# field and laboratory methods for general ecology

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# unit 2

# analysis of habitats

## introduction

"Habitat" and "environment" are related but not synonymous terms. The *habitat* is the place where an organism, or a group of organisms, lives and is described by its geographic, physical, chemical, and biotic characteristics. *Environment* refers to the total set of conditions, biotic and abiotic, that surround and influence the biota and its habitat, including influences from outside the habitat. For example, ozone in the upper atmosphere is an environmental factor that affects the amount of ultraviolet radiation in the habitat.

Another basic ecological concept is the *community,* the aggregation of interacting species in a habitat. Although the habitat has biotic and abiotic components, we must not confuse it with the concept of an *ecosystem,* which is a community plus its interactions with its abiotic environment. Habitat analysis measures and describes the settings in which organisms live, while ecosystem analysis studies a system of exchanges and interactions between a community and its abiotic environment. A related concept is that of the *niche,* the functional role of a species in an ecosystem.

### 1. Divisions of a habitat

The overall habitat of a community of organisms is the *macrohabitat.* It is divided into smaller units, or *microhabitats,* each of which is the portion of the habitat directly encountered by a population of a given species. Thus for example, we may consider the macrohabitat of a deciduous forest and the microhabitat of a population of oaks, or warblers, or millipedes. We may also consider several ecologically related species as occupying a given microhabitat; for example, one may study the soil microhabitat or the microhabitat defined by a rotting log.

The habitat should be treated as a biophysical entity containing many dimensions. Collectively, they can provide a comprehensive and concise profile of where a population or community lives. We may consider five basic dimensions of a habitat: temporal, geographic, physical, chemical, and biotic. Each of these is then subdivisable into other components. The physical dimension, for instance, includes three basic components: the *atmosphere,* the *lithosphere* (substrate), and the *hydrosphere* (aquatic component). Those portions of the atmosphere, lithosphere, and hydrosphere that contain life are collectively called the *biosphere.*

### 2. Habitat studies

No one can perform a detailed analysis of a habitat in one or a few field trips. Therefore you may select one of three options from the sections in unit 2. The first is to make a general habitat (macrohabitat) description by recording information about the geographic, biotic, physical, and chemical factors most important to the ecological community (see section 2A). As a second option you may analyze one or more microhabitats within the macrohabitat by recording the environmental factors important to one or more species. For the third option you may collect detailed data on a specific aspect of the habitat, such as water chemistry, local climate patterns, temperature profile of a lake, or vegetative physiognomy. In certain water pollution studies (section 2E.5), an investigator may measure only particular chemical components of the habitat to assess the influence of human activities.

The type of analysis needed for a specific study may be selected from the methods given in sections 2A through 2F. Section 2A gives information pertinent to both aquatic and terrestrial habitats. Section 2B presents methods for biotic analysis of terrestrial habitats, and section 2E considers aquatic habitats. Sections 2C and 2D emphasize techniques for sampling and measuring aspects of the physical environment. Chemical analyses are discussed in section 2F; the analytical methods for both soil and water chemistry are similar, differing mainly in sampling techniques and sample preparation.

# 2a

# general habitat analysis

## 1. Introduction

Often one wishes to summarize the basic features of a macrohabitat without detailing any specific habitat component. Certain basic information should be recorded in any habitat analysis—the type of habitat, and the observers, time, location, and general weather conditions. A general habitat analysis should also include a brief description of the dominant physical and chemical components of the environment. The physical and chemical factors in the habitat may be considered in each of the three distinct, yet interrelated, portions of the biosphere: the atmosphere, lithosphere, and hydrosphere. In terrestrial habitats, a succinct description of the vegetation should also be included (section 2B.3).

To gather all the information for a general analysis of the habitat, an efficient class activity should involve several teams of a few students each. Each team becomes responsible for a specific component of the analysis: geographic (section 2A.4 below), atmospheric (section 2C), lithospheric (section 2D), biotic (section 2B for terrestrial habitats, section 2E.4 for aquatic), chemical (section 2F), and, for aquatic habitats, hydrospheric (sections 2E.3 and 2E.5). The information recorded by each team can then be transferred to class data sheets for compilation and summarization.

## 2. Naming habitats

There is no universally accepted nomenclature for habitats. In general the name reflects the most dominant physical or vegetative feature. In a forest or prairie, vegetation will generally dominate the visible features of the habitat. In a desert, geophysical features are often the most conspicuous. In an aquatic habitat, hydrophysical and chemical characteristics are dominant. Two approaches to habitat description often encountered are: (1) a description of the biota, particularly the vascular plants, and (2) a description and measurement of the physical environment.

The first approach, used largely by terrestrial ecologists, often de-emphasizes the abiotic components of the environment. This procedure names habitats using the dominant form of vegetation such as "sugar maple forest" or "Indian grass prairie" (see table 2B.1). On the other hand, one may measure only the physical and chemical variables of the environment, such as land form, temperature, humidity, *p*H, nutrients, and light intensity. Although the latter procedure has quantitative appeal and is useful in many ecological studies, it ignores the biotic influences in the environment. It tends to name habitats according to the type of substrate or geophysical conditions, such as "talus slope," "alluvial fan," "sand dune," "flood plain," etc. Climatic terms, such as tropical, temperate, arctic, humid, and arid (see section 2C) are also encountered in habitat names. Where possible, the names of habitats should include both physical and vegetative terms, such as "alpine tundra" or "sagebrush desert."

## 3. Temporal information

The accurate recording of temporal information is important for all habitat analyses. Record the date, time of day, and season. Although time is not a material part of the habitat it does relate to the daily and seasonal habitat changes. The distribution and amount of the physicochemical components vary in both time and space, and in turn influence the distribution and abundance of the biotic components. Time is also important in that plants, animals, and many physicochemical variables exhibit daily and seasonal patterns. More extensive records of time can be included in the habitat study to obtain a historical, seasonal, or daily profile of the habitat.

## 4. Locality information

Certain basic geographic information is required for all habitat studies. For this purpose topographic maps are very useful.* From these, locality can be specified by latitude, longitude, and section number. The habitat location should be described in detail, including the major political units from the largest to the smallest, such as: country, state or province, county, and township. The specific locality is given as the distance (in kilometers) and compass direction from the nearest city or village, and the elevation (in meters) of the study area above sea level. (Appendix B gives metric conversions.) Names of bodies

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# 2a

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of water or special landmarks in or near the habitat should also be recorded.

## 5. Topographic information

*Topography* refers to the surface features of the habitat and should be recorded in a habitat description. The spatial arrangement and form of the surface features greatly affect important physical factors such as drainage, soil properties, temperature, and light intensity. Features such as land form, elevation, water bodies, relief, and geological formations all affect the habitat.

Record general land forms (such as mountains, hills, valleys, or plains) and nearby bodies of water (such as rivers, lakes, ponds, marshes, or streams). Approximate dimensions of major land forms should be given. Table 2A.1 lists some of the land forms encountered. Bare regions (such as rocky outcrops, cliffs, or eroded areas) should be recorded, along with their approximate sizes. Record also the nature and size of man-made features, such as buildings, towers, power lines, bridges, fences, roads, railroads, or cemeteries.

**Table 2A.1.** *Some common land forms.*

| | |
|---|---|
| *Alluvial* (water body deposits) | *Coastal* |
| alluvial fan | delta |
| terrace | coastal plain |
| flood plain | outwash |
| meander | dune |
| levee | spit |
| *Glacial* (formed by glaciers) | *Arid* |
| till sheet | dune |
| moraine (elevated deposit) | mesa |
| outwash | canyon |
| *Mountain* | badlands (highly eroded) |
| ridge | playa (dried up lake basin) |
| talus | |
| volcano | |

For a more detailed study of the habitat topography, aerial photographs are very useful, and an exciting new field of study has developed around the remote sensing of habitats (see Johnson, 1972).* Aerial photographs can yield important information on neighboring habitat types and present land uses. Often you can outline the boundaries of a study site and estimate its area by partitioning it into grid squares, simple geometric forms such as triangles, or, more accurately, by using a planimeter. The photograph area may then be converted to land area if the scale of the photograph is known.

Record the slope of the study area and the direction of the slope. The difference in elevation between two points may be expressed relative to the horizontal distance between them (e.g., a slope of 15 m per 100 m). Measurement of elevation may use the same principles as shown in figures 2B.3 and 2B.4. In figure 2B.3, the observer holds a meter stick vertically and sights up the slope to a point as far off the ground as is the observer's eye. (This is conveniently done by sighting the head of a person standing upslope.) Then, the slope of the land is $h'/d'$, where $h'$ is the vertical distance on the meter stick between the eye height and the line of sight, and $d'$ is the horizontal distance from the eye to the meter stick. Slope is often expressed as a percentage; for example, if the slope were 15 m per 100 m, we could speak of a $15/100 = 15\%$ slope; or if $h' = 10$ cm and $d' = 50$ cm, the slope could be expressed as $10/50 = 20\%$. The slope may also be expressed as an angle, by determining, from trigonometric tables, what angle has a tangent of $h'/d'$. Alternatively, an Abney level may be used (figure 2B.4) to measure directly the angle of slope, again sighting a point upslope that is as high above the ground as is the observer's eye.

## 6. Suggested exercises

1. Describe the terrestrial macrohabitat in terms of topography, general community type (section 2B), general climate (section 2C), and soil type (section 2D).
2. Describe the topographic differences between two habitats, examining areas having different slopes or different directions of slope.

## 7. Selected references

Avery, T. E. 1968. Interpretation of aerial photographs. Burgess Publishing Co., Minneapolis.

Johnson, P. L. 1972. Remote sensing as a tool for study and management of ecosystems, pp. 468–483. *In* E. P. Odum, (ed.), Fundamentals of ecology. W. B. Saunders Co., Philadelphia.

Strahler, A. N. 1969. Physical geography. John C. Wiley & Sons, New York.

U.S. Geological Survey. 1969. Topographic maps. U.S. Geological Survey, Washington, D.C.

U.S. Geological Survey. 1971. Aerial photographic reproductions. U.S. Geological Survey, Washington, D.C.

* Information on the availability of aerial photographs and photographic surveys of government agencies and commercial firms may be obtained from the Map Information Office, U.S. Geological Survey, Washington, DC 20242, or from local U.S. Soil Conservation Service offices.

# 2b

# biotic analysis of habitats

## 1. Introduction

In terrestrial habitats, vegetation greatly influences physical and chemical factors in the habitat and thus the resident biological populations. Microclimate, light penetration, and soil conditions are largely determined by the dominant plants, which also afford protection and feeding and nesting sites for animals. We are here concerned not with a species description of the plant community, but with a summary of the vegetation features that affect the habitat. Aspects of plant community analysis are treated in sections 3A, 3B, 3C, and 5A.

## 2. Vegetation analysis

Three different methods have been used to describe the habitat in vegetative terms. First are detailed floristic lists, but these exclude many considerations useful to habitat analysis and generally require a well-trained taxonomist. A second approach involves a broad classification of community types using the dominant species names such as "mixed hemlock and sugar maple forest," or "big bluestem prairie." However, this approach characterizes only one aspect of the habitat and provides very little useful detail. The third approach, *physiognomy,* consists of description and measurement of the form and appearance of the vegetation and is the one used in this section.

The idea that the form, structure, and spatial arrangement of vegetation affects the ecology of a habitat is an important ecological principle. Therefore, it is not surprising that ecologists have turned to this type of habitat analysis. Physiognomic aspects of vegetation play a greater role in affecting the environment than does the species composition in the habitat. Physiognomic description of vegetation is a botanical procedure easily used by a nonspecialist; it results in a description of the basic organization, general appearance, and specific forms of the vegetation.

At least six important features of vegetation affect the environment: dominant species, life form, stratification, foliage density, coverage, and plant dispersion. When combined with measurements of physical variables, physiognomic description has the advantages of being detailed yet nontechnical, accurate yet not quantitatively overwhelming, and organized yet flexible. The system used here is based on those used by Emlen (1956) and Kuchler (1949). For more details on various physiognomic systems consult Phillips (1959) and Dansereau (1957).

## 3. Community type

A *biome* is a large geographic area characterized by a common predominant climax community (see section 5D). Within a biome, however, may occur several different community types, most of them seral (i.e., intermediate successional stages). The major types of the communities should be recorded, using accepted names such as in table 2B.1 (see section 2E.4 for description of vegetation in lakes, ponds, and streams). Record the dominant species of plants, those species important because of their controlling influence over the amount of light, heat, nutrients, soil, wind, and moisture in the habitat. Note the successional stage of development, by naming the seral stage or climax community. Any known historical events that have influenced the community type (recent burn-

**Table 2B.1.** *Major community types.*

*Tundra* Cold and treeless; found in arctic regions or high mountain elevations; consists of low shrubs, forbs, lichens, and sedges.

*Grassland* Grasses the dominant vegetation. Grasses are short in semiarid *plains* (called "steppes" in Eurasia), tall in semihumid *prairies.*

*Field* Early successional stage of grasses and forbs common on abandoned farmland and other disturbed areas.

*Meadow* Moist grassland.

*Marsh* Herbaceous vegetation in standing water.

*Swamp* Woody vegetation in standing water.

*Bog* Standing water, usually with poor drainage, typically in northern latitudes, with sphagnum moss, sedges, heath shrubs, and peat formation.

*Deciduous forest* Close stand of broad-leaved trees which shed their leaves during the cold or dry season.

*Coniferous forest* Close stand of evergreen needle-leaved trees.

*Broad-leaf evergreen forest* Trees of warm and humid regions that maintain foliage the entire year.

*Scrub* Dense shrubs or small trees, often thorny or having small tough leaves.

*Shrub* Dominant vegetation is tall shrubs. Semiarid shrublands are often called *chapparal.*

*Woodland* Open growth of small trees, often evergreen, with well-developed growth of grasses.

*Savanna* Grassland with scattered trees or groves of trees.

*Desert* Hot and arid, with sparse thorny or scrubby vegetation (or, in extreme cases, no vegetation).

ings, floods, lumbering, grazing) should also be recorded.

Along with the community type, include the name of the general climatic region, determined by latitude, altitude, and relative moisture availability (see section 2C.2). From north to south in the Northern Hemisphere, these regions are: arctic, cold temperate (or boreal), temperate, subtropical, and tropical. In mountains, montane refers to the lower moist zone, while alpine describes the extremely high cold regions. Humid, subhumid, semiarid, and arid refer to relative moisture availability. For example, one may categorize a given habitat as a subtropical montane coniferous forest. Record the general land form (section 2A.5).

### 4. Plant form

Terrestrial plant life forms, foliage forms, and seasonal conditions commonly are described by terms such as in table 2B.2. For example, a white oak-shagbark hickory forest might contain plants of the following descriptions: green broad-leaved deciduous trees, budding broad-leaved thorny shrubs, green broad-leaved vines, and green elongated-leaved herbs. For more detail, the relative abundances of these categories can be quantified by the considerations of sections 3A through 3C. A subjective quantification of dominant, abundant, common, uncommon, or rare is adequate for a general study. If taxonomic detail is required, then a brief list of the common plants can be included (see section 3A.6 for guidance).

**Table 2B.2.** *Descriptions of plant form and condition.*

| Life form | Foliage form | Seasonal condition |
|---|---|---|
| fungus | broad-leaved | green |
| lichen | needle-leaved | yellow/brown |
| moss | palmlike | defoliated |
| liverwort | fernlike | budding |
| fern | grasslike | flowering |
| herb | thorny or spiny | fruiting |
| sod grass | sclerophyllous | |
| bunch grass | | |
| broad-leaved | | |
| vine, or liana | | |
| succulent | | |
| cactoid | | |
| woody | | |
| vine, or liana | | |
| succulent | | |
| cactoid | | |
| bush | | |
| shrub | | |
| tree | | |
| deciduous | | |
| evergreen | | |
| others | | |
| epiphyte | | |

### 5. Stratification

Stratification refers to the more or less distinct layers found in most habitats. In forests, for example, a description of stratification would include ground, herbaceous, shrub, understory, and canopy levels (figure 2B.1). In some forests, stratification may be complex enough to have more than one shrub or understory level, while in others some strata may be missing. Plant life forms generally inhabit specific strata, as do many animal forms. The ground stratum may be divided into litter, surface, and subsurface layers. Surface plant taxa include mosses, lichens, and fungi. Herbs consist of many forms of annuals and perennials. In the shrub stratum one finds bushes, shrubs, and young trees. In the understory are found both canopy and noncanopy species, while the canopy consists mainly of dominant tree species. In some habitats, the description of stratification may be rather subjective in the absence of clear distinction between shrubs, understory, and canopy. In grasslands, one gen-

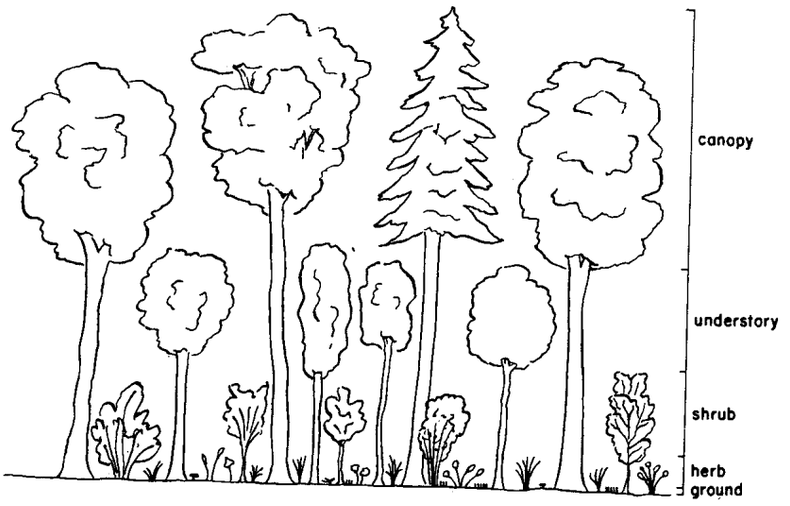


**Figure 2B.1.** Stratification in a mixed deciduous forest.


**Figure 2B.2.** Stratification in a prairie.

erally describes the root stratum, ground stratum, forb stratum, and aerial grass stratum (figure 2B.2). For a general habitat analysis, a qualitative description of the stratification often is adequate, but a quantitative index is described in section 2B.9 below.

For a grassland or field community one can directly measure the average height of the grassy vegetation above ground level. A quantitative estimate of tall vegetation heights can be made using a meter stick, as follows. Tie a marker at eye level around a tree to be measured, and then stand at least 10 meters from the base of the tree. Hold the meter stick at arm's length, perpendicular to the ground. Sight the top of the tree and the marker, and record the vertical distance between these two sightings on the meter stick. As shown in figure 2B.3, we are dealing with two congruent right triangles, so that:

$$h/d = h'/d', \tag{1}$$

and

$$h = h'd/d', \tag{2}$$

where $h$ is the height of the tree above the eye level marker, $d$ is the horizontal distance from the observer to the tree, $h'$ is the vertical distance between the two sightings on the meter stick, and $d'$ is the horizontal distance from the observer's eye to the meter stick. The total height of the tree is, then, the height $h$ plus the height of the marker from the ground. For example, if the distance $d$ is 10 meters, $d'$ is 0.5 meter, and $h'$ is found to be 0.9 meter, then the tree top extends $h = h'd/d' = (0.9)(10)/0.5 = 18$ meters above the eye level marker. A number of randomly selected trees can be measured in this fashion, and the mean height determined for each stratum.

A more precise measurement of tree height is possible using an Abney level or surveyor's level (figure 2B.4). By knowing the angle ($\theta$) at which the top of the tree is sighted, and the horizontal distance from the tree ($d$), the height ($h$) of the tree above eye level is:

$$h = d \tan \theta. \tag{3}$$

Note that if $\theta = 45°$, then $\tan \theta = 1.0$, and $h = d$. That

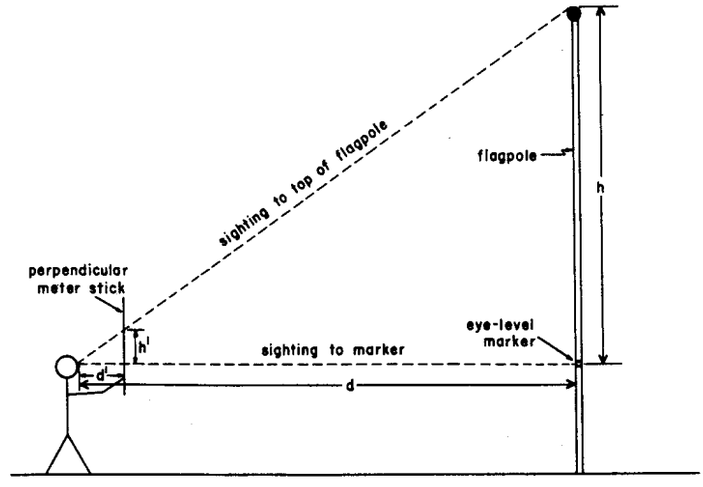


**Figure 2B.3.** Estimating the height of an object (as a tree or a flagpole) using a meter stick and elementary trigonometry.

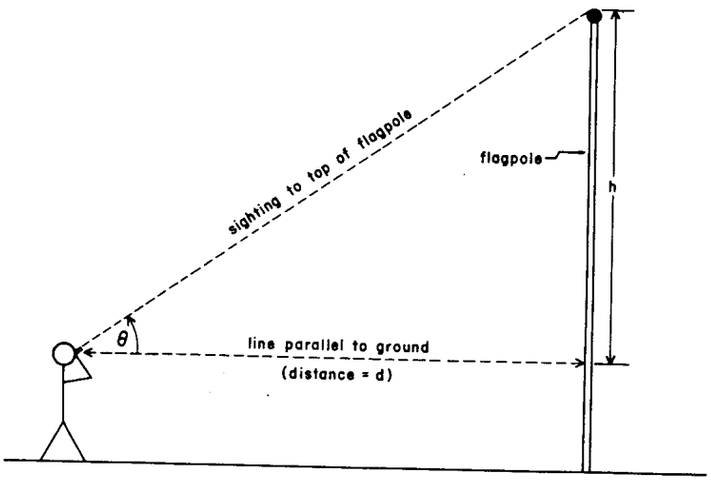


**Figure 2B.4.** Estimating the height of an object (as a tree or a flagpole) using an Abney level and elementary trigonometry.

is, if the sighting angle is 45°, then the height of the tree above eye level is equal to the horizontal distance of the observer from the tree.

### 6. Foliage density and screening efficiency

*Foliage density* is the density of leaves within a given volume of the habitat. This vegetative feature has a large influence on light intensity, temperature, soil moisture, and habitat space for animals. Unfortunately, there is no simple direct measure of foliage density, as either numbers, volume, or weight of leaves per volume of habitat. Usually the best we can do is measure the mean thickness or height of the foliage of each stratum (see section 2B.5 above).

*Screening efficiency* is the relative amount of shading or concealment of the ground by the vegetation. It may be estimated as a percentage of the background obscured by a layer of foliage of a given thickness. The visible background may be a percentage of bare soil visible in a field, or the percentage of the sky visible from the forest floor. A simple method for determining screening efficiency uses a 0.5-$m^2$ clear plastic square (approximately 70 × 70-cm) marked off in a 10 × 10 grid. One holds the grid directly overhead and counts either the number of grid squares that do or don't contain visible sky. After taking 20 random readings, one can calculate the proportion of squares concealed from the sky. This proportion (a value from 0 to 1), or its corresponding percentage (from 0 to 100%), is an expression of screening efficiency.

Light intensity, also a measure of screening efficiency, must be standardized since it is subject to other factors as well. When using a light meter one should measure the light intensity in an open area and compare it to an area under the vegetation at the same time of day and under the same cloud conditions. Record the screening efficiency as the percent of light transmitted in the habitat divided by the light intensity in the open. See section 2C.4.1 for further discussion of light measurement.

### 7. Coverage

A third measure of the quantity and distribution of foliage is *coverage,* the amount of an area covered by a perpendicularly projected outline of vegetation. The categories of sparse, medium, and dense may be used in a general habitat analysis, as: *dense,* a species or plant life form whose foliage outline covers more than 75% of the habitat area; *medium-dense,* 50–75%; *medium,* 25–50%; *medium-sparse,* 5–25%; and *sparse,* less than 5%. Since coverage is an outline measurement, and does not reflect the height or density of foliage, it does not measure light penetrability well and, therefore, is not the same as screening efficiency (see section 2B.6 above). For a more detailed analysis, quantitative measurement of coverage may be performed as described in sections 3A, 3B, and 3C.

### 8. Dispersion

Spatial distribution of plants may be one of these three types: *even* or *uniform* (as in rows); *random; clumped* or *aggregated.* Further, the plants may be said to be widely spaced (sparse), or closely spaced (dense). For a quantitative assessment of dispersion, consult section 4C. Often a distinct zonation of vegetation may occur within a habitat as a result of topography, moisture, or succession. Record and describe the presence of such zonation.

### 9. Habitat diversity

Diversity of species in a community (section 5B) is in part a function of diversity of the habitat. A description of horizontal habitat diversity would consider the variety and proportionality of land forms and plant life forms in the total habitat. For example, a homogeneous stand

of coniferous trees would offer very low habitat diversity to animals, compared to a habitat containing coniferous trees, deciduous trees, bare ground, and standing water.

Shannon's index of diversity (section 5B.2.3) is suitable as a quantitative measure of habitat diversity:

$$H' = -\Sigma p_i \log p_i, \qquad (4)$$

where $H'$ is the diversity index and $p_i$ is the proportion of the total habitat area covered by the $i$th category of coverage. For example, if 40% of a habitat area is covered by litter, 15% by rocks, 20% by sand, and 25% by standing water, the habitat diversity would be:

$$\begin{aligned} H' &= -[0.40 \log 0.40 + 0.15 \log 0.15 \\ &\quad + 0.20 \log 0.20 + 0.25 \log 0.25] \\ &= -[0.40(-0.398) + 0.15(-0.824) \\ &\quad + 0.20(-0.699) + 0.25(-0.602)] \\ &= -[-0.159 - 0.124 - 0.140 - 0.151] \\ &= 0.574. \end{aligned}$$

The above calculation employs logarithms to the base ten (Appendix D, table D.2), but other bases could be used. $H'$ makes a good measure for comparing different habitats. (See section 5B for further discussion of diversity indices and their interpretation.)

Vertical habitat diversity is also important as a determinant of species diversity of animals inhabiting several strata, such as birds and insects. A measure of stratum diversity would be $H'$ (equation 4) computed where $p_i$ is the proportion of the total foliage height occupied by each successive stratum. For example, consider a deciduous forest in which herbs are 20 cm (0.2 m) high, shrubs rise to 2.5 meters, understory trees are 10 meters tall, and canopy trees are 21 meters tall. We would assign the following heights to the four strata: 0.2 m, 2.3 m (2.5 m − 0.2 m), 7.5 m (10 m − 2.5 m), and 11 m (21 m − 10 m). Therefore, $p_i$, the proportion of heights in each category, would be:

$$\begin{aligned} p_1 &= 0.2 \text{ m}/21 \text{ m} = 0.010 \\ p_2 &= 2.3 \text{ m}/21 \text{ m} = 0.110 \\ p_3 &= 7.5 \text{ m}/21 \text{ m} = 0.357 \\ p_4 &= 11 \text{ m}/21 \text{ m} = 0.524 \end{aligned}$$

Using table D.2 in Appendix D, we can calculate:

$$\begin{aligned} H' &= -[0.010 \log 0.010 + 0.110 \log 0.110 \\ &\quad + 0.357 \log 0.357 + 0.524 \log 0.524] \\ &= -[0.010(-2.000) + 0.110(-0.959) \\ &\quad + 0.357(-0.447) + 0.524(-0.281)] \\ &= -[-0.020 - 0.105 - 0.160 - 0.147] \\ &= 0.432. \end{aligned}$$

While this is a rather crude index of the vertical habitat diversity available to denizens of the habitat, it can be used for comparing different habitats. A better index of vertical habitat diversity would be one where $p_i$ is a proportion of the foliage density (or screening efficiency or some similar measure) in each stratum. MacArthur and MacArthur (1961) called such a measure *foliage height diversity* (FHD) and found it highly correlated with bird species diversity.

## 10. Suggested exercises

1. Compare the plant life forms in two similar habitats, such as a field and prairie or an oak forest and maple forest.
2. Determine the vertical habitat diversity for two different terrestrial habitats. What are the effects of life forms, stratification, screening efficiency, and dispersion on the plant and animal inhabitants of the two communities?

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# 2c

# atmospheric analysis

## 1. Introduction

Climate, season, and weather affect the distribution and activity of both terrestrial and aquatic organisms. *Climate* refers to the general prevailing atmospheric conditions over the years in a given region. Climates are usually characterized by seasonal temperature, humidity, and precipitation. *Weather* refers to the momentary conditions of the atmosphere. Four major physical factors comprise the atmospheric component of a habitat: air moisture, temperature, wind, and solar radiation. Extremes, rather than averages, of these variables usually affect the distribution and abundance of organisms.

The chemical components of air are rather uniform over the earth and are only measured as a matter of concern in the analysis of air pollution and in soil microhabitats. Unlike in aquatic habitats, oxygen is abundant in aboveground terrestrial situations.

In this section we shall be concerned with the analysis of climatic factors. They largely determine the type of biotic community in an area and the distribution of individual species. We will pay similar attention to the analysis of weather conditions that largely affect the daily and seasonal behavior and abundance of species. A good account of the ecological significance of atmospheric factors is given in Daubenmire (1974).

## 2. Climate

Climates are often broadly categorized by latitude, as polar (or arctic), cold temperate (or boreal), temperate, and tropical, with terms such as subtropical or subarctic denoting intermediate climates. The Köppen system considers temperature and precipitation, and the associated vegetation type. The major divisions in this system are: arid (subdivisable into deserts and arid grasslands), temperate humid (subdivisable into areas moist all year, those dry in winter, and those dry in summer), tropical humid (including tropical rain forest and tropical savanna), cold temperate or boreal (including areas moist in all seasons and those having dry winters), and arctic or polar (subdivisable into tundra regions and regions of perpetual ice and snow).

For a more detailed picture of the climate for a given region, ecologists use two types of *climatographs*. In figure 2C.1, the mean monthly temperature and the mean monthly precipitation are plotted for each month of the year, and the plotted points are connected sequentially to form an irregular polygon. Data for this type of graph are available from local weather stations or from government documents.

A second method of presenting the climate of a given region is to graph the mean monthly precipitation and mean monthly evapotranspiration as a function of time of year. Evapotranspiration includes loss of water to the atmosphere through both evaporation and plant transpiration. This measure gives a better picture of water availability to plants than does the temperature-precipitation graph of figure 2C.1. However, evapotranspiration data often are not available and must either be measured by the investigator or roughly approximated from temperature, humidity, and wind data.

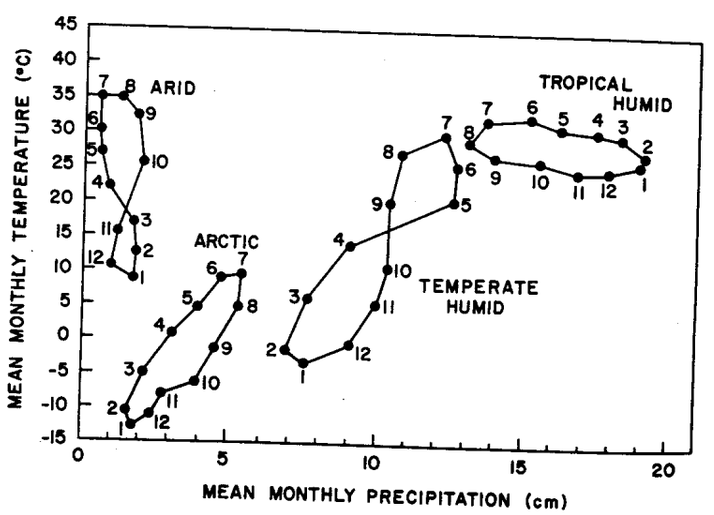


**Figure 2C.1.** Climatographs, describing climate in terms of mean monthly temperature and precipitation.

Figure 2C.2 is an alternative presentation that helps to diagram water availability based on readily obtained temperature and precipitation data. Since evapotranspiration is directly related to temperature, a plot of seasonal changes in temperature will be similar to a plot of evapotranspiration. A temperature of 10°C is considered roughly equivalent to 20 mm of monthly precipitation in terms of evapotranspiration (Walter, 1973). Consequently, points on figure 2C.2 where temperature and precipitation curves intersect represent a condition where the amount of water lost through evapotranspiration is about equal to the amount gained through precipitation. Thus in figure 2C.2, July and August would have a water deficit in the Pacific Northwest but would experience a water surplus for the mid-Atlantic coast of the United States.

### 3. Microclimate

Variation in the local climate due to such factors as elevation, slope, and shade can result in temperatures, humidities, and light intensities quite different from those of surrounding areas. (See Smith, 1974, for a good discussion of microclimates.) For example, the atmospheric conditions in a forest on a north-facing slope are quite different from those on a south-facing slope. Also, conditions near the ground are generally different from those a few meters above the ground. Therefore, when conducting a study of the microhabitat, one should determine the vertical profile of temperature, light intensity, relative humidity, and wind velocity (see section 2C.4 below). For such profiles, portable electronic instruments are conveniently used. Detectors having long leads are placed on an extendable pole and elevated to the desired heights, and measurements are taken at 0.5- or 1-meter intervals. The detectors may also be attached to a cord thrown over a high tree branch and raised to the desired heights. One then graphs the measured variables as a function of height in the habitat.

A horizontal profile of these variables may be made where zonation or patchiness occurs within the habitat. A microhabitat study may also include analysis of these variables in specific locations, such as animal burrows, nests, and hollow trees or logs. These microhabitats are generally sheltered from large variations in the macrohabitat and represent rather moderate and stable microclimates for species that would not otherwise survive in the area.

### 4. Atmospheric measurements

Record atmospheric conditions at the time of sampling, since animal activities and plant functions may be dependent on them. Sampling of animals (as described in sections 3D through 3G) will often yield different results under different weather conditions. Therefore, always record air temperature, relative humidity, wind velocity and direction, relative amount of cloud cover, light intensity, and any occurrence of precipitation (light rain, thunderstorm, snow).

**4.1. Light Intensity** The intensity and duration of solar radiation not only affects other atmospheric variables (such as temperature, relative humidity, and wind), but also the amount of energy available for production and the timing of seasonal cycles of plants and animals. (See Daubenmire, 1974, for a discussion of light as an ecological factor.)

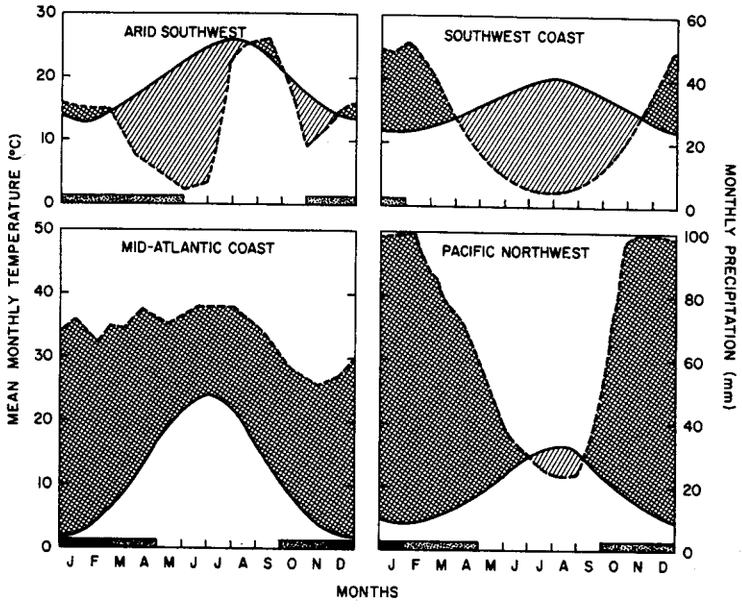


**Figure 2C.2.** Climatographs, emphasizing water availability. Since a mean monthly temperature of 10°C and a monthly precipitation of 20 mm are considered equivalent in terms of evapotranspiration, diagonal lines indicate periods of drought and cross-hatching indicates periods of water surplus. Stippled bars denote months with frost, and solid bars indicate months with freezing temperature (after Walter, 1973).

*Luminous flux* is the amount of light energy per unit time. The *lumen** is the unit of luminous flux, but, since the lumen is dependent on wavelength, light measurements are difficult to interpret as solar energy input (e.g., calories). (See Gates, 1962, for a discussion of solar energy as related to energy exchanges in an ecosystem.)

*Luminous intensity* (measured in units called *candelas,** or *candlepower*) refers to the amount of light emitted by a source, measured relative to the so-called *standard,* or *international, candle.* The amount of light received one meter from a standard candle is a *lux**; that received at a distance of one foot is a *footcandle**.

A light meter may be calibrated to either lux or footcandles (1 footcandle = 10.76 lux; 1 lux = 0.0929 footcandles). When measuring luminance in a given habitat, determine its value at ground level under the vegetation and in open sunlight (outside the habitat, if necessary). Relative luminance may then be expressed as lux at ground level divided by the lux in open sunlight. This value may be expressed as percent transmittance in that habitat. We can estimate an *absorption coefficient,* analogous to the "extinction coefficient" of section 2E.3.3, equation 4, by designating the height of the tallest stratum (as determined in section 2B.5) as $d$, the luminance at ground level as $I_d$, and the luminance in the open (assumed to be the same as that above all foliage) as $I_o$.

In a markedly stratified habitat, a light sensor either attached to an extendable pole or flung over a tall branch can be used to measure the screening efficiency in each stratum (sections 2B.5 and 2B.6). Then make a profile of light extinction for that habitat by graphing the percentage of light transmittance as a function of vegetation height.

**4.2. Temperature** Air temperature should be measured at ground level and compared to a measurement made in the open. Use a simple mercury thermometer, but for a temperature profile of the habitat use electronic telethermometers (employing thermistors). A temperature probe may be placed at different heights as described in section 4.1 above, and the temperature at various intervals plotted as a function of height in the habitat.

**4.3. Wind Velocity** An electronic wind meter measures wind velocity most accurately. However, determinations may also be made using an anemometer or a simple wind meter in which the wind causes a small light ball to rise in a tube. Record the direction as well as the velocity of the wind. Wind velocity not only affects certain animal activities (e.g., insect flight) but also affects the rate of evapotranspiration of water from the habitat.

Determine the wind velocity on the ground and in the open. For a profile of wind velocity, record measurements at different heights, as explained in section 2C.4.1 above.

**4.4. Precipitation** Noting the type and intensity of any precipitation is sufficient during a single field trip. However, if one is sampling animals over a series of days, quantitative precipitation measurements are necessary. Simple rain gauges may be set out in the habitat and read daily. Precipitation data from local weather stations may suffice, but actual measurements in the habitat are often different, due to local variations. In dense vegetation much less rainfall may reach the ground surface than would fall on bare ground. Rain intercepted by plants may evaporate from them or be directed down their stems.

**4.5. Humidity** Atmospheric humidity, highly variable, is the amount of water vapor in the air. It has important biological effects on plant respiration, on rates of transpiration and evaporation, and on the amount of cooling of surfaces from which evaporation takes place. The amount of water vapor in air is expressed as *vapor pressure,* the partial pressure of water vapor in the air. It may be stated as millibars (mb) or as an equivalent height of a mercury column, as in a barometer:

$$1 \text{ mm Hg} = 1.333 \text{ mb}; \quad 1 \text{ mb} = 0.7501 \text{ mm Hg} \qquad (1)$$

$$1 \text{ in. Hg} = 33.86 \text{ mb}; \quad 1 \text{ mb} = 0.02953 \text{ in. Hg} \qquad (2)$$

The maximum amount of water vapor that the air can hold when in equilibrium over liquid water is called *saturation vapor pressure* and is directly related to temperature (see table 2F.1). The *vapor pressure deficit* is the difference between the saturation vapor pressure and the actual vapor pressure.

The commonest measure of atmospheric water vapor content is *relative humidity,* the actual vapor pressure expressed as a percentage of the saturation vapor pressure. It is important to note that rates of evaporation are not directly related to relative humidity, but are a function of the vapor pressure deficit and the air temperature.

Relative humidity is conveniently measured with a hygrometer or a sling psychrometer (or an electronic humidity meter standardized with one of the former). A psychrometer consists of two thermometers, one having a dry bulb and the second having a bulb wrapped with a wick continually moistened with distilled water. (If the air temperature is below freezing, then the wick will of course be impregnated with ice.) Evaporation of water from the wet bulb cools the second thermometer; since the rate of evaporation (hence the cooling of the thermometer) is directly related to the vapor pressure deficit, the relative humidity can be estimated from the difference between the wet bulb and dry bulb temperatures.

Swing the psychrometer in a circle until the wet bulb temperature ceases to decline. Be careful to keep a safe

* Standard abbreviations for photometric units are: lumen, lm; candela, cd; lux, lx; footcandle, fc.

distance from people and other objects while swinging the instrument, as it is easy to injure a person or damage the thermometers. Read the wet bulb temperature immediately after swinging; record the wet bulb and dry bulb temperatures and calculate the difference between the two. The relative humidity is then determined by consulting table 2C.1. For example, if the dry bulb temperature were 22°C and the wet bulb 18°C, the difference in temperature would be 4°C, and the relative humidity for 22°C would be 68%.

**Table 2C.1.** *Determination of percent relative humidity from dry bulb and wet bulb temperatures (°C) from a psychrometer.* Tabled values are for a barometric pressure of 743 mm Hg. For other barometric pressures, see table 2C.2 and the note at the bottom of that table.*

| dry bulb (°C) | difference between dry and wet bulbs (°C) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| −10 | 60 | 31 | | | | | | | | | | | | | | | | | | | | | | | |
| −8 | 65 | 39 | 13 | | | | | | | | | | | | | | | | | | | | | | |
| −6 | 70 | 46 | 23 | | | | | | | | | | | | | | | | | | | | | | |
| −4 | 74 | 53 | 32 | 11 | | | | | | | | | | | | | | | | | | | | | |
| −2 | 78 | 58 | 39 | 21 | | | | | | | | | | | | | | | | | | | | | |
| 0 | 81 | 64 | 46 | 29 | 13 | | | | | | | | | | | | | | | | | | | | |
| 2 | 84 | 68 | 52 | 37 | 22 | 7 | | | | | | | | | | | | | | | | | | | |
| 4 | 85 | 71 | 57 | 43 | 29 | 16 | | | | | | | | | | | | | | | | | | | |
| 6 | 86 | 73 | 60 | 48 | 35 | 24 | 11 | | | | | | | | | | | | | | | | | | |
| 8 | 87 | 75 | 63 | 51 | 40 | 29 | 19 | 8 | | | | | | | | | | | | | | | | | |
| 10 | 88 | 77 | 66 | 55 | 44 | 34 | 24 | 15 | 6 | | | | | | | | | | | | | | | | |
| 12 | 89 | 78 | 68 | 58 | 48 | 39 | 29 | 21 | 12 | | | | | | | | | | | | | | | | |
| 14 | 90 | 79 | 70 | 60 | 51 | 42 | 34 | 26 | 18 | 10 | | | | | | | | | | | | | | | |
| 16 | 90 | 81 | 71 | 63 | 54 | 46 | 38 | 30 | 23 | 15 | 8 | | | | | | | | | | | | | | |
| 18 | 91 | 82 | 73 | 65 | 57 | 49 | 41 | 34 | 27 | 20 | 14 | 7 | | | | | | | | | | | | | |
| 20 | 91 | 83 | 74 | 66 | 59 | 51 | 44 | 37 | 31 | 24 | 18 | 12 | 6 | | | | | | | | | | | | |
| 22 | 92 | 83 | 76 | 68 | 61 | 54 | 47 | 40 | 34 | 28 | 22 | 17 | 11 | 6 | | | | | | | | | | | |
| 24 | 92 | 84 | 77 | 69 | 62 | 56 | 49 | 43 | 37 | 31 | 26 | 20 | 15 | 10 | 5 | | | | | | | | | | |
| 26 | 92 | 85 | 78 | 71 | 64 | 58 | 51 | 46 | 40 | 34 | 29 | 24 | 19 | 14 | 10 | 5 | | | | | | | | | |
| 28 | 93 | 85 | 78 | 71 | 65 | 59 | 53 | 48 | 42 | 37 | 32 | 27 | 22 | 18 | 13 | 9 | 5 | | | | | | | | |
| 30 | 93 | 86 | 79 | 73 | 67 | 61 | 55 | 50 | 44 | 39 | 35 | 30 | 25 | 21 | 17 | 13 | 9 | 5 | | | | | | | |
| 32 | 93 | 86 | 80 | 74 | 68 | 62 | 57 | 51 | 46 | 41 | 37 | 32 | 28 | 24 | 20 | 16 | 12 | 9 | 5 | | | | | | |
| 34 | 93 | 87 | 81 | 75 | 69 | 63 | 58 | 53 | 48 | 43 | 39 | 35 | 30 | 26 | 23 | 19 | 15 | 12 | 8 | 5 | | | | | |
| 36 | 94 | 87 | 81 | 75 | 70 | 64 | 59 | 54 | 50 | 45 | 41 | 37 | 33 | 29 | 25 | 21 | 18 | 15 | 11 | 8 | 5 | | | | |
| 38 | 94 | 88 | 82 | 76 | 71 | 66 | 61 | 56 | 51 | 47 | 43 | 39 | 35 | 31 | 27 | 24 | 20 | 17 | 14 | 11 | 8 | 5 | | | |
| 40 | 94 | 88 | 82 | 77 | 72 | 67 | 62 | 57 | 53 | 48 | 44 | 40 | 36 | 33 | 29 | 26 | 23 | 20 | 16 | 14 | 11 | 8 | 6 | | |
| 42 | 94 | 88 | 83 | 78 | 72 | 67 | 63 | 58 | 54 | 50 | 45 | 42 | 38 | 35 | 31 | 28 | 25 | 22 | 19 | 16 | 13 | 11 | 8 | 6 | |
| 44 | 94 | 89 | 83 | 79 | 73 | 68 | 64 | 59 | 55 | 51 | 47 | 43 | 40 | 36 | 33 | 30 | 27 | 24 | 21 | 18 | 16 | 13 | 10 | 8 | 6 |

* From the more extensive table 1 of the U.S. Weather Bureau (1953). Interpolation may be made with an error of less than 1% relative humidity. (For example, the relative humidity associated with a temperature difference of 5°C for a dry bulb temperature of 9°C may be estimated as 42%, the midpoint of the values of 40% and 44% for air temperatures of 8° and 10°C, respectively.)

**Table 2C.2.** *Correction factors, c, for use with table 2C.1 to determine percent relative humidity from dry and wet bulb temperatures.**

| dry bulb temperature ($T$, in °C) | correction factor ($c$) | dry bulb temperature ($T$, in °C) | correction factor ($c$) |
|---|---|---|---|
| −10 | 0.0304 | 16 | 0.00492 |
| −8 | 0.0260 | 18 | 0.00433 |
| −6 | 0.0224 | 20 | 0.00383 |
| −4 | 0.0193 | 22 | 0.00339 |
| −2 | 0.0166 | 24 | 0.00302 |
| 0 | 0.0144 | 26 | 0.00268 |
| 2 | 0.0125 | 28 | 0.00239 |
| 4 | 0.0109 | 30 | 0.00212 |
| 6 | 0.00945 | 32 | 0.00190 |
| 8 | 0.00827 | 34 | 0.00170 |
| 10 | 0.00724 | 36 | 0.00152 |
| 12 | 0.00634 | 38 | 0.00136 |
| 14 | 0.00559 | 40 | 0.00123 |

* If the dry bulb temperature is $T$ (in degrees °C), the difference between dry and wet bulb temperature is $\Delta T$ (in °C), the relative humidity in table 2C.1 is RH, and the barometric pressure is $P$ (in mm Hg), then the corrected relative humidity is:

$$RH_c = RH + c\Delta T(743 \text{ mm} - P). \quad (3)$$

Values in this table were calculated from table 1a in U.S. Weather Bureau (1953). Note: The above correction is seldom needed (unless at high altitudes). It results in $RH_c$ being different from RH by no more than 2% for $P$ ranging from 714 to 770 mm Hg at 0°C, and with even less error at most other temperatures. The correction should routinely be used at altitudes over 600 m. If barometric pressure is not measured directly, it may be assumed to decrease about 9 mm Hg per 100 m altitude up to about 800 m, about 8 mm Hg per 100 m from 900 to 1700 m, and about 7 mm Hg per 100 m thereafter up to about 2500 m (from Golterman, 1969).

## 5. Suggested exercises

1. Construct climatographs for your region as illustrated in figures 2C.1 and 2C.2.
2. Collect data on light intensity and temperature in the different strata of a forest community, and plot these variables as a function of height.
3. Compare variables such as temperature, humidity, wind, and light in a forest to those in a nearby field or grassland.

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# 2d

# substrate analysis

## 1. Introduction

The portion of the lithosphere directly important to the ecologist is the top few meters of soil and aquatic sediments. Soil is a heterogeneous substance; it varies somewhat with season and interacts with climate and vegetation. Given below are some basic physical measurements important in soil analysis. Section 2F describes chemical analyses.

## 2. Sampling methods

All substrate samples should be collected at random and taken in replicate (see section 1A). One commonly uses a soil corer (figure 2D.1) for soil samples. This consists

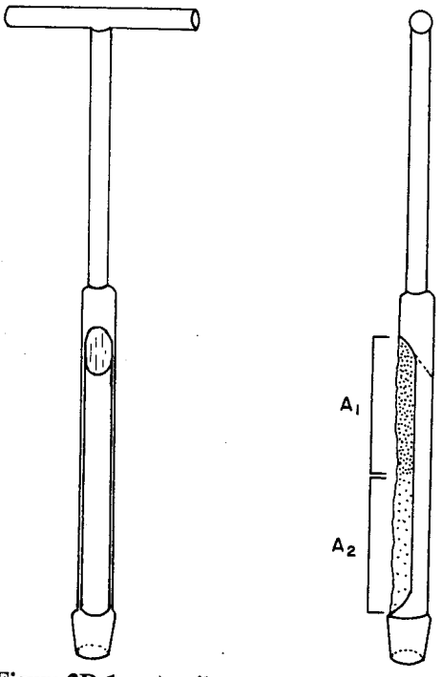


**Figure 2D.1.** A soil corer, empty on the left, and containing a core sample with $A_1$ and $A_2$ horizons on the right.

of a hollow, half-open metal tube. The tube is pushed into the soil until its top is just at the ground surface, and then carefully pulled from the soil and examined. (The corer should be cleaned before taking the next sample.) For larger samples, small plots may be dug with a sharp, flat-tipped spade.

For sampling aquatic sediments, benthic grab samplers (described in section 3E.2.3) are often used. But to obtain cores of soft, lake sediments, you must use a specially designed corer. The simplest type is a metal tube with a heavy weight. The sampler is attached to a line and dropped into the water; the weight of the sampler drives it into the sediment. For deeper cores, specialized corers have an additional weight which is sent down the line repeatedly to drive it deeper into the sediment. After retrieving the corer, you extract the sample by pushing the core out with a rod or piston.

Samples should be stored in sturdy, tightly sealed plastic bags or tubes and analyzed as soon as possible, since some of the physical and chemical properties change with storage. For example, determine the *p*H of sediments in the field if possible.

Some types of analysis require that a sample be dried first to remove moisture, while others require the use of a fresh sample. In either case, final results are expressed relative to the dry weight of the soil sample, rather than to its fresh weight. Therefore, dry weights must be determined separately for samples requiring fresh material. Determination of the dry weight of a soil subsample and water percentage in the sample may proceed as for the dry weight of biological material (section 6A.2). The dry weight of the fresh sample is then estimated by multiplying the ratio of dry weight to fresh weight by the fresh weight of the sample.

Some procedures require that the soil or sediment be ground into fine particles to insure homogeneity of the material. To do this, take a 5- or 10-g substrate sample and pulverize it in a mortar and pestle so that all particles pass through a 100-mesh screen, whereupon the material is weighed and analyzed.

## 3. Parent material

Parent material is the substrate from which the soil or sediment originated and may have been removed by wind, water, and gravity. Soil origin may be *residual* (formed in place), *alluvial* (deposited by water), *aeolian* (deposited by wind), *colluvial* (deposited by gravity), or *glacial* (deposited by glacier). For a determination of the parent material in your study area, consult local soil maps. These are available from the U.S. Soil Conservation Service and may be found in governmental and university map libraries.

### 4. Soil profile

Soils exhibit vertical zones, called *horizons* (figure 2D.2). The O horizon is the layer of deposited organic matter. The A horizon is characterized by mineral soil having a

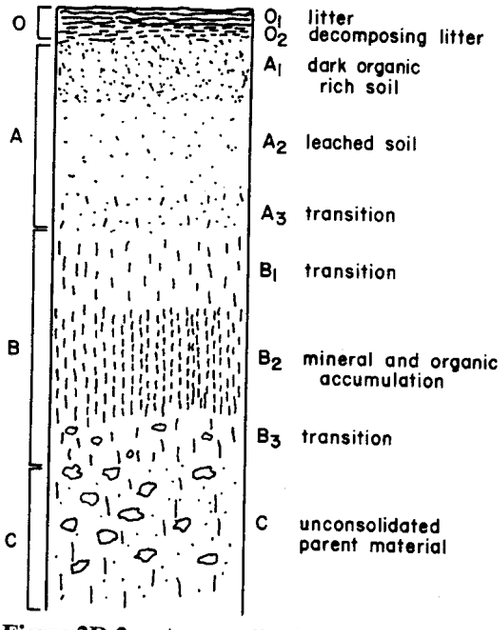


**Figure 2D.2.** A generalized soil profile. (The layer of decomposing organic matter ($O_2$) is sometimes referred to as $A_0$, and the litter layer ($O_1$) as $A_{00}$ or L.)

granular, platelike, or crumb structure. The B horizon collects the leached materials from the A layer and generally has a prismatic, blocky, or columnar structure. In arid regions, high evaporation rates inhibit percolation of water, and a "hardpan" may form in the B horizon. This is a hard deposition of salts impervious to water, roots, and burrowing animals. The C horizon contains weathered parent rock material unconsolidated into soil. Differences in color, structure, and chemistry within these major horizons are referred to by subdivision designations, such as $A_1$, $A_2$, $B_1$, $B_2$, etc. The basic soil horizons (and their subdivisions if possible) should be identified in a habitat analysis; measure the thickness of each. Soil profile characteristics are important in classifying basic soil types (section 2D.9 below).

For a macrohabitat analysis, a soil core will give enough information concerning the O and A horizons of the soil. Occasionally, complete soil profiles can be studied conveniently from a recent excavation in an area, but usually one has to dig a pit about 1.5 meters wide and 1.5 meters deep. However, dig such a pit in an area where it will not severely impact the habitat nor be a safety hazard. The pit may be safely covered with a lid, so that it can be used for demonstration for many years. For each viewing, remove a fresh slice of soil with a sharp flat-tipped shovel a few centimeters thick from the side of the pit to show an unweathered view of the profile.

### 5. Soil moisture

For a general habitat survey, a relative measure of moisture content will suffice. A qualitative categorization would be: *dry soil* (crumbly or hard and dry to the touch); *moist soil* (pliable and moist to the touch); and *wet soil* (exuding water when squeezed, leaving the hand muddy).

Pocket-sized moisture meters are available for qualitative estimation of soil moisture. However, they basically measure conductivity and depend, therefore, not only on the moisture content of the soil but on salt content and *p*H. Therefore, such a meter should be standardized in the laboratory with a soil sample from the habitat of interest and calibrated against moisture content known from dry weight determinations, as explained below.

For precise determination of the percent moisture in the soil, obtain samples using a soil corer, seal the samples in separate plastic bags, and dry them in the laboratory for 24 hours at 105°C. See section 6A.2 for dry-weight-determination techniques. Fresh weight minus dry weight equals the amount of water in the soil and is expressed in grams of water per 100 grams of dry soil.

The amount of moisture in soil is related to the amount of rainfall, evapotranspiration, and drainage, and the water-holding capacity of the soil. The last factor is difficult to measure accurately, but it is related to soil texture and soil organic matter. For example, sand has a low water-holding capability, while silts, clays, and soils rich in organic matter have a high one.

### 6. Soil temperature

Soil temperature is a variable that affects the ecology of plants, animals, and microorganisms. Therefore, a profile of soil temperature is useful. A dial thermometer with a long metal stem can record shallow temperatures. If measurements of deep soil temperatures are needed, then thermistors may be buried at different depths. Allow the thermistor to equilibrate with the soil for at least half an hour before recording the temperature. For a profile of soil temperature, plot the temperature on the horizontal axis and the depth on the vertical axis of a graph, thus obtaining a plot resembling the temperature profile of a lake (figure 2E.2).

### 7. Soil organic matter

Soil organic matter is a major determinant of soil texture, moisture, *p*H, and nutrients. Chemical procedures for estimating organic carbon exist, but a simple approximation can be made by determining ash-free dry weight. This procedure is the same as described for biological

samples in section 6A.3. Obtain a sample of the O and $A_1$ horizons. The O horizon is best sampled using a plot, but the $A_1$ may be sampled with a corer. Prepare the soil litter as described for plants in section 6A. Air dry the soil sample and pulverize it as described in section 2D.2 above; then determine the oven-dry weight and ash-free dry weight. The percentage of organic matter is found from the difference between the oven-dry weight and the ash-free dry weight divided by the oven-dry weight.

## 8. Soil fractions

For a general habitat survey, classify the soil textural types, by sight and touch, as *gravel, sand, silt, clay,* or *loam.* (Loam is a mixture of sand, silt, and clay.)

However, a more precise procedure is required for a detailed microhabitat study. There are several methods to estimate the fractions of sand, silt, and clay in substrate samples. That discussed here is one of the easiest; it is based on a physical principle ("Stoke's law"), which states that the velocity of a particle settling in a liquid is directly proportional to its size and density. Thus particle sizes can be estimated by knowing the density of the soil suspension at various settling times. This can easily be measured with a soil hydrometer* (Day, 1956, 1965; American Society for Testing and Materials, 1966).

The procedure is: break up a sample of air-dried soil with a wooden roller, without grinding, to keep the natural particles unbroken. Shake the sample on a number 10 (2.0-mm) mesh sieve. Weigh and record the material not passing through the sieve (gravel and larger components). Weigh a portion of the sieved sample and determine the oven-dry weight as described in section 6A.2. Use a 25- to 50-g sample for fine-textured soils and 50 to 100 g for sandy soils. Place the oven-dried material in a 600-ml beaker. Prepare a 5% solution of sodium metaphosphate (also known as sodium hexametaphosphate, or Calgon), by dissolving 50 g in 1 liter of distilled water. This solution should be made up fresh each month and adjusted to a *p*H of 8 or 9 with sodium carbonate. Add 100 ml of the sodium metaphosphate solution and 400 ml of distilled water to the beaker; the sodium metaphosphate acts as a dispersing agent and neutralizes charges on the soil particles that might impede settling. Mix the suspension for 5, 10, or 15 minutes with an electric mixer. The longer two mixing times are used for silts and clays, respectively. Transfer the suspension to a calibrated 1000-ml glass cylinder, and add the rinsings from the beaker; bring the volume to one liter with distilled water. Mix the contents of the cylinder by capping it and inverting it 60 times; avoid shaking since it may cause foaming and air bubbles in the suspension. A special mixing plunger may be used instead.

Immediately after mixing, begin recording the time to the nearest second during the first hour and to the nearest minute thereafter. Carefully lower the hydrometer into the suspension to avoid disturbing it; allow at least 20 seconds before reading the hydrometer. Read the *top* of the meniscus, as grams of soil per liter in suspension, after 0.5, 1, 2, 5, 15, 30, and 60 minutes, and 4, 8, and 24 hours. Record the temperature and the precise time of each hydrometer reading. (To prevent temperature fluctuations, the cylinder may be kept immersed in a constant temperature bath.) The reading times may be varied as long as the time of the recording is accurately determined. Remove and rinse the hydrometer after each measurement (except after the 0.5-minute measurement). Let us call a hydrometer reading $R$.

The diameter ($d$) of the largest particle in suspension may be estimated at the time of each hydrometer reading as:

$$d = c/\sqrt{t}, \qquad (1)$$

where $d$ is the particle diameter (in microns), $t$ is the settling time (in minutes) until the time of reading, and $c$ is a value given in table 2D.1 for a temperature of 25°C

**Table 2D.1.** *Values of* c *(for equation 1) for calculating particle size for soil hydrometer (ASTM 152H) readings,* R, *taken at 25°C.**

| R | c | R | c | R | c |
|---|---|---|---|---|---|
| 0 | 52.0 | | | | |
| 1 | 51.6 | 21 | 46.2 | 41 | 39.9 |
| 2 | 51.5 | 22 | 45.9 | 42 | 39.5 |
| 3 | 51.2 | 23 | 45.5 | 43 | 39.0 |
| 4 | 50.8 | 24 | 45.3 | 44 | 38.8 |
| 5 | 50.7 | 25 | 45.0 | 45 | 38.4 |
| 6 | 50.3 | 26 | 44.6 | 46 | 38.2 |
| 7 | 50.2 | 27 | 44.4 | 47 | 37.7 |
| 8 | 47.8 | 28 | 44.0 | 48 | 37.3 |
| 9 | 49.5 | 29 | 43.6 | 49 | 37.1 |
| 10 | 49.3 | 30 | 43.5 | 50 | 36.6 |
| 11 | 49.0 | 31 | 43.1 | 51 | 36.2 |
| 12 | 48.7 | 32 | 42.9 | 52 | 35.9 |
| 13 | 48.5 | 33 | 42.5 | 53 | 35.5 |
| 14 | 48.2 | 34 | 42.1 | 54 | 35.0 |
| 15 | 47.8 | 35 | 41.9 | 55 | 34.8 |
| 16 | 47.6 | 36 | 41.5 | 56 | 34.3 |
| 17 | 47.3 | 37 | 41.1 | 57 | 34.1 |
| 18 | 46.9 | 38 | 40.9 | 58 | 33.6 |
| 19 | 46.8 | 39 | 40.5 | 59 | 33.1 |
| 20 | 46.4 | 40 | 40.1 | 60 | 32.8 |

* Values of $c$ were computed as described by Day (1956, 1965), using the effective hydrometer depths given by the American Society for Testing and Materials (1966).

* The standard soil hydrometer referred to is the American Society for Testing and Materials (ASTM) hydrometer 152H, which is graduated in grams of soil per liter. This is available from scientific suppliers, such as Scientific Glass Apparatus Co., Bloomfield, NJ; Soiltest, Evanston, IL; and Nasco Agricultural Sciences, Ft. Atkinson, WI or Modesto, CA.

and a standardly assumed soil density of 2.65 g/cm³. (For some soils, e.g., those with much organic content, certain pretreatment is necessary before this procedure is employed, and the references in section 2D.11 below should be consulted.)

For example, if after 65 minutes the hydrometer reads 21 g/l, then the maximum particle diameter remaining in suspension would be estimated to be:

$$d = 46.2/\sqrt{65} = 5.7 \text{ microns, or } 0.0057 \text{ mm.}$$

The values in table 2D.1 take into account the specific gravity of the sodium metaphosphate and the viscosity of water at 25°C. If this procedure is performed at another temperature, simply multiply the table 2D.1 value of $c$ by the appropriate factor given in table 2D.2. Or, multi-

**Table 2D.2.** *Conversion factors for* c, *or* d *(in equation 1) for soil hydrometer readings taken at various temperatures.**

| temperature (°C) | factor |
|---|---|
| 20 | 1.060 |
| 21 | 1.048 |
| 22 | 1.035 |
| 23 | 1.023 |
| 24 | 1.011 |
| 25 | 1.000 |
| 26 | 0.989 |
| 27 | 0.978 |
| 28 | 0.967 |
| 29 | 0.957 |
| 30 | 0.947 |

* Calculated from water viscosities, as described by Day (1956, 1965).

ply the computed $d$ by this factor; if the above example had been a hydrometer reading at 23°C, then calculate:

$$d = (5.7 \text{ microns})(1.023)$$
$$= 5.8 \text{ microns, or } 0.0058 \text{ mm.}$$

Now estimate the relative amounts of sand, silt, and clay in the substrate sample. Place 100 ml of the sodium metaphosphate solution in a clear cylinder and bring the volume to 1 liter with distilled water. Reading the *top* of the meniscus, take a hydrometer measurement (call it $R_b$) of this "blank" solution containing no soil. (If the readings on the soil suspensions are not all obtained at the same temperature, then a "blank" should be read for each temperature.) Then, the weight of soil left in the suspension at time $t$ is:

$$W_t = R - R_b. \qquad (2)$$

Therefore,

$$p = W_t/W_d \qquad (3)$$

is the proportion (i.e., $100p$ is the percentage) of the dry weight ($W_d$) of soil originally placed in the cylinder still in suspension.

For each hydrometer reading on the soil suspension one should plot the percent of soil remaining in solution against the logarithm of the calculated maximum particle size left in suspension, as in figure 2D.3. As shown, the

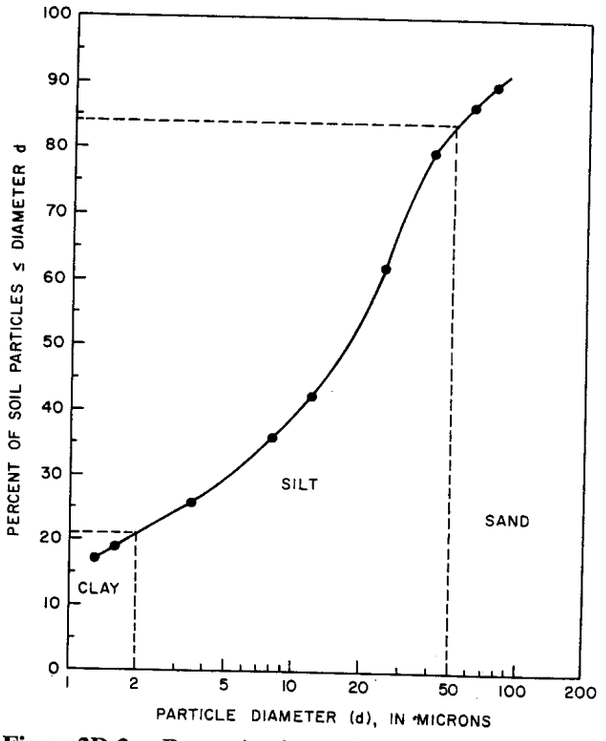


**Figure 2D.3.** Determination of the percent clay, silt, and sand composition of a substrate sample.

several data points are then connected by eye into a smooth curve. By consulting table 2D.3, you can see that the boundary particle sizes between clay, silt, and sand are 2 and 50 microns, and can locate these two points on the horizontal axis and determine where these sizes intercept the curve (the vertical dashed lines in figure 2D.3). These interception points on the curve are then read off of the vertical axis as percentages (horizontal dashed lines in figure 2D.3). For the results in figure 2D.3, for example, the sample contained 21% clay, 84% − 21% = 63% silt, and 100% − 84% = 16% sand. Then, according to figure 2D.4, this soil would be classified as silt loam.

## 9. Soil classification

Long-term interactions of climate, topography, and biota with parent substrate have resulted in a variety of soils in different regions. Two systems of classification of major soil types are in use today. The more recent system is that recommended by the U.S. Department of Agricul-

**Table 2D.3** *Size categories of soil particles.**

| *U.S. Department of Agriculture (USDA) System* | | | *International Soil Science Society System* | | |
|---|---|---|---|---|---|
| | **particle diameter** | | | **particle diameter** | |
| **category** | **mm** | $\mu$ | **category** | **mm** | $\mu$ |
| clay | <0.002 | <2 | IV | <0.002 | <2 |
| silt | 0.002–0.05 | 2–50 | III | 0.002–0.02 | 2–20 |
| very fine sand | 0.05–0.10 | 50–100 | | | |
| fine sand | 0.10–0.25 | 100–250 | II | 0.02–0.2 | 20–200 |
| medium sand | 0.25–0.5 | 250–500 | | | |
| coarse sand | 0.5–1.0 | 500–1000 | | | |
| very coarse sand | 1.0–2.0 | 1000–2000 | I | 0.2–2.0 | 200–2000 |

* From Soil Survey Staff (1951).

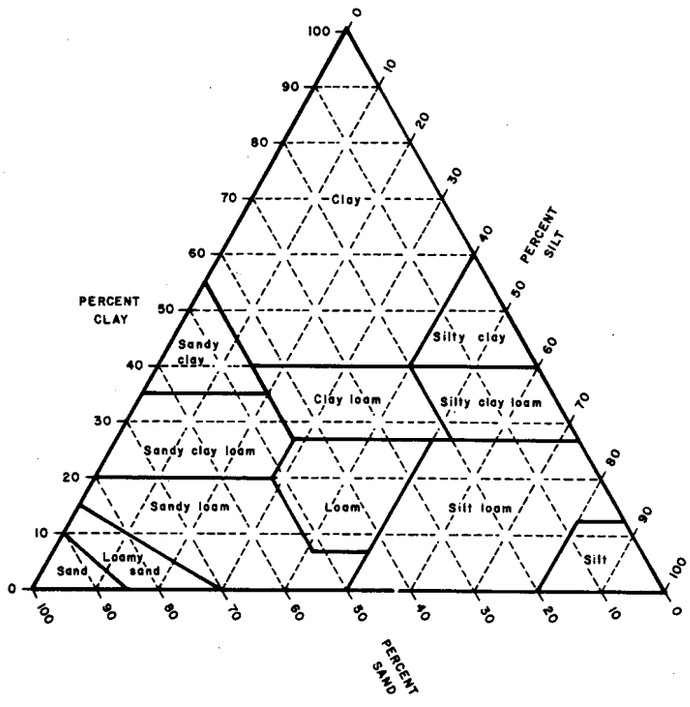


**Figure 2D.4.** Soil types based on percentages of sand, silt, and clay (as given in Millar et al., 1965).

ture Soil Conservation Service (SCS) (Soil Survey Staff, 1960, 1967). However, the older system is still in wide use by ecologists and will only gradually be replaced by the new classification in future literature. Both systems classify soils in a manner similar to biological classification. The older system has three orders subdivided into great soil groups and then into soil families, series, and types. The SCS system is a complete revision of the soil orders and great soil groups. In it there are ten soil orders divided into a number of suborders. The suborders resemble the old great soil groups, although there are many differences. Space does not permit description of the SCS classification categories; for a recent nontechnical discussion of them, consult Wolfanger (1971), from which you can obtain the name of the major soil suborder for your particular region.

The name of the soil type includes a description of the texture as well as an indication of the soil series (e.g., Miami silt loam). A series is comprised of soils of different textures but alike in color, depth, structure, and organic content of the horizons. It is generally named after the place or geophysical form in which it was first found and described. The soil type then represents the textural classification within a particular series. In the example above, the soil series is Miami, and the soil type Miami silt loam. (The Miami series was first described near the Miami River in Ohio.) To determine the series name, consult an SCS soil map for the local area.

## 10. Suggested exercises

1. Examine a soil profile from two different forests (e.g., a coniferous and a deciduous forest). What factors are responsible for the differences observed?
2. Examine the effects of topography on the soil moisture in different habitats.
3. Compare the soil texture in two habitats using the hydrometer method.
4. Compare the soil temperature profiles of a forest and a nearby field or grassland.

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# 2e

# analysis of aquatic habitats

## 1. Introduction

*Limnology* is the study of fresh waters, including both their physical and biological aspects; *oceanography* considers the physical and biotic components of marine and estuarine environments. Many of the basic principles and concepts concerning terrestrial habitats have parallels in aquatic habitats, although many details and patterns are unique to the latter. The aquatic habitat can be divided into certain basic dimensions, such as time, space, and physical and chemical components. Contrary to the terrestrial ecologist, the aquatic ecologist generally emphasizes physical and chemical factors, rather than biological factors, when describing the habitat. In aquatic systems these factors are often more complex than in terrestrial environments, and vegetation has but a minor role in modifying the physical characteristics of the habitat. This section will deal with methods for analyzing physical factors such as light, temperature, current, and conductivity. Section 2F presents techniques for analyzing chemical factors.

There are two basic types of freshwater habitats: *lentic* (calm) waters and *lotic* (running) waters. *Lakes* and *ponds* are lentic habitats. Lakes are deep and generally stratified with respect to temperature, oxygen and nutrients; ponds are shallow bodies of water without seasonal stratification and whose waters mix regularly from top to bottom. A common system of classifying lakes refers to relatively young, deep, cold, and nonproductive lakes as *oligotrophic;* relatively shallow, warm, and productive lakes as *eutrophic;* and lakes having intermediate characteristics as *mesotrophic.* Ponds may be *temporary,* especially in dry climates; *vernal* ponds are those that fill in the spring and dry up in the summer. Shallow lentic habitats having emergent and often floating vegetation are called *marshes, swamps* if the predominant vegetation is woody.

A lentic body of water often exhibits distinct zonation. The *littoral zone* is the shallow portion along the shore, in which light penetrates with sufficient intensity to sustain a significant photosynthetic rate down to the bottom. Rooted vegetation is commonly found in this region. In the open water beyond the littoral zone a depth exists—the *compensation depth*—at which light penetration is so poor that the photosynthetic rate is just equal to the respiratory rate. Above the compensation depth is the *limnetic* region of the lake; below, the *profundal* zone. The littoral and limnetic waters often are collectively termed the *euphotic* zone, that portion of the lake where photosynthetic rate exceeds respiratory rate.

*Streams* are lotic, being flowing bodies of water. *Creeks* are small streams which are narrow, shallow, and may consist of relatively still areas (*pools*), areas of rapid shallow flow over gravel or rock (*riffles*), and areas of deeper flows (*channels*). *Rivers* are wide and deep streams, and may have more violent *rapids,* rather than riffles. Some small streams flow only seasonally, or only intermittently, during periods of rainfall.

## 2. Temporal and spatial information

When studying an aquatic habitat, record the date, time of day, and the name of the observers. Recorded spatial information (noted in subsection 2A.4) should include specific locality, topography, and drainage characteristics.

Since most freshwater drains from or into some other body of water, the major drainage system—the *watershed*—should be identified along with the name of the water body. The watershed, which incorporates the energy and material exchanges of the terrestrial and aquatic ecosystems within it, is named by the major river system that eventually collects the water from that basin. These are generally the rivers that eventually enter the ocean, such as the Mississippi, St. Lawrence, Columbia, Colorado, and Hudson rivers. One may also include the smaller watershed that immediately drains the body of water.

A topographic description of the study area (see section 2A.5) should include the type of water body: e.g., creek, river, pond, lake, or reservoir. Record surface features such as the slope and form of the surrounding terrain and shoreline, form of stream channel, and formations such as riffles, rapids, falls, or islands. Record the size of the water body and its approximate center depth. If water, substrate, or biological samples are taken, the distance from shore and the depth of the sampling should be included.

For lakes, the surface area may be estimated from a topographic map or aerial photograph (see section 2A.5). An important variable in limnological studies, particularly those dealing with lakes, is the ratio of the surface area to the volume of the lake. The larger the surface area relative to its volume, the greater will be the

amount of gas exchange and mixing due to winds. If the volume and surface area are known, then:

$$\text{mean depth} = \text{volume/surface area.} \quad (1)$$

But the surface area, and especially the volume, of lakes is usually difficult to measure, so a simple ratio of the width of the water body divided by the center depth can be used as a rough index of the surface area-volume ratio. In elongated lakes, the length of the lake may be considered instead of the surface area, particularly if the long axis is parallel to the direction of the prevailing winds. It may be of interest, especially in deep lakes, to express the pressure at particular depths. This may be done as:

$$P = 1 + 0.0967d \quad (2)$$

(Wetzel, 1975), where $P$ is the combined atmospheric and hydrostatic pressure, in atmospheres (1 atmosphere = 760 mm Hg), at a water depth of $d$ meters.

### 3. Physical environment

A description of the physical factors affecting the aquatic environment includes information on atmospheric conditions and substrate, as well as water. Atmospheric conditions control the climate, season, and daily weather conditions which of course affect the amount of incipient light at the surface, volume of water, temperature, and water currents, and, subsequently, the distribution of organisms in the body of water. Since biotic sampling results may vary with short-term changes in weather conditions, record the following atmospheric information: climatic zone, air temperature, wind velocity and direction, cloud conditions, and type and intensity of precipitation (see section 2C).

The substrate of the water body provides habitat for a distinctive animal aggregation called the *benthos* (see section 3E.1). Record the type of bottom sediment as clay, silt, sand, gravel, or rock. Methods for physical analysis of the sediment are given in section 2D. Streams with swift currents may lack sediment, having a bottom of bedrock or large rocks and boulders. Such rock may be recorded as sandstone, shale, limestone, granite, or other specific type. The slope of the bottom, the depth of any silt, and the occurrence of riffles, rapids, channels, and pools are also to be recorded. Samples of substrate, other than rock, and the benthos therein, may be obtained by the methods of section 3E.2.

For a general analysis of an aquatic habitat, field record the following basic water measurements: surface water temperature, current velocity, turbidity, and conductivity. For a general chemical survey (section 2F), hardness, dissolved oxygen, alkalinity, and *p*H are chemical properties easily measured in the field and should be included in a general habitat description. The Kemmerer water sampler (figure 2E.1) can collect a known volume

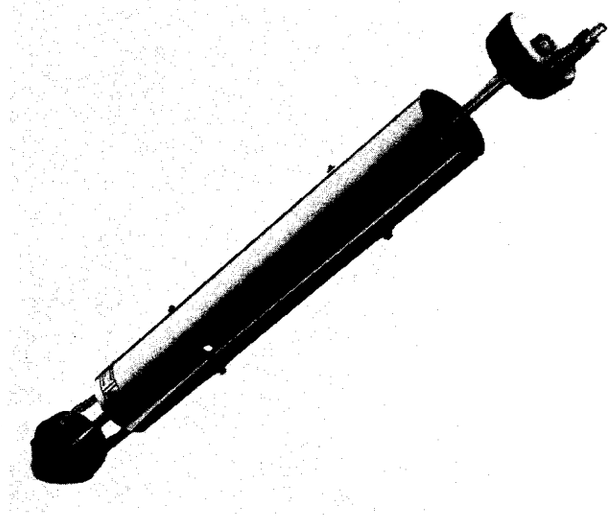

**Figure 2E.1.** The Kemmerer sampler, with which water and plankton samples may be obtained. The sampler pictured has a capacity of 1.2 liters. (Photograph courtesy of the Wildlife Supply Company, Saginaw, Michigan.)

of water (as well as the organisms suspended therein). The sampler is lowered to the desired water depth and closed by dropping a "messenger" (a metal weight) down the supporting line. In lentic habitats also record water temperature, dissolved oxygen, and *p*H measurements taken from just above the bottom.

**3.1. Temperature** In lakes and ponds water temperature varies with depth and location. Importantly, it affects not only the distribution of organisms but the density of the water and the solubility of minerals and gases. For a general analysis of the habitat, measure the water temperature a few centimeters below the surface and just above the bottom, record this from a number of locations, and calculate the mean surface and bottom temperatures. For a more detailed study of a lake, take temperatures at one-meter intervals at a number of different depths to make a *temperature profile* of the pond or lake. For this purpose, a maximum-minimum thermometer or a thermistor with a long extension is useful. Temperatures of water samples from different depths can be measured immediately after the sample is taken, but this will be accurate only if a large volume of water is collected and measured very rapidly. Some commercial water samplers contain a thermometer readable through a plastic window in the sampler. To graph a temperature profile, it is customary to place water temperature on a horizontal axis and depth on the vertical axis, with the water surface (zero depth) at the top (figure 2E.2). A lake may be *stratified* thermally, having layers of water at distinctly different temperatures. If it is, there is often a short range of depths—the *thermocline*—in which the water temperature changes very abruptly. The water above the

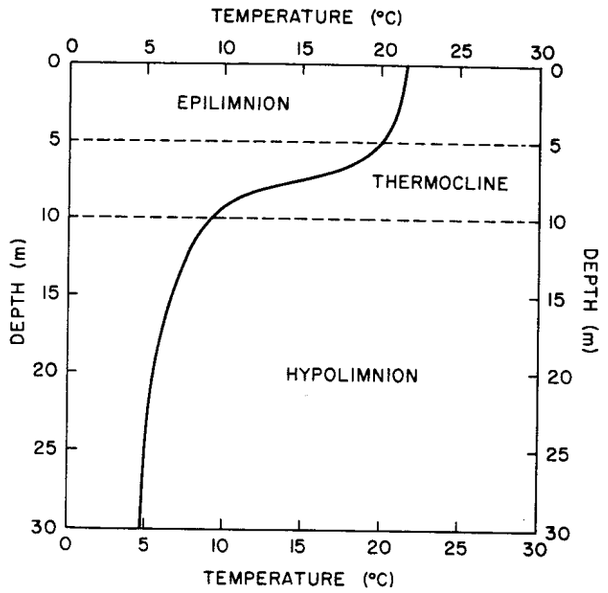


**Figure 2E.2.** The temperature profile of a lake.

thermocline is the *epilimnion;* that below it is the *hypolimnion.*

**3.2. Current** Use a current flow meter to measure the current velocity in streams at a number of locations. If such a meter is unavailable, the velocity can be approximated through use of a Pitot tube, an L-shaped glass tube marked off in linear units. The base of the L is placed in the stream with the tube's opening facing the current and its upper arm perpendicular to the surface. Pressure created by the current will cause water to rise in the tube. The height of the water column is related to the stream velocity, which can be estimated using the following equation:

$$v = 0.977\sqrt{2gh} \qquad (3)$$

(Welch, 1948), where $v$ is the velocity of the water (cm/sec), $g$ is the gravitational constant (981 cm/sec$^2$), and $h$ is the height of the water in the tube (cm). Take a number of readings across the stream at the same depth, and calculate the mean surface velocity. This procedure is not recommended when turbulence is great or current is slow. Keep in mind that you are measuring the surface velocity and not the mean velocity of a cross-sectional area of the stream, which is more difficult. Velocity varies with distance from the shore and depth of the stream.

*Discharge,* another measurement, is the volume of water flowing past a given section of a stream per unit time. It may be calculated as the mean velocity of the stream times its cross-sectional area. The cross-sectional area is approximated from the mean width of the stream times the mean depth.

**3.3. Turbidity** An optical property of water, *turbidity* causes light to be scattered or absorbed in the water, resulting in a decrease in water transparency. It is a function of at least three variables: (1) dissolved chemicals, such as tannins, acids, or salts; (2) suspended particles, such as silt, clay, and organic matter; and (3) density of microbial life.

Turbidity should be measured because the depth of light penetration affects the distribution and intensity of photosynthesis in the body of water. (See section 2E.1 above for a description of the compensation depth and the euphotic zone.) One scale of turbidity measurement employs the *Jackson turbidity unit* (JTU). This unit, on a logarithmic scale, considers the height of a column of water that extinguishes the light emitted by a standard "candle."* (A height of 2.30 cm that extinguishes the candle image represents 1000 JTU.) Though difficult to interpret ecologically, this scale of turbidity measurement is useful mainly in comparing different sites or times.

A common and sounder measurement of turbidity is the *extinction coefficient:*

$$E = 2.30 \log(I_o/I_d)/d, \qquad (4)$$

where $E$ is the extinction coefficient, $d$ is the depth at which the measurement is taken, $I_d$ is the light intensity at that depth, and $I_o$ is the light intensity at zero depth, or just below the surface. (Use table D.2 in Appendix D to obtain logarithms.) This coefficient may be measured with a waterproof light meter lowered to the desired depths. Ideally, these measurements should be taken at about the same time of day and under fairly clear skies. The extinction coefficient is a measure of the amount of light absorbed per unit depth of the water, and can therefore be related easily to the photosynthetic potential of that body of water.

A second method for measuring turbidity uses a colorimeter or a spectrophotometer. A water sample is shaken well to avoid settling and is placed in a colorimeter tube to its marked level. The percent transmittance ($T$) is compared to that of distilled water. The wavelength of the spectrophotometer is set at 450 nm, since this blue-green wavelength is an optimal one for photosynthesis. (Most of the light at the other photosynthetically optimal wavelength of 650 nm in the red-orange region is rapidly absorbed by water and thus has little role in photosynthesis below the first meter of depth.) Since the percent transmittance is $100(I_d/I_o)$, an extinction coefficient may be estimated by substituting $100/T$ for $(I_o/I_d)$ in equation 4; the value of $d$ represents the inside diameter or light path distance of the colorimeter tube. Since artificial white light or a specific wavelength is being used, the extinction coefficient will not be identical to that of a direct field measurement given above, which employs sunlight.

A third, but more subjective, method of turbidity mea-

* This refers to luminous intensity as described in section 2C.4.1.

surement uses the *Secchi disc*. This is a metal disc having four quadrants, two opposing ones painted black and the other two either white or unpainted. The disc is suspended from the center by a cord or chain and is usually lowered from a boat into the water. It is lowered slowly until no longer visible; the depth at this point is recorded. The disc is lowered further and then slowly raised until it just becomes visible; then the depth at this point is recorded. Calculate the mean of these two determinations and repeat the procedure at a few other locations. This method is a quick and easy method for relative comparisons of degrees of light penetration, but exercise care when interpreting the results since the method is difficult to standardize between individual observers and between different overhead light conditions.

**3.4. Conductivity** The inverse of electrical resistance, *conductivity,* is another useful physical measurement in aquatic habitats. The greater the conductivity, the greater the amount of ions in the water. Thus conductivity is an indirect measure of salinity, which reflects the osmotic concentration of solutes. And osmotic concentration is an important physical property of water related to the water and salt balance of organisms. Since polluted waters have a higher conductivity than natural waters, this measure is often used as an index of pollution. The unit of conductivity is mho/cm and represents the amount of current that can be conducted between two electrodes one centimeter apart. Commercial conductivity meters are convenient, but you may also use a standard resistance test meter with platinum electrodes spaced one centimeter apart. Since conductivity is dependent on temperature, a correction for this variable must be made. See section 2F.5 for details on measuring conductivity.

## 4. Biological components

Biological components in aquatic environments are not as important as physical and chemical factors for rapid habitat descriptions in the field. Unlike terrestrial habitats, where plants dominate the community and strongly influence the physical environment (see section 2B), aquatic habitats are less conspicuously affected by organisms. Their effect is largely on the concentrations of dissolved nutrients and gases. Here, the task of the ecologist is sample taking and quantitative tabulation of the more common plant and animal forms (see section 3E). Except in ponds, marshes, and swamps, most aquatic plants are suspended algae and make up the part of the community termed *phytoplankton*. Enumeration of certain "indicator" species is common practice in water pollution studies (see section 5.1 below).

In the littoral zone of most ponds and marshes, and often along river edges, a well-developed pattern of vegetation occurs, described as free-floating plants (duckweeds), rooted floating plants (pond lilies), submerged plants (stoneworts, hornworts), and emergent plants (arrowweed, sedges, rushes, and cattails).

## 5. Water pollution

Few bodies of water remain free of human contamination. Contaminants, or pollutants, have drastically altered the ecology of many lakes and streams. Therefore some measure of the degree of pollution should be included in an aquatic habitat description.

Some pollution involves introduction of excess amounts of naturally present substances (organic matter, nitrates, phosphates). Other pollutants (most pesticides) are substances foreign to natural habitats. The major sources of pollution are: *industrial* (chemical, organic, and thermal wastes), *municipal* (largely sewage consisting of human wastes, other organic wastes, and detergents), and *agricultural* (animal wastes, pesticides, and fertilizers). Different sorts of pollution may have vastly different effects on an ecosystem. For example, some characteristics of organically polluted waters include low dissolved oxygen, high biochemical oxygen demand (BOD), high turbidity, and high concentrations of such nutrients as phosphates, nitrates, and ammonia. However, acid mine drainage may be associated with water that is rich in oxygen, clear, low in nutrients, and low in organic carbon, and if introduced into the above waters could have devastating ecological effects.

**5.1. Biological Indicators** Some organisms serve as indicators of organically or nutrient enriched waters, such as fecal coliform bacteria, "blooms" of blue-green algae, sludge worms (Tubificidae), and the so-called rat-tailed maggots of some syrphid flies. Organisms not present in such an environment are either intolerant of it or depend for food on organisms intolerant of it. Indicator organisms are described by Gaufin (1973), Goodnight (1973), Hart and Fuller (1974), Palmer (1962, 1969), and Patrick (1973). These authors, as well as Warren (1971) and Wilber (1969), discuss the use and misuse of indicator organisms in water pollution studies. Often the greater the density of these organisms the greater the degree of organic pollution. Also, biological indicators can signal the occurrence of pollution even if the pollutant is temporarily absent at the time of measurement.

However, be cautious about conclusions drawn from the presence or absence of indicator organisms. The presence of a pollution-tolerant species is not always an indication of pollution since these species occur naturally under less disturbed conditions. Likewise, the absence of such clean water forms such as stonefly naiads, mayfly naiads, caddisfly larvae, or damselfly naiads may be due to habitat conditions other than pollution. Also, organisms that indicate specific types of pollution may differ in different geographic regions or different types of habitats. Differences between the species composition of two

areas can be quantitatively measured (see section 5C).

**5.2. Species Diversity** A popular comparative measure of water pollution and other habitat disturbances is the species diversity index (Wilhm, 1967; Wilhm and Dorris, 1968) (see section 5B). In general, the more polluted a body of water the lower is the diversity index, but the use of such an index is difficult to standardize because a variety of factors other than pollution will affect it. The use of artificial substrate samplers (section 3E.2.5) helps alleviate many standardization problems.

A rapid and very simple method has been used (Cairns et al., 1968) to obtain a relative measure of diversity without requiring any taxonomic knowledge. Mix thoroughly the collection of organisms by shaking them in a container of water or preservative, and then examine them, one at a time, *at random*. (A subsample from a suspension may be placed on a microscope slide and the slide examined systematically, from left to right, from top to bottom. Or, a well-mixed collection of macroinvertebrates may be placed in a shallow pan marked with lines or a grid for systematic examination.)

In examining each organism, decide only whether it looks like the previous organism examined (on the basis of shape, size, color, or other obvious characteristics). If so, it is a member of the same "run"; if not, it is said to belong to a new "run." For example, a series of organisms observed at random might look like this (where different letters depict taxa subjectively judged to be different):

$$\underline{A}\ \underline{B\ B}\ \underline{A}\ \underline{C\ C\ C}\ \underline{B}\ \underline{A\ A}\ \underline{B}\ \underline{C\ C}\ \underline{D}$$

Here, a total of 14 individuals appear in a sequence forming nine runs (a run indicated by an underline).

A *sequential comparison index* may then be expressed as:

$$\text{SCI} = \text{number of runs}/n, \qquad (5)$$

where $n$ is the number of specimens examined. For the above example,

$$\text{SCI} = 9/14 = 0.64.$$

Obviously, the greater the variety (diversity) of organisms in the collection, the higher will be the computed SCI. The greatest possible diversity would be when each individual was unlike each preceding individual (SCI = 1.0); and the lowest possible diversity would be indicated by each of the $n$ specimens being judged identical (SCI = $1/n$).

If the collection contains a large number of organisms, a performance curve (section 1A.3) may be used to determine how many individuals should be counted. Count 50 specimens and calculate the SCI; count another 50 and calculate the SCI for all 100; then proceed to the next 50, and so on. Each time a value of SCI is computed for the cumulative number of organisms, plot it. Counting may be terminated when the performance curve levels off.

The counted organisms should then be returned to the collection and the latter thoroughly mixed once again. A second SCI should be determined for that same collection in the same manner as the first. Calculate the mean of the two replicate determinations of SCI. Cairns and Dickson (1971) have found that a mean of two replicates is sufficient to analyze most ecological assemblages. For more precision, however, six to eight replicates should be obtained for each collection.

The sequential comparison index (SCI) may be transformed into a somewhat more refined index of diversity with little additional effort. While determining the SCI one can also keep track of the total number of different taxa (four in the above example), and calculate a diversity index as:

$$\text{DI} = \text{SCI} \times \text{number of taxa}. \qquad (6)$$

For the present hypothetical data,

$$\text{DI} = (0.64)(4) = 2.56.$$

Field experience has shown that "healthy" streams have DI values greater than 12.0, whereas communities in polluted habitats have DI values of 8.0 or less (Cairns and Dickson, 1971).

**5.3. Biochemical Oxygen Demand** *Biochemical oxygen demand* (BOD) is a bioassay of the amount of biodegradable organic carbon in water. Two samples of water are taken in glass-stoppered bottles. Then, the amount of dissolved oxygen is determined in one of them, as described in section 2F.6. The second sample is stored for five days at 20°C, after which its dissolved oxygen is determined. The difference in the concentration of oxygen in the original sample and the stored sample represents the amount of oxygen (in mg/l, or parts per million [ppm]) consumed by microorganisms while decomposing organic material:

$$\text{BOD} = (C_1 - C_2)/c, \qquad (7)$$

where $C_1$ and $C_2$ are the original and final dissolved oxygen concentrations, respectively, and $c$ is the dilution factor. For polluted water, the sample should be diluted 1:10 or 5:10 (resulting in $c$ values of 0.1 and 0.5, respectively), depending on the expected concentration of organic matter.

Since BOD represents a laboratory measurement, extrapolation of this value to the actual oxygen demand of a body of water is questionable. However, it has become standard procedure for comparing the relative amounts of organic enrichment of streams, lakes, or waste waters. In nature BOD may range from a trace to 5 ppm oxygen consumed over a five-day period. Ten to 20 ppm oxygen would indicate a high level of organic pollution, and some waste waters may have BOD values over 100 ppm.

Measurement of BOD can be biased by free chlorine in the water, supersaturation of oxygen, large concentrations of acids or bases, reduced inorganic compounds in the water (sulfide, sulfite, ammonia, nitrite), and reduced iron. The type of available microorganisms can also affect the results.

**5.4. Physical and Chemical Factors** Biological indicators, diversity indices, and bioassays do not reveal the exact identity of pollutants. For this, a chemical and physical analysis of the water should be made. The chemical analyses of section 2F can determine pollutant quantities.

In habitats where nutrient enrichment is suspected of causing algal blooms, phosphate and nitrate concentrations should be determined. However, if the algal bloom is far advanced, most of the soluble nutrients would be in the algal biomass and an analysis of soluble phosphate and nitrate may reveal low concentrations. Salt contamination, if suspected, is determined from measurement of conductivity and an analysis of chlorides. And acid mine drainage is indicated if results show a low *p*H and high amounts of sulfates.

Low values of dissolved oxygen when accompanied by a high BOD will often result in greater concentrations of ammonia. High values of BOD are also accompanied by high turbidity and conductivity. However, high turbidity and conductivity are also associated with siltation, the major contaminant in many streams, lakes, and reservoirs. But siltation will not necessarily be associated with a high BOD or low dissolved oxygen.

Thermal pollution is easily detected by measuring the temperature of various parts of a lake or stream. This form of habitat alteration, unlike that caused by siltation or organic wastes, is less visible and may have more subtle effects on the diversity, productivity, and species composition of a body of water. Slight increases in the temperature of a water body may increase the rate of nutrient cycling, alter the reproductive efficiency of certain fishes, and even encourage algal blooms.

## 6. Aquatic habitat profile

How does one use all of these seemingly disjunct pieces of data from a habitat? One can simply but confusingly graph each of the physical and chemical variables as a function of space or time, as in a temperature profile of a lake in relation to depth. Such illustrations are useful for evaluation of individual physical and chemical variables, but one generally needs a holistic impression of the habitat. Kaill and Frey (1973) have attempted to summarize habitat data into an environmental profile, based on measurements taken at dawn and dusk. The following procedure, while using a lake as the example, may also be applied to streams and terrestrial habitats. In the latter case, use physical and chemical soil data and atmospheric measurements.

To prepare an environmental profile, construct a histogram of the measured variables for each ecological situation (location or time) being studied (figure 2E.3). In

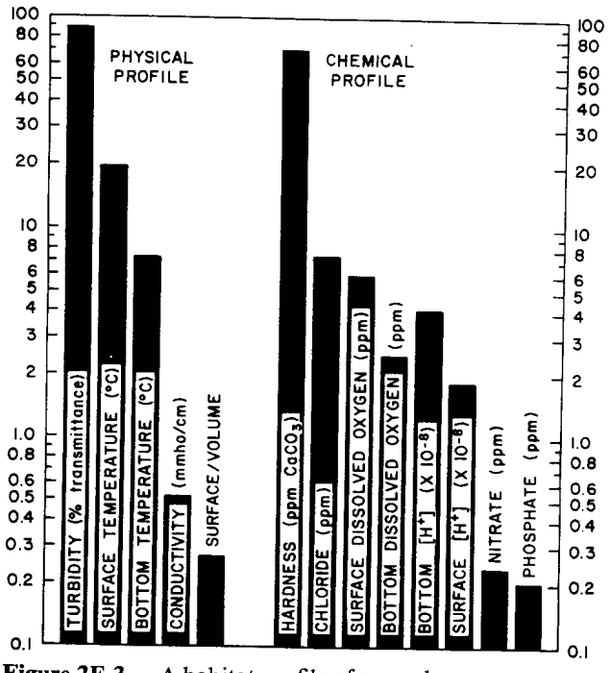


**Figure 2E.3.** A habitat profile of a pond.

these histograms the logarithm of the value is plotted on the vertical axis, and the environmental factors are sequenced along the horizontal axis. (Commercially available 3- or 4-cycle semilogarithmic graph paper is very convenient for this purpose.) The logarithmic scale is used so that very small and very large numbers may be placed on the same graph. The order of the environmental variables is arbitrary but should be consistent from one profile to another. For convenience physical measurements may be placed together and chemical determinations grouped together. (Biotic measures, such as abundance and species diversity, are not included in a habitat profile.)

Since the extinction coefficient is a logarithm, it is convenient to graph the percent transmittance instead. The plotting of *p*H presents a problem since this variable normally falls in a very narrow range of 6.5 to 8.5. Thus a small but important difference would appear insignificant on the graph, so it is recommended that *p*H be converted to the hydrogen ion concentration $[H^+]$:

$$pH = \log (1/[H^+]); \qquad (8)$$

therefore,

$$[H^+] = 1/(\text{antilog } pH). \qquad (9)$$

Logarithms and antilogarithms may be obtained from table D.1 in Appendix D. For example, if the *p*H of a water sample was 7.62, we would use equation 9 to compute:

$$[H^+] = 1/(\text{antilog } 7.62)$$
$$= 1/(4.17 \times 10^{7})$$
$$= 0.240 \times 10^{-7} \text{ or } 2.40 \times 10^{-8}.$$

The selection of units of measurement is done to allow the bars in the graph to fall within easily plotted limits. For example, conductivity values less than 0.1 mmho/cm may be plotted as $\mu$mho/cm; hardness values exceeding 100 ppm $CaCO_3$ may be plotted as ppm $\times 10^{-2}$. Acidity is represented as $[H^+] \times 10^{-8}$ (so a *p*H of 8 would appear on the profile graph as 1, a *p*H of 7 would appear as 10, a *p*H of 6 as 100, and so on).

Measurements such as temperature, turbidity, conductivity, dissolved oxygen, and *p*H should be made near the surface and near the bottom of a lake, and both surface and bottom values should be graphed. The measurement of these variables only near the surface can lead to a poor representation of the lake.

## 7. Suggested exercises

1. Compare the habitat profiles of two different ponds, lakes, or streams. Explain the differences between the physical and chemical variables observed.
2. Compare the habitat profiles of a polluted and an unpolluted body of water.
3. Compare the habitat profile of a riffle and a pool in a stream.
4. Select environmental variables such as temperature, turbidity, and oxygen, and determine the profile of these as a function of depth in a lake or pond (see figure 2E.2).
5. Sample a polluted stream, both upstream and downstream from the source of contamination, attempting to sample in habitats with similar currents, depths, and substrates. Identify the major taxa of algae or benthic invertebrates and note the relative abundances of typical clean-water or polluted-water taxa.
6. In a stream pollution study such as above, calculate a measure of taxonomic diversity at each sampling location. Determine how this changes with distance from the source of contamination.

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