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21 Apr 1984	Lc present, one colony found.
23 Jun 1984	Lc not found in very brief search. T = 11 C. Cond. = 747. Flow very slight.
14 Jul 1984	Lc not abundant but four colonies found. T = 12.5 C. Cond. = 830. Flow very slight.
27 Dec 1984	Lc not found. T = 7 C. Cond. = 830. Flow slight or absent.
31 Mar 1986	Lc not found.
26 Mar 1989	Lc not found. No flow. Water level in pool down by about 1 metre.
13 Jul 1991	Lc present but not abundant. Two colonies found on a stick. No noticeable flow. Water level down about 0.7 metres.
29 Mar 1997	Lc not found. Searched all dead wood within reach and a few dead leaves. No visible flow. Water level down by about 0.7 metres, with rabbit burrows in soil that would normally be below water level.
27 Dec 1997	Lc not found. No flow. Water level down by at least 1 metre. Spent 20 minutes searching submerged branches and leaves.
10 May 98	Lc not found. Water levels very high and flow strong. Main pool covered about an acre.
28 Dec 1998	Lc present. About 25 colonies on fallen branches and a willow trunk. Strong flow.
13 Jun 1999	Lc present on twigs. Not a prolonged search. Strong flow.

Postscript

On 5 August 2001, a 20 minute search found two *Lophopus* colonies on a detached barkless branch of about 4 cm diameter. There was a moderately strong flow of water from the main pool though the water level was down by about 30 cm.

THE WASPS AND BEES (HYMENOPTERA: ACULEATA) OF KIRKBY MOOR IN WATSONIAN LINCOLNSHIRE

Michael E. Archer

Kirkby Moor (plate 9) is a very good site for aculeate wasps and bees with 84 recorded species including three of national importance. The aims of this paper are to describe the wasp and bee fauna of Kirkby Moor, compare this fauna with other Lincolnshire sites and to use non-parametric statistical procedures to estimate potential species diversity.

Kirkby Moor (TF2262) is situated about 1.5km west of Kirkby-on-Bain and about 7.5km south of Horncastle in Lincolnshire. It is a nature reserve of the Lincolnshire Trust for Nature Conservation which manages its wildlife. The 75ha reserve is a remnant of the once extensive heathlands on the sands and gravels of the Woodhall district in the North Lincolnshire Coversands and Clay Vale Natural Area.

The open parts of Kirkby Moor are dominated by heather, bracken and wavy hair grass with moss and lichen communities. Areas of bare sand, associated with pathways and other disturbed areas, are used as nesting sites for the subterranean species. At the southern end of the reserve is oak, birch and pine woodland as well as developing birch, hawthorn and sallow shrubs. The open areas of the woodland and the shrubs provide nectar, pollen and prey resources, besides sunning and mating places, for the aculeate wasps and bees. The walls of the buildings associated with Foxhill Cottage are used as sunning sites and nesting sites for some aerial nesting species.

Sampling methods
Between 1989 and 1999, 14 visits were made to the Moor distributed throughout the year as follows: April (1 visit), May (3), June (3), July (3), August (3) and September (1). All visits occurred during warm sunny weather. During each, approximately three hour, visit all species of aculeate wasps and bees were recorded and usually collected with a hand net for identification. In the following account, the nomenclature follows that of Kloet and Hincks (1978).

Species present and seasonal progression of species
A full list of the species is given in the Appendix. At the family level, Table 1 shows the taxonomic distributions of species and records. A record represents a specimen differing in one of the following three variables: name, sex and day of visit. The solitary wasp family, Sphecidae, and the solitary bee families, Andrenidae, Halictidae and Anthophoridae, are dominant in terms of number of species and records, although the Pompilidae are well represented in terms of the number of records.

Table 1 The number of species and records of aculeate wasps and bees recorded from Kirkby Moor.

	No. species	Records
Solitary wasps		
Chrysididae	5	10
Sapygidae	1	1
Pompilidae	8	18
Eumenidae	4	8
Sphecidae	18	51
Total solitary wasps	36	88
Solitary bees		
Colletidae	3	8
Andrenidae	11	30
Halictidae	10	24
Megachilidae	3	5
Anthophoridae	9	15
Total solitary bees	36	82
Total solitary wasps & bees	72	170
Social species		
Vespidae	3	
Apidae	9	
Total social species	12	
Total wasp & bee species	84	

June and July were the best months for recording species of solitary wasps, with May, June and July being +/- equally productive for the first recording of species (Table 2).

Table 2 The number of species and first records of species of solitary wasps and bees recorded per month at Kirkby Moor.

	April	May	June	July	August	September
Solitary wasps						
First records		10	12	12	2	
Recorded		10	18	22	8	1
Solitary bees						
First records	4	13	5	8	6	
Recorded	4	17	9	11	9	4

The species most evident were the pompilid *Priocnemis schioedtei*, the sphecids

Ammophila sabulosa and *Mellinus arvensis* and the mason wasp, *Ancistrocerus oviventris*. These species are subterranean nesters except for *A. oviventris* which built its mud nests, particularly on the brick walls of the ponds. The burrows of *M. arvensis* are particularly associated with rabbit holes.

May was the most productive month for both the number of species and first recording of solitary bees (Table 2). The species most evident in the spring were *Andrena scotica* with its cleptoparasites *Nomada marshamella* and *N. flava*, and *A. barbilabris* with its cleptoparasite *Sphecodes pellucidus*. These *Andrena* bees were often found on the flowers of the hawthorn. The species most evident in the summer, particularly while foraging from heather flowers, were *Colletes succinctus* with its cleptoparasite *Epeolus cruciger* and *Andrena fuscipes* with its cleptoparasite *Nomada rufipes*. The sweat bee, *Lasioglossum calceatum* with its probable cleptoparasite *Sphecodes monilicornis*, although only found during the summer, is also usually found in the spring. All the above host bees are subterranean nesters.

Species-area relationship

A problem in the study of any site is the difficulty of knowing when the species list is sufficiently complete so that comparisons with other sites may reasonably be made. One way to resolve this problem is the use of the species-area relationship where the number of species and the area of the sites, both expressed as natural logarithms (ln), can show a positive linear relationship (Usher, 1986). If the number of species in relation to the area of a site falls within the range of other sites which show a statistically significant species-area relationship, then the site may reasonable be compared with other sites. The dot for Kirkby Moor falls within the range of 19 sites from the north and north midlands of England (Archer, 1999). Thus the species list from Kirkby Moor is reasonably complete to compare with other Lincolnshire sites.

Species quality

Three species of national importance have been recorded from the Moor: one Red Data Book species (Shirt, 1987), *Nomada fulvicornis*; one national notable or scarce species (Falk, 1991), *Priocnemis schioedtei*; and *Tachysphex nitidus* as established by recent work of the Bees, Wasps and Ants Recording Society (BWARS) (Edwards, 1998). *N. fulvicornis* and *T. nitidus* are on the northern edge of their range in Lincolnshire while *P. schioedtei* is distributed throughout England, Wales and Scotland.

To take account of all species and the latest information from BWARS, Archer & Burn (1995) introduced a new national quality scoring system and Archer (1999) gave definitions for the six national statuses. High quality species have a scarce, rare or very rare status while low quality species have a universal, widespread or restricted status. By giving each of 72 species of solitary wasps and bees a national status a national quality score of 136 can be calculated (Table 3) with a national species quality score of 1.9 (136/72).

Table 3 The Archer national quality scores of the species of solitary wasps and bees recorded from Kirkby Moor (Species quality score = 136/72 = 1.89)

Status	Status value (A)	No. species (B)	Quality score (A x B)
Universal	1	50	50
Widespread	2	19	38
Restricted	4	0	0
Scarce	8	2	16
Rare	16	0	0
Very rare	32	1	32
Total		72	136

How do these scores relate to those of other Lincolnshire sites? Table 4 summarises the quality characteristics of Risby Warren (Archer, 1994), Gibraltar Point NNR (Archer, 1998) and Saltfleetby-Theddlethorpe NNR (Archer, 2000). Although the quality scores, and the number of solitary and high quality species will be influenced by the areas of the sites, the species quality scores are relatively independent of site area (Archer, 1999), so can be used to compare sites. The species quality scores of the four sites are similar so that Kirkby Moor can be considered as important as the others. Since two of the sites have NNR status, the aculeate data would qualify the other two sites for NNR status.

Table 4 Species quality characteristics of solitary wasps & bees from Lincs sites.

	No. solitary species	Total high quality spp.	Quality score	Species quality score	Area (ha.)
Gibraltar Point	86	4	140	1.7	437
Risby Warren	63	3	114	1.8	170
Saltfleetby-Theddlethorpe	63	4	114	1.8	313
Kirkby Moor	72	3	136	1.9	75

Estimating the potential number of solitary wasp and bee species

Another problem in the study of any site is the difficulty of knowing how many more species are present yet unrecorded. Recent advances in non-parametric statistical procedures offer a way of addressing this problem. The presence/absence quantitative estimate of Chao (in Colwell & Coddington, 1994) is based on the number of species that are observed in one (unique species) or two (two occasion species) samples or visits. The jackknife procedure (Heltshe & Forrester, 1983) only depends on the unique species. Because some aculeate species are only active in the spring or summer it is advisable that samples be taken throughout the months of adult activity. The software to carry out the statistical procedures was provided by Pisces Conservation Ltd.

The statistical procedures were run 14 times for the species of solitary wasps and bees. The software takes 1, 2, etc. samples at random 14 times, each time calculating a mean estimate of potential species diversity. With a small number of samples the Chao estimates are erratic, but as more samples are selected the estimates may stabilise giving confidence in the estimates. With an increasing number of samples the jackknife estimates may approach an upper asymptote. The Chao estimates do stabilise and the jackknife estimates approach an upper asymptote (Fig. 1, 2). The final Chao and jackknife estimates are within about 1% of each other so giving additional confidence in the

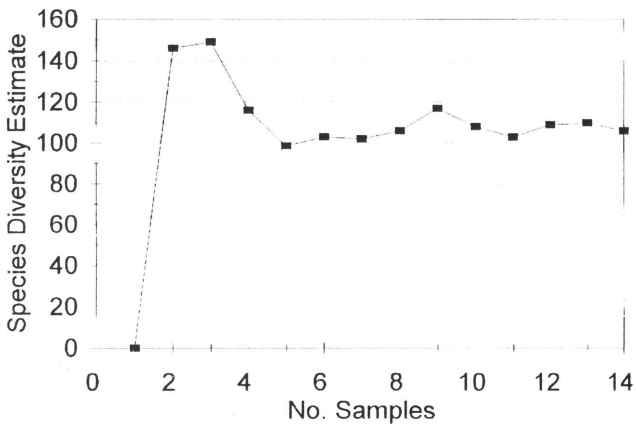

Figure 1 The Chao presence/absence estimate of species richness for Kirkby Moor

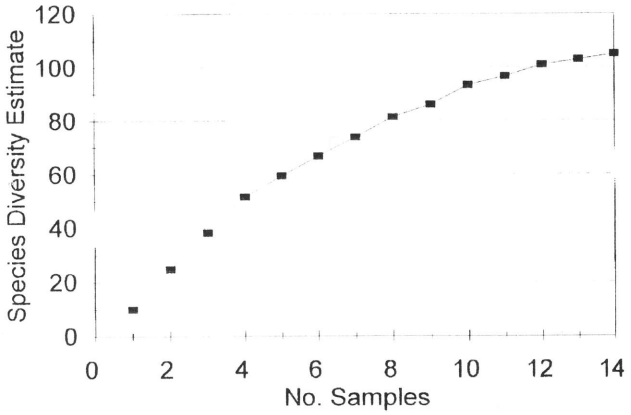

Figure 2. The jackknife estimate of species richness for Kirkby Moor.

estimates (Table 5). Table 5 also gives the 95% confidence limits of the estimates (meaning that there is a 95% chance that the potential number of species falls within this range) and shows that about 70% of the potential number of species have been recorded.

Table 5 Non-parametric estimates of species richness of solitary wasps and bees at Kirkby Moor using presence/absence Chao and jackknife procedures.

	Chao	Jackknife
No. recorded species	72	72
Estimates	106	105
95% confidence limits of estimates	80-132	84-126
% of species recorded	68	69

One possible complication in making estimates is the presence of vagrant species among the unique species. Vagrant species are species that are accidentally present in the samples, being outside their normal range. The presence of unique vagrant species would artificially increase the estimate of the potential number of species. Fortunately none of the recorded species can be regarded as vagrant.

Cleptoparasitic load

The cleptoparasitic load (CL) is the percentage of aculeate species that are cleptoparasites (or parasitoids) on other host aculeates. Wcislo (1987) showed that parasite behaviour among aculeate Hymenoptera correlated with geographical latitude. Thus the parasitic rates are higher in temperate regions as host populations are more synchronised in their life-history characteristics. This finding probably does not hold for desert climates where the occurrence of rainfall would tend to synchronise life history characteristics. From a review of the literature Wcislo (1987) found that the CLs for bees in Europe varied between 16% and 33%, a range of 17%

The CLs for the solitary bees from north and north midland sites of England vary between 22% and 37%, a range of 15% (Archer, 1999). The range of values of CL for the northern English sites is similar to the wider European sites (Wcislo, 1987). The CL for the solitary bees from Kirkby Moor (Table 6) falls within the range from the northern English sites.

Wcislo (1987) gives no CL values for wasps. However, for the north and north midland sites of England, CL values for the solitary wasps varies between 10% and 22%, a range of 12% (Archer, 1999). The narrow range of this variation indicates that the argument Wcislo (1987) developed for the bees also applies to the solitary wasps. The CL for the

solitary species of wasps from Kirkby Moor (Table 6) falls within this range.

Table 6 The relative frequency of the cleptoparasitic (or parasitoid) species among the solitary wasps and bees recorded from Kirkby Moor.

	No. hosts (H)	No. cleptoparasites (C)	Cleptoparasitic load CL = 100 x C/(H + C)
Solitary wasps	29	7	19.4
Solitary bees	23	13	36.1

All the social species are host species, except for the *Psithyrus* species, which are social parasites on the *Bombus* species.

Aerial nester frequency

The aerial-nester frequency (AF) is the percentage of host aculeate species that have aerial nest sites. Aerial nesters may use old beetle burrows in dead wood, central stem cavities, e.g. bramble, old snail shells, or crevices in old walls or exposed on the surface of rock or other hard material. Subterranean nesters nest in the soil, usually in burrows dug by themselves, but sometimes holes and crevices are used after being altered.

The AF for all the British solitary bees is 17.9, which is similar to the AF of solitary bees from Kirkby Moor (Table 7), while the AF for all British species of solitary wasps is 46.2% which is much higher than the AF of the solitary wasps from Kirkby Moor (Table 7). The low AF value could be a consequence of failure to find more aerial-nesting species or the lack of suitable aerial-nesting habitat. Further visits will be needed to resolve this.

Table 7 The nesting habits of the host species of solitary wasps and bees recorded from Kirkby Moor.

	No. aerial nesters (A)	No. subterranean nesters (S)	Aerial nester frequency AF = 100 x A/(A +S)
Solitary wasps	7	22	24.1
Solitary bees	4	19	17.4

All the species of social wasps and *Bombus* are subterranean nesters, although *B. pratorum* is known to nest in aerial situations such as old birds' nests. Aerial nests of wild honeybees, *Apis mellifera*, were not found.

Conclusions

1. Kirkby Moor is a very good site for aculeate wasps and bees with 84 recorded species including three species of national importance.
2. The number of recorded solitary species is that which would be expected in relation to the area of the site.
3. The species quality score is similar to those of other outstanding Lincolnshire sites.
4. The species diversity estimates indicate that on average about another 30 solitary species have yet to be recorded.
5. The cleptoparasitic loads for the solitary wasps and bees support Wcislo's proposal.
6. The number of recorded aerial-nesting species of solitary wasps is relatively low.

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Appendix - Species List

Chrysididae - *Hedychridium ardens* (Latreille in Coquebert), *Chrysis ignita* (Linn.), *C. impressa* Schenck, *C. ruddii* Shuckard, *Trichrysis cyanea* (Linn.).
Sapygidae - *Sapyga quinquepunctata* (Fab.).
Pompilidae - *Priocnemis schioedtei* Haupt, *P perturbator* (Harris), *Pompilus cinereus* (Fab.), *Arachnospila anceps* (Wesmael), *A. spissa* (Schiødte), *Evagetes crassicornis* (Shuckard), *Anoplius infuscatus* (Vander Linden), *Episyron rufipes* (Linn.).
Eumenidae - *Ancistrocerus oviventris* (Wesmael), *A. parietinus* (Linn.), *A. parietum* (Linn.), *A. trifasciatus* (Müller).
Vespidae - *Dolichovespula sylvestris* (Scopoli), *Vespula rufa* (Linn.), *Paravespula vulgaris* (Linn.).
Sphecidae - *Tachysphex nitidus* (Spinola), *T. pompiliformis* (Panzer), *Trypoxylon figulus* (Linn.), *Crabro cribrarius* (Linn.), *C. peltarius* (Schreber), *Crossocerus elongatulus* (Vander Linden), *C. ovalis* Lepeletier & Brullé, *C. tarsatus* (Shuckard), *C. wesmaeli* (Vander Linden), *C. podagricus* (Vander Linden), *C. quadrimaculatus* (Fab.), *Oxybelus uniglumis* (Linn.), *P. dalbomi* (Wesmael), *Psen equestris* (Fab.), *P. lutarius* (Fab.), *Ammophila sabulosa* (Linn.), *Argogorytes mystaceus* (Linn.), *Mellinus arvensis* (Linn.).
Colletidae - *Colletes similis* Schenck, *C. succinctus* (Linn.), *Hylaeus communis* Nylander.
Andrenidae - *Andrena barbilabris* (Kirby), *A. bicolor* Fab., *A. chrysosceles* (Kirby), *A. fucata* Smith, *A. fulva* (Müller in Allioni), *A. fuscipes* (Kirby), *A. haemorrhoa* (Fab.), *A. helvola* (Linn.), *A. nigroaenea* (Kirby), *A. scotica* Perkins, *A. subopaca* Nylander.
Halictidae - *Halictus rubicundus* (Christ), *H. tumulorum* (Linn.), *Lasioglossum albipes* (Linn.), *L. calceatum* (Scopoli), *L. leucozonium* (Schrank), *L. rufitarse* (Zetterstedt), *Sphecodes geoffrellus* (Kirby) (=*fasciatus*), *S. gibbus* (Linn.), *S. monilicornis* (Kirby), *S. pellucidus* Smith.
Megachilidae - *Osmia leaiana* (Kirby), *Megachile centuncularis* (Linn.), *M. willughbiella* (Kirby).
Anthophoridae - *Nomada flava* Panzer, *N. fulvicornis* Fab., *N. leucophthalma* (Kirby), *N. marshamella* (Kirby), *N. panzeri* Lepeletier, *N. ruficornis* (Linn.), *N. rufipes* Fab., *Epeolus cruciger* (Panzer), *E. variegatus* (Linn.).
Apidae - *Bombus lucorum* (Linn.), *B. terrestris* (Linn.), *B. lapidarius* (Linn.), *B. pratorum* (Linn.), *B. hortorum* (Linn.), *B. pascuorum* (Scopoli), *Psithyrus bohemicus* (Seidl), *P. vestalis* (Geoffroy in Fourcroy), *Apis mellifera* Linn.