Chapter 8

Energetics of an Aquatic Ecosystem

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Introduction

This is a laboratory activity for university general biology which develops fundamental concepts of energy flow through an aquatic ecosystem. The investigation can be carried out in a classroom laboratory using stocked aquaria, or in almost any natural pond or marsh. Although it is designed for an introductory biology course, it could also be used in ecology or aquatic biology by collecting more extensive data and further quantifying observations.

This investigation is unique in that there are typically few ecologically-oriented activities in commercial laboratory manuals, and even fewer which develop basic concepts in ecosystem energetics. This investigation also represents direct student experience and training in science inquiry processes.

The objectives of this activity are as follows:

1. The student will define: **ecosystem, energy pyramid, food chain, food web, abiotic factors, producer, trophic level,** and **entropy.**
2. The student will identify important abiotic factors in an ecosystem and explain how these factors affect the community.
3. The student will construct an energy pyramid, food chain, and food web for an aquatic ecosystem, given the names and relative numbers of familiar organisms in this ecosystem.
4. The student will explain what energy concepts are represented by a food web and energy pyramid.

The time required for preparation of this activity will depend upon whether a natural pond is conveniently available as a data source. In most universities, transporting large numbers of general biology students to a local pond is likely to be awkward and expensive. Also, the climate in many areas of the country renders natural ponds inaccessible or difficult to sample. If students are taken to a pond the only preparation necessary is gathering the collecting and sampling equipment. If you wish to conduct the activity in a classroom laboratory there are two options. One is to order from a supply house the necessary live organisms and stock a large aquarium in each laboratory to be used. The maximum time needed for preparing and balancing the aquarium will be 4–5 hours. The second option is to stock aquaria with organisms from a local pond. In this case you will need to allocate the time needed to bring several gallons of pond water per aquarium to the laboratory.

Student Materials

Background

An ecosystem is a specific group of organisms and their physical environment which interact with each other. Many ecosystems consist of a community of organisms living in a similar environment, such as a forest, grassland, or pond. Most ecosystems are self-sustaining, and can be relatively independent of other organisms in other ecosystems. Every ecosystem has a multitude of dynamic interactions related to the organisms' homes and sources of energy. A consideration of these interactions is especially important because, although the ecosystem itself is independent of other systems, most organisms *within* an ecosystem are interdependent.

It can be argued that the Earth itself is an ecosystem because it receives no matter from the rest of the universe, is self-sustaining, and interdependent (all earthly organisms are ultimately dependent on others for their survival). One can also argue that an aquarium is an ecosystem. Most aquaria, of course, are not independent and self-sustaining. But aquaria which have the correct balance and variety of producers and consumers can sustain themselves for relatively long periods of time.

An aquarium has been specially prepared or a pond selected for this investigation. Through careful selection of the organisms for this environment, an attempt has been made to have it represent a natural ecosystem. If an aquarium is used as a facsimile, you should assume for this investigation that it meets all the requirements of an ecosystem.

Materials

Natural pond with a variety of organisms *or* an aquarium (at least 10–gallon) containing a variety of primary producers and consumers at different trophic levels.

Microscope; slide; coverslips; Pasteur pipette; light meter; meter stick; Celsius thermometer.

If a pond is used: sampling materials such as a seine, hip waders, tape measure and collecting jars.

Vocabulary

You will need to know the following terms before you proceed further:

ECOSYSTEM (defined above)

COMMUNITY All the organisms in an ecosystem

ABIOTIC The physical conditions (light, soil, temperature, etc.)—nonliving components

PRIMARY PRODUCER Photosynthetic plant, autotroph

PRIMARY CONSUMER Plant-eater, herbivore

SECONDARY CONSUMER Animal-eater, carnivore

DECOMPOSER Consumer which reduces decaying organisms to smaller particles, recycles organic debris

BIOMASS Weight of *living* matter, in grams or kilograms

TROPHIC LEVEL Position of food source for an organism in a food pyramid

Procedures

I. Abiotic Factors

A. Measure the water temperature in degrees Celsius. ________

B. Describe the physical objects in the ecosystem (and surroundings if a pond). ________

____

____

____

C. Estimate the average dimensions of the ecosystem in meters (or fractions of a meter):

Width ______ m Length ______ m Height ______ m

Surface area (WxL) = ______ m^2 Volume (WxLxH) = ______ m^3

D. Measure the light intensity falling upon the surface of the water. Use a light meter which measures in footcandles. A footcandle (ft-c) is the amount of light energy falling on one square foot from one standard candle at a distance of one foot. A typical office or laboratory with fluorescent lighting will have about 50 ft-c at desk level, and direct sunlight on a clear day at noon will generate about 10,000 ft-c at the surface of the ground.

Take readings at three different sections of the water surface and average your readings.

______ ft-c ______ ft-c ______ ft-c ______ ft-c
sample 1 sample 2 sample 3 AVERAGE

E. Describe the movement and aeration of the water. ________

____

____

____

____

II. Macrobiotic Community

Your laboratory instructor will place on the board the common names of all species in the ecosystem which can easily be seen with the unaided eye. Locate each species in the ecosystem and notice its relative abundance. List each species in Table 8.1, describe its appearance, and indicate its relative numbers with a word such as abundant, many, some, few, or rare. If you can easily count the total number of organisms, record that number instead.

Table 8.1. Macrobiotic community

NAME	*DESCRIPTION*	*RELATIVE NUMBER*

III. Microbiotic Community

You are likely to observe four types of microorganisms: 1) *phytoplankton* (single- or several-celled green organisms which generally do not move about); 2) *zooplankton* (single- or several-celled organisms lacking pigment which generally move about); 3) *worms* (multicellular wormlike organisms); 4) *arthropods* (insects or crustaceans which have noticeable eyes and legs and scurry about).

Using a pipette, take a one-drop sample from near the surface and examine it under the microscope. Do not attempt to identify the specific name of any organism. Instead, determine which of the above four groups it belongs to. List the organisms on Table 8.2 as you did for the macrobiotic community on Table 8.1. Assign a subnumber to each different organism observed. (For example, assign P1 to the first single-celled green organism observed. A new and quite different green microbe would be given the number P2. The first new organism of the zooplankton group would be given the identity Z1, and so on.) Repeat the sampling procedure at the middle of the aquarium or pond and again near the bottom. Taking two more one-drop samples (replicates) from two other areas at each of the top, middle, and bottom levels of the aquarium or pond, record these results also.

IV. Data Analysis

A. Which of the categories from the microbiotic community would be the ones which photosynthesize? ______________________

____

What can you likely assume about the ecological role of the organisms which photosynthesize? ______________________

____

Which term from the vocabulary list best applies to the above organisms?

____

B. Fig. 8.1 is a model of some common energy relationships in an ecosystem. This is frequently called an *energy pyramid* and is divided into three trophic levels. Place the name (or code name) of each organism from Tables 8.1 and 8.2 into the box in Fig. 8.1 which represents the trophic level of that organism. Include with the name the word or number you used to describe its relative numbers in the ecosystem.

C. You will recall that the energy pyramid is drawn as a series of boxes stacked upon one another. You will also recall that each box is smaller than the one below it, thus creating an overall pyramid-like

LEVEL	*SAMPLE*	*CODE*	*DESCRIPTION*	*RELATIVE #'s*
SURFACE	1			
	2			
	3			
MIDDEPTH	1			
	2			
	3			
BOTTOM	1			
	2			
	3			

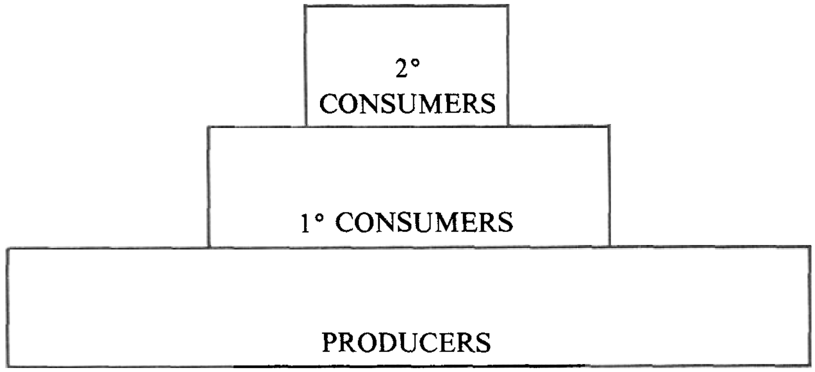

Figure 8.1. A simple food pyramid

structure. The sizes of these boxes indicate the relative biomass of all organisms at each level. Examine the relative numbers you entered for each trophic level in Fig. 8.1. Assume that numbers and biomass are closely related.

1. Do the sizes of the boxes correspond to your perception of the *total* biomass at each level? ____________________

   ____

2. If you answered "yes", explain why this is apparent. If you answered "no", explain the differences in proportions between the model and your data and why this might occur. ____________

   ____

   ____

   ____

   ____

D. Using *one* organism from each of the trophic levels, construct a likely food chain. A food chain shows the order in which one organism consumes another with an arrow between each pair of organisms in the direction of the consumer.

E. Study the food web (Fig. 8.2) for an entirely different ecosystem. Note that the web shows many different possible trophic relationships among organisms.

F. You may have noticed that Fig. 8.2 included a group of organisms called *decomposers*. These organisms are mostly bacteria and fungi and they feed on decaying organisms. Decomposers consume most

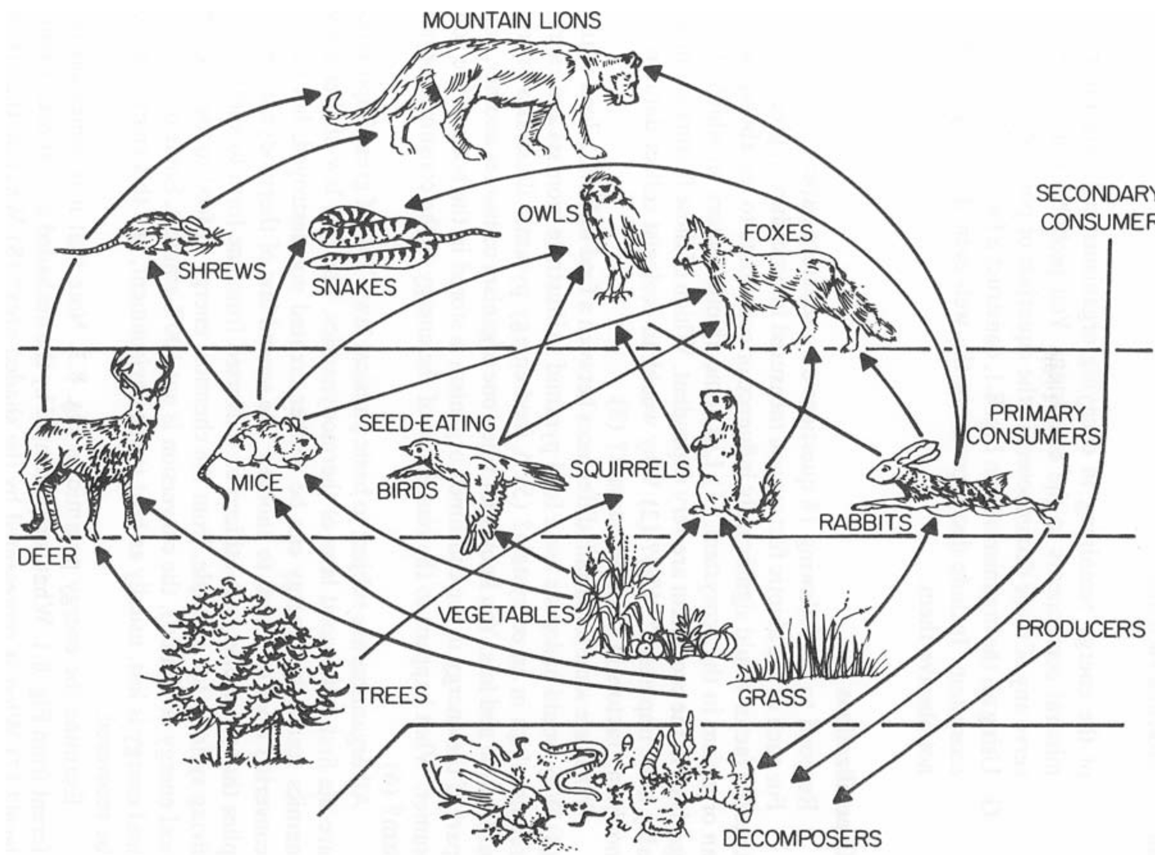

Figure 8.2. An example of a simple food web.

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of the energy remaining in decaying organisms and help return mineral components to the ecosystem. You probably did not observe any of these decomposers in the aquarium or pond. Why not?

G. Using all the organisms from Fig. 8.1, construct a food web for your ecosystem. Include decomposers in the web even though you did not observe them.

Generalizations

Respond to the following 18 questions on a separate paper.

For each of the abiotic factors you measured in procedure 1, give one way that the factor would significantly influence or contribute to the abundance of an organism in the ecosystem. (1) List some abiotic factors on which all organisms in the ecosystem are very dependent. Which of these factors are probably most important? Why? (2) Why would an ecologist collect data on the nonliving factors in the environment? (3)

What are some important differences between a food web and a food chain? (4) Why would biologists use a food pyramid to illustrate biomass and energy relationships in an ecosystem? (5) A food-energy pyramid illustrates energy utilization and loss. You know that when one organism consumes another, only part of the energy in the consumed organism is stored in the body of the consumer. What happens to the remainder of the energy in the consumed organism? (6)

All organisms are subject to basic physical laws. Two of great importance are the first and second laws of thermodynamics. The first law of thermodynamics states that energy can be neither created nor destroyed, but can be converted from one form to another. The second law of thermodynamics implies that when energy is utilized or converted from one form to another in a living system (for example, from the chemical energy of food to the mechanical energy of motion), the conversion is not 100% efficient. Some of the original energy is lost, usually as heat to the environment, and this energy cannot be recovered.

Examine the energy pyramid in Fig. 8.3. Note that it is somewhat different from Fig. 8.1. What is represented by the unshaded area at each trophic level? (7) What is represented by the shaded area? (8) What do the arrows represent? (9) How does Figure 8.3 illustrate the first law of thermodynamics? (10) How does Figure 8.3 illustrate the second law of thermodynamics? (11)

Entropy is a measure of disorder. The second law of thermodynamics states that entropy tends to increase when energy is converted from one form to another. Biologists often use this principle to help explain an energy pyramid. Using what you have learned about energy, entropy, and trophic levels, write

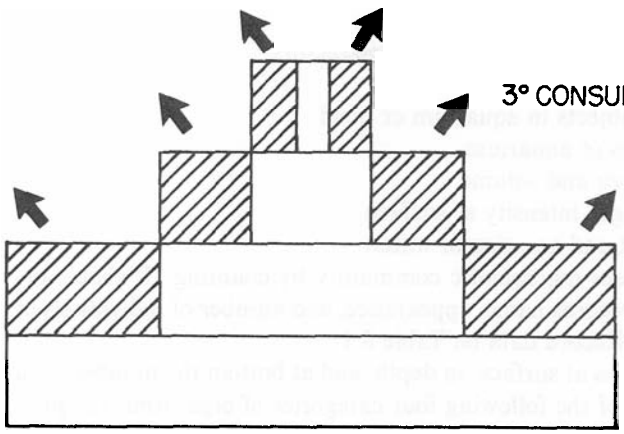

Figure 8.3. An example of a food-energy pyramid.

a complete explanation of an energy pyramid. Pretend that you are explaining Fig. 8.3 to someone unfamiliar with an energy pyramid. (12)

Which organisms in the ecosystem are absolutely dependent upon some other organism? (13) Are there any organisms in the ecosystem which are not dependent upon others? Explain. (14) Suppose that an entire population of producers in your ecosystem were killed by a poison in the environment. How would their absence affect other producers? (15) How would it affect consumers? (16) How would the death of a population of dominant consumers affect the community? (17) What would be the catastrophic results of the death or absence of decomposers in the ecosystem? (18)

Instructors' Materials

Procedures

The student procedures of this activity are in four phases: Prelab Discussion, Data Collection, Data Analysis, and Generalizations. Each will be described completely in conjunction with the flow chart.

A. PRELAB DISCUSSION

Instructor discusses:

- Objectives
- Aquarium vs. Natural Ecosystem
- Sampling Techniques
- Working Definition of Species

B. DATA COLLECTION

1. Student measures and records abiotic factors:
   a. water temperature
   b. physical objects in aquarium or pond
   c. dimensions of aquarium
   d. surface area and volume
   e. average light intensity at surface
   f. movement and aeration of water.
2. Student assesses macrobiotic community by counting all visible organisms and records name, appearance, and number of individuals of each species. Record data on Table 8.1.
3. Student samples at surface, in depth, and at bottom the numbers and kinds of each of the following four categories of organisms: (a) *phytoplankton,* (b) *zooplankton,* (c) *worms,* and (d) *arthropods.* Record data and descriptions on Table 8.2.

C. DATA ANALYSIS

1. Answer Question 1: Ecological role of photosynthesizers
2. Answer Question 2: Write into food pyramid (Fig. 8.1) estimated numbers of individuals at each of these trophic levels
3. Answer Question 3a, 3b: Converting population to biomass
4. Answer Question 4: Construct probable food chain using one organism from each trophic level
5. Study food web for a forest (Fig. 8.2)
6. Answer Question 6: Role of decomposers
7. Answer Question 7: Construct a food web for all organisms in the study

D. GENERALIZATIONS

1. Answer Question 1: Effects of abiotic factors
2. Answer Question 2: Dependence upon abiotic factors
3. Answer Question 3: Importance of abiotic data
4. Answer Question 4: Differences between food web and food chain
5. Answer Question 5: Use of food pyramid
6. Answer Question 6: Heat energy loss
7. Answer Question 7: Representation of food energy in pyramid
8. Answer Question 8: Representation of heat energy loss in pyramid
9. Answer Question 9: Representation of heat lost to environment
10. Answer Question 10: First law of thermodynamics
11. Answer Question 11: Second law of thermodynamics
12. Answer Question 12: Explanation of energy pyramid
13. Answer Question 13: Absolute organism dependence
14. Answer Question 14: Organism non-dependence

15. Answer Question 15: Effects of death of population of producers upon producers
16. Answer Question 16: Effects of death of population of producers upon consumers
17. Answer Question 17: Effects of death of dominant consumers
18. Answer Question 18: Effects of death of decomposers

Materials and Preparation

1. Per group of 4 students at student lab station:
   4—plain microscope slides and coverslips
   4—Pasteur pipettes 10 cm long
   4—pipettes at least 30 cm long
   4—meter sticks
   2—thermometers (Celsius)
   2–4—light meters which read in footcandles. (The G.E. type 214 is recommended. These can be purchased from Sargent-Welch for about $40 each.)
2. IF THE ECOSYSTEM IS A STOCKED AQUARIUM IN THE CLASSROOM
   Per class of 24 at central area:
   1—large (at least 10–gallon) aquarium with appropriate filtering system containing an aquatic ecosystem

   The exact organisms are not critical, but the ecosystem should have balanced biomasses of a variety of primary producers, primary consumers, secondary and tertiary consumers, and decomposers. The aquarium should be stocked with known organisms in such quantities that student sampling will not deplete their populations. It is recommended that the bottom contain several inches of clean sand and that the water be relatively clear. A good light source is important for producer growth. Sunlight, such as from a window, is best. The ecosystem should have been established several days in order for quantities of algae to be growing on the glass sides. A relatively small number of organisms will serve as a starter culture if you add about 1 gm of Rapid Grow per gallon of water and let the culture set for a week or two (at room temperature).

   Recommended organisms for a stocked aquarium are:

   a. Primary producers: Algal cultures (*Ankistrodesmus, Scenedesmus,* etc.): Level in aquarium should be around 10,000 cells/ml. This will give the water a slight cloudiness. The cells tend to sink so you may want to try motile forms like *Chlamydomonas.* Macrophytes (*Ceratophyllum, Chara, Elodea*) can be added to the extent desired. Floating some *Lemna* on top also would be a good addition.
   b. Herbivores: Microcrustaceans (*Daphnia,* copepods): Use about 10 to 20 per l. Snails: Use around 2–3 per macrophyte strand plus 10 to 20 for the tank (fewer if snails are large). Hydrophilidae (water scav-

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engers), etc. could be used. If they are, reduce the number of snails somewhat. Metamorphosis in midge larvae can be delayed by keeping them cold until ready to use. Corixidae (water boatmen) may be used also.

c. Carnivores: Fish: Around 5 minnows such as *Notropis lutrensis* (red shiner) or fry of bluegill or crappie (keep these small). The aquarium will appear somewhat bare, but if more are used they will quickly clean out the herbivores. *Ambystoma* (tiger salamander larva) is another vertebrate which will feed on zooplankton. If one is added, remove one or two fish. Insects: Odonata (dragonfly, damselfly) larvae are good predators. Large ones will even eat small fish. Again, emergence is a problem. Other predators are the backswimmers (Notonectidae) and dytiscid beetles.
d. Others: Crayfish may be added. They are showy and fill a variety of niches (carnivores on snails; scavengers; sometimes herbivores). Bivalves could be used as a filter feeder. One to 20 may be added depending on their size. Many other types of insects could be used depending on what is available.

   Avoid the temptation to add too many large consumers because the aquarium looks empty compared to home aquaria. It may be necessary to add algae, because most filtration systems are designed to remove algae. The macrophytes and good aeration will help slow this down.

3. IF ORGANISMS ARE OBTAINED FROM A LOCAL POND

   In many cases it will be much easier to bring "a pond" to the students rather than take students to a pond. The pond environment could then be set up in the laboratory classroom and would result in a much wider variety of organisms than could be afforded from a biological supply company. "Gaps" in the pond collection could be purchased commercially. Using fresh pond samples to stock the aquarium also has the advantage that students consider the ecosystem to be more real instead of simulated. If you have a local ecosystem from which you can collect your samples, consult Appendix A, "Suggestions on Sampling a Local Pond Ecosystem."

4. IF THE ECOSYSTEM IS A NATURAL POND VISITED BY THE STUDENTS

   Probably the most desirable ecosystem is an undisturbed natural pond with a lush variety of organisms. If you can take your students to such a pond they should bring the equipment to measure the physical environment. If they are to examine the microbiota back in the laboratory they should bring collecting equipment as well. You will also want to familiarize them with the collecting procedures in Appendix A.

5. Prelab Information to Students
   a. It is essential that students understand the objectives and the intro-

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ductory three paragraphs. It is recommended the objectives be reviewed at this time.

b. Point out to students that the aquarium in the lab is set up to model a natural ecosystem. You may want to have students list ways in which this is different from a natural ecosystem and predict how long it would be self-sufficient.

c. You may wish to discuss briefly sampling techniques for the microorganisms in the aquarium or pond.

6. Miscellaneous.
   a. It is strongly recommended you check out or keep very close account of the light meters as they are very easily "misplaced".
   b. Be sure you have previously identified all the recognizable organisms in your ecosystem.
   c. Timing: The data collection (parts I-III) must be done in lab or the field and should take an average student approximately an hour. Part IV (data analysis) will take about an hour and is best done in lab or classroom while students can be assisted by the instructor. The work on the answer sheet can be handled in a number of ways. The faster students will finish most or all of the answer sheet by the end of a 3–hour lab period. An average student will need to do at least some of the answer sheet at home, in which case the answer sheets can be declared due at the next lab meeting. If for any number of reasons students do not proceed as rapidly as planned, this investigation can be broken into two 2½ to 3–hour lab periods and easily completed by the end of the second period.

Flow Chart for Student Procedures

PRELAB DISCUSSION: Instructor-led 15 min.

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DATA COLLECTION: Abiotic Factors
Macrobiotic Assessment
Microbiotic Sampling. 60 min.

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DATA ANALYSIS: Generate responses to Questions 1–8. 40 min.

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GENERALIZATIONS: Respond to Questions 1–8. 30 min.

Typical Results by Student

Sample Table 8.1. Macrobiotic community

Name	*Description*	*Relative Number*
Elodea	plant, large, green, long strands	very abundant
Snails	small, brown, motile, with shell	about 25
Planaria	small, brown, motile, worm-like and flattened	many—about 20
Minnows	thin, many different sizes, fish with black stripe	some—12 to 15
Insects		none
Crayfish	large, about 6″ long, 2 pincers, 8 legs, brown-red, crawls on bottom	one

Sample Table 8.2. Microbiotic community

Level	*Sample*	*Code Name*	*Description*	*Rel. #*
SURFACE	1	P1	Motile algae, spheres hooked together	few, 3–4 per slide
		P2	Round non-moving green algae	many, 25 per slide
	2	P1	As above	some, 10 per slide
	3	P2	As above	some, 10–12 per slide
MIDDEPTH	1	P1	As above	some—8
		Z1	Daphnia—round, almost clear animal	few, 1–2 per slide
	2	P2	As above	some, 6–8 per slide
		Z2	Other small flagellates —unidentified	few, 3
	3	Z1	Daphnia	3–4
BOTTOM	1	P3	Fibrous algae, strands	many—more than 20
	2	P3	As above	
	3	P2	As above	rare
		P3	As above	some—5 per slide

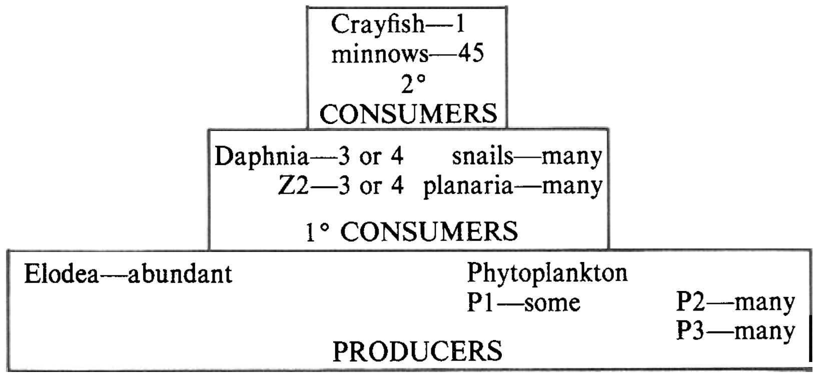

Figure 8.4. Food pyramid from data collected.

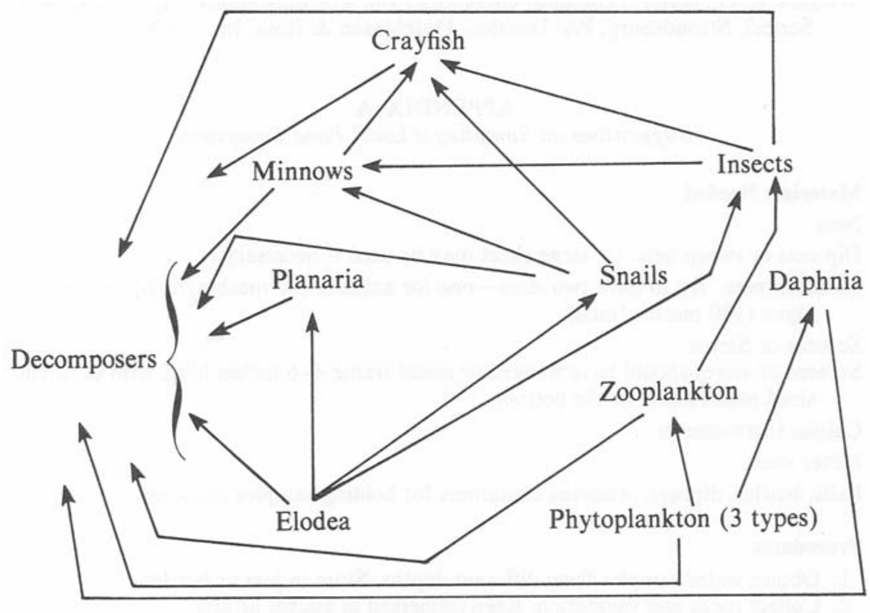

Figure 8.5. Sample food web from organisms in Figure 8.1.

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APPENDIX A
Suggestions on Sampling a Local Pond Ecosystem

Materials Needed

Nets

Dip nets or sweep nets. (A large sheet may be used if necessary.)

Plankton nets. Try to have two sizes—one for animals (60 meshes/inch) and one for algae (180 meshes/inch).

Screens or Sieves

Screens or sieves should have wooden or metal frame 4–6 inches high, with different-sized metal mesh on the bottom.

Celsius thermometer

Meter stick

Pails, bottles, dippers. Assorted containers for holding samples collected.

Procedures

1. Obtain water samples from different depths. Store in jars or bottles.
2. Collect rocks and vegetation. Keep immersed in bucket or jars.
3. Sample mud on bottom using screen or sieve.
4. Collect more extensive bottom samples by dragging a scoop sampler (or weighted conical net with strap iron handles and rigid opening) along the bottom.
5. Use various sizes of plankton nets to take small samples at various water depths. Store samples in small jars or bottles.
6. Form a tow net (a weighted cloth cone held open at one end) and drag through the water at various depths.
7. Use a sweep net at the surface to collect surface-dwelling forms.

Possible Forms Collected from Pond Ecosystem

1. Algae and phytoplankton and zooplankton
   An array of various forms will be found at differing depths.
2. Macrobiotic Organisms
   Surface forms: Water spiders, whirligig beetles
   Stone- and weed-dwelling forms: Stonefly, mayfly, dragonfly and diptera larvae, snails, leeches, *Planaria,* caddis fly larvae
   Floating forms: Water fleas and copepods, rotifers and protozoans
   Swimming forms: Various fish and amphibians
   Burrowing forms: Annelids, some diptera larvae