# field and laboratory methods for general ecology

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# 1a

# ecological sampling

## 1. Introduction

Ecologists generally wish to collect quantitative information about a habitat, community, or population. However, it usually is impossible or impractical to monitor the entire habitat or to obtain measurements of all the organisms in a given area. A biologist rarely can collect all of the data about which he wishes to draw conclusions. For example, it may be desired to draw conclusions about the body weights of all mice in a particular habitat. The only way to make statements about the weights of all mice with 100% confidence would be to weigh every mouse, probably an impossible task. Instead, only some of the total number of mice are weighed, and we can then infer from this portion of the total the weights of all the mice. The entire set of data of interest (i.e., the weights of all of the mice) is called a *statistical population;* and the actually measured portion, or subset, of the population is a *statistical sample.*

Established sampling procedures exist for obtaining information about organisms and their environment. In this section we will deal with the general principles of sampling underlying the specific techniques of sampling habitats and biological populations given in units 2 and 3. The theoretical bases for ecological sampling procedures may be followed further in such texts as Grieg-Smith (1964), Pielou (1969), Poole (1974), Seber (1973) and Southwood (1966).

A *statistical population* is that entire set of data about which one wishes to draw conclusions. This is not to be confused with a *biological population,* which is the aggregation of individual organisms of a single species inhabiting a given area. A statistical population, then, is an entire set of measurements from a habitat, a community, a biological population, or a portion of a biological population. Though a *statistical sample* is a portion of a larger set of data (the statistical population), a *physical sample* is a portion, or subset, of a collection of one or more material objects, either biotic or abiotic. As an example of physical sampling, we can take a 1-liter sample of pond water (meaning we collected a portion of the entire volume of water in the pond), or a sample of vegetation from a forest (i.e., a small portion of all the forest vegetation), or a sample of 100 mice from an entire biological population of that species. A *statistical sample,* on the other hand, refers to a collection of data such as measurements of the temperature or phosphate content of pond water, the biomass of vegetation, or the tail lengths of mice.

When collecting samples in an ecological study, one *must* know what natural entity is being sampled. A particular study may require a precise definition of the strata, zones, microhabitats, and/or times being sampled. Also, one may wish to study only a certain taxon or a particular collection of taxa. For example, if we obtain a collection of pond animals with a fine-mesh plankton net, we have not sampled all the pond fauna. Rather, we must be aware of the particular kinds of animals the sampling procedure can collect. Sweeping an insect net through the herbaceous vegetation of a forest would not yield a sample of all animals in that forest, but only a sample of those forms inhabiting a particular portion of the ecological community (i.e., the herb stratum, rather than the soil, shrub, or tree stratum), and only those which do not escape capture by the net. Also, a sample of an ecological population seldom contains all the stages of the life cycle, important to realize when making inferences about a population or community. No single sampling device or technique can provide data on an entire habitat, community, or biological population. This is why we must always define the ecological entity actually sampled by a given procedure.

## 2. Selecting samples

After defining the ecological entity to be sampled and choosing the sampling technique (detailed in unit 3), one can then do the actual sampling. However, assurance of a truly representative sample of the defined population, community, or habitat is usually a difficult problem in ecology. Normally, samples should be taken at random. Random sampling implies that each measurement in the population has an equal opportunity of being selected as part of the sample, and that the occurrence of one measurement in a sample in no way influences the inclusion of another. Sampling procedures are *biased* if some members of the population are more likely to be recorded than others, or if the recording of some affects the recording of others. If the sample is taken at random from a statistical population, legitimate conclusions may be drawn (with known chance of error) about that population, even though only a small portion of it has been measured.

A table of random numbers (table 1A.1) often helps obtain random samples. In table 1A.1, each integer from 0 to 9 has an equal and independent chance of occurring at any location in the table, each two-digit number from

**Table 1A.1.** *Random Numbers*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 72965 | 92280 | 85318 | 98478 | 05200 | 26558 | 04697 | 63195 | 41679 | 24133 |
| 25182 | 09959 | 91375 | 97794 | 50193 | 25930 | 47938 | 95633 | 22271 | 15628 |
| 78812 | 39100 | 81576 | 84683 | 47466 | 04204 | 86339 | 31919 | 83404 | 48293 |
| 87264 | 75327 | 92529 | 25409 | 52589 | 20914 | 58768 | 46171 | 32657 | 89750 |
| 21571 | 57796 | 67813 | 88705 | 52576 | 51712 | 12407 | 00644 | 81748 | 04204 |
| 98532 | 11191 | 63198 | 79306 | 04193 | 00859 | 83906 | 30625 | 67175 | 37774 |
| 38981 | 76006 | 33931 | 22225 | 00014 | 37716 | 67499 | 90402 | 08962 | 88602 |
| 11305 | 19964 | 22932 | 62300 | 64508 | 32996 | 05699 | 06536 | 22619 | 89725 |
| 96753 | 89989 | 67869 | 65743 | 65353 | 55722 | 91650 | 77833 | 05353 | 05950 |
| 28316 | 27206 | 32507 | 96140 | 83430 | 75357 | 57822 | 75247 | 93486 | 20481 |
| 24390 | 09214 | 19493 | 94975 | 71393 | 54675 | 51712 | 00581 | 11187 | 73464 |
| 23995 | 32726 | 41075 | 32118 | 63946 | 62464 | 60599 | 81670 | 73097 | 78553 |
| 41920 | 60706 | 55864 | 70343 | 61238 | 06810 | 53263 | 07815 | 56588 | 29384 |
| 78281 | 15410 | 26154 | 70445 | 27828 | 38282 | 29051 | 13433 | 84405 | 82969 |
| 92910 | 17017 | 92704 | 25210 | 63833 | 04909 | 02571 | 58402 | 62649 | 86771 |
| 29265 | 89779 | 95437 | 51929 | 75534 | 70858 | 54623 | 99661 | 87146 | 16775 |
| 60422 | 65242 | 57037 | 95091 | 25582 | 76743 | 95890 | 09033 | 08368 | 62677 |
| 42748 | 43783 | 94238 | 97764 | 64110 | 68935 | 21057 | 14994 | 94235 | 53722 |
| 39611 | 11320 | 52913 | 20490 | 84147 | 59510 | 45967 | 93742 | 71756 | 09298 |
| 74011 | 92403 | 54878 | 91689 | 20402 | 20287 | 05402 | 16617 | 86101 | 28192 |
| 49056 | 17282 | 52320 | 73306 | 91759 | 85329 | 88229 | 62615 | 25802 | 28655 |
| 06572 | 13935 | 69948 | 12322 | 84900 | 85760 | 67583 | 36717 | 75897 | 39169 |
| 32726 | 45220 | 41600 | 61236 | 55701 | 08181 | 26259 | 49841 | 88968 | 83197 |
| 13800 | 03061 | 28494 | 09432 | 95359 | 92550 | 11251 | 76533 | 51923 | 34450 |
| 09838 | 95794 | 39792 | 06406 | 81584 | 49541 | 20520 | 91941 | 43448 | 91692 |
| 86499 | 23583 | 61444 | 72616 | 78692 | 50822 | 10283 | 23499 | 17883 | 21908 |
| 19618 | 23145 | 32406 | 91793 | 50163 | 72615 | 61939 | 18183 | 20368 | 51482 |
| 04145 | 26409 | 44737 | 98157 | 14158 | 94981 | 66518 | 84956 | 65372 | 00578 |
| 44083 | 35657 | 49215 | 93131 | 41815 | 34454 | 46347 | 02783 | 27988 | 86461 |
| 13883 | 40605 | 76333 | 56473 | 27866 | 16074 | 00939 | 05149 | 14090 | 70080 |
| 08697 | 34971 | 19204 | 70701 | 56065 | 23839 | 45794 | 62036 | 07594 | 36604 |
| 86447 | 56887 | 61107 | 63246 | 88350 | 51579 | 95387 | 03708 | 16441 | 64848 |
| 37914 | 39110 | 60363 | 95348 | 96498 | 17447 | 18058 | 36020 | 57301 | 50492 |
| 08771 | 12569 | 06379 | 51277 | 88233 | 45879 | 89353 | 82759 | 16691 | 20680 |
| 65529 | 84747 | 61160 | 19575 | 98709 | 23055 | 37992 | 82397 | 62884 | 63738 |
| 53783 | 03060 | 00563 | 21869 | 41559 | 85468 | 37401 | 81331 | 62733 | 10999 |
| 40881 | 01466 | 66439 | 92600 | 95878 | 43878 | 76006 | 93166 | 20603 | 76173 |
| 81424 | 81842 | 17993 | 63784 | 39351 | 41580 | 89006 | 47888 | 92753 | 45323 |
| 47362 | 92940 | 89774 | 05283 | 49461 | 21521 | 72572 | 37403 | 90574 | 22562 |
| 79898 | 44180 | 49706 | 58783 | 47012 | 90892 | 89032 | 56904 | 56473 | 38246 |
| 98433 | 36491 | 48288 | 53653 | 77220 | 82969 | 70063 | 58551 | 20025 | 83414 |
| 79849 | 94549 | 69691 | 11789 | 43233 | 46831 | 08737 | 25992 | 11296 | 69195 |
| 26004 | 14598 | 80743 | 25043 | 45287 | 35345 | 46914 | 71487 | 10345 | 48236 |
| 46218 | 40835 | 82386 | 91946 | 14266 | 77484 | 02759 | 92164 | 77842 | 21600 |
| 49618 | 10730 | 47690 | 44746 | 09566 | 36769 | 39108 | 47001 | 62935 | 10227 |
| 66259 | 25266 | 88651 | 56018 | 68181 | 45119 | 91387 | 37257 | 83610 | 53138 |
| 65170 | 81485 | 14727 | 22898 | 63815 | 17317 | 68293 | 06449 | 91890 | 49994 |
| 82679 | 72969 | 04512 | 11079 | 95969 | 87389 | 46263 | 96780 | 78124 | 04120 |
| 37900 | 90316 | 47434 | 60701 | 89649 | 51773 | 26139 | 39231 | 72264 | 17654 |
| 27111 | 31679 | 71539 | 61375 | 58691 | 20215 | 91170 | 44290 | 91396 | 90173 |

This table was prepared using an International Business Machines Corporation (1968:77) algorithm. Larger tables of random numbers are found in Dixon and Massey (1969:446–450), Rohlf and Sokal (1969:153–156), Snedecor and Cochran (1967:543–546), Steel and Torrie (1960:428–431), and Zar (1974:577–580).

00 to 99 has a random chance of occurring anywhere in the table, and so on. Each time this table is used, it should be entered at random; that is, do not always begin at the same point in the table. Once entered, numbers in the table may be read in any predecided direction—horizontally, vertically, or diagonally. If members of a population of objects (e.g., mice or trees) could be numbered, then a random sample of *n* objects from that population could be designated by considering *n* different numbers from the random number table. This is equivalent to placing each member of the population in a hat and drawing *n* of them by chance. However, this method generally is impractical since numbering the individuals in the population would mean obtaining all of its members; if this could be done there would be little need for sampling.

Random numbers may be used to select random map coordinates or numbered sampling sites. Sampling sites can be numbered easily by arbitrarily selecting a point within the habitat and marking off four compass directions (N, E, S, W) from this point to define four quadrants. A randomly selected number could represent the number of meters, or tens of meters, along one axis of a quadrant, and a second random number could do the same along the other axis for that quadrant. Thus, each pair of random numbers would establish a specific point in the quadrant at which to collect a physical sample. This process could be repeated for all four quadrants until a sufficient number of random points had been selected.

### 3. Sampling replication

A single measurement generally is insufficient to draw conclusions about an ecological characteristic. This is because of the inability to know how reliably that characteristic had been estimated. Repeated measurements may vary greatly, and hence a single value would have an uncomfortably high probability of being far from the average value. Therefore, a series of repeated, or *replicated,* measurements should be taken. From this collection of replicates (i.e., the statistical sample) we can estimate the mean of the statistical population and determine how much error exists in making this estimate (see sections 1B.2.1 and 1B.2.4).

How many replicate data are needed to obtain a reliable estimate of some aspect of a statistical population (i.e., of a characteristic of an ecological population, community, or habitat)? There is no set answer, but a number of procedures can aid in determining whether enough measurements have been collected. Two common methods—the species-sample curve and the performance curve—are discussed here. A procedure using statistical considerations is discussed in section 1B.2.5.

In a *species-sample curve,* the cumulative number of species is plotted against the cumulative number of physical samples, where each sample might be a plot, transect interval, point-quarter point, net effort, seine haul, etc. (see unit 3). If the cumulative number of species is plotted against the cumulative size of the area sampled, this is called a *species-area curve.*

Figure 1A.1 is a presentation of the data in table 1A.2.

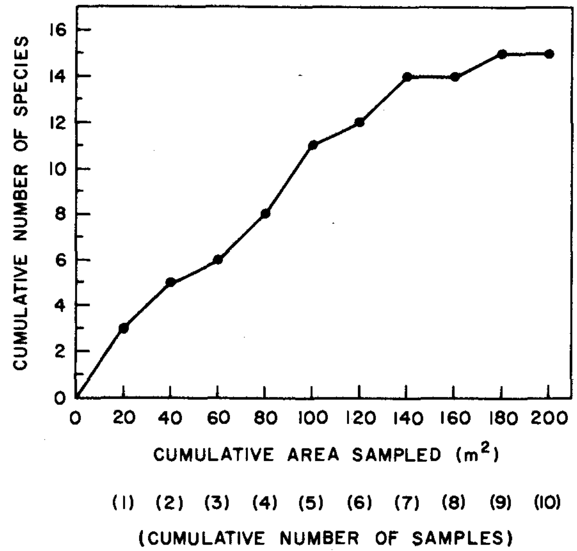


**Figure 1A.1.** A species-area curve for the data in table 1A.2, plotting cumulative number of species against area sampled. If the cumulative number of species is plotted against the cumulative number of ecological samples (indicated in parentheses), this would be a species-sample curve.

**Table 1A.2.** *Data for generating the species-area curve of figure 1A.1. Each ecological sample is from a 20 $m^2$ area.*

| Sample number | Cumulative area sampled ($m^2$) | Number of species | Number of new species | Cumulative number of new species |
|---|---|---|---|---|
| 1 | 20 | 3 | 3 | 3 |
| 2 | 40 | 4 | 2 | 5 |
| 3 | 60 | 5 | 1 | 6 |
| 4 | 80 | 3 | 2 | 8 |
| 5 | 100 | 4 | 3 | 11 |
| 6 | 120 | 4 | 1 | 12 |
| 7 | 140 | 4 | 2 | 14 |
| 8 | 160 | 3 | 0 | 14 |
| 9 | 180 | 5 | 1 | 15 |
| 10 | 200 | 4 | 0 | 15 |

Here each datum is a species enumeration for a 20 $m^2$ area. One finds three species in the first sample. Since the second sample has four species, but two are species found in sample 1 and two are species newly found in sample 2, then there are 3 + 2, or 5 species found in a total of 40 $m^2$ of sampling. The number of samples is considered sufficient after the curve levels off (see figure 1A.1).

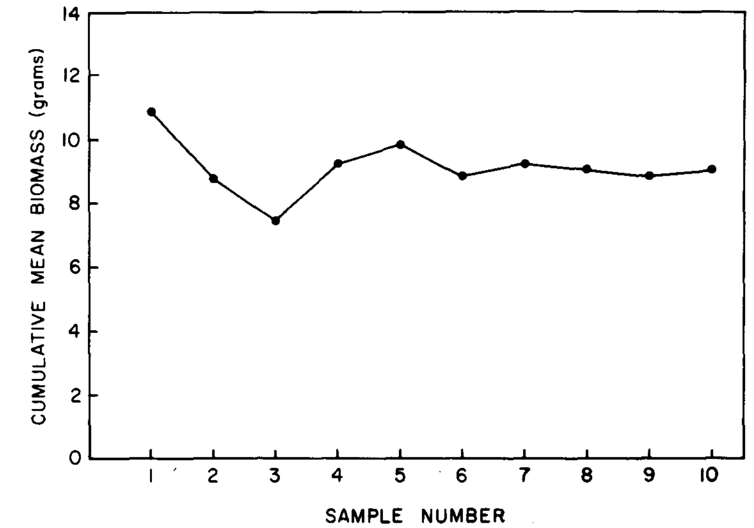


**Figure 1A.2.** A performance curve for the data in table 1A.2, plotting cumulative mean biomass against cumulative number of samples.

However, if the curve levels off after only a very few samples, then the area in each sample is too large. The species-sample curve is an aid in evaluating both the number of replicates and the size of the physical sample. Physical samples that are too small may require a very large number of replicates. On the other hand, if the physical samples are too large then fewer samples may be taken than necessary to allow for a satisfactory estimate of statistical error. The species-area curve is also useful for comparing the diversity of different communities and may be used in conjunction with sections 5A and 5B.

A *performance curve* examines the mean value of a set of measurements for an ecological variable. For example, the mean density or biomass for a given species (or for all species) may be plotted as a function of the cumulative number of samples or the cumulative area sampled (figure 1A.2). It is analogous to a species-area curve, except it plots a cumulative mean of some variable, rather than the cumulative number of species. For a small number of ecological samples, such a mean fluctuates widely from sample to sample, but as the number of replicates increases the fluctuation of the mean decreases (see figure 1A.2). The number of replicates may be considered sufficiently large when such fluctuations are so slight that the cumulative mean has become insensitive to variations in the data. For example, the data of table 1A.3 represent ten measurements of biomass as determined from ten physical samples.

**Table 1A.3.** *Biomass data for generating the performance curve plotted in figure 1A.2.*

| Sample number | Biomass (g) | Cumulative mean biomass (g) |
|---|---|---|
| 1 | 10.9 | 10.9 |
| 2 | 6.7 | 8.8 |
| 3 | 4.9 | 7.5 |
| 4 | 14.7 | 9.3 |
| 5 | 12.3 | 9.9 |
| 6 | 3.9 | 8.9 |
| 7 | 11.7 | 9.3 |
| 8 | 7.7 | 9.1 |
| 9 | 7.3 | 8.9 |
| 10 | 10.9 | 9.1 |

## 4. Subsampling

Occasionally, ecological samples are taken in the field and only portions of them, or *subsamples,* are later examined in the laboratory. The principles of subsampling are like those of sampling; the subsample must be randomly taken from the sample. This may require (as in a chemical analysis) shaking, mixing, or blending the sample before taking the subsample. In this way subsample characteristics reflect the characteristics of the entire sample.

## 5. Experimental design

Closely associated with the concept of sampling is that of *experimental design*—the planning of field or laboratory studies. Experimental design does not deal with the experimental techniques employed in the study but with the selection of variables to be studied and the choice of a sampling program. The design is constructed, prior to the data collection, with specific procedures of sampling and data analysis in mind (see section 1B and units 2 and 3). There are many complex designs by which data may be collected and analyzed, and a few of the simplest and commonest will be discussed here and in section 1B.

The most commonly used experimental design in ecological work is the two-sample comparison. Here, one selects two situations in which all conditions but one are nearly equal. For example, one may measure the population density of caddisfly larvae in a stream to conclude whether there is a difference between the densities in two different current velocities. One then selects two sites with similar habitat characteristics (dissolved oxygen, stream substrate, depth, etc.) but with different current velocities. On examining the collected data, you may conclude that the population density of caddisfly larvae is different at the two current conditions. However, you cannot automatically conclude a direct cause and effect relationship and assert that the difference in population size was due to the current *per se* (e.g., faster current may result in more food availability or better protection from predators.)

## 6. Selected references

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# 1c

# writing research reports

## 1. Introduction

After a study's data have been collected and analyzed, the results should be presented in a formal report. A research report is both a work record and a means of communicating your ideas. Also, writing, rewriting, and evaluating research findings make the author think more deeply and critically about the study. A scientific research report provides you with an academic experience different from that of a library term paper since a research report is based on one's own data and personal involvement in organized investigation.

## 2. Content and style

The style of a scientific report varies depending on the writer and his/her audience. Generally a biological paper has a title and byline, followed by such sections as Introduction, Materials and Methods, Results, Discussion, Summary, and Literature Cited (or References). Often an abstract at the beginning of the report will appear in place of or in addition to the summary. Manuscripts are typed with double spacing and margins of one to one and one-half inches, and each page is numbered. Avoid the use of footnotes, and for referencing follow the style discussed in section 8 below. A heading is customarily typed for each of the major sections of the report. Indented subheadings in a section may also be included for clarity.

The writing style of many scientific papers often is poor, largely because the authors lack experience and training. For the preparation of biological papers, the *CBE Style Manual* (Council of Biological Editors, 1972) is the standard reference for form and style. It is a book with which every serious biological scientist should become familiar. A good summary of report writing fundamentals, with an ecological emphasis, is provided by Scott and Ayars (1969). The following general guidelines gleaned from these sources should be helpful.

(1) Wherever possible, use the first person ("I," "we") instead of awkward indirect statements ("this author," "these researchers").

(2) Avoid long involved sentences and overuse of polysyllabic words. Long, run-on sentences often obscure your meaning, and frequent use of cumbersome words reduces the readability of the paper. Check for excessive use of commas and conjunctions ("and," "but," "or"). These often connect clauses that can be clearly separated into two or more sentences.

(3) Use the active voice instead of the passive voice. For example, "I measured the water temperature" is preferable to "The water temperature was measured by the author," as it uses fewer words and is unambiguous (i.e., it is clear who measured the temperature).

(4) Avoid excessive use of nouns as adjectives. Such use of nouns often is acceptable (as "*temperature* stratification," or "*tree* height"), but it frequently is overused (e.g., "*morning lake water temperature profile record sheet* format").

(5) Be positive in your writing. Don't hide your findings in noncommittal statements. For example, "the data could possibly suggest" implies that the data really may show nothing; simply state "the data show."

(6) Avoid noninformative abbreviations such as "etc." and phrases such as "and so on" or "and the like."

(7) Keep specialized jargon to a minimum. If (but only if) vernacular terminology is just as accurate, use it. Similarly, excessive use of Latin nomenclature should be avoided. If acceptable common names exist for organisms, introduce them together with the Latin names, and thereafter use the former. (Whenever Latin genus or species names are written they are to be either italicized or underlined; higher taxonomic ranks—e.g., family, order, class, phylum—are not italicized nor underlined.)

(8) Avoid repeating facts and thoughts. Decide in which portion of the report different statements are best placed, and do not repeat them elsewhere.

(9) Refrain from drawing unsupported conclusions. On the other hand, don't pad the report with data irrelevant to the purpose or conclusions of the study.

## 3. Introduction section

In the introduction of the paper state the nature of the problem and a brief background of the field of study. Also, a brief review of the literature generally is given in this section. Relate the problem and its significance to the general area of study. This part of the paper presents the background, justification, and relevance of your study.

## 4. Materials and methods section

Procedures in research reports are usually detailed enough for the reader to have an accurate idea of what was done in the study or to be guided to appropriate literature for this information. A good description of materials and methods used would enable a reader to duplicate your investigative procedure. Keep to a minimum the details of standard and generally known procedures (such as how an item was weighed). Detailed published accounts, such as chemical formulations for reagents, may be omitted but should be referenced.

**5. Results section**

This portion of a report gives the facts found, even if they are contrary to hypothesis or expectation. Listings of raw data are rarely presented, except occasionally in a class activity or as an appendix to the report. Instead, data typically are summarized using means, frequency tables, percentages, or other descriptive statistics for presentation and analysis in some appropriate statistical manner (see section 1B). These data summaries may be incorporated into figures or tables if this results in additional clarity or helps illustrate a pattern or trend.

In general, the number of data collected should be indicated, and some measure of variability of the data should accompany statements of means (see section 1B). Statistics used, type of data analysis performed, and mode of presentation depend on the study and type of data collected. Statistical comparisons of different groups of data are often called for, as explained in section 1B.

The *Results* section is not just a data summarization or a collection of tables and figures; it should contain an explanation and description of the data. Tell the reader exactly what you found, what patterns, trends, or relationships were observed. For example, do not just say "The species-area curve is shown in figure 1." Tell the reader what is being presented, as "Figure 1 shows that the number of species in the habitat increases as the area of the habitat increases."

Illustrations in the *Results* section may consist of graphs, photographs, or diagrams that visually depict your results. All such illustrations are individually numbered and cited in the text and referred to as a figure (e.g., "Dominance of sugar maple is shown in figure 4"). Labeling and citing tables of data in the text is done in the same manner as for graphs. If a graph will summarize the data as well or better than a table, then the graphical presentation typically is preferable. Each figure and table should contain an explanatory legend. In standard thesis and publication manuscripts the figure number, figure title, and legend are generally on a separate page from the illustration. Be sure the axes of all graphs are fully and correctly labeled with a scale marked off and the units of measurements given; units of measurement (preferably metric) must also be given for tabular data. (Appendix B provides conversion factors for common measurement scales.) Avoid the tendency to cram too much information into one graph or table, thus losing readability.

**6. Discussion section**

In the previous section of the paper the results are summarized and described. In this section they should be interpreted, critically evaluated, and compared to other research reports; and conclusions should then be drawn based on the study and its findings. Whereas the *Results* section presents the "news," the *Discussion* section contains the "editorial." Some research reports have a combined *Results and Discussion* section, and in some the conclusions are placed in a separate section.

In the discussion, examine the amount and possible sources of variability in your data. Examine your results for bias and evaluate its consequences in data interpretation. Develop arguments for and against your hypotheses and interpretations. Do not make generalized statements that are not based on your data, known facts, or reason. Be sure to relate your findings to other studies and cite those studies. Draw positive conclusions from your study whenever possible.

**7. Summary section**

The end of your paper should contain a summary, which is a concise but exact statement of the problem, your general procedure, basic findings, and conclusions. It should not be just a vague hint of the topic covered, an amplified table of contents, or a shortened version of the report. In many scientific journals, an abstract of the paper at the beginning of the paper replaces a summary.

*Example of a poor summary:*

> The food habits of various amphibians were studied in detail by the authors. The data were analyzed statistically and the findings were discussed at length. Certain similarities and differences were found between the species studied and the habitats in which they were found. Conclusions about feeding habits, habitat relationships, and niches were made for these species.

This summary or abstract is merely an expanded table of contents with verbs added to make complete sentences. Notice that no specific information is given to the reader.

*Example of an acceptable summary:*

> Stomach contents of the red eft, red-backed salamander, and dusky salamander were identified. Analysis of overlap of food taxa shows that the feeding habits of only the latter two species were similar. As an example of niche segregation, the salamanders show less feeding overlap in habitats where they are living together.

**8. Literature cited section**

No comprehensive literature survey is required for a class report; however, you are expected to use some sources other than a textbook. These sources should be cited in the body of your report. Useful references are given at the end of each section in this manual, in textbooks, and in the *Literature Cited* or *References* sections of scientific papers. It is up to you to select the most useful references. All references given in your paper must appear in the *Literature Cited* section. Rarely (e.g., in an instructional report), it may be desirable to list references in addition to those cited in the paper. In this case the heading *Literature Cited* should be replaced by *Bibliography,* or *Suggested References,* or *Selected References.*

References may be cited in the text of your paper in one (not both) of two forms: (1) by author and year, or (2) by number. Citation by author and year is more common in biological writing; for example:

> "Smith (1974) stated that eastern grasslands are either tame or seral."

or,

> "Eastern grasslands are either tame or seral (Smith, 1974)."

If there are two authors of the reference, then they are referred to as "Smith and Jones"; if there are more than two, then "Smith et al." is written (although all authors will be listed in the *Literature Cited* section). All references are then listed in the *Literature Cited* section in alphabetical order of the first author's surname. (If there are more than one reference for an author, they are listed chronologically for that author.)

If the reference numbering system is used, then the text citation would be of the following form:

> "Eastern grasslands are either tame or seral (21)."

and the *Literature Cited* section would consist of a listing of references in numerical instead of alphabetical order.

For a book in a list of references, the general form is:

> Smith, R. L. 1974. Ecology and field biology. Harper & Row, New York.

where the author (all authors if more than one) is followed by the year of publication, the title, and the name and location of the publisher. Sometimes the number of pages is also indicated at the end of the citation (e.g., ". . . 850p.").

For a journal article, the general form of citation is:

> Greenwald, G. S. 1956. The reproductive cycle of the field mouse, *Microtus californicus.* J. Mammal. 37: 213–222.

where the author (all authors if more than one) is followed by the year of publication, the title, and the journal name, volume, and page numbers. In journal citations it has been customary to use standard abbreviations for the name of the journal (as above), but there is an increasing tendency to spell out the entire name.

Consult the *Literature Cited* in this and other biological publications for further examples of accepted form. The Council of Biological Editors (1972) provide a thorough summary of these.

## 9. Some common problems

1. Use, evaluate, and interpret your data. Failure to do so is the most common problem students have in report writing. Many will calculate their results and make figures and tables, thereafter leaving these data to sit idly in the paper without any explanation or elaboration.
2. Do not ignore results because they differ from textbook generalizations. Your data are not incorrect just because they do not agree with some general principle or a conclusion in another report.
3. Use reference material pertinent to your data. Often, much irrelevant information is brought into reports.
4. Be careful about making small differences seem important. Different values are not necessarily significantly different. If you have not used statistical testing, you should at least consider in your subjective evaluation the amount of variability in your data.
5. Do not discard data because of variability and biases. There are some errors in nearly all scientific data. If recognized and accounted for in interpretation of results, errors of reasonable size need not discredit your data.
6. Round off final quantitative results to no more digits than can be reasonably justified. What sense does it make to compare two numbers such as 17.289761 and 19.82946? Do the last several digits have any special meaning? Reporting 17.3 and 19.8 may suffice in your case.
7. Label figures and tables properly and thoroughly and cite them in your text. Too often figures and tables are inserted in a report without explaining their purpose to the reader.
8. Play around with your data before preparing the final graphs and tables. Get your mind working over the data; attempt to find clear patterns and trends. Try to organize the data in various ways, since different presentations may elucidate different patterns.
9. Do not select or reject data in order to make desired results apparent. Any "fudging" of data is dishonest and unacceptable.
10. Do not perform calculations on data just for the sake of calculating. Have a reason for, and draw conclusions from, the calculations performed. Padding your report with excess though honest numbers serves no useful function.
11. Document ideas, conclusions, and hypotheses with data, facts from the literature, and sound reasoning. Do

not leave your ideas up in the air without support or they will fall with the first touch of the instructor's red pencil.

12. Relate your results and conclusions to accepted principles and concepts. Explain any discrepancies.

## 10. Selected references

Council of Biological Editors, Committee on Form and Style. 1972. CBE style manual. American Institute of Biological Sciences, Washington, D.C.

Scott, T. G. and J. S. Ayars. 1969. Writing the scientific report, pp. 53–59. *In* R. H. Giles, Jr. (ed.), Wildlife management techniques. Wildlife Society, Washington, D.C.