ON THE GRAPHICAL PRESENTATION OF QUANTITATIVE DATA

By J. H. CROTHERS*

The Leonard Wills Field Centre; Nettlecombe Court, Williton, Taunton. Somerset TA4 4HT

ABSTRACT

Scientists draw graphs as an aid to their understanding and subsequent communication of quantitative data. This paper reviews the methods of graphical presentation selected by earlier contributors to *Field Studies* and discusses their suitability for various purposes; first report, published paper, or as a transparency to illustrate a lecture. The graph is never an end in itself, it is not the "result", and it is important to assess the Usefulness of a presentation as well as such criteria as Clarity (? = Simplicity), Accuracy, Space and Speed when deciding which technique to employ.

INTRODUCTION

It is easy to collect data. Any quantitative field or laboratory work can cover the pages of a notebook with numerals in no time at all. The problems come with interpretation of those data and, later, in their communication to others. There are people who are able to visualise patterns in columns of numbers, but they do not usually become biologists or geographers. Some sort of graphical presentation is much easier for most of us to understand.

Graphical presentation is never an end in itself. The graph is not the "result" of an investigation. Its sole purpose is as an aid to interpretation and it is fair to say that, unless the graph is easier to understand than was the original table, there was no merit in having drawn it.

This paper reviews the techniques employed by various contributors to *Field Studies* and discusses their suitability for different purposes. It is not concerned with pictorial diagrams and will concentrate on graphical rather than cartographical (map-drawing) presentation.

DATA

The word "data" (singular "datum") is used to denote the numerical results of an experiment or survey. It is not used for descriptive impressions, but rather for the kind of factual information that can be listed in a table or plotted on a graph. The term "raw data" is used to distinguish the original information from "derived", "processed" or "transformed data" which have been obtained by summing, averaging or applying other mathematical processes.

It is not the purpose of this paper to advise, far less instruct, the reader whether it is better to plot actual numbers or to deal with means, percentages, ratios or whatever. Sometimes there is so much information that only by taking averages is it possible to reduce the data to manageable proportions: and averaging does have the added advantage of smoothing out chance irregularities. Inevitably, however, much of the (perhaps important) detail is lost in the process.

It is important to discriminate between the different types of data when considering graphical presentation. The material may be in the form of discrete measurements or counts, or it may have been grouped into classes; the numbers

*Present Address.
Council for the Conservation of the Environment and Prevention of Pollution Ruwi, MUSCAT, Sultanate of Oman.

may form a continuous series, or they may bear little or no obvious relationship to each other. Perhaps it is most important to distinguish isolated points from lumped totals when both form parts of a continuum. For example: hourly measurements of stream flow as compared with monthly rainfall totals.

Only data based on actual counts and measurements may be arithmetically manipulated: averages of estimates or abundance scale grades have little or no meaning. Abundance scales are widely employed by fieldworkers but are no more than "pseudo-quantitative" groupings. Field botanists often record the cover of plant species as dominant, abundant, frequent, occasional or rare. It is clear that "abundant" is not necessarily midway between "dominant" and "frequent", and it is important to remember this when, for clarity of recording, abundance scale grades have been scored as 5, 4, 3, 2, and 1. The defence for using abundance grades (Dr D. H. Dalby, *personal communication*) is that they are often close approximations to logarithmic transformations of the raw data, and if this is accepted then it follows that one can perform the manipulations of normal arithmetic upon these transformations. Many ecologists happily accept that, for example, Domin scales for plant abundance can be converted numerically in this fashion and be then subjected to computer analysis (presumably they are aware that the programme is adding, dividing etc., the scores as if they were "proper" numbers).

SELECTING A TECHNIQUE FOR GRAPHICAL PRESENTATION OF DATA

A scientist may draw a graph for several reasons. He may use it as a working tool during the preparation of his first report. Later, when he comes to publish the work, clear Figures will save him many words and render the paper more readable. He may also wish to lecture about his work and to illustrate the talk with transparencies.

There is no single ideal method of graphical presentation, and the first consideration when pondering over which type of graph to draw is its PURPOSE: what is it intended to show and to whom?

Having thought about that, it is necessary to assess its USEFULNESS: does it help the reader/viewer to understand the data? Before discarding a technique as useless it is worth re-examining the original material. Have you plotted the right variables? Most graphical techniques require the scientist to select two variables—x and y. The graph can only indicate whether or not there is a relationship between x and y: it is still up to a human mind to ask the right questions.

It goes without saying that ACCURACY is important, although it is necessary to keep a sense of proportion. Just as there is no merit in quoting results to six decimal places (simply because the calculator will display that many) if the raw data were only taken to one, so too there is no value in attempts at excessive precision when plotting a graph.

CLARITY, a word that summarises simplicity of design with neatness of execution, must also come high on any list of criteria. In this context, it is also important to take the size and shape of your display into account: the SPACE it will occupy when complete. Will it fit onto the page? Will it have to be reduced to such a small scale as to become indecipherable?

Finally, there is often a time factor. Many people seem to work to a deadline of some kind and the SPEED with which a satisfactory result can be obtained may be important.

Purpose

For a working tool, or when preparing the preliminary report of some project, a simple quick presentation is all that is required. Accuracy is important but, provided the graphs will fit onto the paper, the size and number of the Figures is not. It is probable that some will be discarded at a later stage and it is not worth spending much time on them. Anyone reading the report will probably have a fair idea of the work already, and be sufficiently interested in the subject to want to understand it. They will certainly be more interested in the usefulness of the graphs than in the standard of graphical presentation.

When preparing Figures for publication there are two additional considerations. One is that space costs money and almost all editors will endeavour to reduce the number of figures. The other is that the graph will be printed near relevant sections of the text and the reader may cross-refer between text, caption, Figure and table as often as he likes. Furthermore, it is frequently a time-consuming business to draw and label them neatly and, taken together, these additional factors tend to result in fewer more complicated Figures—such as the example reproduced as Fig. 1. Such
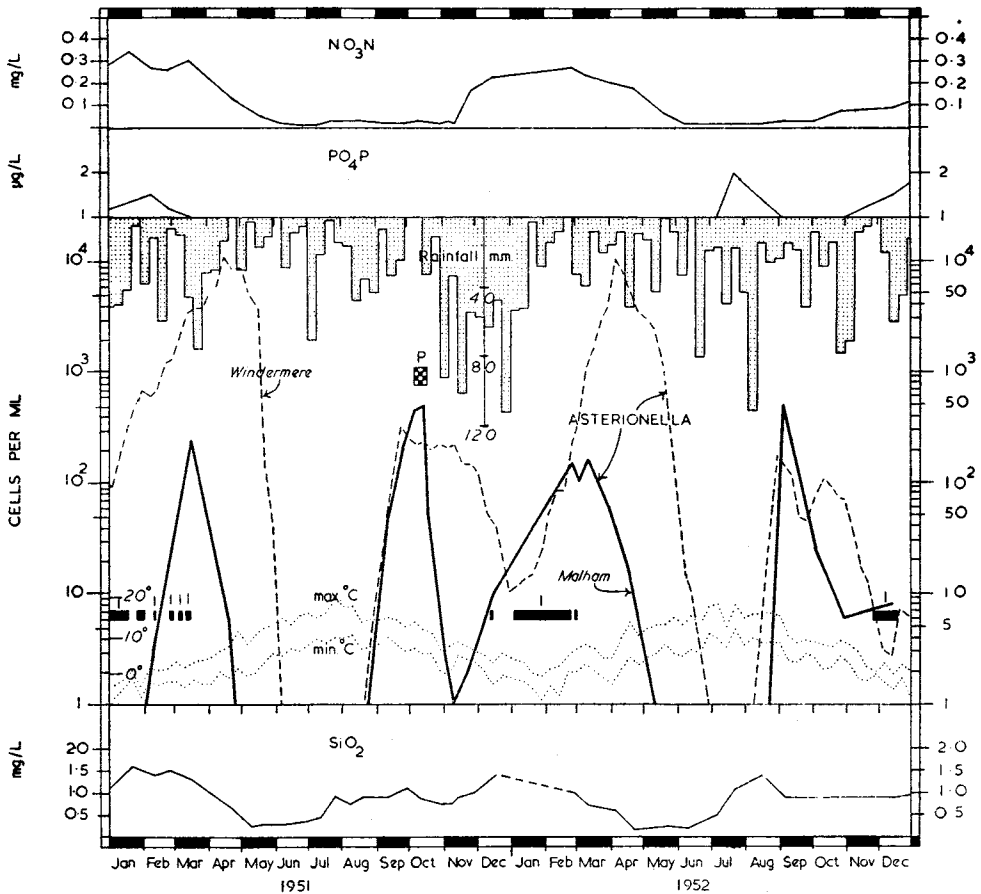

FIG. 1

An example of a complicated Figure appropriate for a published paper or book but less so for a lecturer's transparency. From Lund (1961) and drawn to display the seasonal cycle of *Asterionella formosa* in Malham Tarn as compared with Windermere, against the background of rainfall, nitrate nitrogen, phosphate phosphorus, silica, maximum and minimum temperatures and ice cover (the black blocks).

Figures must be drawn with great care if they are to be intelligible but, as several thousand people are going to read the work, it is worth taking the trouble to get them right. Fortunately, almost all printers now use a photographic process to reproduce illustrations, therefore material can easily be reduced in size. Most editors recommend authors to submit graphical material at about one-and-a-half times their ultimate size although they may be able to accept even larger originals. A photo-reduction from a larger drawing always looks neater than the same material drawn to the required size.

It is also worth taking a lot of trouble when producing graphs to illustrate a lecture, expecially if (as is usually the case) the material is to be used on several occasions. But here the similarity ends. The lecture audience cannot cross-refer from one illustration to another. Most lecturers appear to require their listeners to appreciate the full importance of a transparency in about a minute, and then move on to the next.

Far too many lecturers use as transparencies the Figures prepared for the published version of the work. Complicated tables should NEVER be used to illustrate a lecture. One wonders how many audiences would immediately appreciate Fig. 1 should it be flashed onto a screen. I have seen people project a slide of this nature and then ask the audience to ignore most of it and concentrate on, say, the fluctuations in nitrate nitrogen.

SIMPLICITY is now the most important consideration. Ideally each graph presented to the audience should be intended to communicate a single idea; two at the most. There is rarely any serious restriction on the number of transparencies that may be shown during a lecture and it is far, far better to use a series of simple transparencies than one complicated one. In the present example the seasonal changes in nitrate, phosphate and silica could be displayed on one transparency: temperature and rainfall on a second: and the plant abundance on a third, before presenting the pattern in its entirety. Using a slide projector one would thus build up the relationship with a series of slides. An overhead projector allows transparencies to be superimposed and hence this equipment offers additional opportunities for building up complicated pictures by simple stages.

A final difference between published and projected versions of the same material concerns the captions and any labelling. Most editors ask authors to so label and caption their Figures that these may be understood without detailed reference to the text. For the display slide it is much better to under-label than over-label: it can always be said that "height" on the vertical axis means "Height above mean sea level". Sequential Figures are much easier to understand if they are labelled in a coherent manner, keeping parameters in the same units and on the same axes whenever possible.

The projected graph is intended to increase the audience's understanding of the lecture. This objective will not be achieved if that audience is concentrating so hard on the lettering that it is unable to listen at the same time.

A REVIEW OF SOME GRAPHICAL TECHNIQUES USED IN
FIELD STUDIES

a) *Line Graphs*
To many people a line graph appears to be the simplest, neatest and quickest

means of displaying sequential data. Trends are immediately apparent and conclusions may be drawn easily.
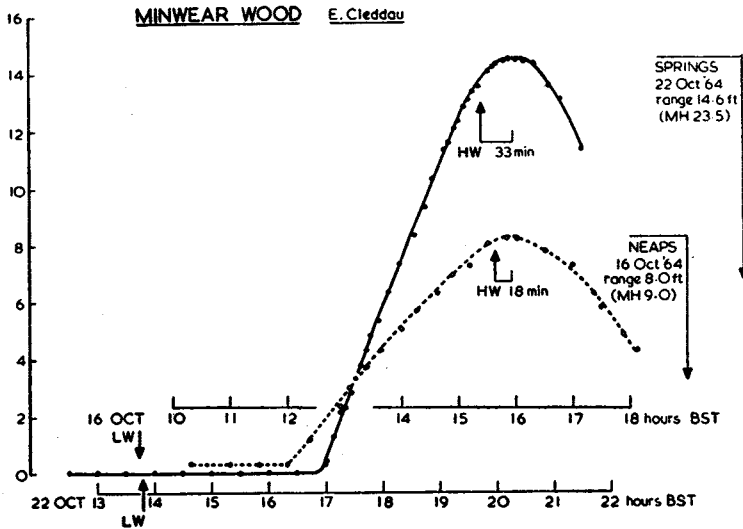

FIG. 2

An example of a line graph from Nelson-Smith (1965) recording the height of the tide at springs and at neaps near the head of Milford Haven. The two curves are superimposed so that the times of highwater coincide. Dots mark the actual observations: the lines correctly indicate changes between observations.

When plotting a graph on two axes it is conventional to plot the dependent variable up the *y* axis against the independent variable along the *x* axis. However, this convention is not mandatory and may be disregarded if the graph would be easier to interpret the other way round. Thus, in Fig. 3, under the convention, temperature should have been plotted upwards and depth horizontally, but the author decided that his readers would find it easier to interpret the Figure with depth on the *y* axis: depth is, after all, a vertical measurement.
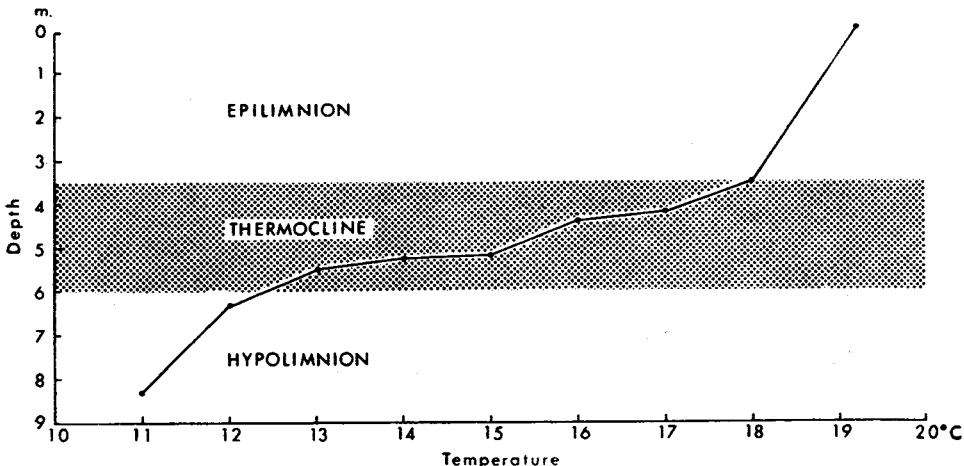
FIG. 3

A line graph flouting the convention concerning axes. Sinker (1962) chose to plot depth vertically on the *y* axis even though it was the independent variable.

Isolated points present problems when drawing any graph. If the data represented by Fig. 4 had been plotted in the usual way the single high value for *Microcyctis flos-aquae* in November would have so dominated the picture that all the detail for the bottom section—values of 4 and below—would have been lost. A break in one of the axes is a perfectly valid way of accommodating disparate points on a graph, but I question the meaning of the straight line drawn to link that November figure to the counts for August and December. Assuming that a meaningful line can be drawn with this data (see below) I would favour the drawing of those lines at appropriate angles to allow for the break on the *y* axis.

Whatever the scale on the axes it is usually best to draw straight lines between the points, as in Figs 3 and 4. When a very large graph is greatly reduced for publication (Fig. 5) a large number of short straight lines appear to adopt a curve. In this example the apparently continuous line is made up of some 335 very short lines linking daily readings. It may be acceptable to draw a smooth curve through the points in a case such as that illustrated in Fig. 6 where the general trend of the data is well established. The line is, of course, used to indicate regular change. Interpolating, the line shows that the water was 3 ft deep at 2200 hours on March 1st.

All too often examples are found where a line has been drawn on a graph despite the fact that there was no gradual change. In Fig. 7 lines have been drawn between annual totals. There are, of course, no intervals between these points that can be linked by a line—and it would clearly be nonsense to attempt to read off intermediate values from this figure.
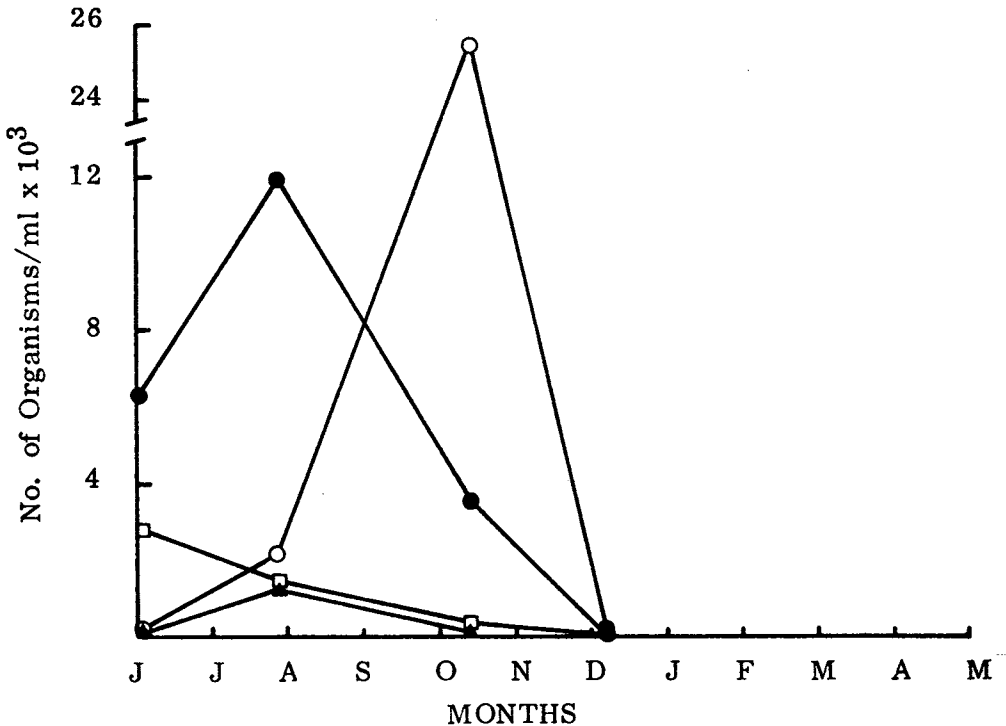

FIG. 4

To illustrate the use of a break in an axis to accommodate an isolated point. Jones and Benson-Evans (1974) drew this graph to show the periodicity of the major phytoplanktonic algae in Llangorse Lake during 1966/1967.

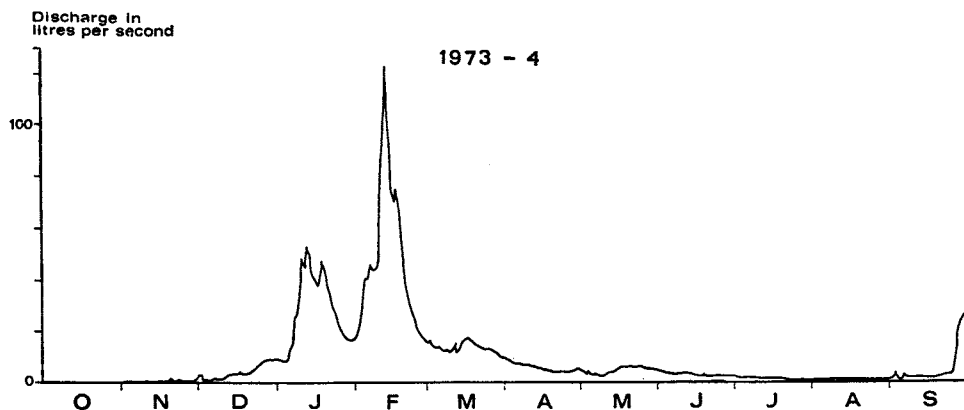**Discharge in litres per second**

1973 – 4

FIG. 5

A very large number of short straight lines may appear to adopt a curve when a large drawing is greatly reduced for publication. From Howcroft (1977) and displaying the pattern of stream discharge from daily records over an 11 month period.
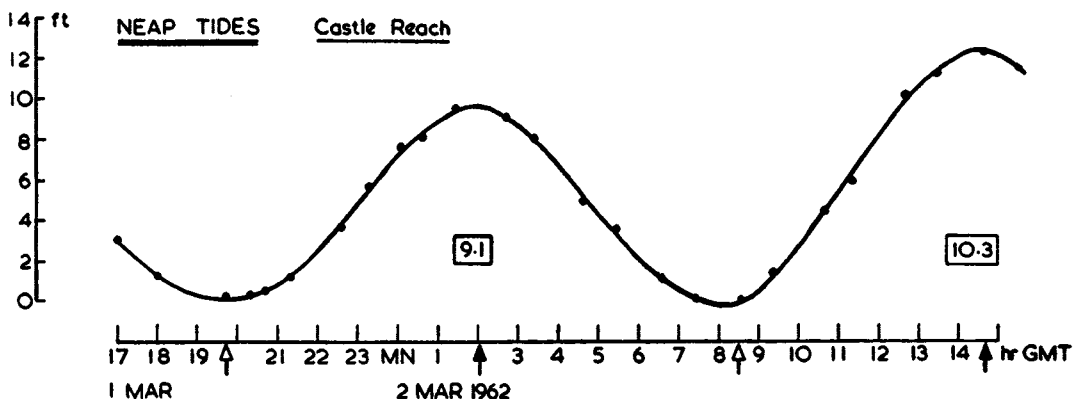
NEAP TIDES   Castle Reach

9.1

10.3

17 18 19 20 21 22 23 MN 1 2 3 4 5 6 7 8 9 10 11 12 13 14 hr GMT

1 MAR   2 MAR 1962

FIG. 6

A curved line may be drawn through the points if the data are known to fit a curved pattern. Depth of water in the Daucleddau from Nelson-Smith (1965).

Fig. 2   Annual Rainfall.   Snowdon NNR

Rainfall   (CEGB Rain Gauges)
in inches

Llyn Teyrn 1050 ft   (644544)
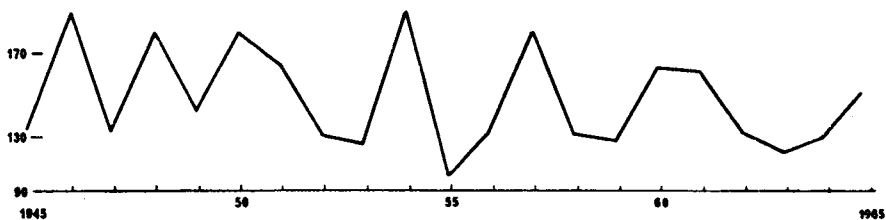
FIG. 7

An example of the improper use of lines from Ball, Mew and Macphee (1969).

Although the lines undoubtedly draw the reader's attention to the fluctuations in annual rainfall these data should really have been plotted as contiguous histograms (p. 496). You cannot interpolate from these lines; there are in fact no intervals between the points.

There are, then, very real limitations to the use of line graphs which also apply to pollen diagrams and kite diagrams (which are variants of the simple line graph). In a pollen diagram (Fig. 8) a series of line graphs are plotted for the number of pollen grains found in samples collected at different depths below the present ground surface. In this case counts were made at 10 cm intervals and the lines have been drawn to indicate the changes in abundance of the grains between samples. One may speculate whether the changes were quite as regular as the straight lines would suggest. Pollen diagrams are always drawn in apparent contradiction to the dependant variable/independant variable convention: soil depth, the independant variable is alway shown vertically, but the graph is always drawn against this axis.

Kite diagrams, so beloved of seashore ecologists, are only a set of symmetrical line graphs. There is no particular reason why the data for both Figs 8 and 9 should not have been plotted as kites, or plotted in the manner of a pollen diagram. Each technique has its devotees: I find the kites a clearer means of compressing a lot of information into the available space. Williams' kites (Fig. 9) are based on counts and, provided that the author was sure that numbers really did change in an approximately regular manner between sampling stations, there can be no criticism of his Figure which portrays seasonal changes in the *Monodonta* distribution very clearly. It is, however, the only acceptable example of a kite diagram illustrating a rocky shore survey that I can find in *Field Studies*! The other authors, including
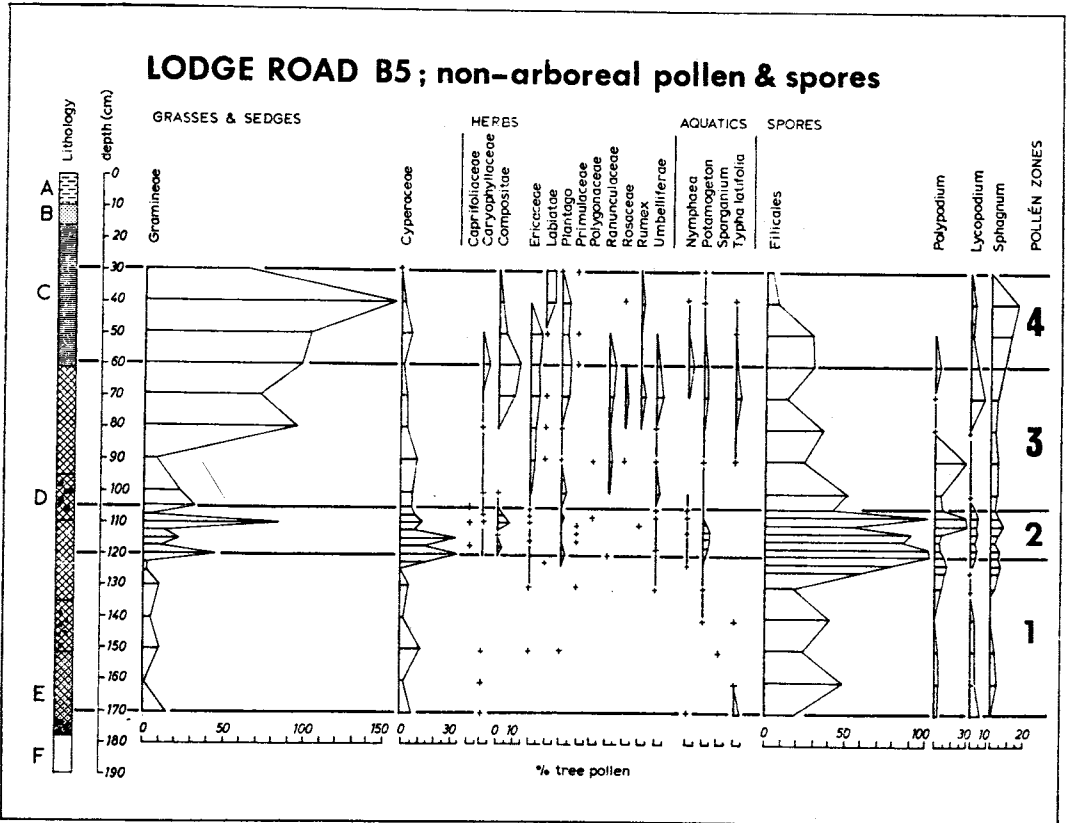

FIG. 8
A pollen diagram for a site in Epping Forest, from Baker, Moxey and Oxford (1978).
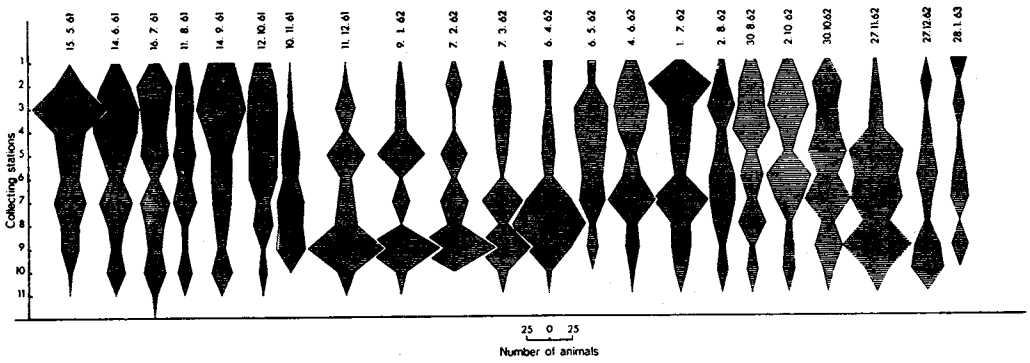
FIG. 9

A kite diagram drawn by Williams (1965) to show the movement of a population of topshells *(Monodonta lineata)* up and down the shore according to season.

myself (Crothers, 1976), have plotted kites based on abundance scale data—and you cannot draw lines between abundance grades that have any meaning. McCarter and Thomas (1980) were well aware of this, but maintained the tradition in order to facilitate comparison between their work and that of others published earlier. (Figs. 10 and 11). The data were recorded on a 7-point abundance scale:- Extremely abundant; Superabundant; Abundant; Common; Frequent; Occasional; and Rare. For convenience in recording, these grades are often noted as abundance 7, 6, 5, 4, 3, 2 and 1. It has already been noted that such data cannot be averaged—"frequent" is not half "superabundant" even though 3 is half 6. What is less obvious is that these are grouped data. Extremely Abundant (for limpets) is $200+m^{-2}$: Superabundant, $100—200\ m^{-2}$: Abundant, $50—100\ m^{-2}$ and so on. There are no gaps between the grades. Line graphs of any kind are clearly inappropriate, and some form of histogram or bar graph (Fig. 11) is required. Histograms and bar graphs are not the same. The area of a histogram indicates the value plotted, whilst it is the length of a bar graph that is important. Many people use the terms indiscriminately, and this may be justified for rectangular histograms.
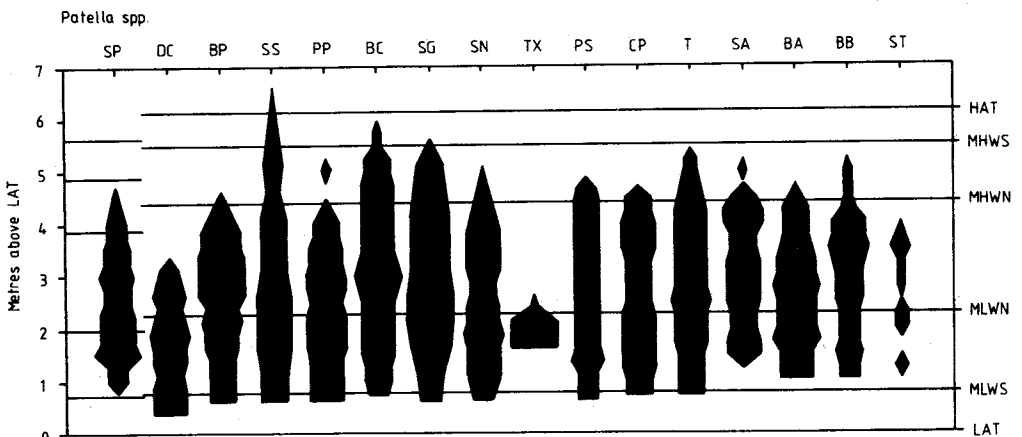

FIG. 10

To illustrate a familiar misuse of kite diagrams: The abundance of limpets, assessed on an abundance scale, at different heights up some rocky shores in South Devon (McCarter & Thomas, 1980).
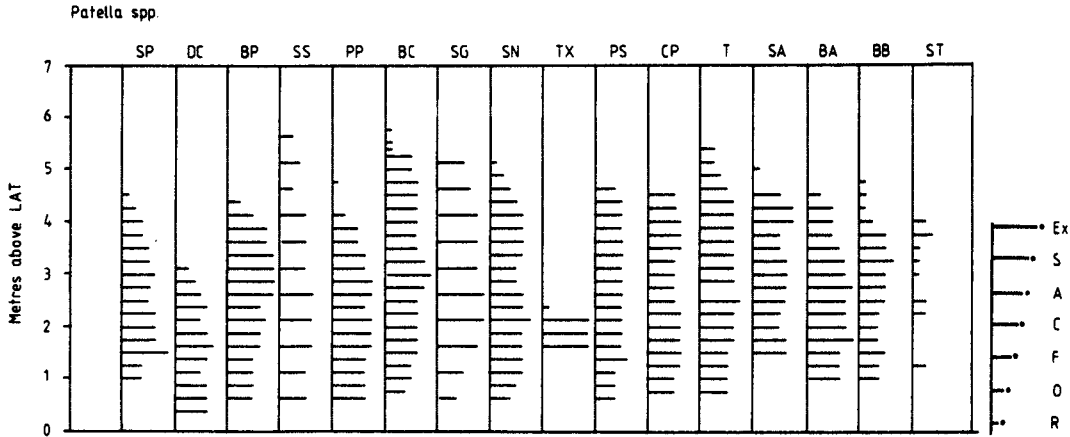
Patella spp.

FIG. 11
The data misplotted in Fig. 10 replotted as bar graphs (McCarter & Thomas 1980).

b) *Histograms*

Some authors, e.g. Dresser (1959), appear to have used line graphs and histograms as equivalent alternatives, which they are not. Histograms are probably the best way of plotting annual totals or any form of discontinuous data when there is insufficient information to permit the drawing of an acceptable line between the points. Histograms are equally applicable for the display of actual totals (Fig. 12) or percentages (Fig. 13) The former conveys the real preponderance of beef cattle over dairy cattle, but the latter is more effective in showing the different distribution patterns shown by crabs in Dale Roads. A direct plot of crab numbers in this latter case would have been confused by the very large catches of one species, *Carcinus maenas*, in comparison to some of the other species. When several sets of data are to be displayed on the same axes there are at least three alternative techniques available:- one may plot a series of graphs (as in Fig. 13), one may superimpose one graph on another (Fig. 14) or one may plot two sets of data adjacent to each other (Fig. 15). Superimposition is probably the best solution when the total area of the combined histogram means something useful. It is important to write the caption clearly when producing these more complicated displays. In Fig. 12 left, the top line indicates the changing numbers of beef cattle (not total cattle) whilst in Fig. 14 the top line shows total employees, not the total number of casual workers. In these
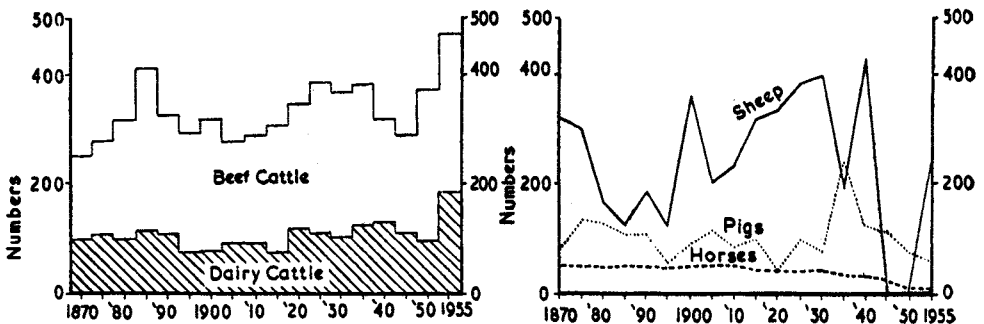

FIG. 12
Dresser (1959) used histograms and line graphs as equivalent alternatives for this display of 5-yearly totals for livestock in the parish of Dale (Pembrokeshire). Histograms are correct: line graphs inappropriate.
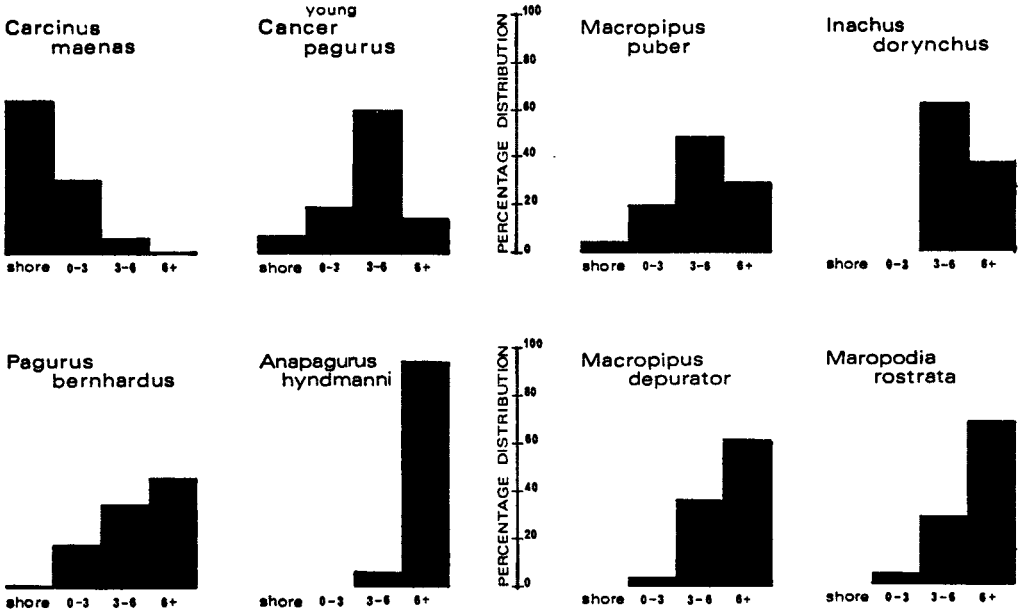
FIG. 13

The percentage distribution of eight common species of crabs with depth (in fathoms) in Dale Roads (Milford Haven). Note the spelling mistake, *Maropodia rostrata* instead of *Macropodia*. An editor is unlikely to spot an author's error on his figures (Crothers, 1969).
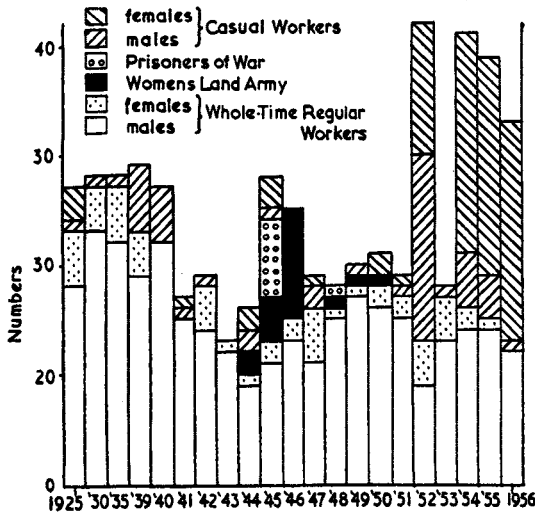

FIG. 14

Superimposed histograms showing the total number of people employed on the land in the Parish of Dale (Dresser, 1959). The *y* axis should read 0, 10, 20, 30, 40.

examples the meaning is pretty obvious and nobody should be confused, but that is not always the case.

Fig. 12 left is so clear because numbers of beef and dairy cattle are discrete; but it would be difficult to superimpose the data for Fig. 15 in this manner without loss of clarity (the situation becomes even worse should the sets of data cross over), but
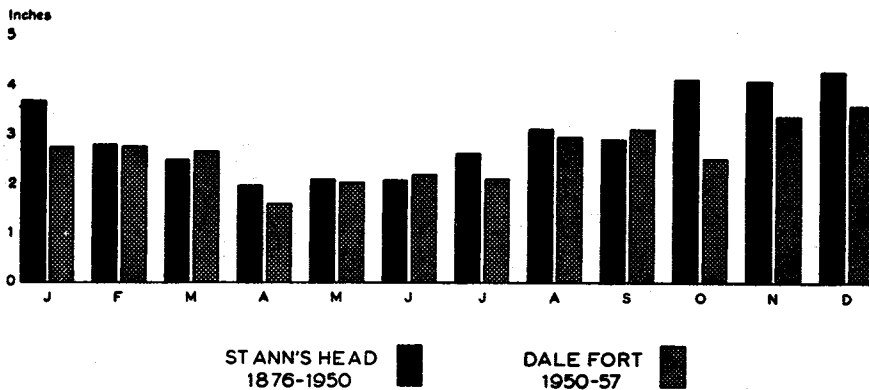
FIG. 15

Juxtaposition of histograms where the two sets of data are too similar for a superimposed plot. From Oliver (1959).
Alternatively, one set of data could have been plotted down from the x axis.

there would be little merit in attempting superimposition in this case: combined monthly rainfall totals at Dale Fort and St. Ann's Head from different years is hardly a meaningful quantity.

Summarised data, of the form illustrated in Figs. 12–15, can be sensibly represented by contiguous histograms, but this technique should not be used to portray isolated events. Fig. 16 shows the numbers of individual spiders caught in pitfall traps at Malham. From the illustration and its original caption it might be interpreted as portraying total monthly catches, as Fig. 15 portrays total monthly rainfall, but the text reveals that the data relate to trappings carried out at monthly intervals. These data could well have been represented by spaced histograms, such as were used for Fig. 17: and, conversely, the data plotted in that Figure should have been contiguous because there are no gaps in the record. Each point represents the number of crabs trapped during the previous hour.

As with all other techniques, it is necessary to think out the design of histograms before committing pen to paper. It is all a matter of common sense; much more obvious to the critical reader than to the author!
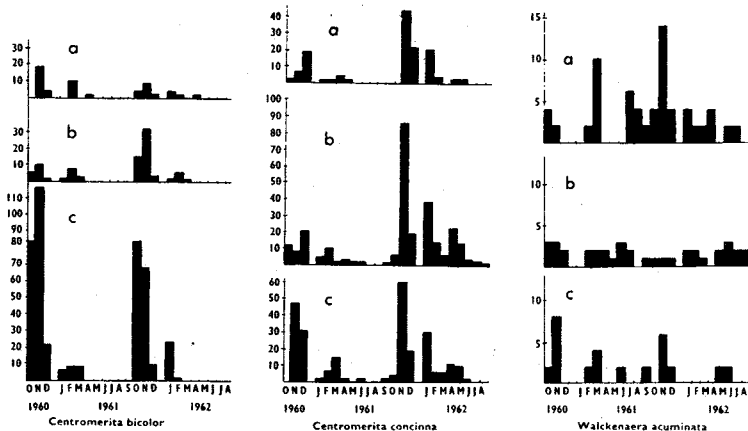

FIG. 16

Misleading use of contiguous histograms: the data refer to pitfall catches taken on one day a month—not to monthly catches. From Duffey (1963).
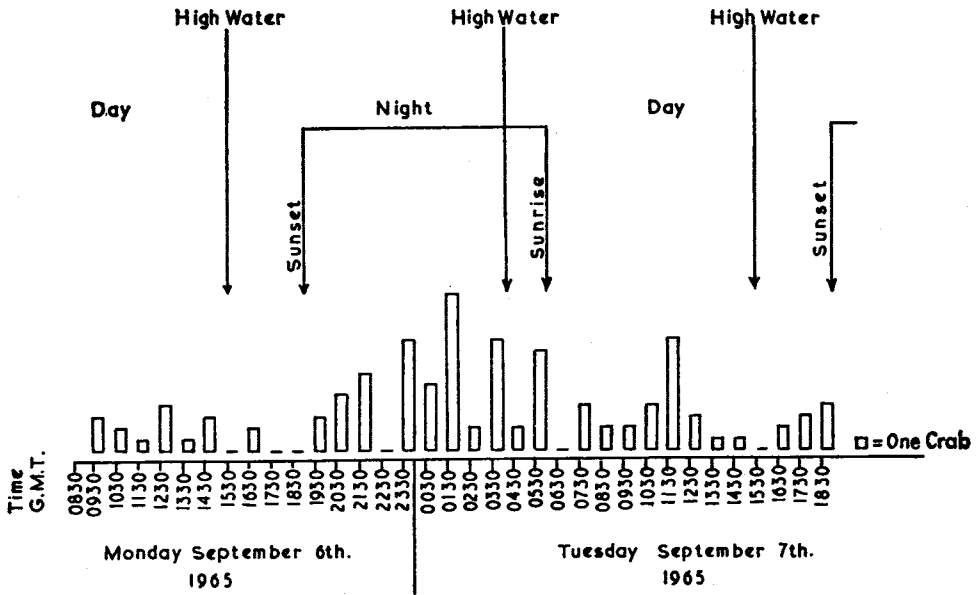
FIG. 17

Misleading use of spaced histograms: the data are continuous. A trap was laid in the sea off Dale Fort and lifted at hourly intervals. Any crabs caught during the previous hour were counted, released and the trap reset. From Crothers (1968).

Histograms may also be drawn against a circular baseline and this amendment can be very usefully applied when direction is one of the variables to be plotted. Probably the most familiar example is the wind rose (Fig. 18). In this case the data have been plotted as percentages although there is no convention against showing the numbers directly. As in all histograms area within the rectangle is proportional to the value plotted.

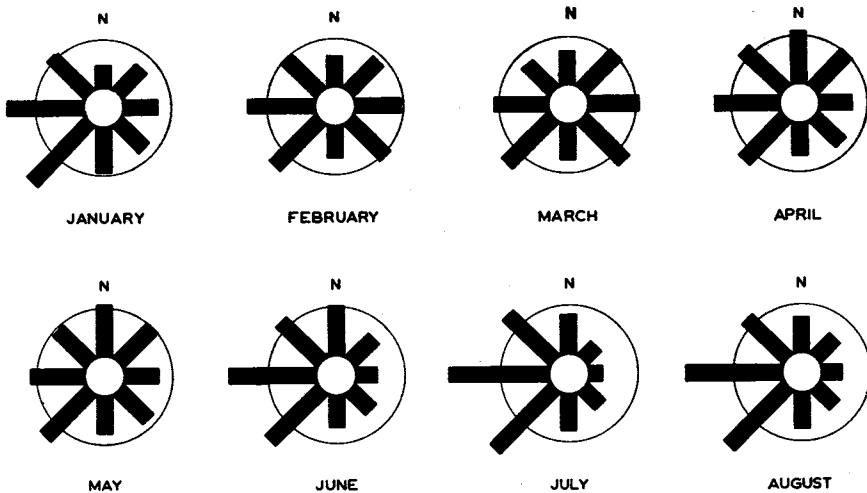The wind rose principle has been adapted to various other purposes and two

FIG. 18

Wind roses for St Ann's Head from Oliver (1959). In this case data are expressed as percentages: the outer circle indicates 12½ per cent.

examples are shown here. In Fig. 19, Job and Jarman (1980) have used a circular plot to display the home-settlements of people sampled whilst shopping in Shrewsbury. Unlike the actual wind rose (Fig. 18), the length of the line indicates the distance travelled, its width the number of shoppers, and the direction is plotted directly, as on a map. Fig. 20 provides an example of circular display used to show the orientation of individual stones within a gravel deposit. Note that the authors of both Figs. 19 and 20 have superimposed their graphs onto a map, thereby adding additional information for the reader/viewer. Both papers have more detailed maps elsewhere to locate the study area within a wider context.
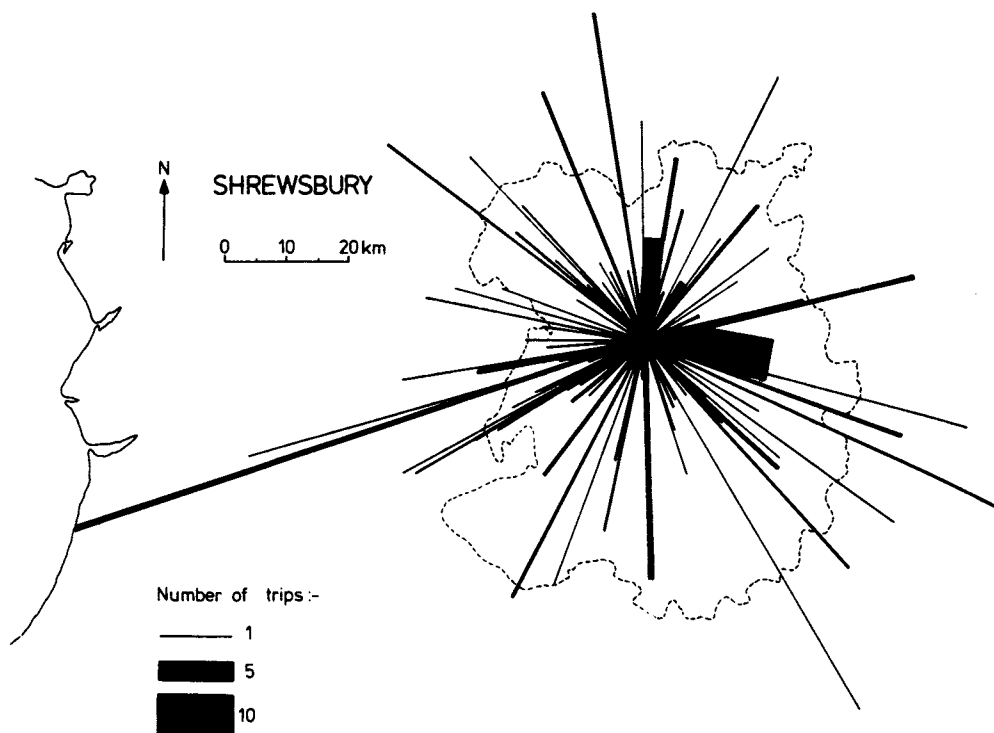

FIG. 19

A modification of the wind rose principle used by Job and Jarman (1980) to indicate the movement of shoppers into Shrewsbury from surrounding towns and villages.
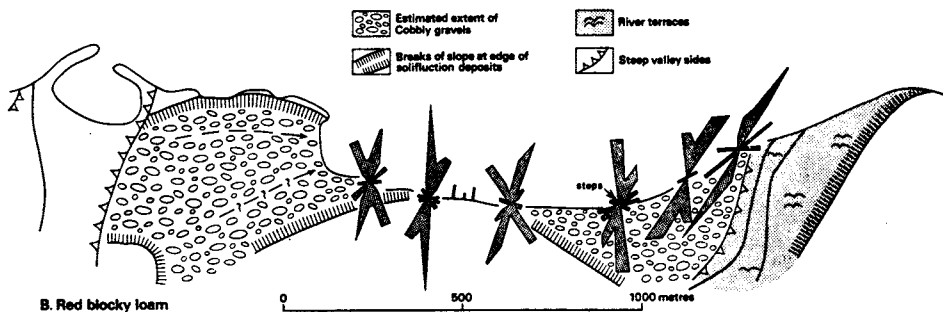

FIG. 20

The preferred long axis stone orientation of pebbles in the red loam deposit between Doniford and Watchet (Gilbertson & Mottershead, 1975).

c) *Dots*

Line graphs and histograms are not appropriate in all cases, sometimes it is best to plot the points as dots and leave the reader to interpret them. In Fig. 21, the upper string of points represent the predictions for high tide throughout September 1974 (the *x* axis indicates time) whilst the lower string represents predictions for low tide. A line linking the high water predictions would be meaningless for the tide does not proceed directly from one high tide to another, but rather passes from high tide to low before rising to high again. If a line were to be drawn it would have
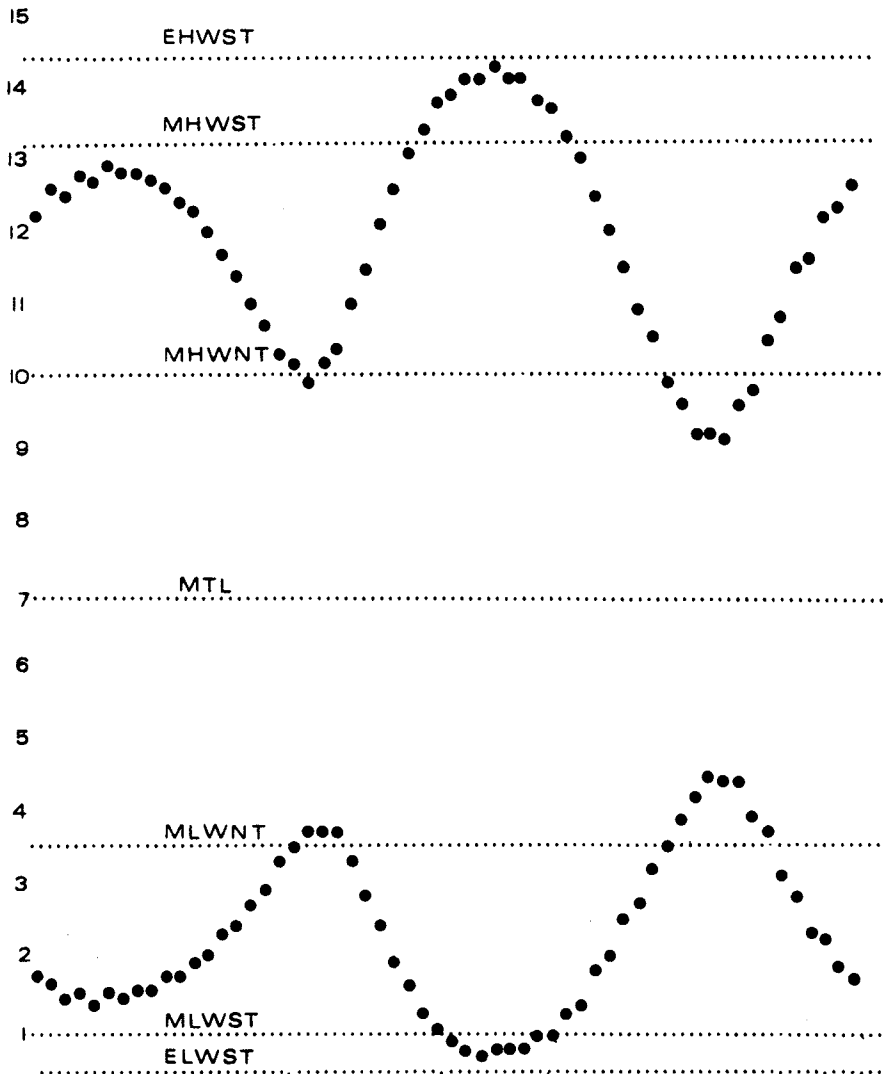
Tidal Predictions

September 1974

FIG. 21

Points through which it is impossible to draw histograms or meaningful lines without loss of clarity (Crothers, 1976). The dots indicate predictions for heights of high (top series) and low (bottom series) tides at Avonmouth during September 1974. *y* axis represents height above chart datum: the *x* axis is time.

to zigzag up and down from high to low and back again, but the water does not rise and fall at a constant rate so, strictly speaking, the zigzag line would have to take that into account as well. Adding a mass of lines to that Figure would not improve the clarity of the presentation. It is also impossible to draw meaningful histograms, for each high tide level is associated with two low tide levels (and vice versa).

Where it is necessary to discriminate between different sets of dots it is possible to use a variety of symbols—closed and open circles, triangles, squares, stars and crosses. The temptation to over complicate graphs with a multitude of symbols, simply because a sheet of transfer symbols is at hand, should be resisted. There was no advantage gained from using closed and open circles and stars in Fig. 22—they could all have been one or the other.

No results from reciprocal averaging, or other similar computer-based techniques have yet appeared in *Field Studies* but I hope that the paper incorporating Figs. 23 and 24 will do so before too long. These figures represent the transect data published by Crothers (1976) subjected to reciprocal averaging by Dr. D. H. Dalby. Taking the most abundant score for each species of animal and plant recorded at each of the 12 transect sites, the programme was first run through the computer to rank the sites in order of their greatest dissimilarity (Axis 1) and then to rank them in order of the next most important dissimilarity (Axis 2). When plotted (Fig. 23) it is seen that Axis 1 has something to do with geographical position along the West Somerset coast, sites on the left of the plot lie to the east of those on the right. Axis 2 is exposure to wave action; Minehead harbour wall (a vertical concrete face) and Hurlstone Point are much more exposed than Blue Ben or Gore Point. Lines could be drawn around some of these points, to indicate groupings, but not through them. Histograms would be meaningless: the stars are co-ordinates on a plot, not numerical values.

The analysis continues on Fig. 24 where the programme has been run again to show the affinities of rocky shore animal species to Axis 1 and Axis 2. The interest
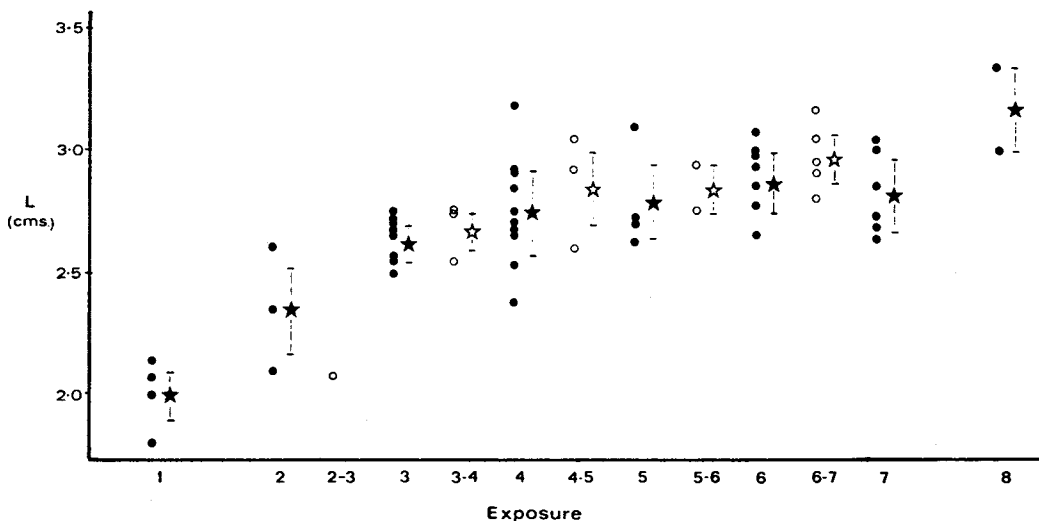

FIG. 22

To illustrate the use (misuse) of different symbols on a dot graph. Crothers (1974) plotted mean length of dog-whelk shells against the exposure of the animal's habitat to wave action. Black symbols were used for exposure grades, open ones for intergrades (for no good purpose). Stars indicate the mean and standard deviation for their adjacent set of circles.

Sites

Minehead Harbour Wall

Hurlstone Pt. E.

Greenaleigh

Hurlstone Pt. W.

Hinckley Point

Watchet

Blue Anchor

Helwell Bay

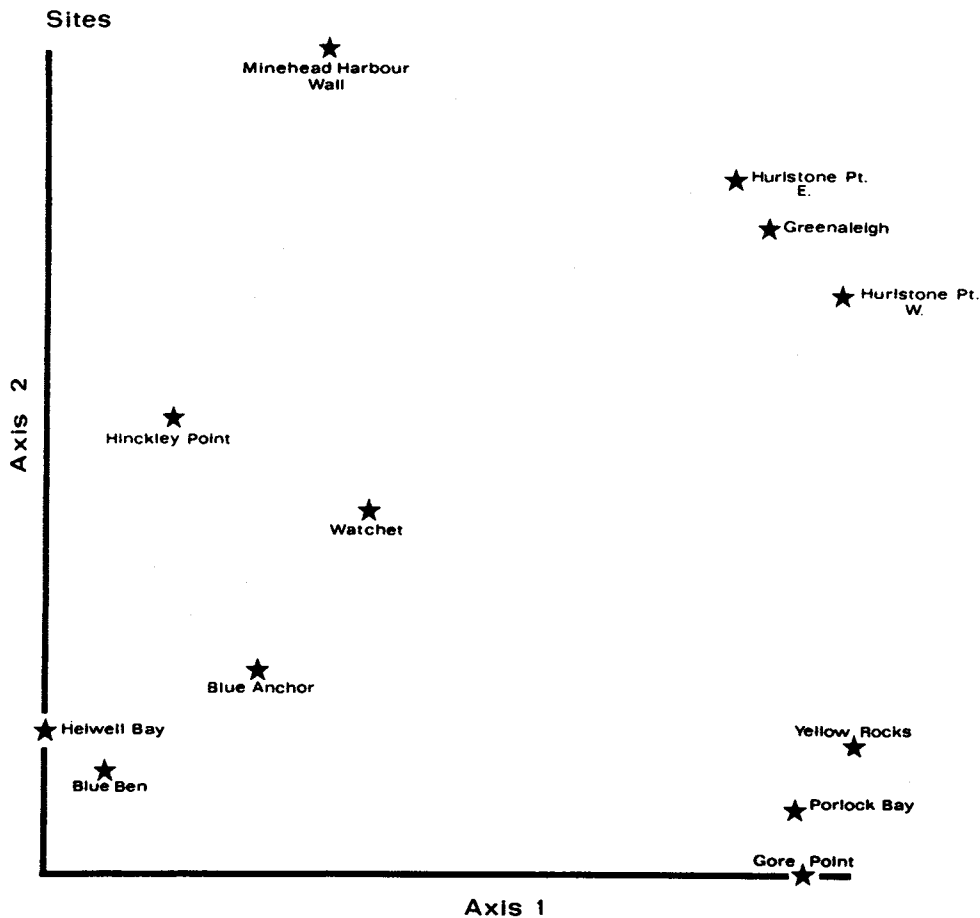Yellow Rocks

Blue Ben

Porlock Bay

Gore Point

Axis 1

Fig. 23

A hitherto unpublished reciprocal averaging analysis carried out by Dr D. H. Dalby on the transect data from Crothers (1976). Axis 1 appears to represent approximate geographical position E-W: Axis 2 is exposure to wave action.

lies in comparing Figs 23 and 24. No animal species is particularly associated with the artificial harbour wall, but the small winkle *Littorina neritoides* clearly correlated with the exposed Hurlstone Point. The barnacle *Elminius modestus* (an immigrant species still expanding its range in the area) with co-ordinates of 50:50 is little affected by either Axis.

This type of dot graph is usually called a scatter diagram.

d) *Scatter diagrams with a superimposed regression line*

Despite the last example there are many cases where the dots *do* follow a detectable pattern that may be highlighted by the drawing of a line. In the line graphs considered earlier, lines were drawn to link the points together. When dealing with scatter diagrams it is the "best-fit" or regression line that is required, which may not pass through any of the points! Nowadays, it is usual to calculate the regression directly from the data and not from the plot, but it is often possible to obtain a fair approximation by holding up the graph to the eye and looking along the field of dots.
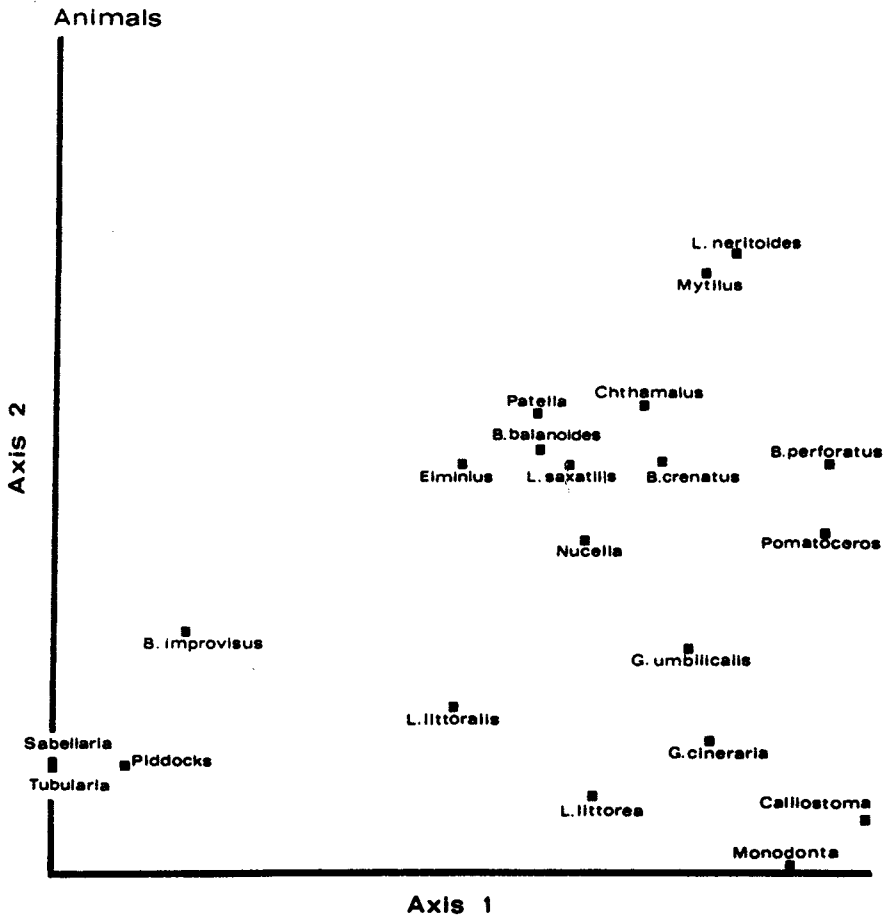
FIG. 24

A hitherto unpublished reciprocal averaging analysis carried out by Dr D. H. Dalby on the transect data of Crothers (1976). When compared with Fig. 23, it is seen that no species is particulary associated with Minehead harbour wall, *Balanus improvisus,* piddocks, *Sabellaria* and *Tubularia* appear to be associated with Blue Anchor, Watchet etc. Most species favour the western (right hand) side of the plot and the barnacle *Elminius modestus* comes out with co-ordinates of 50:50, it is equally common on almost all transects.

The graph is not drawn solely to justify, visually, the calculated regression line. Frequently the greatest interest lies in the departure of certain dots from the general pattern. Are they erroneous in some way? Or do they represent a real departure from the remainder? Either way they highlight areas for further investigation.

It is much easier to calculate a linear regression than a curved one. Some pocket calculators enable the first to be obtained as easily as the mean, whilst only those people who are able to summon the help of a computer are likely to attempt the second. It is also easier to estimate a straight line when holding the paper up to an eye—compare Figs 25 and 26.

For these and other reasons (such as clarity) it is worth considering transforming arithmetical data into logarithms if, by so doing, a curve is eliminated. Usher (1980)—Fig. 27—illustrates the value of this procedure and it will have been noticed that Fig. 25 uses log:log paper.
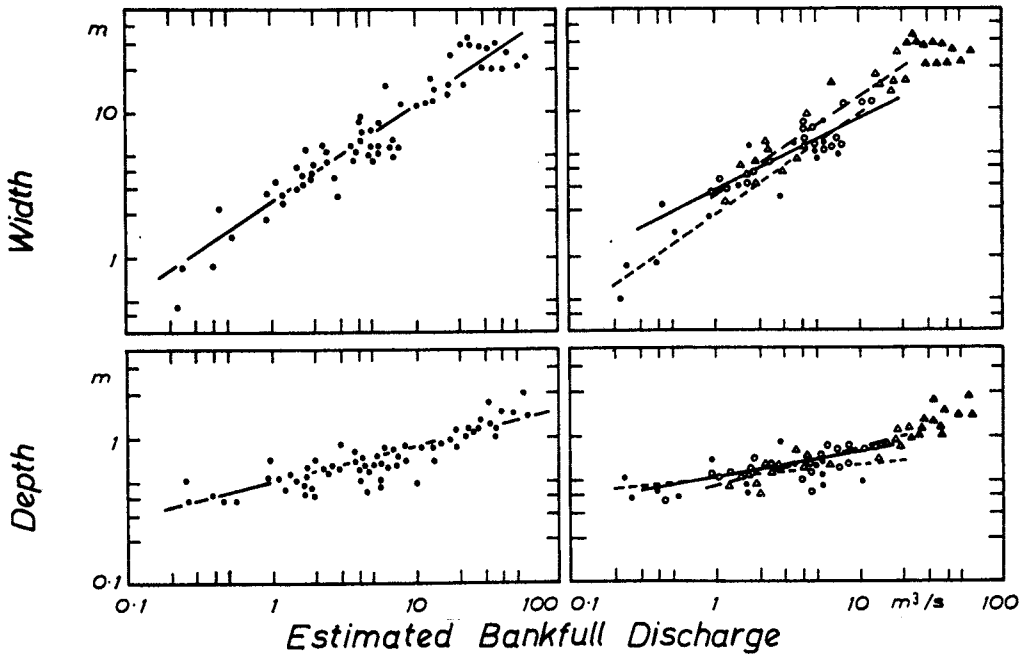
FIG. 25

Park (1978) plotted data for four River Dart tributaries separately on the right and together on the left. He calculated a regression line for each set (except the black triangles) and superimposed it on the dots. There clearly is a relationship between channel width, depth and the estimated discharge in time of spate.
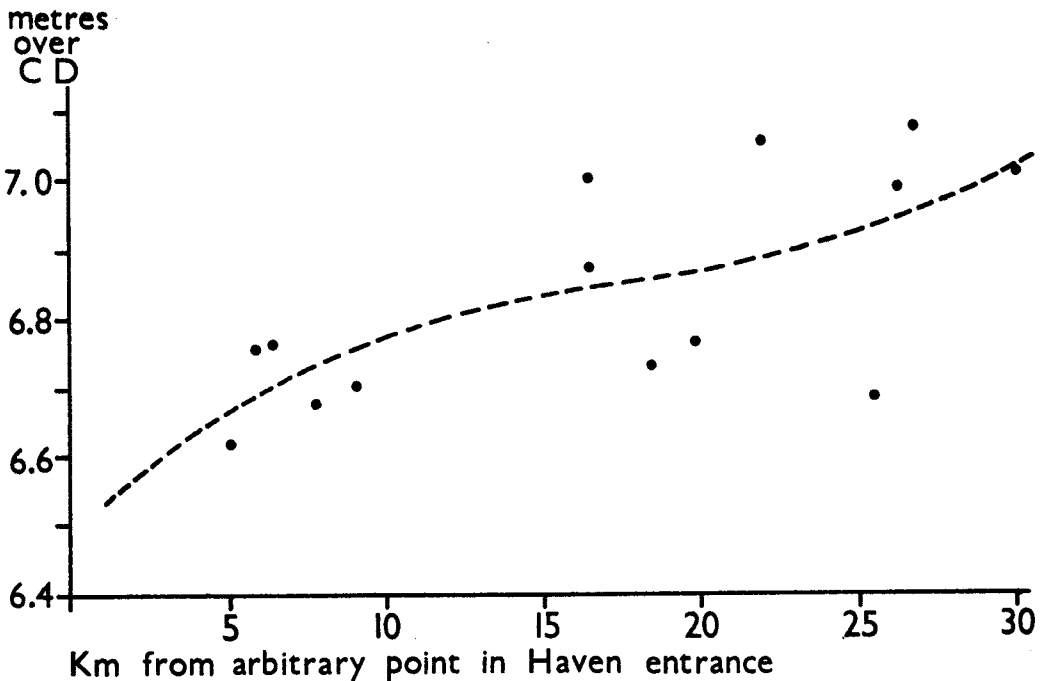

FIG. 26

A fitted third order polynomial regression drawn between points indicating the height of the lowest Festucetum (plant community dominated by the grass *Festuca*) on salt marshes up Milford Haven. From Dalby (1970).
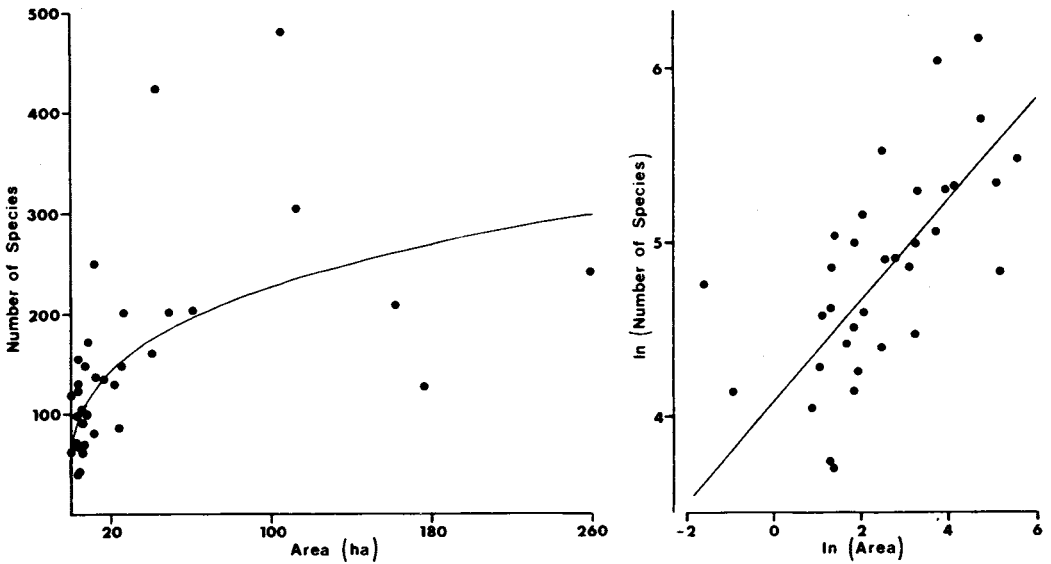
FIG. 27

The use of log: log paper to transform a curve into a straight line. From Usher (1980).

There is a real difference between securing a straight line relationship by transformation and then trying to explain it, as against the situation in Fig. 25 where the theoretical relationships are well established and are known to be power laws so that the log:log graph is the proper way to plot the information.

On the debit side, non-mathematicians will probably find it more difficult to interpret the meaning of a regression from a logarithmic scale.

e) *Pie Charts*

Pie charts are a rather different type of graph. They are used to illustrate proportional data, and are especially valuable when superimposed on a map. The other techniques reviewed so far require the recognition of two parameters, x and y, one of which is plotted against the other to reveal the relationship between them. Pie charts are helpful when it is difficult to define (or quantify) a second parameter.

The land-use data for Fig. 28 could not have been displayed nearly so clearly or concisely on two axes. The biggest disadvantage of this method is the time taken in preparation, the data must be transformed into 360ths before they are plotted as angles. Then, many people experience difficulty in reading off angles. Pie charts do not, of course, have to be as complicated as these and Fig. 29 illustrates a case to show geographical trends in a single variable. Pie charts cannot indicate numbers, only proportions, but it is possible to vary the size of the pies so that the radius is indicative of the size of the sample.

f) *Dendrograms*

This technique appears to have been used but once in *Field Studies,* Fig. 30, but it is a very useful means of displaying differential affinity. The plot is likened to a tree, hence the name, with the major branches, leaving the trunk low down, indicating greatest divergence and adjacent twigs showing greatest affinity. Savage and Pratt (1976) have added the degree of association to their plot. An association of 1.00
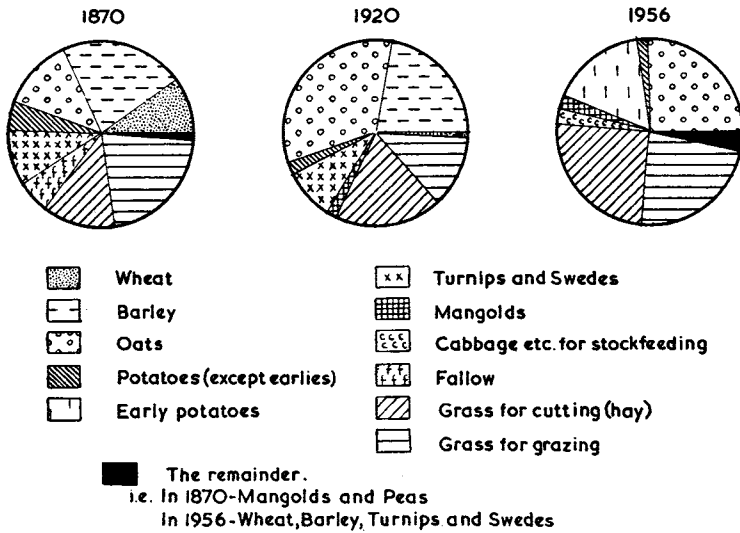
▦	Wheat	⊞	Turnips and Swedes
⊟	Barley	▦	Mangolds
▩	Oats	▦	Cabbage etc. for stockfeeding
▨	Potatoes (except earlies)	▦	Fallow
⊡	Early potatoes	▨	Grass for cutting (hay)
		⊟	Grass for grazing

■ The remainder.
i.e. In 1870-Mangolds and Peas
In 1956-Wheat, Barley, Turnips and Swedes

FIG. 28

Pie charts from Dresser (1959) to show the proportional utilisation of arable land in the Parish of Dale for various crops in three years.
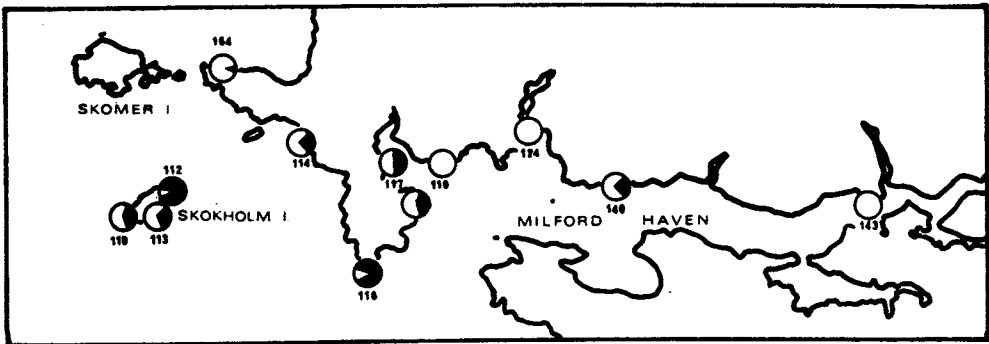

FIG. 29

Pie charts superimposed on a map to show the intensity of stabilising selection in the dog-whelk around Milford Haven. The black portion of each pie represents the decrease of variation with age and hence the degree of selection. Crothers (1974) from Berry & Crothers (1968).

indicates that the corixid fauna was identical in the two (or more) meres, and associations of less than 1 reveal increasing dissimilarity. Dendrograms can be drawn as if the tree was "growing" upwards, downwards or horizontally. There are, in addition, other tree-like diagrams (minimum spanning trees, Wagner trees etc.) but these are of quite sophisticated construction and beyond the scope of this paper.

g) *Other methods*

There are, of course, many other methods of presenting data graphically that have not been used, so far, by contributors to *Field Studies*. Most are rather complicated and difficult for the uninitiated to interpret, but no review would be complete without a mention of *Polar Co-ordinates* and *Three Dimensional Graphs*.
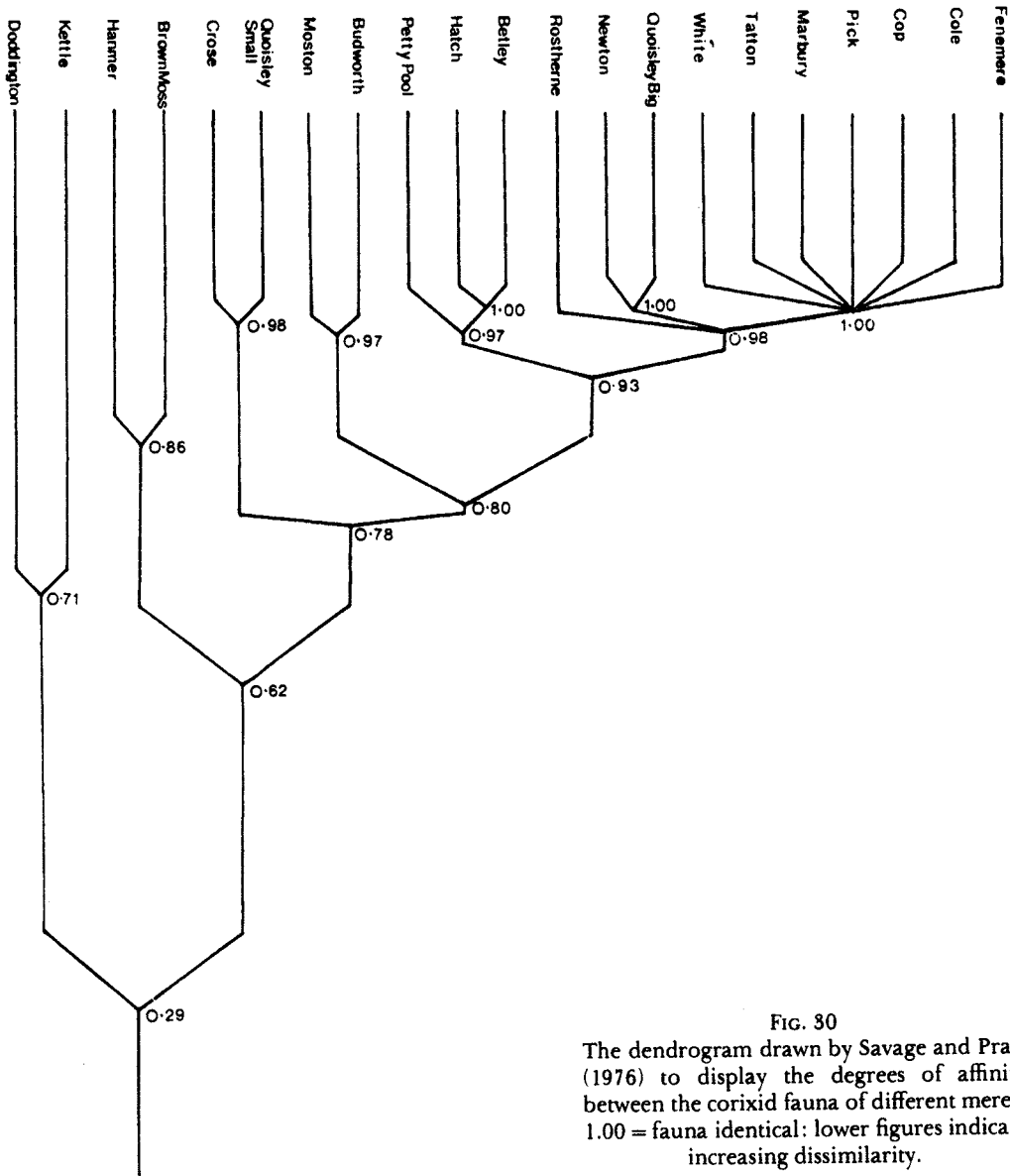
FIG. 30
The dendrogram drawn by Savage and Pratt
(1976) to display the degrees of affinity
between the corixid fauna of different meres.
1.00 = fauna identical: lower figures indicate
increasing dissimilarity.

Polar co-ordinates (or Hemispherical Plots), Fig. 31, are a useful variant of the familiar two-axis graph when one parameter is orientation. It is the scatter diagram equivalent of the wind rose. A third dimension may be introduced either by varying the size of the dot to show abundance, or by the use of different symbols (as in Fig. 31) for different habitat factors.

It is possible to draw three dimensional graphs directly by using x, y and z axes on isometric paper but they take a long time to draw and are frequently difficult to read: Fig. 32 was chosen as a particularly clear example.
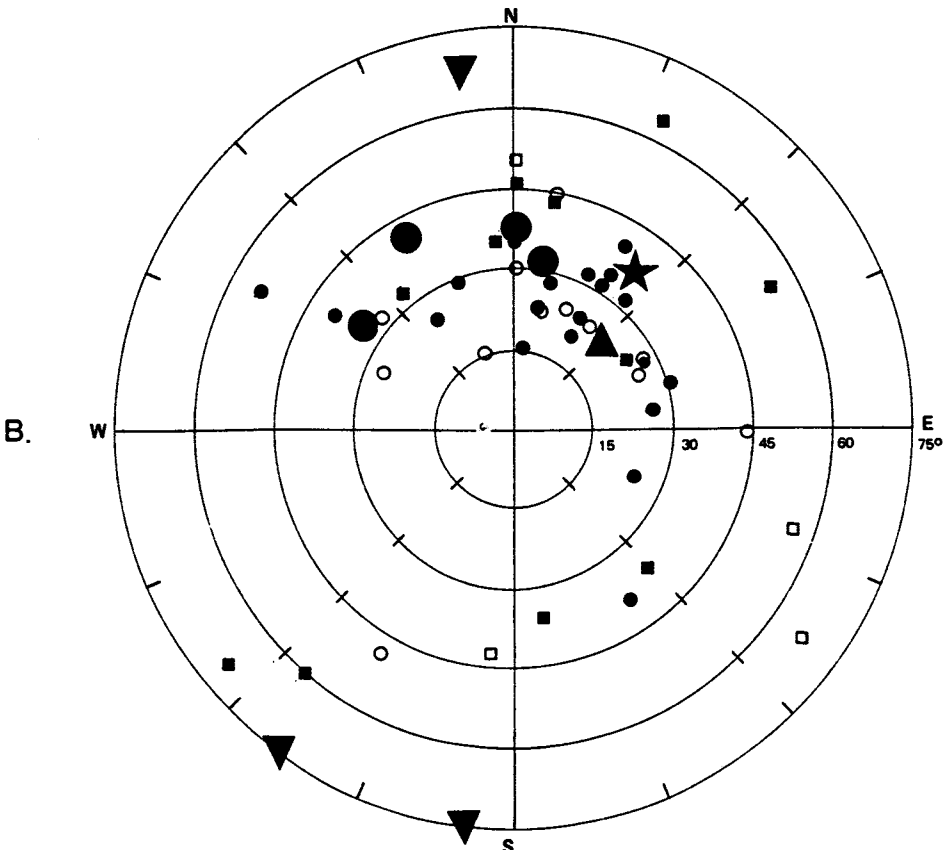
Fig. 31

Polar co-ordinates used to display the occurrence of *Oxalis acetosella* according to aspect, slope (the concentric rings represent 15°, 30°, 45° gradient) and habitat—the various symbols indicate different types of habitat. From Packham (1979) by permission.
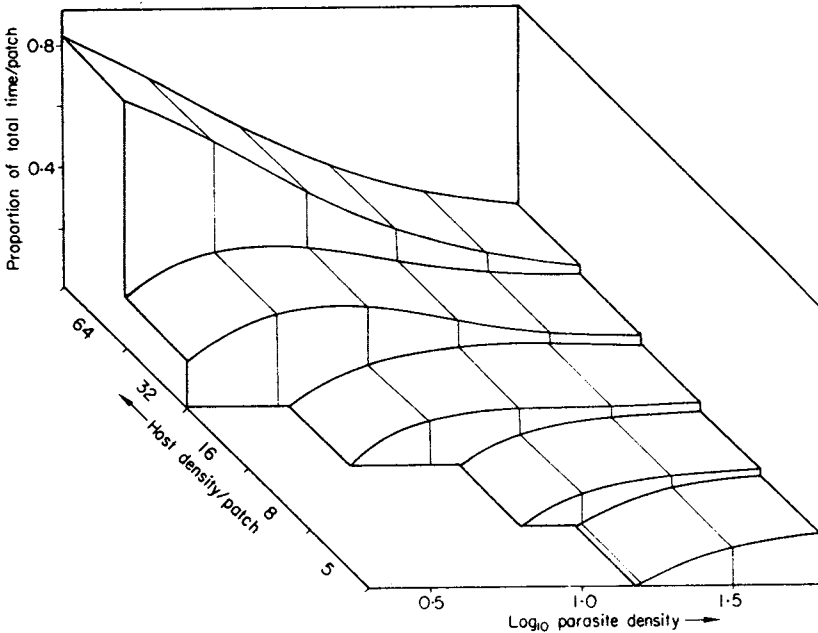

Fig. 32

A three dimensional plot from Cook and Hubbard (1977) predicting the effect of parasite density on the time budget. Reproduced by permission of the British Ecological Society.

DISCUSSION

There is no single ideal method of plotting graphs. The scientist must select the technique most suitable for his purposes and for the data he has available. Very few solutions are actually "wrong", but that does not mean all are equally "right".

The type of data may dictate which method to try first or which to avoid. Line graphs, for example, may be suitable for discrete observations that are following a continuous cycle, but are not for grouped data (like the mean annual rainfall example). In every case the author should be very clear in his own mind what the line is supposed to represent before drawing it on the graph. This is as true for the regression line through dots as it is for the simple line graph. A calculator will produce a linear regression through any set of points, and the fact that a line can be drawn does not mean that it has any relevance to the biological or geographical problem.

Histograms take rather longer to draw than line or dot graphs. They are specially useful for grouped continuous data (consecutive monthly means etc.) and can be plotted on straight or circular baselines as desired. The temptation to produce complicated superimposed histograms should be resisted unless the combined totals mean something.

Simple pie charts, especially when superimposed on a map, have many advantages where proportional representation is required: complicated ones are difficult to interpret. All take a surprisingly long time to produce. It is not only pie charts that can usefully be superimposed on a map—histograms of all kinds, and hemispherical plots, can also be displayed in this manner, usually to advantage when an areal pattern is involved.

Simple solutions are almost always better than complicated ones: not only are they quicker to draw, but they are also easier for the uninitiated to understand. Enthusiasm for developing some special new type of display should be tempered by the realisation that a number of readers/viewers will fail to comprehend it and will actually be distracted by the presentation and so fail to understand the message that the author wished to communicate.

REFERENCES

BAKER, C. A., MOXEY, P. A. and OXFORD, PATRICIA M. (1978). Woodland continuity and change in Epping Forest. *Field Studies*, 4, 645-669.

BALL, D. F., MEW, G. and MACPHEE, W.S.G. (1969). Soils of Snowdon. *Field Studies*, 3, 69-107.

BERRY, R. J. and CROTHERS, J. H. (1968). Stabilising selection in the dog-whelk, *(Nucella lapillus). Journal of Zoology*, 155, 5-17.

COOK, R. M. and HUBBARD, S. F. (1977). Adaptive searching strategies in insect parasites. *Journal of Animal Ecology,* 46, 115-125.

CROTHERS, J. H. (1968). The biology of the shore crab *Carcinus maenas* (L.). 2. The life of the adult crab. *Field Studies,* 2, 579-614.

CROTHERS, J. H. (1969). The distribution of crabs in Dale Roads (Milford Haven: Pembrokeshire) during summer. *Field Studies,* 3, 109-124.

CROTHERS, J. H. (1974). On variation in the shell of the dog-whelk, *Nucella lapillus* (L.). 1. Pembrokeshire. *Field Studies,* 4, 39-60.

CROTHERS, J. H. (1976). On the distribution of some common animals and plants along the rocky shores of West Somerset. *Field Studies,* 4, 369-389.

DALBY, D. H. (1970). The salt marshes of Milford Haven, Pembrokeshire. *Field Studies,* 3, 297-330.

DRESSER, BARBARA, J. (1959). Land use and farm practice in the Parish of Dale. *Field Studies,* 1, (1) 17-39.

DUFFEY, E. (1963). Ecological studies on the spider fauna of the Malham Tarn area. *Field Studies,* 1, (5) 65-87.

GILBERTSON, D. D. and MOTTERSHEAD, D. N. (1975). The quaternary deposits at Doniford, West Somerset. *Field Studies,* 4, 117-129.

HOWCROFT, HEATHER, J. (1977). The hydrology of a small catchment. *Field Studies,* 4, 555-573.

JOB, DAVID and JARMAN, MAGGIE. (1980). Central Place provision in theory and practice: an evaluation in Shropshire. *Field Studies,* 5, 259-288.

JONES, R. and BENSON-EVANS, K. (1974). Nutrient and phytoplankton studies in Llangorse Lake. *Field Studies,* 4, 61-75.

LUND, J.W.G. (1961). The algae of the Malham Tarn district. *Field Studies,* 1, (3) 85-119.

MCCARTER, N. H. and THOMAS, A. D. (1980). Patterns of animal and plant distribution on rocky shores in the South Hams (South Devon). *Field Studies,* 5, 229-258.

NELSON-SMITH, A. (1965). Marine Biology of Milford Haven: the physical environment. *Field Studies,* 2, 155-188.

OLIVER, J. (1959). The climate of the Dale Peninsula, Pembrokeshire. *Field Studies,* 1, (1) 40-56.

PACKHAM, JOHN, R. (1979). Wood sorrel on the Long Mynd. *Caradoc and Severn Valley Field Club Occasional Paper* No. 3, 1-14.

PARK, C. C. (1978). Stream channel and flow relationships—recent techniques illustrated by studies on some Dartmoor streams. *Field Studies,* 4, 729-740.

SAVAGE, A. A. and PRATT, MARY, M. (1976). Corixidae (Water Boatmen) of the Northwest Midland Meres. *Field Studies,* 4, 465-476.

SINKER, C. A. (1962). The North-Shropshire Meres and Mosses: a background for ecologists. *Field Studies* 1 (4) 101-138.

USHER, M. B. (1980). An assessment of conservation values within a large Site of Special Scientific Interest in North Yorkshire. *Field Studies,* 5, 323-348.

WILLIAMS, E. E. (1965). The growth and distribution of *Monodonta lineata* (da Costa) on a rocky shore in Wales. *Field Studies,* 2, 189-198.