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A classification of the genus *Lycosa* (Araneae : Lycosidae)

R. H. Smith[1] and M. B. Usher[2]
Department of Biology,
University of York

Introduction

The Linnaean system of classification, based on the observation and weighting of characters to form a hierarchical structure of groups of related organisms, has been almost universally accepted by biologists despite its main shortcoming of subjectivity. Since computers have become generally available an alternative system has come into use, that of numerical taxonomy. The present study compares the results of different methods used to classify the spider genus *Lycosa*.

Numerical taxonomy is based on principles outlined by the French botanist Adanson (1727-1806) who realised that natural taxa are based on the concept of overall resemblance or affinity. He advocated the use of many characters given equal weight instead of a few chosen ones. However, numerical methods did not find favour until computers became generally available, largely because of the long and tedious calculations involved in deriving the classification.

Sokal and Sneath (1963) define numerical taxonomy as "the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities". The groups thus formed are polytypic, that is, they are based on members sharing a high proportion of characters rather than one or two important ones, and they take no account of phylogenetic considerations such as parallel or convergent evolution. The ancestry of some groups is fairly well known, but there are large groups such as the insects and arachnids which have left virtually no fossils. The aim of classifying a group such as the *Lycosa* can therefore either be to aid identification (as in Locket and Millidge (1951) and Wiebes (1959)) or to investigate ecological features based on overall similarity (as in the present study).

The Genus *Lycosa*

The genus *Lycosa* is represented by seventeen species in Britain. Locket and Millidge (1951) divide the genus into four groups, based mainly on the structure of the female epigyne. Wiebes (1959) produced a similar classification except that he placed *L. prativaga* and *L. pullata* in a separate group from *L.amentata, L.hortensis, L.nigriceps and L.lugubris.*

For the purposes of this study each species was assigned a reference number and these are given, together with the groups of Locket and Millidge, in Table 1.

Choice of Characters and Collection of Data

Mayr *et al.* (1953) list five types of taxonomic characters - morphological, physiological, ecological, ethological (behavioural) and geographic. In the present study only external morphological characters have been used, observed on single, preserved, adult specimens. Characters that were obviously correlated were avoided, and quantitative measurements were expressed as ratios. In order to check the reliability of character selection and coding based on single specimens, two female specimens of *L. amentata* were included and these were found to have a larger correlation coefficient (r=0.931) than any other pair of species. A full list of the ninety characters used is reproduced in Table 2. Any characters that were unmeasurable or doubtful for a particular specimen were not used in deriving the classification.

Most of the specimens studies were from the A. M. Wild collection at Leicester Museum, the rest are in M.B.U's collection. All females in the genus were included, but five of the seventeen males were not obtained. For recording characters the specimens were immersed in 70% alcohol, illuminated from above, and observed with a binocular microscope. The legs of the spiders were held very gently between cover-slips to keep them horizontal during measurement. The complete scores for the characters are given by Smith (1970).

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[1] present address: Department of Zoology, University of Reading

[2] present address B.R.R.I., University P.O. Box 40, Kumasi, Ghana

Species and Group	Reference No.
Group 1:	
L. arenicola O.P-Cambridge	1
L. agricola Thorell	2
L. agrestis Westring	13
L. purbeckensis (F.O.P.-Cambridge)	3
L. monticola (Clerck)	4
L. tarsalis Thorell	5
L. tarsalis var. *herbigrada* Blackwall	14
Group 2:	
L. pullata (Clerck)	6
L. prativaga L. Koch	7
L. amentata (Clerck)	8, 18
L. nigriceps Thorell	9
L. lugubris (Walckenaer)	10
L. hortensis Thorell	11
L. proxima C.L.Koch	15
Group 3:	
L. traillii O.P.-Cambridge	16
L. paludicola (Clerck)	12
Group 4:	
L. rubrofasciata (Ohlert)	17

Table 1:

The classification of the genus *Lycosa* into four groups (Locket & Millidge, 1951). Reference numbers relate to Fig. 1.

Treatment of Data

After the data had been collected it was standardised to give zero mean and unit variance for each character. The measure of similarity between spiders used was Pearson's product moment correlation coefficient (see Sokal and Rohlf, 1969) which is estimated as follows:-

$$r_{ij} = \frac{\text{covariance between spiders i \& j}}{\text{square root of product of variances of spiders i \& j}}$$

Two clustering methods were used to bring spiders together at different levels of correlation. These are described by Sokal and Sneath (1963). It was found that Sneath's single link clustering method gave more meaningful results than the weighted pair group method of clustering. Principal components analysis, a multivariate method described by Hope (1968) and Seale (1964), was also used to show relationships between spiders. This involves the extraction of the eigenroots and eigenvectors of the matrix of correlation coefficients. The first few vectors represent the major components of variation between spiders. These components may reflect a number of characters, and weightings assigned to spiders for particular components bring out relationships between species, as outlined by Gower (1967).

When the raw data was used the correlation coefficients between pairs of species were all very large (the smallest was 0.51). Since these reflect the effect of a few characters that are measured as larger numbers, matrices based on raw data were not included in the analyses. When, however, the data was standardised so that every character had a zero mean and unit variance, a more interesting pattern of correlation coefficients emerged (Table 3). The effect of the standardisation has been to ensure that every character has an equal weight. It can be seen from Table 3 that the two specimens most resembling each other are *L. amentata* (8 and 18) with r=0.56. The values for many of the coefficients show that there is no correlation between most pairs of species.

Results

Since the structure of the sexual organs has formed a basis of classifications of this genus, separate analyses have been performed on male and female data. The results of the two analyses of each sex are presented in Fig. 1.

The first analysis to be performed included all characters listed in Table 2. From the dendrograms it can be seen that there is little similarity between the two analyses - clusters of females do not correspond with clusters of males (a cluster contains species that show a degree of similarity to each other). As a check of the method it can be seen that the two specimens of *L. amentata* (8 and 18) were the most closely associated, whilst the next most strongly associated pair was *L. tarsalis* (5) and its variety *herbigrada* (14). Despite these apparent checks on the method, the resulting dendograms do not include in clusters, groups of species that coincide with Locket and Millidge's (1951) classification. If Locket and

Leg characters

1- 4. Tarsus/metatarsus for legs 1-4
5- 8. Tarsus/tibia for legs 1-4
9-12. Tarsus/patella for legs 1-4
13-16. Tarsus/femur for legs 1-4
17-20. Metatarsus/tibia for legs 1-4
21-24. Metatarsus/patella for legs 1-4
25-28 Metatarsus/femur for legs 1-4
29-32. Tibia/patella for legs 1-4
33-36. Tibia/femur for legs 1-4
37-40. Patella/femur for legs 1-4
41-46. Total lengths of legs 1/2, 1/3, 1/4, 2/3, 2/4, 3/4 respectively.

Other characters common to both males and females

47. Annulations on tarsi - present/absent
48. Annulations on metatarsi - present/absent
49. Annulations on tibiae - present/absent
50. Annulations on femora - present/absent
51. Retrolateral row of spines on tibia 1 - present/absent
52. Retrolateral row of spines on metatarsi 1 - present/absent
53. Extra long hairs on tarsus 1 and metatarsus 1 - present/absent
54. Ground colour of carapace - grey-brown/red-brown
55. Colour of median light band of carapace - reddish-brown/yellow
56. Shape of median band at anterior end - pointed/blunt/dilated
57. Lateral light carapace bands - absent/divided down centre/continuous
58. Lateral light carapace bands - absent/broken across/continuous
59. White hairs on carapace bands - present/absent
60. Greyish pubescence on carapace - present/absent
61. Ground colour of legs - light-yellow/reddish-brown/yellow-brown/dark-brown
62. Continuation of lateral carapace bands around head - present/absent
63. White hairs on head - present/absent
64. Mottling on side of head - present/absent
65. Colour of clypeus - yellow/red-brown/brown/dark-brown/black
66. Dark region in middle of clypeus - present/absent
67. Ground colour of abdomen - grey-brown/yellow-brown/red-brown/dark-brown/black
68. Two converging rows of small white spots on abdomen - present/absent
69. White hairs on sides of posterior region of abdomen - present/absent
70. Black speckling on abdomen, dorsally and laterally - present/absent
71. Grey mottlings on abdomen - present/absent
72. Small dark dots on abdomen ventrally - present/absent
73. Anterior, median, abdominal stripe - yellow/light-brown/brown/black
74. Black edging around anterior median stripe of abdomen - present/absent
75. Pair of black stripes running outwards and backwards across the posterior sides of the abdomen - present/absent
76. Ground colour of sternum - yellow-brown/red-brown/dark-brown/black
77. Light median streak on sternum - present/absent
78. Ground colour of chelicerae - light-yellow/yellow/yellow-brown/red-brown/dark-brown/black
79. Dark, parallel-sided stripe from mid-point of basal to outer side of apical end of chelicerae - present/absent
80. Dark streaks running longitudinally down chelicerae - present/absent
81. Ground colour of mandibulae - grey/yellow/yellow-brown/brown/dark-brown
82. Ground colour of labia - yellow/yellow-brown/brown/dark-brown
83. Dark spot opposite each coxa on sternum - present/absent
84. Anterior row of eyes - straight/slightly procurved

Females only (epigyne)

85. Dense white hairs on and around epigyne - present/absent
86. Breadth/length of septum of epigyne - 2/1½
87. Longitudinal groove in posterior, central region of septum of epigyne - present/absent
88. Dilation at rear of septum - absent/once/twice
89. Lateral outgrowths on upper margin of epigyne - present/absent
90. Prominent, conspicuous chitinous plate on epigyne - present/absent
91. If present, shape of posterior corners of plate - angular/rounded

Males only (palps)

85. Scattered white hairs on tibia - present/absent
86. Dense, black hairs on tibia and tarsus - present/absent
87. Colour of tibia and tarsus - yellow/light-brown/brown/dark-brown/black
88. Colour of femur and patella - yellow/light-brown/brown/dark-brown/black
89. Median apophysis of tibia - short/long
90. Median apophysis of tibia - blunt/tapering
91. Marginal sclerite - jagged/not jagged

Table 2: List of characters used in deriving the classification. Characters 1-46 are discussed in the text as "leg characters". Except for the "leg characters" the states in which a character was scored are shown in the table. The terminology follows Locket & Millidge (1951).

Millidge's habitat notes on the species are used, then the classifications show some slight resemblance to groupings of species according to the environment in which they live. Using the female analysis, the group of five species on the right of the dendogram contains species with a very wide distribution, except for *L. traillii* (16). In another group there is *L. rubrofasciata* (17), a species of fen land, *L. paludicola* (12) and *L. pullata* (6). This group was suggestive of the damper environments. There was, however, no clear cut grouping of the species.

If the results of a numerical classification are not of immediate systematic interest (the clusters seemed to have no morphological meaning) it seemed interesting to probe further the possibility of ecological use. The classification was derived from purely morphological characters, so which of these could have ecological implications and which might merely obscure any ecological classification? It seemed reasonable to use the long series of leg characters, separated in Table 2, to do this. From Locket & Millidge's notes the genus can occur in a number of situations. *L. nigriceps* is partly aboreal, others occur in long vegetation (e.g. *L. tarsalis* in heath, *L. lugubris* in the vicinity of woods, and *L. purbeckensis* in salt marshes), whilst others occur where vegetation is sparse (e.g. *L. arenicola* on shingle coasts and *L. traillii* on scree). So the series of leg characters may bear some relationship to the environment in which the spiders live. These results are also presented in Fig. 1.

The results of analyses for males and females show a number of similarities, indicating three groups of species. One group, *L. agricola, L. purbeckensis* and *L. lugubris* (2, 3 and 10) is clearly identified in both analyses. Similarly *L. pullata* and *L. prativaga* (6 and 7) show association in both analyses. There is a more diverse group, represented on the right of each dendrogram, by *L. tarsalis* and *L. amentata* (5 and 8) with *L. hortensis* and *L. paludicola* (11 and 12). Despite the similarities in the results of the analyses, these three groups do not appear to correspond with any habitat preference of the species within each group. Similar analyses performed on the set of characters excluding the leg characters also gave results that could not be interpreted.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	100																	
2	5	100																
3	-3	-1	100															
4	-17	-31	-1	100														
5	-24	-6	0	8	100													
6	-22	3	5	-30	7	100												
7	-7	-13	-18	-11	-20	17	100											
8	-3	14	-26	-8	-15	4	-10	100										
9	-14	-23	21	2	8	-2	2	-13	100									
10	21	15	-11	-12	-38	-13	6	8	-33	100								
11	-2	-16	-22	15	-8	-38	-1	-6	-3	1	100							
12	-32	6	-14	1	-7	9	-13	9	-13	-20	-10	100						
13	-13	-17	4	14	5	-16	11	-20	-2	-35	-10	1	100					
14	-5	-4	-8	4	30	-3	5	-7	-9	9	-12	-25	-15	100				
15	-8	2	10	-16	9	-16	-30	9	13	-7	7	-2	-17	-12	100			
16	-21	-38	-4	16	12	-24	-6	-20	-3	-9	18	11	16	-20	2	100		
17	-9	-1	1	-23	-16	26	-11	-28	9	-14	-21	3	13	-30	-8	-13	100	
18	6	8	-28	-9	-25	4	-2	56	-17	9	17	-2	-30	-16	-1	-23	-11	100

Table 3: The correlation matrix for the females using data standardised so that each character had a zero mean and unit variance. All entries in the table should be divided by 100 to give correlation coefficients. Since this matrix is symmetric, only the lower triangle has been shown.

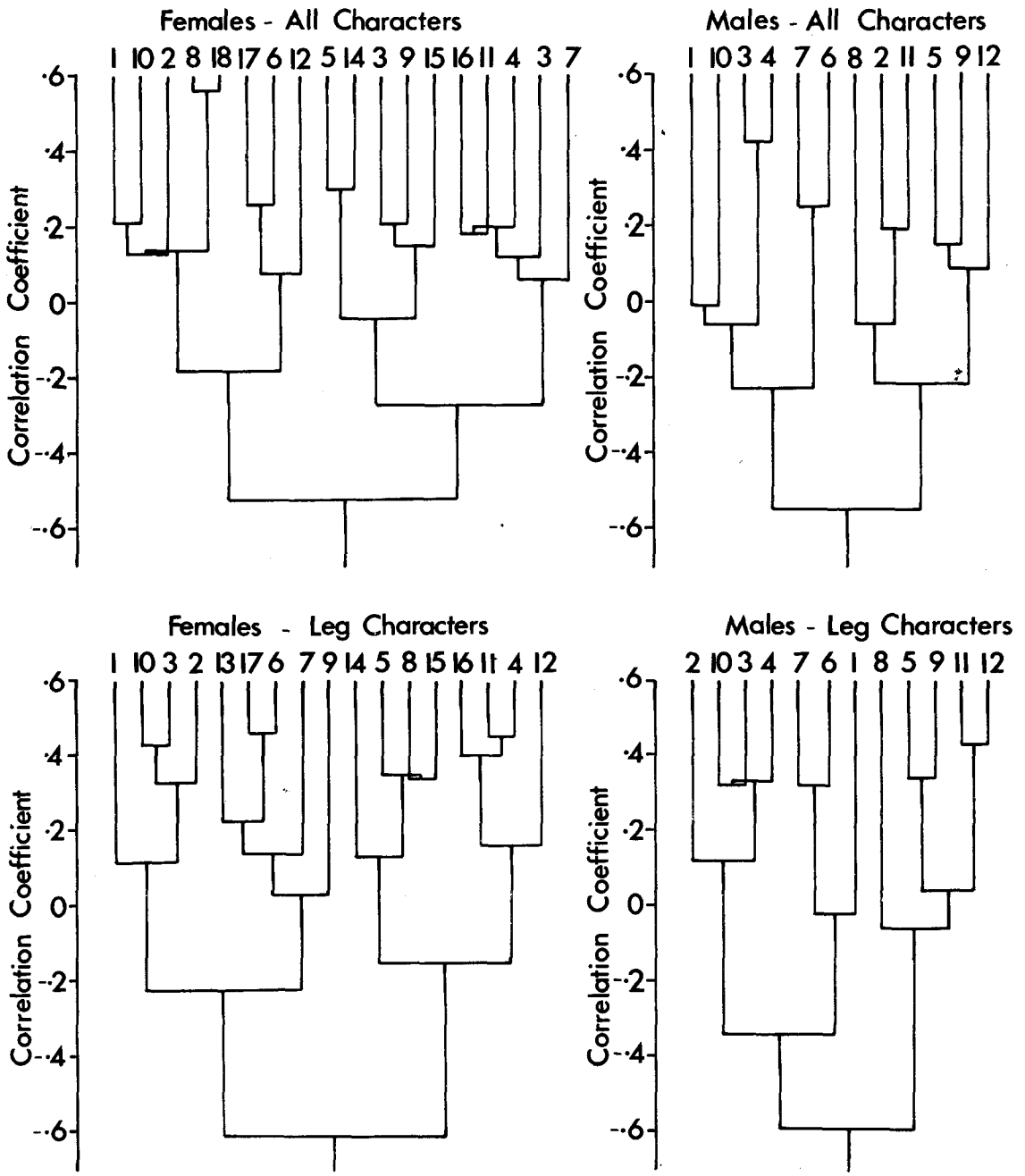

Fig. 1: The results of clustering correlation matrices by Sneath's single link method. The details of the analysis are given above each dendrogram.

Discussion

Classifications of spider genera are based mainly on the morphology of the sexual organs. In the present study, although sexual characters were used, they were not given more weight than any other character. For instance, Locket and Millidge (1951) separate their group 1 as having an epigyne with a prominent, conspicuous chitinous plate, wider behind than in front, or male palps with central apophyses blunt rather than aculeate. Their group 2 females have much smaller chitinous tongues and males have slender, pointed median apophyses in their palps. These groups, separated on the basis of a small number of sexual characteristics, help in identification but make no attempt to represent ecological similarity or family relationships.

In this study the whole set of characters indicated that the hierarchical classification might correspond with the environment in which the spider was living. However, critical studies of sub-sets of the data, and principal component analysis of the whole data, have failed to demonstrate any clear division of the genus into ecological groupings. As far as we know no numerical classification, based on a series of morphological characters, has ever produced ecological rather than morphological clusters of similar species. The ecological implications in the preliminary analyses indicated that the genus *Lycosa* might be interesting for an investigation of the relation between morphology and ecology. The general generic study has not supported this indication, but it seems likely that a similar analysis, based on one species, say *L. prativaga,* from several localities may show the relation between small morphological modifications and the environment.

Although numerical taxonomy is based on the initial premise that all characters are equal, it is of course likely that some characters are more important than others. In this study, the identification of a classification based on habitat suggests that characters such as leg morphology, pattern and colour could be causing the separation into groups, and it might be possible to erect a classification on the basis of these characters alone. Probably the most efficient means of distinguishing characters important in this context, is to repeat the computer analysis to form groups of characters based on their scores on spiders, thus deriving some sort of weighting for the characters used in the analysis. More efficient clustering techniques have recently been developed and canonical variates, as explained by Seale (1964), can be used to establish maximum discrimination between groups.

The biggest criticism of this study must be the assumption that the specimens that were used were typical. Unfortunately one is prevented from carrying out replication by using more than one specimen of each species by the amount of time and effort involved. This time factor is probably the biggest single drawback to the more general use of the techniques of numerical analysis in the taxonomy and systematics of spiders.

Summary

The methods of numerical taxonomy are used to produce a polythetic classification of the spider genus *Lycosa*. The seventeen British species were coded for ninety morphological characters. A computer was used to calculate affinities between species and to devise a classification based on the similarity of species, one to another. The resulting classification was compared with previous classifications and it was also found to indicate the ecological (habitat) characteristics of the species.

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