Presenting summaries of plant density data that are meaningful to your readers — a case for giving the median as well as the mean

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Abstract

The distribution of plant density counts is sometimes highly skewed and presenting only the mean can give a misleading impression of the pasture as a whole, but indications of skewness or dispersion are rarely given in the literature. To evaluate this, 89 data sets from field experiments were analysed to examine the relationship between the mean plant density, the median plant density, and simple measures of skewness and dispersion. In new sowings, the mean seedling density, whether sown by hand in small plots or by machine in larger plots, was consistently close to the median density. In established pastures, the mean:median ratio was <1.5 in approximately half of the 39 analyses undertaken but was more than 2 in about one-quarter of the analyses, *i.e.*, the data were highly skewed. The latter instances commonly occurred when the CV of the individual quadrat entries of any plant count was >150%. When this occurs, to avoid misleading impressions, we consider it important for authors to present the median as well as the mean. If the data are not skewed, the authors should present the CV or SD as well as the mean.

Introduction

The problem

Measurements of plant density are a common feature in studies of both improved and native pastures. However, commonly, the distribution of plant numbers per quadrat is skewed; there can be a few quadrats with very high numbers of plants with most quadrats containing few or even no plants. In these situations, the mean number of plants per quadrat gives a misleading impression of the pasture as a whole, but in most publications mean values are presented without any indication of variability (*e.g.* SD, CV) (Gould and Steiner 2002).

Common sources of the problem

Conceptually, it is reasonable to assume that most pastures sown into a cultivated seed-bed would have a reasonably uniform distribution of seedlings. In older pastures, there are at least 2 situations that could lead to a skewed distribution. Firstly, take a simple case where there is variation in a site attribute such as soil type over the experimental paddock. If a species is well suited to one soil type but not to others, this would lead to high numbers of plants in one soil type and very low numbers in the remainder of the paddock. This would be a "large scale" source of variation and could be acknowledged in a publication by giving the densities and proportions of the 2 or more soil types within the paddock. However, such comments are rare in agronomic papers. Furthermore, the variation is usually more complex than in the simple example given above, and this would deter authors from describing and acknowledging the problem.

Secondly, the original population, which was presumably uniformly distributed from the original sowing, will gradually die over time. Hence, even in sown pastures, many or all plants may have resulted from seedling recruitment or vegetative spread (Hay *et al.* 2000). It is reasonable to assume that, over time, differential rates of recruitment and death over a small scale, perhaps of even 1 m or less, could result in spatial variation in plant density. Heterogeneity is a common feature of grazed pastures (Laca and Lemaire 2000) and there are abundant data to show how seedling

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recruitment and stolon density can be controlled by presentation yield or patch grazing of pastures (Jones 1982; McDonald and Jones 2002).

Data transformation — a solution for analysis but not for presentation

To analyse skewed datasets the standard procedure is to do a transformation. Commonly, square root, log, or when the data contain zeros, log (x+1), are used. However, there are a number of shortcomings of transforms, particularly log transforms, when it comes to data presentation:

- a transformation will not necessarily restore normality to a skewed data set; it will help but not necessarily solve the problem;
- the same transformation may not be suitable for all treatments in the dataset (Finney 1989);
- normality is a requirement for parametric analyses, *e.g*. ANOVA. It is not a requirement for means, medians, CV *etc*., or for non-parametric tests, so researchers may not have a need to normalise their data;
- even if the researcher does a transformation, **what summary data should be presented in the paper?** The problem lies in interpreting this mainly statistical value in biologically meaningful terms. Finney (1989) states 'A sound general principle is that data are usually most clearly interpreted on the original scale of measurement'. By way of example, if the mean of some log(x+1) transformed data was stated as 0.46 with a SD of 0.378, what would it tell the reader about the data? They would probably guess (or have been told in the Methods) that the variances had been heterogeneous, so there was need for transformation; the SD is nearly as big as the mean, so the data were reasonably variable; but what would the situation be in the paddock? The data can be back transformed to give a mean of 1.9, which is a bit more meaningful, but it is not appropriate to back transform the SD. However, using the same data set, stating that the mean was 3.5 and the median was 1, would immediately provide a reasonable understanding of the data, both statistically and biologically. Statistically, the data are highly skewed to the lower end and, biologically, there are a lot of areas with few plants, offset by a few areas with many plants.

This study

This study makes no attempt to investigate the analysis of skewed data or the methodologies that might be used, but investigates the type of pasture experiment and/or level of variance/asymmetry in plant density data when information, additional to the mean, should be presented. Firstly, we investigate if the findings of Gould and Steiner (2002) apply across a wider range of journals.

Secondly, seedling or plant density counts of legumes, taken as routine experimental measurements in newly sown small plots where seed was sown by hand, newly sown larger plots where seed was sown by machine and well established pastures are used to investigate:

- at what level of variability/asymmetry does the mean become potentially misleading?
- in what type of experiments does the problem exist?
- what summary statistics can be used to make the presentation biologically meaningful to the reader?

In each case, we explore the extent and nature of the variability in plant density, with particular reference to the relationship between the mean and the median.

Methods

Check of the literature

We scanned our own collection of several hundred references from ecological and agronomic journals and extracted all references that presented data on plant density. While the 140 references extracted may not represent a completely random sample of the literature, they do represent an unbiased sample. Two people collected the references, independently, over a period of 30–40 years, from a wide range of Australian and international journals, and for purposes other than their use in this study.

Data sets used

In most of the data sets used, large quadrats (up to 0.5 m^2) were used with low densities and small quadrats (down to 0.04 m^2) with high densities; hence, the actual numbers of plants per quadrat among the different trials were somewhat similar.

For this reason, analyses of the 105 data sets were based on plants per quadrat and not plants/m^2. The actual counts used were taken at random from old data files, excluding counts where more than half the quadrats contained no plants, because in these cases the median will always be zero and no mean:median ratios can be determined. The problem of excess zeroes has received considerable attention elsewhere (*e.g.* Lambert 1992; Welsh *et al.* 1996). This left 89 datasets for the study. It should be noted that counts were mostly of legumes.

For clarity of presentation, data sets were grouped into 3 categories:

1. *Seedling counts in newly sown small plots*

Plots were typically 25–50 m^2 with seedling density measured in 20–25 quadrats, usually 0.2 × 0.2 m, per plot.

Seedling density data were analysed from 39 counts. These contained 2 groups: (a) 18 counts of temperate species (including 16 different accessions of annual species of *Medicago*, *Lotus* and *Trifolium* and 1 accession each of *Phalaris* and *Lolium* spp.); and (b) 21 counts of tropical species, including 7 different grass accessions (from 6 species) and 14 legume accessions (from 12 different species). Data were taken from 5 different sowings at Southbrook (Jones and Rees 1972) and from 2 sowings each at Samford and Dayboro (Jones 2001). The sowings of temperate species were made under cool conditions in late autumn-early winter and the tropical species were sown in summer.

2. *Seedling counts in newly sown larger plots*

Plot sizes ranged from 0.4 to 4.0 ha with seedling density measured in 25–60 quadrats, usually 0.5 × 0.5 m, per plot.

(a) Medic and lucerne seedling counts from 4 sowings, each made in a different year within a crop-pasture rotation trial (Silvey 1974), were analysed. The counts were of recently emerged lucerne (*Medicago sativa*) and barrel medic (*Medicago truncatula*) seedlings resulting from sowing these legumes through a grass seed box into a fully prepared seedbed. As each pasture lasted for 3 years before being returned to cropping, the densities of lucerne plants in the next 2 years were analysed also and included with data from the established plots.

(b) Legume establishment counts in 6 paddocks within a grazing trial near Mundubbera (Jones *et al.* 2000) were analysed. Three paddocks were sown to Wynn cassia (*Chamaecrista rotundifolia*), 2 to siratro (*Macroptilium atropurpureum*) and 1 to finestem stylo (*Stylosanthes hippocampoides*). Counts were made about 1 month after sowing through a grass seed box into a fully cultivated soil.

3. *Plant counts in well established large plots*

Plot sizes ranged from 0.4 to 4.0 ha with seedling density measured in 25–60 quadrats, usually 0.5 × 0.5 m, per plot, and the following datasets were analysed:

(a) Four plant counts of Fitzroy stylo (*S. scabra*) and Wynn cassia within the Series 2 trials near Mundubbera (Jones and Mannetje 1997) — the 1991 and 1995 counts of Fitzroy stylo sown in 1987, and the 1987 and 1989 counts of Wynn cassia sown in 1985.

(b) Five plant counts of stylo within the Series 1 trials near Mundubbera (Jones and Mannetje 1997) — the 1981 count of finestem stylo sown in 1970, the 1985 count of Townsville stylo (*S. humilis*) sown in 1968, and the 1985, 1987 and 1994 counts of Fitzroy stylo sown in 1981.

(c) Eight plant counts, made in 1996, of Wynn cassia in 4 paddocks, shrubby stylo (*S. scabra*) in 3 paddocks and bargoo vetch (*Aeschynomene falcata*) in 1 paddock of the trial of Jones *et al*. (2000), sown in 1986. Seedling counts for the same trial are given under 2b, although not for the same set of paddocks, as analyses were restricted to counts where plants were present in more than 50% of quadrats.

Based on knowledge of plant turnover within Trial 3c (Jones *et al*. 2000), none of the counts in 3a, 3b or 3c would have included any of the original plants from the initial sowing, with the probable exception of the 1987 count of Wynn cassia in Trial 3a.

(d) Four plant counts of siratro within a grazing trial at Samford (Jones and Bunch 1988). The counts were made in 1973 and 1983 in a paddock stocked at 1.7 heifers/ha and in

1972 and 1976 in a paddock stocked at 3.0 heifers/ha. The 1972 and 1973 counts could have included some plants from the original sowing in 1968, whereas the 1976 and 1983 counts would not (Jones and Bunch 1988).

(e) Seven plant counts of shrubby stylo cv. Seca made in 1997, 1998 and 1999 within 2–4 ha sections of paddocks in a grazing trial near Rockhampton, sown in 1988 (Orr *et al.* 2001). It is highly unlikely that any of the plants counted in 1997–1999 were from the original sowing.

Analysis

For each count the following measures were calculated: centrality — mean, median and range/mean; dispersion — range and coefficient of variation (CV); and skewness — mean:median ratio; and the % of quadrats without any seedlings or plants. Regression analyses were used to explore possible relationships between these different measures. For ease of comparison between datasets, we use the relative measure mean:median ratio rather than just the median, and similarly, we use the CV rather than the SD.

Results

Check of the literature

The examination of the 140 references from ecological and agronomic journals showed that only a third gave any indication of variability of the means they presented. Ecological journals were little better than agronomic journals (36% *vs* 27%). Not a single paper gave any indication of skewness, although some indicated the data presented had been transformed.

Seedlings in newly sown plots (small and large plots)

Regardless of whether counts of seedlings were made in small plots, where the seed was hand broadcast, or in large plots sown by machine, there was little difference between the mean and the median values (Table 1). Similarly, there was little difference between these two values in small plots sown in autumn–winter to temperate species or in summer to tropical species. In these small plots, the percentage of quadrats containing no seedlings was higher for tropical species than temperate species. This was related to the lower overall density of the tropical species as compared with the temperate species.

Plants in established pastures

The mean density of lucerne in Trial 2a declined from 5.8 seedlings per quadrat in the establishment year to 4.4 plants (Year 2) and 2.8 plants (Year 3). However, the mean:median ratio was 1.1 in each year. As there was no recruitment of new plants, this suggests that plant mortality was even over the paddocks.

Table 1. The average values of mean, median, mean:median ratio, SD, CV, minimum, maximum and (maximum-minimum)/mean of plant density, and % of zero quadrats in small plots newly sown by hand, large plots newly sown mechanically, and in different pastures in well established trials. The number of data sets (n) within each category (small plots) or trial (large plots) is also indicated. The range of the mean:median ratio for these n samples is given in brackets.

Trial type	n	Mean	Median	Mean : median & (range)	SD	CV	Min.	Max.	% zero quadrats	Range/ mean
Newly sown plots										
Small plots										
1a — Temperate species	18	8.2	7.8	1.1 (0.9–1.3)	4.4	60	2	18	4	2.1
1b — Tropical species	21	3.8	3.4	1.2 (0.9–1.5)	2.4	75	<1	10	12	2.9
Large plots										
2a — lucerne seedlings	4	5.8	5.2	1.1 (1.0–1.2)	4.0	67	<1	16	9	2.5
2a — medic seedlings	4	3.6	3.5	1.0 (0.9–1.2)	2.4	74	<1	9	11	2.6
2b	6	2.7	2.6	1.0 (0.8–1.3)	2.0	79	0	7	14	2.9
Well established pastures										
2a — lucerne (Year 2)	4	4.4	4.0	1.1 (1.0–1.4)	2.3	58	1	10	8	2.1
2a — lucerne (Year 3)	4	2.8	2.8	1.1 (1.0–1.3)	1.7	76	<1	7	18	2.8
3a	4	5.7	4.4	1.4 (1.1–2.1)	5.0	95	0	19	14	3.8
3b	5	6.6	3.4	3.1 (1.3–8.9)	8.5	130	0	33	24	5.5
3c	8	8.4	3.9	2.9 (1.7–4.3)	11.8	157	0	56	32	8.4
3d	4	2.1	1.6	1.3 (1.1–1.5)	2.0	96	0	7	29	3.3
3e	7	14.2	11.0	1.8 (1.0–3.9)	14.7	113	0	53	19	4.1

The difference between the mean and the median in counts in established pastures was usually greater than in newly sown plots. This was reflected in the higher values for the mean:median ratios, the CVs and the ratio of range:mean (Table 1). In the case of Trial 3c, the mean:median ratio 10 years after sowing was 2.7, compared with a ratio of 1.0 for newly emerging seedlings just after the trial was sown. In some trials, the difference between the mean and the median was greater than in others, as reflected in both the average mean:median ratio and the ranges of this ratio.

A good example of where extreme variation causes problems is in Trial 3b (Table 1). One count of fine stem stylo had a mean of 8.9, a median of 1 and a CV of 171. This atypically high variation is reflected in this data set being the outlying point in the plot of mean:median ratios against CV for all counts from trials in Group 3 (Figure 1). In contrast, all 4 counts of siratro on Trial 3d had a low and similar variation, regardless of whether the count was made primarily on original plants or, some years later, on plants resulting from seedling recruitment.

Discussion

Check of the literature

The check of our literature collection confirmed the findings of Gould and Steiner (2002), that most authors are not including measures of variability with the presentation of their data means. However, while Gould and Steiner (2002) indicate that <13% give any measure of variability, 33% of authors in our collection did so, although there were no indications of skewness.

Types of experiments

Although the measures of skewness and dispersion tended to be greater in established pastures than in newly sown ones, there was no consistent pattern in established pastures. The extent to which variation increased with pasture age depended on factors such as soil type and demographic changes. It would appear that seedling counts in newly sown plots will rarely be skewed or highly dispersed, and similarly, there is no

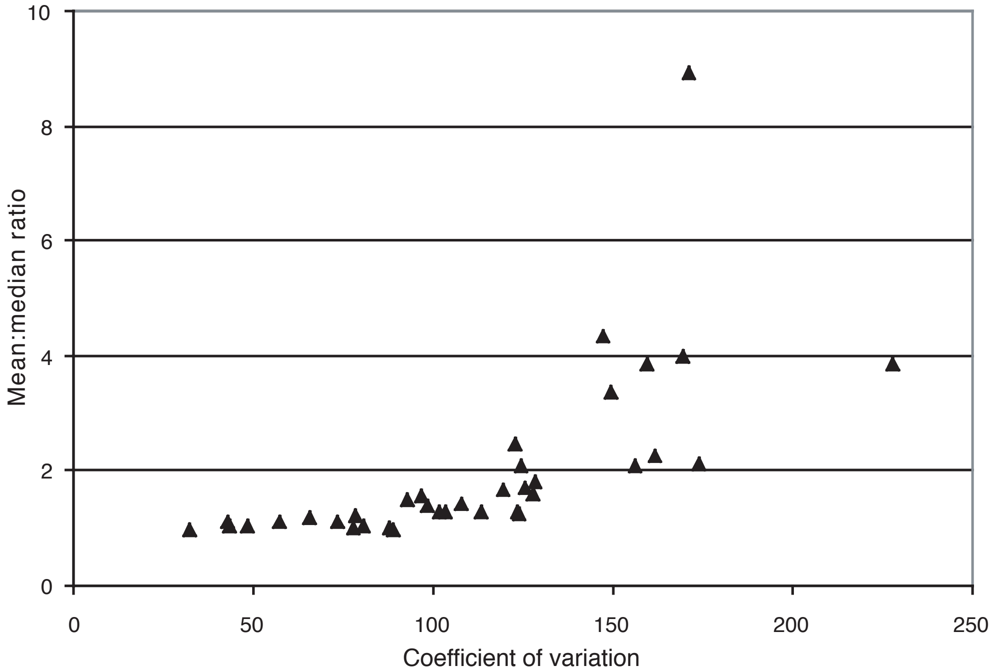

Figure 1. The relationship between the coefficient of variation and the mean:median ratio for 36 different plant counts in established pastures. Counts are the second- and third-year density counts of lucerne in Group 2a and all counts in Group 3 (as described in the text).

indication that tropical and temperate species differ in this respect. However, it is clear that the mean plant density as measured routinely may, in some instances, give a misleading impression of the pasture as a whole. In most cases, this will be due to skewness; in some counts, the mean density was at least twice the median, but this can be due to wide variation in the data also, *i.e.*, a large SD or CV. It should be noted that this study looked at mostly legume counts, and it is possible that responses may differ between legumes and grasses.

The 4 measures — mean:median ratio, CV, range/mean, and % of quadrats without plants — were, as would be expected, inter-related. However, none of these expressions, regardless of the type of relationship, *i.e.*, linear, quadratic or exponential, gave a reliable indication of the others. The best relationship, between CV and mean:median ratio, had an r^2 of only 0.43. Once the CV exceeded 150%, there was a poor relationship between it and the mean:median ratio (Figure 1). A major limitation to calculating the mean:median ratio is that it is limited to situations where plants are present in more than half the quadrats. However, this does not preclude presentation of the mean and the median.

There are other measures of skewness, *e.g.*, a function of the 3^{rd} moment and Pearson's index of skewness; however, these are not as easily interpreted as the mean:median ratio. For example, the values for the 3^{rd} moment measure and Pearson's index for dataset 3b have ranges of 1.5–2.1 and 0.6–1.6, respectively, and for dataset 3c, have ranges of 1.6–4.6 and 1.0–1.6, respectively. What do these values tell the reader? Are they good or bad? While these values may be meaningful to a statistician, they are not very helpful to the average biologist. Similarly, for measures of dispersion, biologists are familiar with SD and CV, so why present something more complicated unless it is necessary? The target audience is biologists, so data should be presented in a form that is meaningful to them.

Presentation of results

The mean plant density will undoubtedly be the value that will continue to be routinely presented in papers. In newly sown pastures, this is appropriate as it is unlikely that the mean will differ greatly from the median. However, for well established pastures, it is likely that the mean could differ greatly from the median or there could simply be a lot of variation in the counts.

Based on the data summarised here, when the CV <100% it is unlikely there will be much difference between the median and the mean, and presentation of the SD or CV with the mean is the most appropriate. However, if the CV >150%, the median value is likely to be less than half of the mean, *i.e.*, the data are highly skewed. The clearest way of documenting these instances is to give the median as well as the mean. In our view, in these instances, the median is a better indicator of the true nature of the pasture than the SD or CV. This view is supported by Byrkit (1987), who states 'If the data set is badly skewed, the median should be used to measure the central tendency of the distribution."

In conclusion, we consider that the most important point arising from this study is that authors should carefully consider what they present. In many cases, presentation of means could be quite appropriate. However, in some cases, simply quoting the mean will be misleading and affect interpretation of the results. If the data have been transformed for earlier analysis, this does not necessarily represent the most effective form of presentation (Finney 1989). If the data are skewed, presenting the median as well as the mean, or giving the SD or CV, and acknowledging any implications in the discussion of the results will be more meaningful to biologists.

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