THE EXPECTATION OF PLANT RECORDS FROM PRESCRIBED AREAS

By J. G. DONY

The success of the Distribution Maps Scheme of the Botanical Society of the British Isles has caused a number of workers on local floras to adopt divisions of 10-kilometre grid squares of the National Grid as a basis for their recording. In 1954 the Birmingham Natural History and Philosophical Society started to use a one-kilometre grid for collecting records for a revision of the flora of Warwickshire. This was, however, slightly amended at a later stage. Two years later, in 1956, E. S. Edees began to use a two-kilometre grid (i.e. four square kilometres) for a survey of the Staffordshire flora. In 1955 the author started work on a revision of the flora of Hertfordshire and in 1957 decided to collect records as Edees had done on the basis of a two-kilometre square, referred to below as a tetrad. Few records were made on this basis until 1959 and the results summarised here are mainly those of four years' field work.

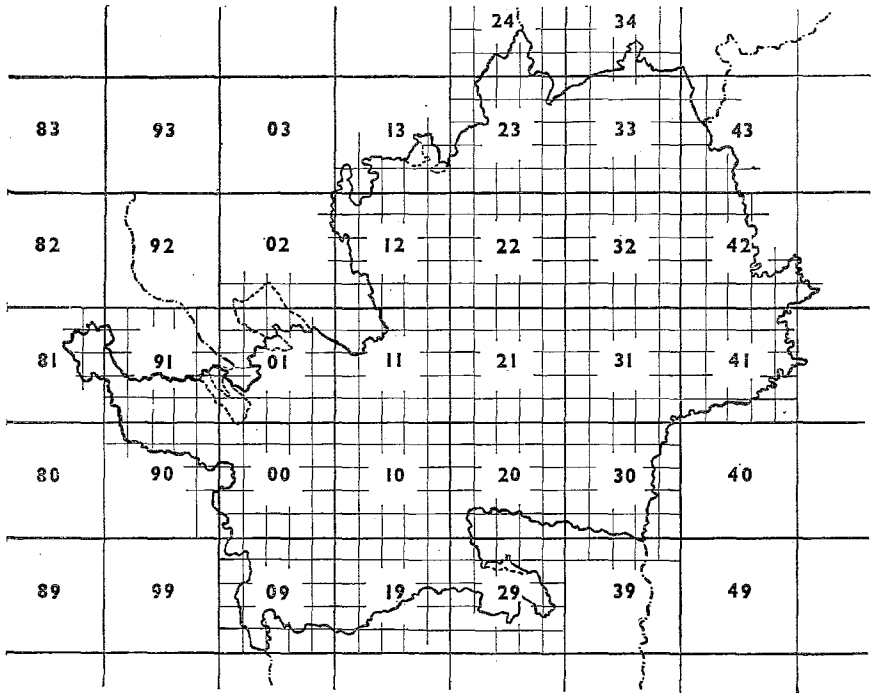

Fig. 1. Hertfordshire. The boundary of Watsonian vice-county 20, Hertford, is shown with a dotted line where it differs from that of the present (1963) administrative county. The prefixing numbers of the 10-kilometre grid squares are omitted but they are given in Table 1.

The area of survey (see Fig. 1) is the present administrative county of Hertfordshire with those parts of the Watsonian vice-county 20, Hertford, which now lie in neighbouring administrative counties. This has a total area of about 1,631 square kilometres and is very irregular in shape. It includes only four complete 10-kilometre grid squares and parts

of twenty-five others, making a total of 336 complete tetrads and parts of 131. The object of this paper is to try to determine the average number of plant species that could be expected to be found in a tetrad or in any other given area in Hertfordshire.

After eight years' intensive field work and the contribution of records from fellow workers the total number of species to be found in the county is reasonably well known and it is unlikely that in the next few years many more will be found other than aliens and casuals. Almost complete records have also been obtained for the full 10-kilometre grid squares and for those the greater part of which is included in the county. From these records it is possible to determine the number of species now known to occur in parts of the county larger than a 10-kilometre grid square.

The species considered for the purpose of this exercise are those given in the *List of British Vascular Plants* (Dandy 1958). Aliens, casuals and garden escapes are not included unless they are in the List, and are neither microspecies nor hybrids. Records made before

TABLE 1.

Summary of records of species made in Hertfordshire (1955–1962).

10-kilometre grid square	*Approximate area in Herts. (sq. km.)*	*Total species recorded*	*Total area (sq. km.)*	*Total Species recorded*
52/24	10	225	19 (A)	282
52/34	9	230		
53/13	12	421		
52/23	85	544	220 (B)	651
52/33	98	521		
52/43	25	415		
52/02	6	303		
52/12	87	499		
52/22	100	604	364 (C)	712
52/32	100	588		
52/42	68	579		
52/52	3	117		
42/81	12	265		
42/91	37	560		
52/01	84	488		
52/11	87	528	493 (D)	834
52/21	100	640		
52/31	99	688		
52/41	73	579		
42/90	25	451		
52/00	96	597		
52/10	100	594	377 (E)	758
52/20	84	561		
52/30	72	591		
51/09	66	647		
51/19	62	554	158 (F)	724
51/29	30	461		
A+B+C (52/24–34, 52/03–13, 52/02–42)			603 (G)	798
E+F (42/90–30, 51/09–29)			635 (H)	836
D (see above)			493 (D)	834
G+D			1096 (I)	899
G+H			1138 (J)	908
D+H			1038 (K)	911
Total			1631	956

The totals of species given above are not totals of the columns from which they are derived, as a species recorded from more than one ten-kilometre grid square is counted only once and so on for the larger areas. A very common species included in the grand total may well have been recorded in all the twenty-seven ten-kilometre grid squares from which the totals have been made.

1955, when the survey began, are also excluded. The results of the work done until the end of 1963 are summarised in Table 1.

These figures enable one to show by means of a simple graph (Fig. 2) the average number of species that one might expect to find in any given part of the county. This emphasises the fact, seen less readily from the figures themselves, that some parts of the county are floristically richer than others. If the whole county were as productive as these the total number of species found in the county would probably be greater. On the other hand, if all the county were as unrewarding as other portions are, the total number of species would be fewer. The gradient of the line drawn to show the probable average of number of species in a given area is, however, too great in the region of the smaller areas to be of any use in determining the average number of species one would expect to find in an area as small as a tetrad.

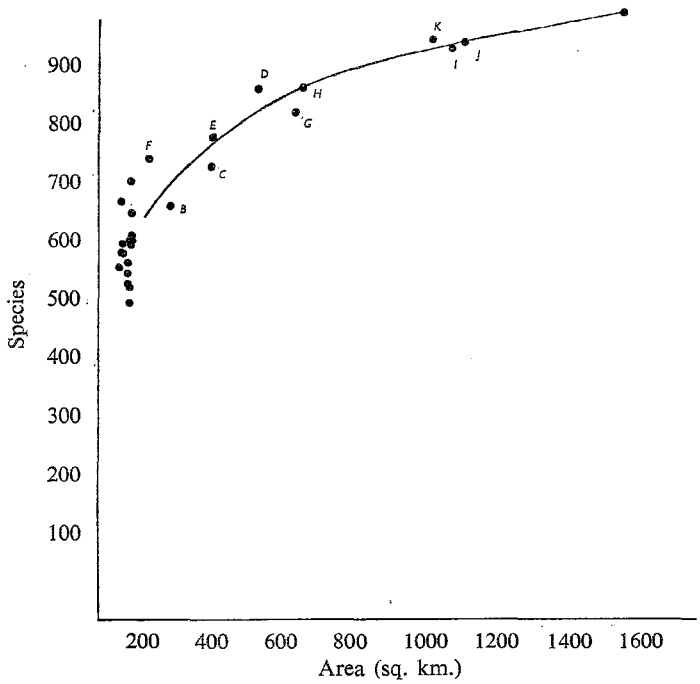

Fig. 2. Distribution of records of species by area in Hertfordshire.

A different result is obtained if a logarithmic scale is used for both the area and the number of species. The curve now approximates to a straight line. Indeed it can in the areas being considered here be assumed to be a straight line. This is shown in Fig. 3 for records from a considerable area of the county, i.e. from 60 square kilometres to the whole of the area. The line drawn shows the expectation of records based on the assumption that as the survey proceeds very few additional species will be found in the whole county or in the larger parts (I, J and K) which are each approximately two-thirds of the county. It is certain, however, that more species already known to appear elsewhere in the county are awaiting record in the smaller areas such as a 10-kilometre square. The present average of species recorded from the complete or almost complete 10-kilometre grid squares (52/33, 52/22, 52/32, 52/21, 52/31, 52/00, 52/10) is 608 and the linear relationship suggests that it should be 623. If additions are made at the rate they have been hitherto in the survey it will probably reach this figure by the time the task is completed.

If this method is to be useful for the purpose in hand it is necessary to consider records from both larger and smaller areas. The species considered are those in Dandy's list, that is 2,137 for the whole of the British Isles (area 310,600 square kilometres) and this

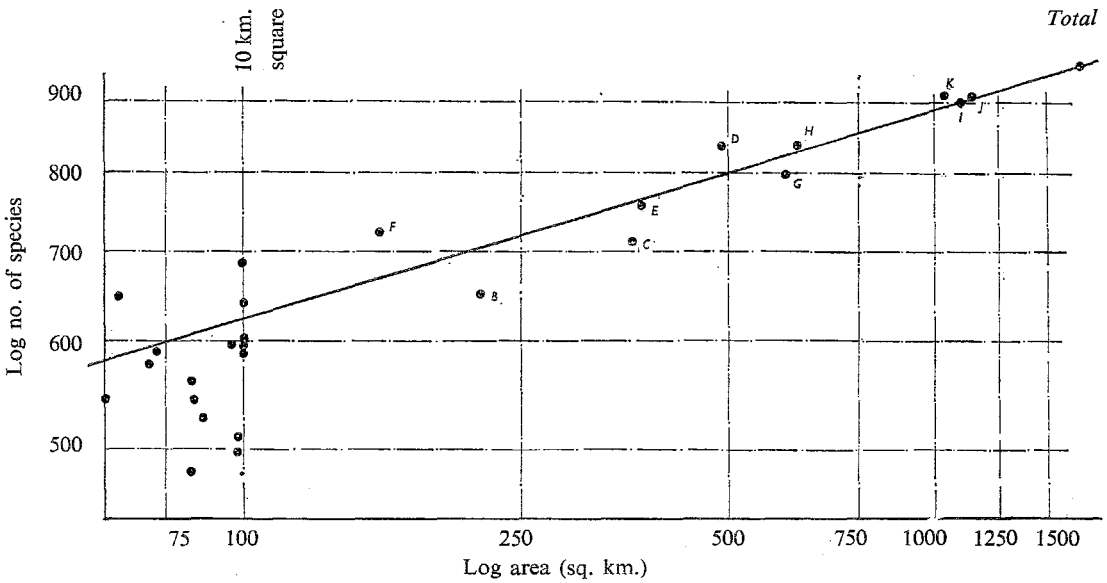

Fig. 3. The expectation of records of species from the larger areas in Hertfordshire. The records shown in Fig. 2 are now shown on logarithmic scales for both area and the number of species recorded for the respective areas. The line drawn to show the average expectation of records is based on the assumption that few additional records will be made for the whole of the county or for the areas shown as I, J and K, each representing about two-thirds of the county. Additional records may, however, be expected from the smaller areas.

gives a maximum reference point. During 1962 close studies were made of 106 small habitats having floras representative of that of the county as a whole. Each study was made in a measured area of five yards radius (65·7 square metres) which was visited twice in the year and the frequencies of the various species noted. The number of species recorded for the studies varied from 82 to 13 with a median of 45. Samples taken from small areas will show a great range in the number of species present as they will include both rich and comparatively barren plant communities. The full results are given in Table 2. Also in

TABLE 2.

Numbers of species recorded in 106 studies in an area of five yards radius (1962).

82, 82, 79, 78, 77, 77, 76, 76, 72, 65, 64, 63, 62, 62, 61, 60, 59, 59, 57, 57, 57, 56, 55, 55, 53, 53, 53, 52, 52, 52, 51, 50, 50, 50, 49, 49, 49, 49, 49, 48, 48, 47, 47, 47, 46, 46, 46, 46, 46, 46, 46, 45, 45, 45, 44, 44, 44, 43, 43, 42, 41, 40, 40, 39, 39, 38, 38, 38, 38, 37, 37, 36, 36, 36, 36, 36, 36, 34, 34, 33, 33, 32, 32, 32, 32, 32, 31, 31, 30, 26, 26, 26, 24, 24, 23, 23, 22, 21, 20, 18, 17, 15, 15, 15, 13, 13.

1962 a town garden with an area, including the house, of 297 square metres, yielded 84 species of wild plants and it is probable that urban sites generally have floras comparable with this.

These figures allow an extension of the line of average expectation (Fig. 4). The change in gradient at 100 square kilometres arises from the fact that Hertfordshire being a lowland county is more floristically rich and varied than the British Isles as a whole. The results show that the average expectation of species in a tetrad is 335 and in a square kilometre 275. It also allows an estimate to be made, with less accuracy, of the maximum and minimum expectation. For a 10-kilometre grid square these are 708 and 500 and the present records for these areas in Hertfordshire range from 688 to 521. The maxima and minima to be expected from a tetrad are 446 and 224 and from a square kilometre 402 and 155.

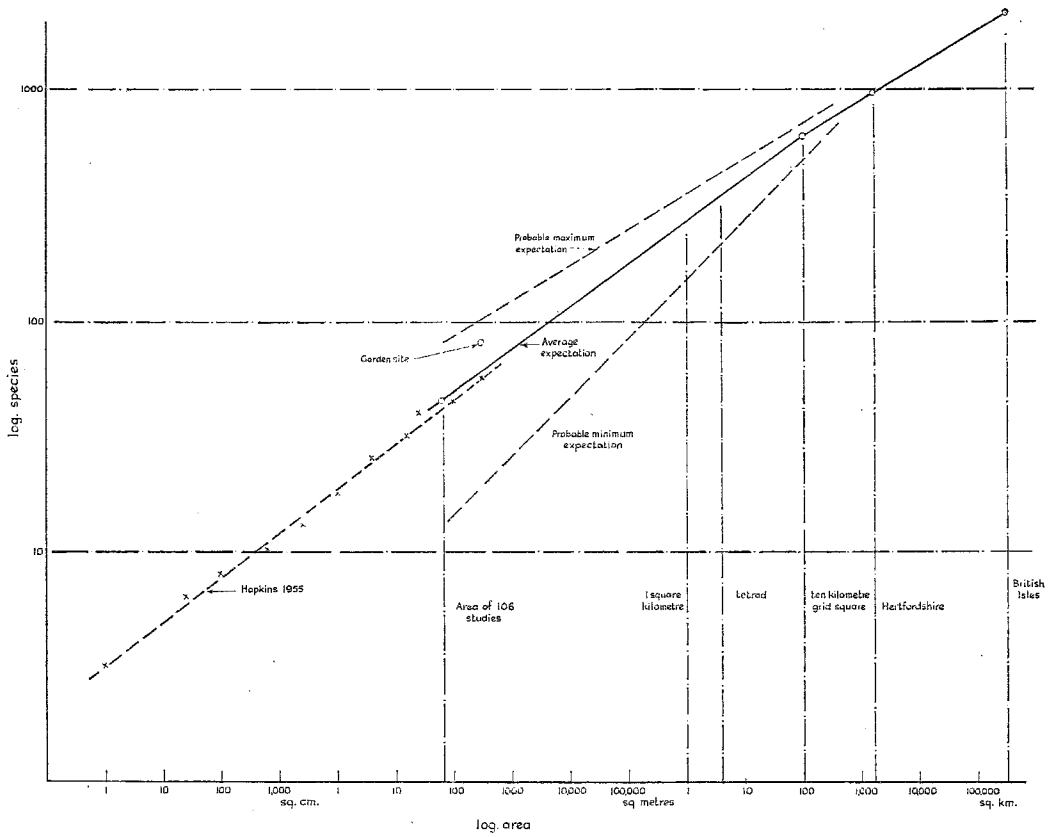

Fig. 4. The average expectation of records of species in Hertfordshire. The dotted line at the lower end of the line of average expectation shows the number of species estimated by Hopkins to occur in various areas in one plant community which he studied. This was not in Hertfordshire and was the community, among the twelve he examined, with the largest number of species. The line drawn to show the average expectation of species is based on two assumptions: the first that the median of the number of species recorded for the 106 studies made of small areas is the average expectation of the number of species that would be found in Hertfordshire in areas of the same size as the areas of the studies: the second that the total number of species to be found in the whole of Hertfordshire is known as this consists of a large number of kinds of habitats each type of which has been studied. The lines of probable maximum and minimum expectation are based on the assumption that the greatest and smallest numbers of species recorded for the 106 studies represent the range of floristic diversity of areas throughout Hertfordshire comparable with the areas of these studies. It is further assumed that this range will diminish as the area is increased to a point somewhat larger than the county.

Records between the average and maximum expectation for tetrads have been obtained as the result of long and thorough search in the field in widely separated parts of the county. The method I have used for enumerating the tetrads is shown in Fig. 5.

31.A. 395* species were recorded by Mr A. G. Brown and Mr H. Williams of the John Innes Horticultural Institution who spent many lunch hours accounting for all the plants that could be found on the Bayfordbury Estate.

31.R. 376 species were recorded largely as the result of a concentrated effort by a number of members of the Wild Flower Society on a one-day field meeting.

32.V. 342 species were found by Dr and Mrs Lloyd-Evans during a number of visits in one season.

Large totals have also been made in some marginal tetrads:

*The number of species given for tetrads from this point in the paper includes some casuals, garden escapes, etc. not included in Dandy's list as I have no easy means of excluding them. They are few and do not affect materially the main conclusions reached

23.B. (area 3·5 square kilometres, expected average 320). 312 species recorded by Mr Harry and Miss Doris Meyer in a semi-urban area they know intimately.

09.R. (area 3·75 square kilometres, expected average 322). 309 species recorded by Mr G. Day who has listed all the plants he could find in Moor Park.

09.J. (area 2·7 square kilometres, expected average 317). 320 species recorded.

E	J	P	U	Z
D	I	N	T	Y
C	H	M	S	X
B	G	L	R	W
A	F	K	Q	V

Fig. 5. The enumeration of tetrads within a 10-kilometre square. Each 10-kilometre grid square (e.g. 52/31) is divided into 25 tetrads which are lettered from A to Z (omitting O to avoid confusion with Q) following the sequence used in the numbering of the 10-kilometre squares themselves in the National Grid. The prefixing numbers, i.e. 42, 51, 52, are omitted as there is no duplication of the second numbers in an area as small as a county. The tetrads thus follow a sequence of 31.A., 31.B., 31.C., etc., beginning at the bottom left-hand corner of the 10-kilometre square.

The average expectation of the number of species to be found in a tetrad may be used as a basis for determining the thoroughness with which an area has been studied. The total number of records made for the 336 full tetrads in Hertfordshire, by the end of 1962, was 72,594, an average of 216 per tetrad. As the expected average is 335 this gives a 61% cover. It would not be possible except by wearisome calculations to determine the cover for marginal tetrads but it is probably at least as high. A summary of the records is given in Table 3.

The peculiar distribution of records in Table 3 arises from targets of 150 and 200 records having been set during the field work. When 200 species had been listed from a tetrad and the rate of recording had slowed down there was a great temptation to move on

TABLE 3.

Summary of records of species made in individual tetrads in Hertfordshire (1955–1962).

Full Tetrads

395, 376, 342, 307, 297, 295, 294, 293, 292, 290, 289, 286, 281, 280, 278, 276, 274(2), 271, 269(2), 268, 265, 264, 262, 256(2), 255(2), 254, 253, 252, 248(2), 247, 245, 242(4), 241(2), 240(2), 239(2), 238, 237(2), 236(2), 235(2), 234, 233, 232(3), 231, 230(3), 229(4), 228(4), 227(3), 226(3), 225, 224(4), 223(2), 222(6), 221(8), 220(3), 219(4), 218(4), 217(6), 216(3), 215(3), 214(7), 213(4), 212(15), 211(9), 210(13), 209(8), 208(2), 207(13), 206(14), 205(21), 204(15), 203(18), 202(16), 201(29), 193, 185, 183(2), 176, 175, 172, 170, 167, 165, 162, 160(3), 159, 158, 157, 155(2), 154, 153(2), 152(2), 151(2). Total: 72,594.

Marginal Tetrads

320, 312, 309, 289, 283, 280, 265, 254, 252(2), 237, 235, 234, 233(2), 230, 229, 226, 223, 220, 219, 218, 217(4), 216(2), 215, 214(3), 213(4), 212, 211, 209(2), 207(6), 206(4), 205(6), 204(4), 203(10), 202(4), 201(6), 196, 187, 185(2), 172(2), 175, 172, 171, 168, 167, 166, 164, 157(2), 154(2), 153(2), 152, 143, 133, 128, 127, 123, 119(2), 117, 115, 114, 105, 102, 97, 91, 80, 67, 55, 54, 33, 27, 5. Total: 22,911.

and begin work in virgin country. As 200 species is 89% of the probable minimum expectation it has proved to be an exceedingly well-chosen target. In some cases it has been very difficult to find this number. It has, however, resulted in the more intensive

search of the less rewarding country to the neglect of the better areas.

After four years of field work and with records made for complete or almost complete tetrads ranging from 143 to 395 there is no species recorded for all. Thirteen are awaiting record from fewer than five tetrads and another twenty-four from fewer than twenty. The records made so far indicate that between seventy and one hundred species may be in all tetrads. It is obvious that a great deal of work could still be done. It must be left to each worker using tetrads as a basis for recording to decide for himself when a satisfactory cover has been made. I have been able to make some very useful maps with a cover of 61% and to pursue the study much further would occupy a long period of time.

The concept of an average expectation has its limitations. If a cricketer has a batting average of sixty it does not follow that he scored this number of runs in his last innings or will score it in the next, neither does it mean that if one's expectation of life is established as eleven years one will indeed live that time. If the average expectation of species from a tetrad is 335 it does not help the worker in the field to know what to expect from any particular tetrad. I recognise in Hertfordshire twenty different types of habitats and the various tetrads may contain one or more of these. A tetrad with only one or two different habitat types would with effort probably yield only 225 species but one with as many as ten habitat types could well give 400.*

The relationship between species and area in very small areas can be solved only by the very close study of plant communities. This I have not done but it has attracted much attention from ecologists (Arrhenius 1921, 1922, Greig-Smith 1957, Gleason 1922, 1925, Hopkins 1955, 1957, Williams 1943, 1944, 1947, etc.). One of the most thorough studies of this kind was the investigation of twelve very different communities by Hopkins (1955). The number of species he recorded was surprisingly small especially as he included bryophytes and lichens as well as vascular plants. On the other hand his studies were limited to one short period and there were 'additional species' in most of his communities which

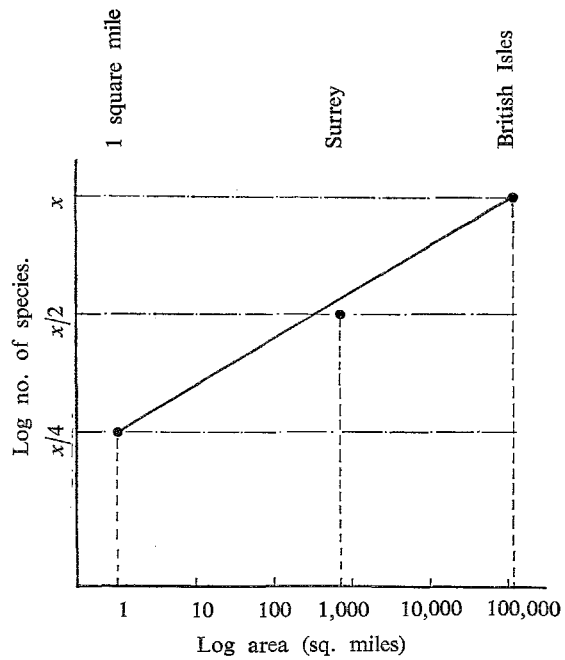

Fig. 6. Watson's Hypothesis. It is obvious from *Cybele Britannica* that Surrey was the county he had in mind.

*This was an experience well known to workers for the Distribution Maps Scheme. One lady returned exhausted after a mapping meeting with the information, amusing to the rest, that she had had a 'big square'. She had only meant that her square contained a large number of plant communities that needed to be visited before the day's work could be said to be done.

did not enter into his samples. I have chosen one of Hopkins' communities with species closely comparable with the lower ranges of my line of expectation and using a log area—log species scale it fits my conclusions perfectly. (Fig. 4.)

Much has been written on the species-area relationship but H. C. Watson was as near the truth as anyone has been or is likely to be when he observed as early as 1835 that 'on the average a single county appears to contain nearly one half the total number of species in Britain; and it would, perhaps, not be a very erroneous guess to say that a single mile contains half the species of a county'. Watson is making in simple language a relationship which, by the use of a logarithmic scale, may be made a linear one (Fig. 6). The matter appears to have rested there until ecologists became interested in the build-up of species in plant communities. It was claimed by Arrhenius (1921) that 'the number of species increases continuously as the area increases' and that this increase could be expressed by the simple formula $\frac{y}{y_1} = \left(\frac{x}{x_1}\right)^n$ when y = the number of species and x = the area containing these species. This gives a linear relationship when log species and log area scales are used as has been demonstrated in this paper.*

The relationship demonstrated by Arrhenius was challenged by Gleason (1922) who suggested that a linear relationship could only be arived at by plotting the number of species against the logarithm of the area. Ecologists have tended ever since to accept this and much work has been done to establish the exact nature of the species—log area curve and the limits of its linear distance. It must be stressed that the problem of the ecologists is different from mine and their attentions have been limited to uniform plant

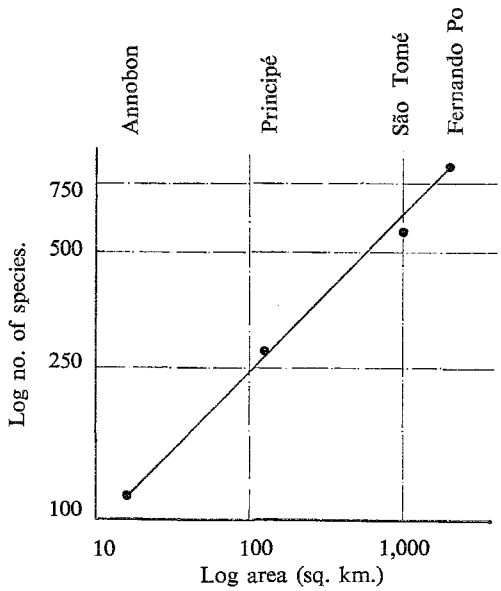

Fig. 7. A comparison of Island Floras, based on the list of 'significant species' given in Exell's *Flora of São Tomé.*

*The above formula can be expressed more simply as $y = ax^n$ where y is the number of species, a is a constant and x is the area. It would appear from the method demonstrated here that the average number of species included in Dandy's list that could be found in any given area of the British Isles can be expressed as

$y = 237\ x^{0\cdot1738}$

given x as the area in square kilometres

or $y = 21.8\ x^{0\cdot1738}$

given x as the area in square metres.

This would give an average expectation of species for a ten-kilometre grid square of 527 which would agree with most botanists' experience in the field.

The corresponding relationship for Hertfordshire and probably most lowland English counties could be expressed as

$y = 275\ x^{0\cdot1772}$

given x as the area in square kilometres

or $y = 21.8\ x^{0\cdot1772}$

given x as the area in square metres.

communities and they have always assumed that the situation changes when the sample areas extend into other communities.

The method outlined here needs to be tested further by making comparisons of the number of species known to occur in the various parts of the British Isles, e.g. England and Wales, Scotland, Ireland and the Isle of Man and also for the separate islands of the Channel Islands group. I give (Fig. 7) its application to some closely grouped islands off the African coast taken from Exell's *Flora of São Tomé*. If the method were confirmed by further data it would be possible to calculate the degree of cover obtained for the Distribution Maps Scheme.

I wish to thank Dr C. B. Williams for suggesting to me the use of the logarithmic scale and helping me to apply it to the Hertfordshire problem; Dr M. C. F. Proctor for drawing my attention to the work done by ecologists with a similar problem; Dr B. Hopkins for allowing me to use the data quoted in his paper; Mr E. S. Edees for helping me to confirm my conclusions by providing me with details of his work in Staffordshire; and my many co-workers who have carried out the wearisome task of providing records from such small areas. Amongst the latter I thank especially Mr and Mrs P. C. Hall who made themselves responsible for collecting records from about 20% of the county in a part which it would have been difficult for me to visit frequently.

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