LABORATORY 43

Communities and Ecosystems

OVERVIEW

Two of the most complex levels in the hierarchy of biological organization are the community and the ecosystem. A **community** consists of all the populations of species living within a particular locality. An **ecosystem** consists of one or more related communities plus the abiotic (nonliving) components that affect them, such as weather conditions and the type of soil present. Ecosystems may be large or small, with the boundaries variously defined. The earth can be considered a single ecosystem, as can a mountain valley or a fishtank in your laboratory. Ecosystems display characteristics other than those contributed by their separate components. Thus ecosystems are often studied in terms of their processes or products rather than by dissecting out the effects of particular organisms or other factors.

The nature of a geographically defined ecosystem is partly determined by its location and the biome with which it is associated. **Biomes** are geographic areas of the earth defined by dominant vegetation types that result from distinct patterns of rainfall and temperature.

During this laboratory period, you will study three factors important to understanding communities and ecosystems: **competition** among species sharing resources; **diversity,** the relative abundance of different types of organisms; and the relationship of **abiotic factors,** such as weather conditions, to particular types of biomes.

STUDENT PREPARATION

Prepare for this laboratory by reading the text pages indicated by your instructor. Familiarizing yourself in advance with the information and procedures covered in this laboratory will give you a better understanding of the material and improve your efficiency.

EXERCISE A Observing Competition Between Species Sharing Resources

In a community, competition may take place among species sharing resources, particularly when these resources are in short supply relative to the demands of the organisms. In this exercise, you will observe competition between two species of *Paramecium* growing in mixed cultures.

If a species exhibits normal growth in a pure culture, but does not grow as well when another species is introduced, this negative effect is the result of competition. One possible outcome of competition is that both species will coexist, but at lowered densities; a second possible outcome is that one of the two species will become extinct. Extinction due to the effects of competition is called **competitive exclusion.**

Objectives

- ☐ Observe the effect of competition between two species of *Paramecium* by comparing their relative abundance over time in pure cultures and in mixed cultures.

Procedure

Three sets of *Paramecium* cultures have been prepared: the first set is one week old, the second set is two weeks old, and the third set is three weeks old. Within each set, cultures are labeled for the species of *Paramecium* they contain. Culture A contains only *Paramecium aurelia;* culture B, only *Paramecium caudatum;* culture C contains both species.

P. aurelia and *P. caudatum* can easily be distinguished using high power (40×) on your light microscope. *P. caudatum* is at least twice the size of *P. aurelia* and has a strikingly large macronucleus.

Work in groups of three students. Each student in the group should select one set of cultures of a certain age. Enter the age (number of weeks cultured) of your culture in Table 43A-1. Follow the steps below to take density estimates and record data.

Table 43A-1 Raw Data for ______ Week-Old Culture

	Number of Organisms in 0.01 ml of Culture Medium		
	(A) *P. aurelia*	(B) *P. caudatum*	(C) *P. caudatum/P. aurelia*
Sample 1			/
Sample 2			/
Average			/

1. To estimate the densities of the species in each culture flask, take two samples using a capillary tube (or micropipette, if available) at a point just above the bottom of the culture flask. The capillary tube will deliver a drop of culture (volume approximately 0.01 ml) that should *not* be larger than the microscope's field of view at high power (40×). Place a drop of your *P. caudatum* culture on a slide (without a coverslip). Count the number of *P. caudatum* within your field of view and record this number in Table 43A-1 as sample 1.
2. Take a fresh drop from the same culture and repeat this procedure. Record your count in Table 43A-1 as sample 2.
3. Repeat steps 1 and 2 first for the *P. aurelia* culture and then for the mixed species culture in your set. In the mixed culture, you will need to count the number of individuals of each species separately.
4. Record the average of your two samples from each culture in Table 43A-1.
5. Enter the starting densities (given to you by your instructor) for the three sets of cultures in Table 43A-2.
6. Enter your averages for each culture in the data table that your instructor has placed on the blackboard. Calculate grand averages for your cultures: add all the average values obtained for these cultures (of the same age) by all students, then divide the sum by the number of students supplying data. Enter the grand averages in Table 43A-2.
7. Obtain the grand averages for the cultures of the other two ages from the class data table and record them in Table 43A-2. When you have completed this table, analyze the results of the competition experiment by answering the following questions.

Table 43A-2 Density Estimates: Summary of Data for Entire Class

	Grand Average Number of Organisms in 0.01 ml of Culture Medium			
	Starting Density	One Week	Two Weeks	Three Weeks
P. aurelia (pure)				
P. caudatum (pure)				
Mixed culture: *P. caudatum*				
P. aurelia				

a. Which species living in pure culture showed the greatest increase in numbers during the three weeks? ________________

b. How was this growth rate (change in number per unit of time) affected by the presence of a competitor? ________________

c. Based on your experimental results, what do you predict will be the final outcome of competition in the mixed culture? (Or, if you have already seen extinction of one species, which one became extinct?) ________________

8. On a separate sheet of paper, make a line graph to show the class data for the effects of species competition over time. Label the horizontal *X*-axis "time (weeks)"; label the vertical *Y*-axis "number of organisms." Draw one line representing class data for the pure *P. caudatum* culture over the three-week period; draw another for the pure *P. aurelia* culture. Draw one line each for *P. caudatum* and *P. aurelia* growing in a mixed culture.

EXERCISE B Measuring the Diversity of a Community

One way of gaining an understanding of a community's structure is to measure its diversity. Diversity is a measure of how many kinds of organisms (numbers of species) and how many of each of these kinds (numbers of individuals) are present in a community. You can calculate a numerical value called a **diversity index** (also known as the Shannon index) from information obtained by taking quantitative samples of organisms from a community. To specify community diversity, this index takes into account both the kinds and the numbers of organisms present. The diversity index can be used to compare the ways in which various communities are structured.

Objectives

- ☐ Estimate the diversity of a community of organisms using a diversity index.

Procedure

Leaf litter from a forest, a woodland, or a riparian environment (an area along a river or stream bank) contains a variety of decomposers feeding on decaying organic material. Although the communities represented by these samples include populations of soil bacteria, fungi, and protozoans, we will, for simplicity's sake, consider only the larger organisms found in leaf litter: the invertebrates.

At some time before this laboratory period the following procedure was performed. Plastic bags containing leaf litter are emptied into a collection apparatus. Litter invertebrates, which are negatively phototactic (that is, move away from light), are forced from the collection area into the funnel by light (and also by heat) from a 100-watt bulb. From the funnel they drop into the Erlenmeyer flask below. Alcohol in the flask both kills and preserves these invertebrates for viewing under the dissecting microscope.

Work in groups of four. Your instructor will supply each of you with a sample of invertebrates from a different environment.

1. Identify each organism in your sample according to its taxonomic class. Your instructor will provide you with sketches of representative organisms of the kinds you might expect to find (see Table 43B-1). The following characteristics should prove helpful in distinguishing invertebrates in leaf litter.

   1. Number of pairs of antennae = 0, 1, or 2
   2. Types of eyes = simple or compound
   3. Number of pairs of wings = 0, 1, or 2
   4. Number of pairs of legs = 0, 6, 8, or more than 8
   5. External organization of the body.

Table 43B-1 Representative Invertebrates Found in Leaf Litter

Phylum	Class	Representative Groups
Nematoda*		Roundworms (nematodes)
Annelida	Oligochaeta	Earthworms
Mollusca	Gastropoda	Snails and slugs
Arthropoda	Insecta	Beetles, bugs, roaches, flies, bees, lice, fleas, collembolans, mosquitoes, and termites
	Arachnida	Spiders, mites, ticks, pseudoscorpions, and harvestmen (daddy longlegs and their relatives)
	Crustacea	Pill bugs and sow bugs
	Diplopoda	Millipedes
	Chilopoda	Centipedes

*Nematodes are difficult to classify. Do not attempt to do so.

2. Record your identifications in Table 43B-2. Add the information recorded by your other group members.
3. Enter your group's data on the class data chart that your instructor has placed on the blackboard. Record class data in Table 43B-3.
4. Using these data, calculate the diversity index (Shannon index), D, of each community using the following formula:

$$D = -\sum \left(\frac{n_i}{N} \times \log_{10} \frac{n_i}{N}\right)$$

The variables in this formula are as follows:

n_i The number of organisms in a given class (n_i for each class of organisms in Table 43B-3).

Table 43B-2 Invertebrates Identified by Individual Students

		Number of Organisms Collected		
Phylum	Class	Woodland	Riparian	Forest
Nematoda				
Annelida	Oligochaeta			
Mollusca	Gastropoda			
Arthropoda	Insecta			
	Arachnida			
	Crustacea			
	Diplopoda			
	Chilopoda			
Other				

Table 43B-3 Class Data for All Invertebrates Collected

		Number of Organisms Collected		
Phylum	Class	Woodland (n_i)	Riparian (n_i)	Forest (n_i)
Nematoda				
Annelida	Oligochaeta			
Mollusca	Gastropoda			
Arthropoda	Insecta			
	Arachnida			
	Crustacea			
	Diplopoda			
	Chilopoda			
Other				
Total (N)				

N The total number of organisms in the sample for the community (N for each community in Table 43B-3).

Σ This symbol, sigma, indicates that you must sum (add) all the expressions in brackets. (If there are four classes of invertebrates in a sample, you will add four terms.) This sum will be a negative number. You must multiply by the minus sign that precedes the sigma to get a positive number for the value of diversity, D. The larger the value of D, the greater is the diversity of the community.

For example, if 20 organisms from leaf litter of the woodland habitat were sampled and found to belong to four classes—8 from one class, 3 from a second, 5 from a third, and 4 from the fourth—then the calculation for diversity of the woodland community would be set up as follows:

$$D = -\left[\left(\frac{8}{20} \times \log_{10}\frac{8}{20}\right) + \left(\frac{3}{20} \times \log_{10}\frac{3}{10}\right) + \left(\frac{5}{20} \times \log_{10}\frac{5}{20}\right) + \left(\frac{4}{20} \times \log_{10}\frac{4}{20}\right)\right]$$

5. Calculate a diversity index for each of the three environments in the space below. Rank the environments, from most diverse to least diverse, using the diversity index, *D*.

a. From the terms in your calculation of the diversity index for each community, which class of invertebrates contributed most to the diversity of the sample? Woodland ______; riparian ______; forest ______.

Which contributed least? Woodland ______; riparian ______; forest ______.

b. Which environment had the greatest number of classes? ______

The least number of classes? ______

c. Which environment had the greatest number of organisms? ______

The least number of organisms? ______

d. What are some differences in the physical conditions of the environments, for example, moisture, temperature, light, and humidity, that might have accounted for the differences in diversity among the leaf-litter communities? ______

During the process of succession, the diversity of an ecosystem and its communities increases as the ecosystem approaches its climax (equilibrium stage in which the community is typical of the biome rather than of a stage in biome development). More simply stated, as an ecosystem matures, it becomes more diverse.

e. Which of the sampled environments represents the most mature ecosystem? ______

EXERCISE C Using Climate Data as an Index to Vegetation

Climate is one of the major determinants of the kind of vegetation that grows in a particular region of the earth. The type of vegetation, in turn, determines what animal life is present. Two important climatic factors that govern the distribution of biomes are temperature and rainfall. Each biome has a characteristic pattern of temperature and rainfall. In fact, you can predict the type of vegetation found in a region from monthly temperature and rainfall data.

Sample data from a weather station are shown in Figure 43C-1a. Temperature and rainfall data are more adequately displayed in a graph called a *climatogram* (Figure 43C-1b), where each point represents average temperature and average rainfall for a given month.

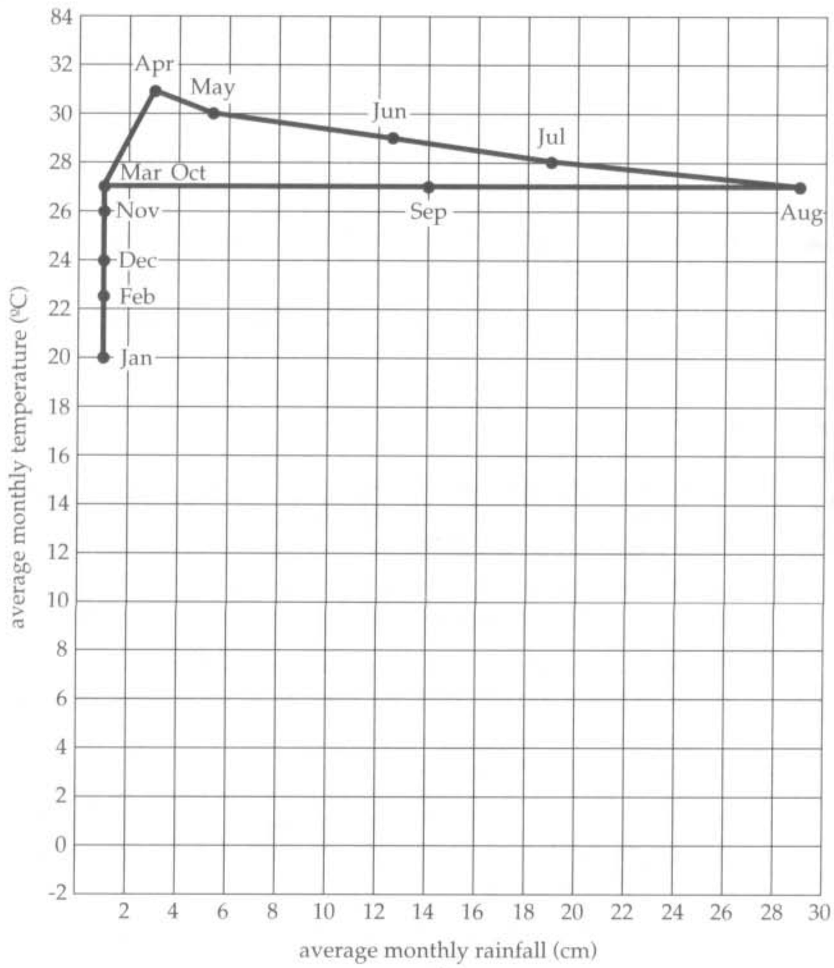
Objectives

- ☐ Predict the biome within which a geographic location lies, based on weather data.

	Station: Kano, Nigeria (Africa)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly rainfall (cm)	1	1	1	3	5.5	12.5	19	29	14	1	1	1
Average monthly temperature (degrees Celsius)	20	22.5	27	31	30	29	28	27	27	27	26	24

(a)

Figure 43C-1 *(a) Sample weather station data. (b) Climatogram graphing weather station data.*



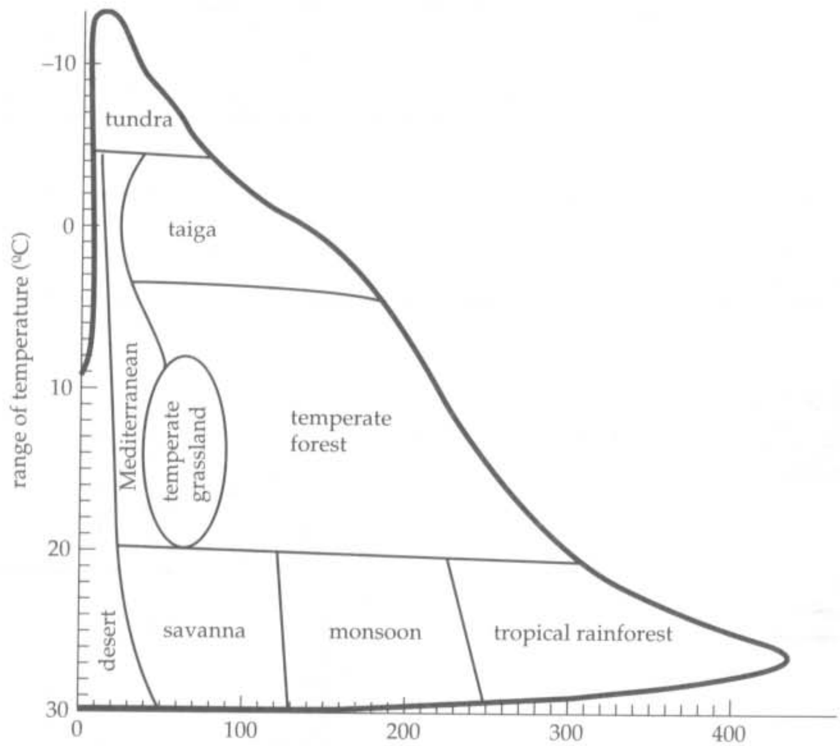
(b)

Procedure

Your instructor will provide you with a handout of weather data for one or more cities.

1. Compute the total annual rainfall for the city by summing the 12 monthly averages given in the handout table.
2. Record the extremes of monthly average temperature that occur in the city.
3. Locate and mark the total annual rainfall of the city along the horizontal axis of the graph in Figure 43C-1b. Locate and mark the two temperature extremes along the vertical axis. Above the annual rainfall mark on the horizontal axis, draw a vertical line between the two temperature extremes. The area of the graph onto which this line falls indicates the biome in which your city lies. Biome: ______________________________

Figure 43C-2 *Composite climatogram, showing biomes.*



4. Now locate the city on a world map and note its longitude and latitude to the nearest degree: longitude ______; latitude ______.
5. Locate the city on the world biome map on the demonstration table. Which biome is indicated? Does this agree with your result in step 3?
6. If time allows, plot a climatogram on a separate sheet of graph paper, using the weather data given in the handout and the sample climatogram of Figure 43C-1b as a guide. Plot the temperature versus rainfall for each month and connect the points on your graph in sequence (January, February, and so on).
7. Repeat steps 1–6 for each city on the lab handout. Referring to the weather data for all the cities you located on the maps, or their climatograms (if you have done them), answer the following questions.

   a. Which of the cities reports the greatest annual extremes in average monthly rainfall?

   ______________ *b. What specific adaptations would plants in this biome exhibit? What adaptations must animals make to such extreme annual conditions?*

   ____

   c. Which of the cities has both the hottest and driest conditions throughout the year?

   ______________ *d. What biological adaptations would be found in this biome?*

   ____

   e. Which biome has the greatest temperature change from one month to another?

   ______________ *f. What changes in the life cycles of plants and animals would you expect at this time of year?* ______________

   ____

Laboratory Review Questions and Problems

1. If the habitat occupied by two competing organisms is made more complex (in the case of the *Paramecium* cultures, capillary tubes, broken into small sections, could be added to the culture), what changes might occur in the competitive interactions of the species? Why?

2. If you were studying a community, would you be more likely to find competitive interactions among more closely related or less closely related species? Why?

3. The overall diversity of a community tends to increase as the community passes through stages of succession toward its stable climax state. Can you explain why this happens?

4. As you travel from the equator to the poles, community diversity declines. What happens to temperature, rainfall, light, and other environmental variables along this geographic transect? In relation to your answer to this question, why does diversity decline?

5. If you began at the base of a tall mountain situated near the equator, what changes would you see in community structure as you climbed that mountain? Can you predict what types of biomes you might traverse during your climb?

6. How might the following factors affect community structure and diversity?

   Photoperiod (length of the day)

   Exposure (north-facing or south-facing slope)

   Location in relation to mountains (on the windward or lee side)

Wind velocity

Partial pressure of gases along an altitudinal gradient

Permanently frozen substratum (permafrost)

Ultraviolet (UV) radiation

Ionizing radiation (cosmic rays, etc.), both natural and the product of human activities

Soil type and texture