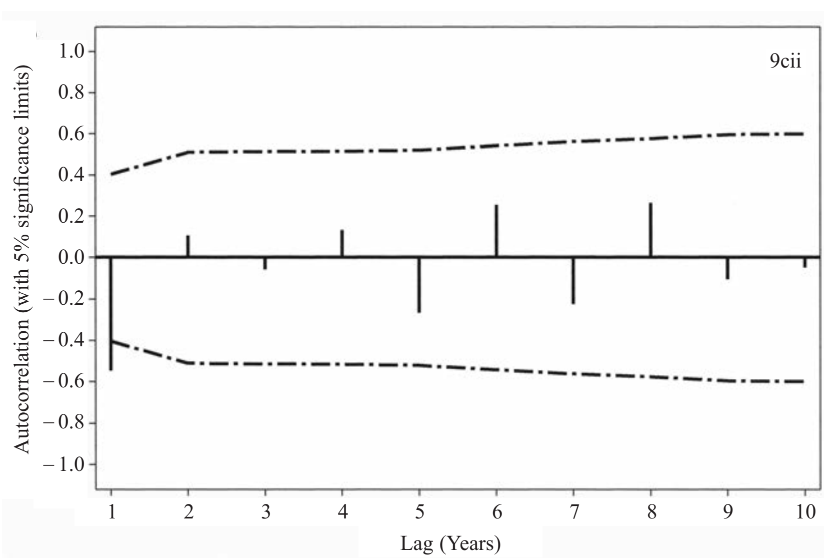




Fig. 9c. — The log number of species versus years with regression lines (i) and correlograms (ii) of *Crossocerus elongatulus* (see text for explanation).

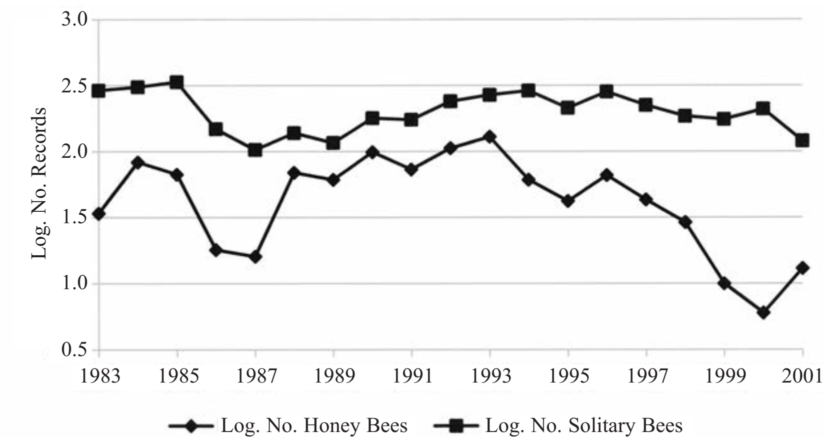



Fig. 10 — The number of solitary and honey bees trapped each year in a Leicester suburban garden.

species diversity to the heterogeneous environments of urban habitats where a great variety of the resource needs of insects can be found. Smith *et al.* (2005, 2006) provide evidence from a study of invertebrates in 61 Sheffield gardens for the importance of this heterogeneous environment.

The lack of a positive trend for the number of individuals trapped (Fig. 4) compared with the positive trend for the number of species (Fig. 1) can be related to the small number of individuals of new species trapped. At least two of these species (*Tiphia minuta* and *Crossocerus distinguendus*, both first recorded in 1998) were new species for Leicestershire. Later these two species continued to increase their range northwards with the record for Yorkshire being in 2001 for *Tiphia minuta* and in 2000 for *Crossocerus distinguendus* (Archer, 2004b). *T. minuta* was trapped during two of the remaining three years of trapping and *Crossocerus distinguendus* in the remaining three years indicating their successful establishment in the garden.

Wcislo (1987) found from a review of the literature of Palaearctic species that the cleptoparasitic load (CL) for bees varied between 12% (Iran) and 33% (Finland) (range 21%). This range is slightly larger than the 15% found by Archer (2011) probably because it covered a larger geographical area. The relative lack of cleptoparasitic bees in the more frequent group has also been found in the garden of Buckingham Palace (CL = 18.2%; Harvey, 2001) and York Victorian Cemetery (CL = 16.7%; Archer, 2004a). Since cleptoparasite species are often found around their host's nest sites, it was suggested by Archer (2007) that the host bees were generally not nesting in the garden but only collecting pollen (not needed by the cleptoparasites) and/or nectar within the garden. Such an explanation would apply to the more frequent species, but not to the less frequent species (Table 3). Probably the less frequent bees, usually cleptoparasites, are casual visitors to the garden looking for nesting sites of their hosts. Wcislo (1987) also reviewed the wasp literature and reached the same conclusion as for the bees, but did not carry out a numerical analysis.

The aerial-nester frequencies (AF) for Leicestershire are relatively high (solitary wasps 61.8%, solitary bees 22.4%; Archer, 1990a), so the relative high AF for the Leicester garden might be expected. However, the AF for the more frequent solitary wasp and bee species were much higher than the Leicestershire data (Table 4). The Leicester garden has very little bare ground and is cultivated with resulting soil disturbance (Owen, 2010). These are features disadvantageous for subterranean nesters. The only bare patch of soil in the garden was below the Malaise trap, where each year there was an aggregation of *Andrena fulva* nests.

Davis (1978) and Davis & Glick (1978) illustrated how urbanisation causes the fragmentation of natural and semi-natural habitats. This results in a general reduction of species richness, particularly of sensitive species. Certainly, the lower Species Quality Score (SQS) of the Leicester garden (2.2) (Table 5) in comparison with four semi-natural Midland sites (SQS 2.6–3.4; Archer, 2006) supports these comments. SQSs can be used to compare sites of varying size; since although the Quality Score for a site is significantly correlated with size, the SQS are not (Archer, 1999). It would seem that the Low and High Quality Species increase together as the area of a site increases. Ball (1992) (see Appendix 2) also used his Species Quality Index (= SQS) rather than the Rarity Score (= Quality Score) to make comparisons between sites since sampling effort between sites could be different. This would affect the number of species and rare species recorded. The SQS from gardens in urban Sheffield (2.0), when compared with South Yorkshire semi-natural sites (2.9), also shows a reduction of SQS (Archer, 2009). Presumably the semi-natural sites with the higher SQS have the resource requirements of the High Quality Species that have been lost or greatly reduced and isolated in an urban setting. Gardens are an important refuge for the commoner, but less so for the rarer, species.

All 23 species (Table 6) showed stationarity and ten species periodicity indicating that some endogenous dynamic is operating to bring a population back to a mean constant level even when the mean constant level or carrying capacity of the environment was increasing or decreasing. Periodic species with a significant negative one-year lag followed by alternately non significant positive and negative lags (Figs 9aii, 9bii, 9cii) indicates an underlying population dynamic of a two-year cycle with an oscillatory damped waveform to a mean constant level (Turchin & Taylor, 1992). Such a population dynamic was shown by species with increasing, decreasing or no yearly trends (Figs 9ai, 9bi, 9ci).

The factors involved in these trends are unknown but some speculations can be made. The increasing trend of *Passaloecus singularis* (Fig. 8ai) could be a consequence of this species finding, during dispersal, favourable resources such as nest sites and food that allowed it to establish in the garden. The increasing trend shown by *Anthophora plumipes*, which does not nest in the garden (Archer, 1990b), could be a consequence of its finding favourable resources such as food and mating sites in the garden. The decreasing trend shown by *Colletes daviesanus*, which similarly does not nest in the garden (Archer, 1990b), could be due to the loss of nesting in the surrounding area since this species often nests in aggregations. The relatively small but decreasing trend shown by *Andrena fulva* (Fig. 9bi) (which nested under the Malaise trap) (Archer, 1990b) could be a consequence of losses through trapping (1338 individuals, Appendix 1). These and other trends (Table 6) could also be reflecting population changes in the surrounding area of the garden. Perturbing factors resulting in the scatter of population counts (e.g. Figs 8i, 9i) around the regression lines indicate stochastic influences (e.g. weather).

More favourable weather conditions, such as increasing temperature, increasing hours of sunshine and decreased rainfall, are known to lead to increasing insect activity (Unwin & Corbet, 1991) (Table 7). The increase of the number of new species from 1992 (Fig. 2), particularly of wasps and spring bees (Fig. 6), could be related particularly to the increasing trend of mean temperature shown for Central England (which includes Leicestershire) during the 1990s and continuing into the early 2000s (Broham *et al.*, 2006).

A review of 24 data sets to investigate possible competition between honey bees and other bees (including social species) found that none of these studies provided conclusive evidence of such competition, or that competition may have been demonstrated when certain assumptions were made (Sugden, 1996). More recently, Steffan-Dewenter & Tscharntke (2000) found no significant correlation between species richness and abundance of wild bees and the density of honey bee colonies or the density of flower-visiting honey bees. The data from the Leicester garden confirms this lack of correlation, at least for the solitary bees.

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# APPENDIX 1
# THE SPECIES AND NUMBERS OF ACULEATA (HYMENOPTERA), AND YEARS WHEN TRAPPED, RECORDED IN A LEICESTER SUBURBAN GARDEN OVER 27 YEARS.

Key: Seasonal activity (Su.=Summer, Sp.=Spring, Sp./Su.= Spring/Summer; Status (see Appendix 2); Cleptoparasitic Load (CL): cleptoparasitic and parasitoid (C) or nest-building species (H); Aerial–Nester Frequency (AF): aerial, A, or subterranean, S, nesting habit of each species trapped, with the host species for cleptoparasitic or parasitoid species listed as aerial, (A), or subterranean nester, (S)

| Species | No. individuals | No. years | Season | Status | CL | AF |
|---|---|---|---|---|---|---|
| *Cleptes semiauratus* (Linn., 1761) | 9 | 7 | Su. | 8 | | |
| *Pseudomalus auratus* (Linn., 1758) | 229 | 26 | Su. | 1 | C | (A) |
| *Pseudomalus violaceus* (Scopoli, 1763) | 72 | 24 | Su. | 8 | C | (A) |
| *Chrysis angustula* Schenck, 1856 | 38 | 9 | Su. | 2 | C | (A) |
| *Chrysis ignita* (Linn., 1758) | 18 | 9 | Su. | 1 | C | (A) |
| *Chrysis impressa* Schenck, 1856 | 9 | 7 | Su. | 1 | C | (A) |
| *Trichrysis cyanea* (Linn., 1758) | 3 | 2 | Su. | 2 | C | (A) |
| *Tiphia minuta* Van der Linden, 1827 | 5 | 3 | Su. | 2 | | |
| *Monosapyga clavicornis* (Linn., 1758) | 1 | 1 | Su. | 8 | C | (A) |
| *Sapyga quinquepunctata* (Fab., 1781) | 15 | 10 | Su. | 2 | C | (A) |
| *Dipogon variegatus* (Linn., 1758) | 6 | 5 | Su. | 1 | H | A |
| *Ancistrocerus gazella* (Panzer, 1798) | 89 | 23 | Su. | 2 | H | A |
| *Ancistrocerus parietinus* (Linn., 1758) | 2 | 2 | Su. | 1 | H | A |
| *Ancistrocerus trifasciatus* (Müller, 1776) | 9 | 7 | Su. | 1 | H | A |
| *Symmorphus bifasciatus* (Linn., 1761) | 4 | 3 | Su. | 1 | H | A |
| *Symmorphus gracilis* (Brullé, 1832) | 1 | 1 | Su. | 2 | H | A |
| *Trypoxylon attenuatum* Smith, 1851 | 68 | 21 | Su. | 1 | H | A |
| *Trypoxylon clavicerum* Lepeletier & Serville, 1828 | 75 | 17 | Su. | 2 | H | A |
| *Trypoxylon figulus* (Linn., 1758) | 2 | 2 | Su. | 1 | H | A |

| Species | No. individuals | No. years | Season | Status | CL | AF |
|---|---|---|---|---|---|---|
| *Crossocerus binotatus* (Lepeletier & Brullé, 1834) | 1 | 1 | Su. | 8 | H | A |
| *Crossocerus distinguendus* (Morawitz, 1866) | 32 | 4 | Su. | 2 | H | S |
| *Crossocerus elongatulus* (Van der Linden, 1829) | 125 | 26 | Su. | 1 | H | S |
| *Crossocerus pusillus* Lepeletier & Brullé, 1834 | 7 | 4 | Su. | 1 | H | S |
| *Crossocerus annulipes* (Lepeletier & Brullé, 1834) | 214 | 27 | Su. | 2 | H | A |
| *Crossocerus capitosus* (Shuckard, 1837) | 22 | 15 | Su. | 1 | H | A |
| *Crossocerus megacephalus* (Rossi, 1790) | 71 | 24 | Su. | 1 | H | A |
| *Crossocerus nigritus* (Lepeletier & Brullé, 1834) | 13 | 7 | Su. | 2 | H | A |
| *Crossocerus walkeri* (Shuckard, 1837) | 1 | 1 | Su. | 16 | H | A |
| *Crossocerus podagricus* (Van der Linden, 1829) | 12 | 6 | Su. | 2 | H | A |
| *Crossocerus quadrimaculatus* (Fab., 1793) | 1 | 1 | Su. | 2 | H | S |
| *Crossocerus dimidiatus* (Fab., 1781) | 9 | 7 | Su. | 1 | H | A |
| *Ectemnius cavifrons* (Thomson, 1870) | 126 | 25 | Su. | 1 | H | A |
| *Ectemnius ruficornis* (Zetterstedt, 1838) | 1 | 1 | Su. | 2 | H | A |
| *Ectemnius sexcinctus* (Fab. 1775) | 3 | 3 | Su. | 2 | H | A |
| *Ectemnius continuus* (Fab., 1804) | 1 | 1 | Su | 1 | H | A |
| *Ectemnius cephalotes* (Olivier, 1792) | 54 | 14 | Su. | 2 | H | A |
| *Rhopalum clavipes* (Linn., 1758) | 64 | 20 | Su. | 1 | H | A |
| *Rhopalum coarctatum* (Scopoli, 1763) | 2 | 1 | Su. | 2 | H | A |
| *Oxybelus uniglumis* (Linn., 1758) | 1 | 1 | Su. | 1 | H | S |
| *Psenulus pallipes* (Panzer, 1798) | 102 | 25 | Su | 2 | H | A |
| *Psenulus concolor* (Dahlbom, 1843) | 100 | 24 | Su. | 2 | H | A |
| *Spilomena beata* (Blüthgen, 1953) | 7 | 2 | Su. | 8 | H | A |
| *Spilomena troglodytes* (Van der Linden, 1829) | 24 | 7 | Su. | 2 | H | A |

| Species | No. individuals | No. years | Season | Status | CL | AF |
|---|---|---|---|---|---|---|
| *Stigmus solskyi* Morawitz, 1864 | 30 | 13 | Su. | 2 | H | A |
| *Pemphredon lugubris* (Fab., 1793) | 385 | 27 | Su. | 1 | H | A |
| *Pemphredon inornata* Say, 1824 | 33 | 15 | Su. | 1 | H | A |
| *Pemphredon lethifer* (Shuckard, 1837) | 211 | 22 | Su. | 1 | H | A |
| *Pemphredon morio* Van der Linden, 1829 | 8 | 6 | Su. | 8 | H | A |
| *Diodontus tristis* (Van der Linden, 1829) | 23 | 13 | Su. | 8 | H | S |
| *Passaloecus corniger* Shuckard, 1837 | 54 | 19 | Su. | 2 | H | A |
| *Passaloecus gracilis* (Curtis, 1834) | 276 | 26 | Su. | 2 | H | A |
| *Passaloecus insignis* (Van der Linden, 1829) | 32 | 10 | Su. | 2 | H | A |
| *Passaloecus singularis* Dahlbom, 1844 | 917 | 27 | Su. | 2 | H | A |
| *Mellinus arvensis* (Linn., 1758) | 2 | 2 | Su. | 1 | H | S |
| *Philanthus triangulum* (Fab., 1775) | 1 | 1 | Su. | 2 | H | S |
| *Colletes daviesanus* Smith, 1846 | 1286 | 23 | Su. | 1 | H | S |
| *Hylaeus communis* Nylander, 1852 | 817 | 27 | Su. | 2 | H | A |
| *Hylaeus hyalinatus* Smith, 1842 | 23 | 13 | Su. | 2 | H | A |
| *Andrena bicolor* Fab., 1775 | 130 | 20 | Sp./Su. | 1 | H | S |
| *Andrena chrysosceles* (Kirby, 1802) | 1 | 1 | Sp. | 2 | H | S |
| *Andrena fucata* Smith, 1847 | 5 | 4 | Sp. | 1 | H | S |
| *Andrena fulva* (Müller *in* Allioni, 1766) | 1338 | 27 | Sp. | 1 | H | S |
| *Andrena haemorrhoa* (Fab., 1781) | 295 | 25 | Sp. | 1 | H | S |
| *Andrena minutula* (Kirby, 1802) | 7 | 3 | Sp./Su. | 2 | H | S |
| *Andrena nigroaenea* (Kirby, 1802) | 151 | 25 | Sp. | 1 | H | S |
| *Andrena praecox* (Scopoli, 1763) | 1 | 1 | Sp. | 2 | H | S |
| *Andrena scotica* Perkins, 1916 | 385 | 26 | Sp. | 1 | H | S |

| Species | No. individuals | No. years | Season | Status | CL | AF |
|---|---|---|---|---|---|---|
| *Andrena subopaca* (Nylander, 1848) | 1 | 1 | Sp./Su. | 1 | H | S |
| *Halictus rubicundus* (Christ, 1791) | 6 | 5 | Sp./Su. | 1 | H | S |
| *Halictus tumulorum* (Linn., 1758) | 1 | 1 | Sp./Su. | 1 | H | S |
| *Lasioglossum albipes* (Fab., 1781) | 3 | 3 | Sp./Su. | 1 | H | S |
| *Lasioglossum cupromicans* (Pérez, 1903) | 3 | 2 | Sp./Su. | 1 | H | S |
| *Lasioglossum fulvicorne* (Kirby, 1802) | 1 | 1 | Sp./Su. | 2 | H | S |
| *Lasioglossum leucopus* (Kirby, 1802) | 37 | 13 | Sp./Su. | 1 | H | S |
| *Lasioglossum morio* (Fab., 1793) | 45 | 16 | Sp./Su. | 2 | H | S |
| *Lasioglossum smeathmanellum* (Kirby, 1802) | 299 | 23 | Sp./Su. | 2 | H | S |
| *Lasioglossum villosulum* (Kirby, 1802) | 39 | 12 | Sp./Su. | 1 | H | S |
| *Sphecodes ephippius* (Linn., 1767) | 3 | 3 | Sp./Su. | 2 | C | (S) |
| *Sphecodes geoffrellus* (Kirby, 1802) | 16 | 8 | Sp./Su. | 1 | C | (S) |
| *Sphecodes gibbus* (Linn., 1758) | 1 | 1 | Sp./Su. | 2 | C | (S) |
| *Sphecodes puncticeps* Thomson, 1870 | 2 | 1 | Sp./Su | 2 | C | (S) |
| *Anthidium manicatum* (Linn., 1758) | 18 | 7 | Su. | 2 | H | A |
| *Chelostoma campanularum* (Kirby, 1802) | 2 | 2 | Su. | 2 | H | A |
| *Osmia caerulescens* (Linn., 1758) | 136 | 23 | Sp./Su. | 2 | H | A |
| *Osmia leaiana* (Kirby, 1802) | 21 | 13 | Sp./Su. | 2 | H | A |
| *Osmia rufa* (Linn., 1758) | 333 | 27 | Sp. | 1 | H | A |
| *Megachile centuncularis* (Linn., 1758) | 109 | 25 | Su. | 1 | H | A |
| *Megachile circumcincta* (Kirby, 1802) | 1 | 1 | Su. | 1 | H | S |
| *Megachile ligniseca* (Kirby, 1802) | 21 | 9 | Su. | 2 | H | A |
| *Megachile versicolor* Smith, 1844 | 4 | 4 | Su. | 2 | H | A |
| *Megachile willughbiella* (Kirby, 1802) | 114 | 22 | Su. | 1 | H | A |

| Species | No. individuals | No. years | Season | Status | CL | AF |
|---|---|---|---|---|---|---|
| *Coelioxys inermis* (Kirby, 1802) | 2 | 2 | Su. | 8 | C | (A) |
| *Coelioxys rufescens* (Lepeletier & Serville, 1825) | 3 | 3 | Su. | 2 | C | (A) |
| *Nomada flava* Panzer, 1798 | 45 | 8 | Sp. | 2 | C | (S) |
| *Nomada goodeniana* (Kirby, 1802) | 3 | 2 | Sp. | 1 | C | (S) |
| *Nomada marshamella* (Kirby, 1802) | 27 | 13 | Sp. | 1 | C | (S) |
| *Nomada panzeri* Lepeletier, 1841 | 77 | 16 | Sp. | 1 | C | (S) |
| *Nomada ruficornis* (Linn. 1758) | 3 | 2 | Sp. | 1 | C | (S) |
| *Anthophora furcata* (Panzer, 1798) | 98 | 26 | Su. | 2 | H | A |
| *Anthophora plumipes* (Pallas, 1772) | 799 | 27 | Sp. | 2 | H | S |
| Totals | 10332 | 27 | 100 | 100 | 98 | 98 |

## APPENDIX 2
## SPECIES QUALITY CODING FOR ENGLAND, WALES AND SCOTLAND.

*Three categories of High Quality Species*:

**Very rare** – recorded from 1 to 15 10-km squares, 1970 onwards, value 32.

**Rare** – recorded from 16 to 30 10-km squares, 1970 onwards, value 16.

**Scarce** – recorded from 31 to 70 10-km squares, 1970 onwards, value 8.

*Three categories of Low Quality Species*:

**Restricted** – recorded from more than 70 10-km squares, 1970 onwards, within southern England, south-west and southern coastlands, about half of England, includes East Anglia, value 4.

**Widespread** – recorded from more than 70 10-km squares, 1970 onwards, within the restricted area and Midland lowlands, central coastlands of England, lowlands Wales, south-west Scotland, but excludes Northumbria, about three-quarters of England, value 2.

**Universal** – recorded from more than 70 10-km squares, 1970 onwards, within the restricted and widespread areas and the rest of England, Wales and Scotland, value 1.

The geographical areas are derived mainly from Pienkowski *et al.*, 1996. Other sources for definitions: Species Quality Coding for species (Ball, 1992); Red Data Book (Shirt, 1987), value 32; Notable A (Falk, 1991), value 16; Notable B (Falk, 1991), value 8; Regionally Notable (Ball, 1989), value 4; Local (Ball, 1989), value 2; Common (Ball, 1989), value 1.