22

The Basics of Ecology

Learning Objectives

In this chapter, you will learn:

➜ How Organisms Respond to Changes in the Environment

➜ Energy Flow Through Ecosystems

Overview

The final unit in AP Biology brings together all that you have learned throughout the year in a discussion of ecology. In this unit, you need to know how organisms use energy and matter and how energy flows through ecosystems. The availability of energy (or lack thereof) in an ecosystem can determine the ecosystem's survival or demise. Ecosystems need to be able to adapt to disruptions in their environments. Communication among organisms is essential and allows them to respond to disruptions in their environments. These responses can lead to changes in populations and the evolution of populations. This chapter will first review how organisms respond to changes in their environment followed by a discussion of the flow of energy through ecosystems.

How Organisms Respond to Changes in the Environment

The survival of organisms often depends on their ability to respond to changes in their environment. Organisms can respond to environmental changes with behavioral or physiological mechanisms.

A change in the environment that triggers a response is called a **stimulus**. One example of a stimulus that can trigger a response is change in day length. Some birds respond to changes in day length by migrating, a **behavioral response**. Other animals may respond to changes in day length by slowing their metabolism to conserve energy, a **physiological response**.

Some stimuli are communicated among organisms. Organisms send signals to each other in response to changes in their environment. These signals can trigger changes in the behavior of other organisms. This communication among organisms can occur through different types of signals:

- **Audible signals**—Birds use audible signals to send warnings to other birds and to attract mates. Some primates use vocalizations to assert dominance or to warn of the presence of predators.
- **Chemical signals**—**Pheromones** are chemical signals released by some plants and animals to illicit a response in other organisms. Skunks release pungent chemicals to scare off potential predators. Female insects release chemicals (that males of the same species can detect) to initiate mating. Some plants release chemicals to warn neighbors when an herbivore is damaging them.
- **Electrical signals**—Sharks and rays send electrical signals through the water to locate prey species.
- **Tactile signals**—Touching between primates can be used to express affection or to indicate dominance. Some plants curl up the delicate parts of their body to shield them away from touch.
- **Visual signals**—Some species use warning coloration, a form of **aposematism**, to scare off potential predators. One example of this are the toxic amphibians in the rain forest that are often brightly colored.

Signaling among organisms can help them find mates, determine social hierarchies, and find needed resources. Natural selection will favor signals and responses that increase survival and the chances of successful reproduction. Over time, this selection can lead to changes in the population and evolution.

Cooperative behaviors can lead to increased fitness of individuals and populations. One example of this are murmurations in starlings.

Murmurations occur when starlings fly in formations of hundreds, or sometimes even thousands, of birds. When flying in these large cooperative groups, starlings are more protected from predators, increasing their likelihood of survival. It is also thought that these large groups help the starlings keep warm.

Meerkats exhibit a wide range of cooperative behaviors. They huddle together for warmth and gather in groups to groom each other, picking parasites out of each other's fur. While some meerkats in the group are foraging for food, other meerkats will serve as lookouts and will send a loud signal when any predators approach. Meerkats have even been known to fight together in groups to ward off larger predators, like cobras.

Energy Flow Through Ecosystems

Organisms use energy to grow, reproduce, and maintain organization. Different species have different adaptations for maintaining energy levels and body temperatures.

Endotherms use thermal energy generated from their metabolism to maintain their body temperature. Mammals and birds are endotherms. **Ectotherms** do not have internal mechanisms for maintaining body temperature and obtain heat from their environment. They must change their behaviors to regulate their body temperature. For example, if a lizard's body temperature drops, it will move to a warm rock or into the sunlight to increase its body temperature. Fish, reptiles, and amphibians are ectotherms.

Metabolic rate is the total amount of energy an organism uses per unit time. Smaller organisms generally have a higher metabolic rate than larger organisms. As the size of an organism increases, its metabolic rate decreases. One reason for this is that smaller organisms have a greater surface area to volume ratio and therefore lose more heat to their environment. Smaller animals need higher metabolic rates to compensate for this loss of heat.

Access to energy is key to maintaining the health of an organism. Organisms are constantly expending energy to survive and obtaining energy from the food they eat (or the carbon-containing molecules they produce if the organism is photosynthetic). A net gain in energy can result in energy storage (such as in fat tissues of animals) or the growth of an organism. A net loss of energy can result in the loss of mass or even the death of the organism.

Changes in energy availability in an ecosystem, such as a reduction in sunlight or in the number of producers, can result in changes in population size. If energy becomes less available in an ecosystem (for example, if a large building reduces the amount of sunlight available), the producers' ability to perform photosynthesis will be reduced, and some producers will die. If the population size of producers in an ecosystem decreases, the entire ecosystem will be disrupted. An example of this is the rise in ocean temperatures, which has led to the death of producers in coral reefs (**coral bleaching**). This, in turn, has led to massive decreases in the number of species and in population sizes of these species in coral reef ecosystems.

Trophic levels represent steps in the food and energy transfers between organisms in an ecosystem. Organisms are classified into trophic levels based on their food and energy sources. Energy is captured by and then moves from producers to **herbivores** (primary consumers) to **carnivores** and **omnivores** (secondary, tertiary, and quaternary consumers).

Food chains show the transfer of energy between these trophic levels. It is important to note that in a food chain, the arrows show the direction of the transfer of energy. Figure 22.1 provides an example of a food chain.

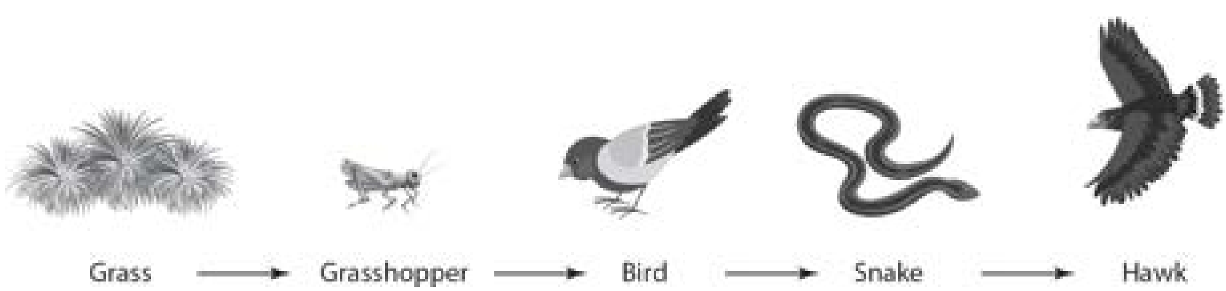


Figure 22.1 A Food Chain

Most organisms do not rely on just one food source and are part of multiple food chains. **Food webs** show the interconnections between organisms in different food chains and provide a more complete representation of energy transfers in ecosystems than food chains. Figure 22.2 provides an example of a food web.

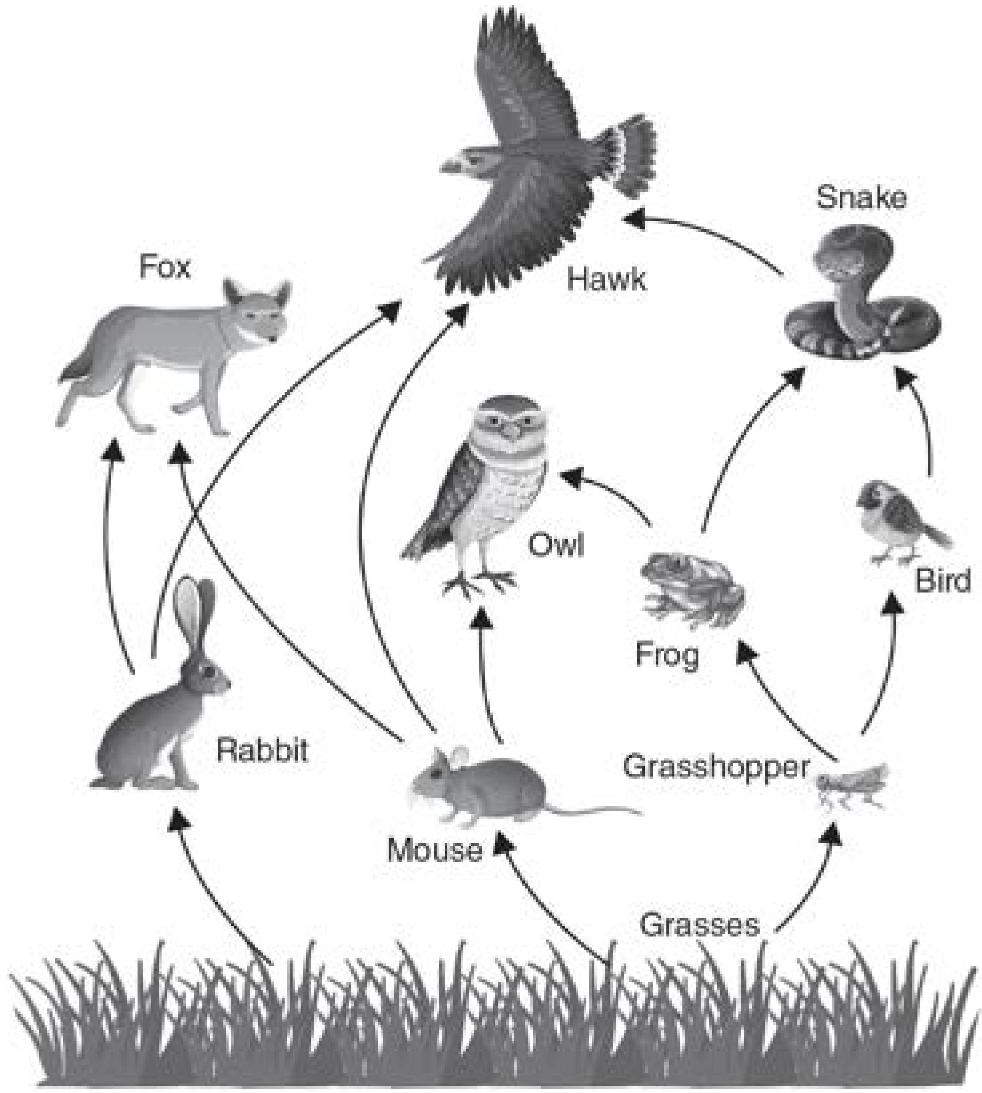


Figure 22.2 A Food Web

Autotrophs (producers) get energy from physical or chemical sources in their environment. **Photoautotrophs** get energy from sunlight. Plants are photoautotrophs. **Chemoautotrophs** obtain energy from small inorganic molecules in their environment. Most chemoautotrophs are bacteria found in extreme environments, such as deep-sea thermal vents or geothermal geysers.

Heterotrophs get energy from carbon compounds made by other organisms. Heterotrophs can obtain energy from carbohydrates, lipids, or proteins by breaking down these macromolecules using hydrolysis reactions. Animals are heterotrophs.

Decomposers break down dead organic material, allowing the nutrients in dead organisms to be recycled through ecosystems. Many fungi and bacteria are decomposers. **Detritivores** are organisms that obtain energy by consuming the organic waste of dead plants and animals. Millipedes, centipedes, and earthworms are examples of detritivores. Both decomposers and detritivores are important in nutrient cycling in ecosystems.

Some organisms show unusual strategies for obtaining energy. A small number of organisms exhibit kleptoplasty. **Kleptoplasty** is when a heterotroph consumes an autotroph that it uses as a food source but removes the chloroplasts from the autotroph's cells and incorporates them into its own cells. The sea slug *Elysia crispata* consumes algae for food and incorporates the chloroplasts (from the algae it consumes) into its own cells. When the sea slug cannot find food to eat, it moves into the sunlight, and the chloroplasts it incorporated into its cells perform photosynthesis, providing food for the sea slug.

As energy moves between trophic levels, energy is lost. This energy is either lost as heat or it is consumed by the necessary metabolic processes that the organisms in that trophic level use. Because less energy is available as you move up trophic levels, higher trophic levels necessarily will have smaller population sizes, as shown in Figure 22.3.

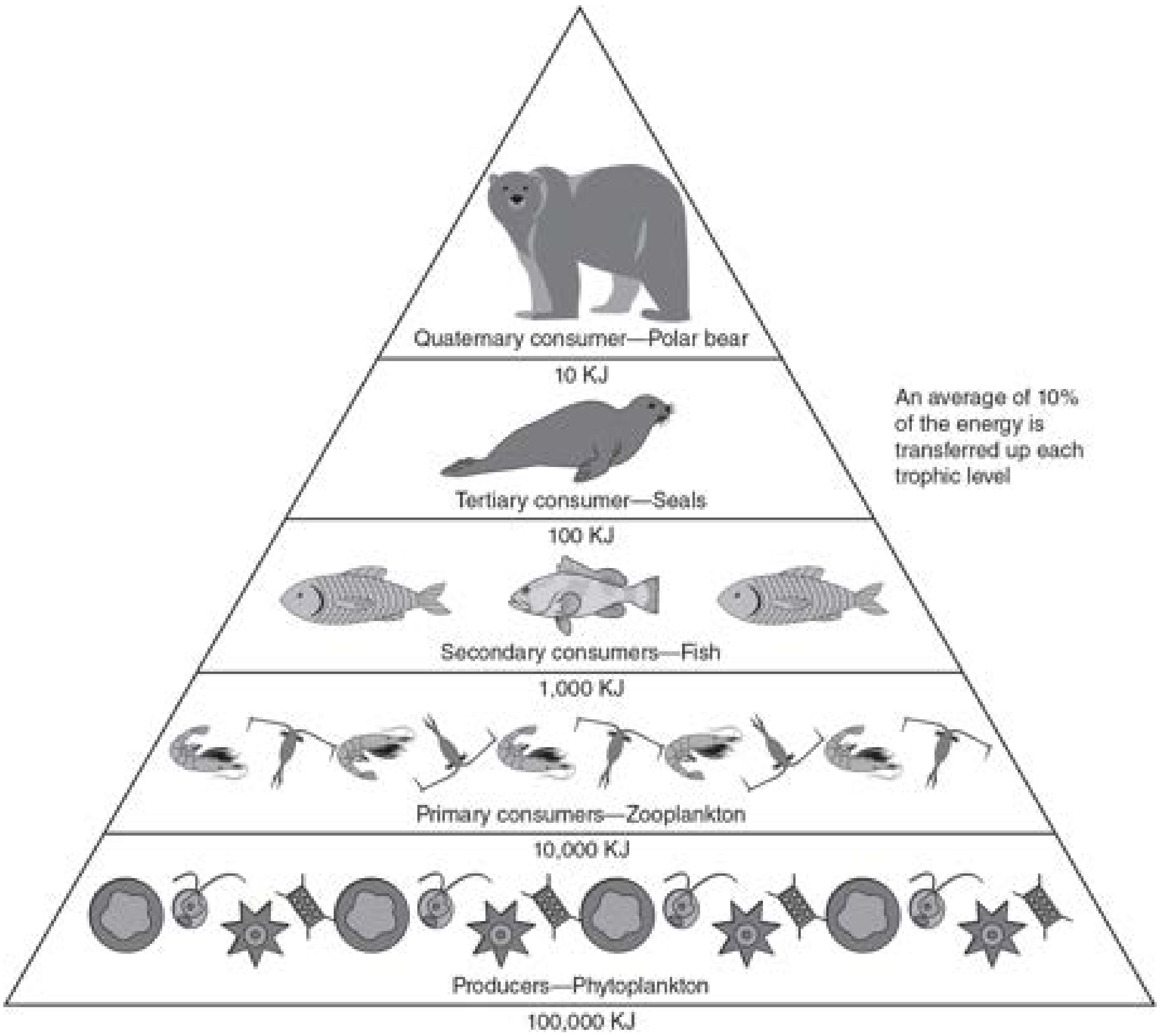


Figure 22.3 Trophic Levels

One polar bear might eat 50 seals in one year. Each seal needs to consume about 15 times its body weight in fish in one year. As you move down the trophic levels in a food chain, the amount of biomass at the lower trophic levels necessarily increases, with the producers possessing the greatest biomass.

If the population size of the producers decreased, there may not be sufficient food or energy for the remaining trophic levels, and the food web may collapse. This is called **bottom-up** regulation of ecosystems. Photosynthetic phytoplankton are the bottom trophic level of many marine ecosystems. Zooplankton feed on the phytoplankton, and sea stars, fish, and even some whales feed on these zooplankton. Runoff from herbicides can pollute the waters, reducing the number of phytoplankton. This can lead to a reduction in the zooplankton population size and the animals that depend on the zooplankton for food, thereby reducing the biodiversity of the ecosystem. This is an example of bottom-up regulation.

Animals at higher trophic levels may help limit the population sizes at lower levels. If these top predators are removed from an ecosystem, the population sizes of other trophic levels may exceed the producers’ ability to produce enough food to support them, and the food web may collapse. This is called **top-down** regulation. An example of top-down regulation can be seen in the rain forests of Venezuela. Manmade construction of dams created isolated islands of rain forests, some of which contained top predators like crocodiles, while others were left without top predators. After a few years, the biodiversity of the sections of rain forests without top predators was greatly reduced (with fewer saplings, trees, and other plants). Without crocodiles, plant-eating animal populations grew at a high rate, reducing the number of plants in these areas. This resulted in less habitats for the organisms that depend on these trees and plants and a reduced number of species in these areas. On the rain forest islands with top predators, crocodiles would eat some of the animals that feed on seeds and plants, limiting the population of these animals and preserving the number of plant species in these areas.

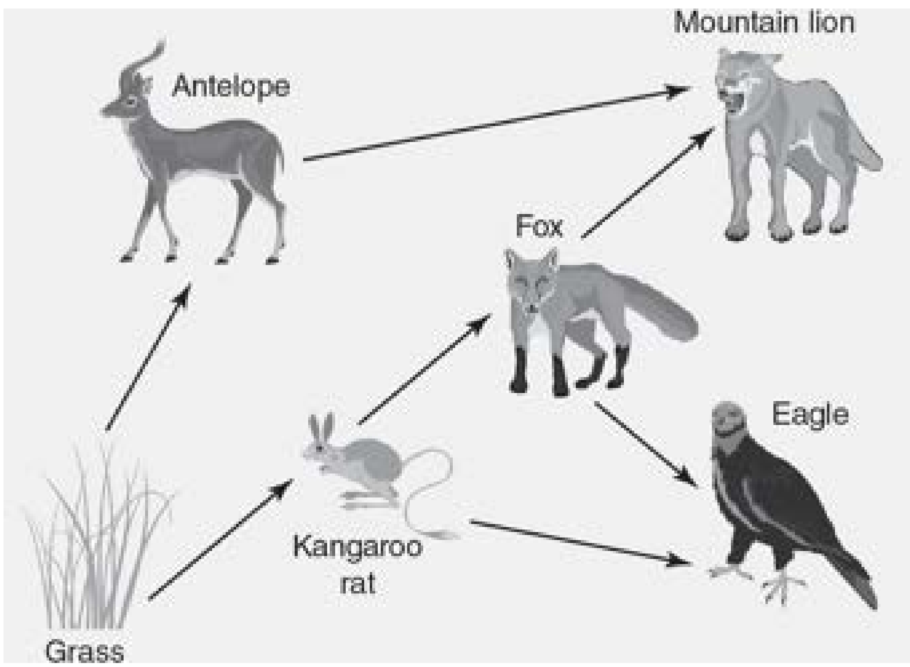
The availability of food and the energy it provides organisms affects these organisms’ reproductive strategies. Different organisms use different reproductive strategies in response to energy availability. Organisms that live in unstable environments (that have less access to energy-containing compounds) will produce large numbers of offspring at a time. Because there is less access to energy-containing food in their environment, the survival rate of the offspring is lower than that of organisms living in a more stable environment. By producing more offspring, organisms increase the probability of at least one of their offspring passing on their alleles to the next generation of organisms. Organisms that live in more stable environments with greater access to energy-containing compounds will produce fewer offspring at a time. Since the likelihood of survival of their offspring is higher, not as many offspring need to be produced to ensure their alleles are passed on to the next generation. Reproductive strategies will be discussed in more detail in Chapter 23.

Practice Questions

Multiple-Choice

Questions 1 and 2

Refer to the following food web.



1. What is a role of the fox in this food web?

   (A) producer
   (B) primary consumer
   (C) secondary consumer
   (D) tertiary consumer

2. The application of rat poison in the area results in the elimination of the kangaroo rat population. Which of the following is the most likely effect of this event?

   (A) The biomass of the producers will increase.

(B) The number of foxes in the ecosystem will likely increase.
(C) The amount of food available to the antelope will decrease.
(D) The mountain lions will eat fewer antelopes and more eagles.

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3. Why is it unlikely that a food web would contain more than five trophic levels?

(A) 90% of the nutrients are lost in each transfer to the next trophic level.
(B) 90% of the energy is lost in each transfer to the next trophic level.
(C) Decomposers can efficiently recycle nutrients for up to four trophic levels.
(D) The biomass at the producer level cannot exceed the biomass at the primary consumer level.

4. Coyotes are a predator of skunks. Coyote urine has a strong scent and is marketed as a skunk repellent. Which type of signal is coyote urine?

(A) audible
(B) chemical
(C) tactile
(D) visual

5. Which of the following is an example of a physiological response to a stimulus?

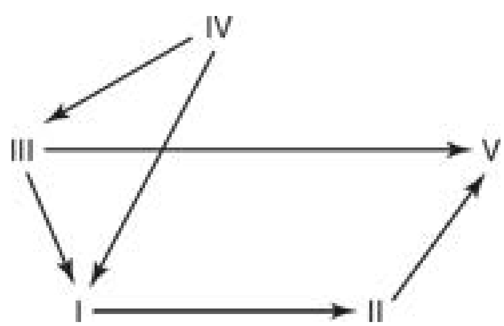
(A) A female bird moves toward a male bird that is singing an appropriate mating song.
(B) A predator avoids a brightly colored frog in the rain forest.
(C) A bear slows its metabolism in response to shortened day lengths and cooler temperatures.
(D) A primate grooms its offspring.

6. Why are the metabolic rates of smaller organisms generally higher than those of larger organisms?

(A) Smaller organisms have shorter life spans and therefore must accomplish more activities in less time. This requires a faster metabolic rate.
(B) Smaller organisms have a higher surface area to volume ratio than larger organisms and lose more heat to the environment.
(C) Smaller organisms are more likely to be ectothermic than larger organisms and therefore need a higher metabolic rate to compensate for this.
(D) Smaller organisms consume less food per gram of body weight than larger organisms and therefore need a higher metabolic rate to compensate for this.

Questions 7 and 8

Refer to the following food web. The arrows show the direction of the flow of energy, and species are represented by roman numerals.



7. Which species in this food web is most likely a producer?

(A) I
(B) II
(C) III
(D) IV

8. Which species is both a primary consumer and a secondary consumer?

(A) I
(B) II
(C) III
(D) IV

Questions 9 and 10

The respiration rate (as measured by oxygen consumption per gram of body weight per minute) was measured in rats, grasshoppers, and newly discovered species animal X. The respiration rates were measured at 5°C and 30°C for all three species. Data are shown in the table.

Organism	Average Respiration Rate at 5°C (mL O_2/min/g)	Average Respiration Rate at 30°C (mL O_2/min/g)
Rat	0.158	0.076
Grasshopper	0.011	0.033
Species X	0.024	0.069

9. Which of the following conclusions about species X is best supported by the data?

(A) Species X is ectothermic since its respiration rate is higher at a higher environmental temperature.
(B) Species X is ectothermic since ectothermic animals always have an increased respiration rate at lower temperatures.
(C) Species X is endothermic since its respiration rate at 30°C is closer to the respiration rate of the rat at 30°C than to the respiration rate of the grasshopper at 30°C.
(D) Species X is endothermic since its respiration rate is higher at a higher environmental temperature.

10. This experiment is repeated with the same animals at a temperature of 37°C. Which of the following is the most likely result?

(A) The rat will have a higher respiration rate than the grasshopper at 37°C because rats are ectothermic.

(B) The grasshopper will have a higher respiration rate than species X at 37°C because grasshoppers are ectothermic and species X is endothermic.

(C) Species X will have a higher respiration rate than the rat at 37°C because rats are ectothermic and species X is endothermic.

(D) The rat will have a lower respiration rate than both the grasshopper and species X at 37°C because rats are endothermic and both grasshoppers and species X are ectothermic.

Short Free-Response

11. The following table shows the diet composition of members of an estuarine ecosystem (a shallow, coastal shelf where a freshwater river empties into a larger saltwater body). Higher percentages indicate a higher degree of reliance on a particular food source. An "X" indicates that the source is not a food source for that organism.

Food Source	Diet Composition (percent)					
	Snails	Oysters	Clams	Crabs	Fish	Birds
Algae	100	100	100	X	30	X
Snails	X	X	X	40	40	X
Oysters	X	X	X	30	20	10
Clams	X	X	X	30	10	10
Crabs	X	X	X	X	X	40
Fish	X	X	X	X	X	40

(a) **Describe** the role of algae in this ecosystem.

(b) **Represent** the relationships between these organisms by **constructing** a food web for this ecosystem.

(c) **Identify** the secondary consumers in this ecosystem.

(d) **Predict** the organism in this ecosystem that will have the lowest biomass. **Explain** why you made this prediction.

12. In order to investigate the possible effects that chemicals in a certain insecticide have on plant growth, a researcher grew 100 plants from each of three different crop species. Fifty plants of each type were grown in a lab in the presence of the insecticide, and the other 50 plants of each type were grown in a lab without insecticide. All plants were grown to maturity and then dried, and the mean dry weight per plant and the standard error of the mean were calculated for each group. Data are shown in the table.

Crop	Mean Dry Weight per Plant Without Insecticide in Grams (± SEM*)	Mean Dry Weight per Plant in the Presence of Insecticide in Grams (± SEM)
A	12.40 ± 0.50	14.02 ± 0.56
B	8.63 ± 0.25	10.02 ± 0.29
C	15.64 ± 0.61	19.54 ± 1.32

*Standard Error of the Mean

(a) **Describe** the effect of the use of the insecticide on the mean dry weight of crop B.

(b) **Calculate** which crop (A, B, or C) had the greatest percent increase in mean dry weight in the presence of the insecticide. Show your work.

(c) The researcher makes the claim that use of this insecticide increases the mean dry weight of all three crops. Using the data from the table, **evaluate** the researcher's claim.

(d) **Explain** why the use of an insecticide could increase the yield of some agricultural crops.

Long Free-Response

13. Plants thought to have evolved in temperate climates use C3 photosynthesis (also known as the light-independent cycle). Plants thought to have evolved in tropical climates use an additional step referred to as C4 photosynthesis. Scientists measured the photosynthetic rate of C3 plants (sugar beets) and C4 plants (sugarcane) in a sealed container under three different temperature conditions. Data are shown in the table.

Temperature (°C)	C3 plants CO_2 micromoles/m^2/minute (± SEM*)	C4 plants CO_2 micromoles/m^2/minute (± SEM)
20	37.0 ± 1.2	35.1 ± 1.1
30	35.2 ± 0.8	38.0 ± 1.0
40	26.8 ± 0.5	37.0 ± 1.2

*Standard Error of the Mean

(a) **Explain** why the rate of carbon dioxide consumption was used in this experiment.

(b) **Construct** a graph of the data, showing 95% confidence intervals.

(c) **Analyze** the data, and **determine** at which temperature(s) there was a statistically significant difference in carbon dioxide consumption in C3 and C4 plants.

(d) *Coleus* is a popular C3 houseplant. A person has a *Coleus* plant inside her climate-controlled home, in which the temperature never exceeds 30° Celsius. If this plant was placed outside for seven days during a heat wave (in which the high temperature each day reached 39°C), **predict** the effect this would have on the plant. **Justify** your prediction.

Answer Explanations

Multiple-Choice

1. **(C)** The fox is a secondary consumer because it gets its energy from a primary consumer (the kangaroo rat). Choice (A) is incorrect because the producer in this food web is grass; foxes are not photosynthetic and cannot be producers. Since the fox shown in this food web does not consume the producer, the fox cannot be a primary consumer, so choice (B) is incorrect. Tertiary consumers get their energy from secondary consumers. In the food web shown, the mountain lion and the eagle are tertiary consumers; the fox is not a tertiary consumer, so choice (D) is incorrect.

2. **(A)** Kangaroo rats eat grass. If the kangaroo rat population was eliminated, less grass would be consumed, and the biomass of the producers (the grass) would most likely increase. The foxes feed on the kangaroo rats, so the elimination of the kangaroo rats would result in less food for the foxes. In that case, the number of foxes would likely decrease, not increase, so choice (B) is incorrect. Choice (C) is incorrect because fewer kangaroo rats would mean more grass for the antelopes, not less. Mountain lions do not eat eagles in this food web, so choice (D) is incorrect.

3. **(B)** On average, 90% of the energy at a given trophic level is used in metabolic processes at that level or is lost as heat and is not transferred to the next trophic level. Choice (A) is incorrect because most nutrients are transferred to the next trophic level when food is consumed. Decomposers break down dead organic matter, regardless of the number of trophic levels, so choice (C) is incorrect. The biomass at the producer level must be larger than the biomass at the primary consumer level, so choice (D) is incorrect.

4. **(B)** Scent is a chemical signal. Choices (A), (C), and (D) are incorrect because audible, tactile, and visual signals depend on sound, touch, and sight, respectively.

5. **(C)** Adjusting metabolism in response to changing environmental conditions is a physiological response to a stimulus. Choices (A), (B), and (D) are examples of behaviors or behavioral responses.

6. **(B)** Smaller organisms do have a greater surface area to volume ratio than larger organisms and lose more heat to their environment per gram of body weight, so smaller organisms need a higher metabolism to help mitigate the heat loss. Not all small organisms have a shorter life span than larger organisms, so choice (A) is incorrect. Choice (C) is incorrect because not all small organisms are ectothermic. Also, ectothermic animals cannot internally control their metabolic rate; ectotherms are dependent upon environmental temperatures to influence their metabolic rate. Smaller organisms do not necessarily consume less food per gram of body weight; in fact, the higher metabolic rate of smaller organisms may require that these small organisms consume more food per gram of body weight, so choice (D) is incorrect.

7. **(D)** Producers transfer energy to other trophic levels and do not receive energy from any trophic level. IV is the only member of this food web that sends energy to other members but does not receive energy from other members of the food web.

8. **(A)** Primary consumers get energy from producers, and secondary consumers get energy from primary consumers (herbivores). In this food web, IV is a producer, I and III are both primary consumers, and I, II, and V are secondary consumers. Choice (A) is the only member of this food web that is both a primary and secondary consumer.

9. **(A)** Ectothermic animals have a higher metabolism at higher environmental temperatures. Since species X's consumption of oxygen is greater at 30°C than at 5°C, it is most likely ectothermic. Choice (B) correctly states that species X is ectothermic but gives incorrect reasoning; ectothermic animals have an increased respiration rate at *higher*, not lower, temperatures. Choice (C) is incorrect because while species X's oxygen consumption at 30°C is closer to that of the rat than to that of the grasshopper, that does not determine whether or not species X is endothermic. Endothermic animals have higher metabolic rates at

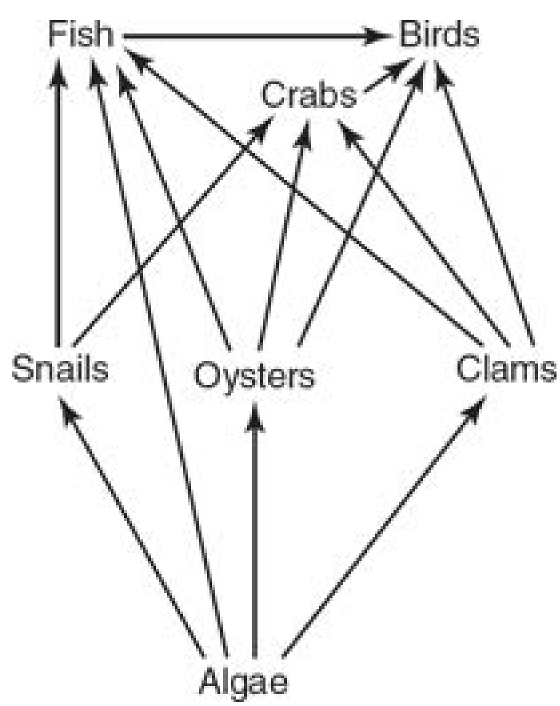
lower temperatures (so they can maintain a constant internal temperature). Therefore, choice (D) is also incorrect.

10. **(D)** At a higher temperature, the respiration rate of ectotherms (the grasshopper and species X, in this example) increases and the respiration rate of endotherms (the rat, in this example) decreases. Choice (A) is incorrect because rats are endothermic. Species X is most likely ectothermic, so choice (B) is incorrect. Choice (C) is incorrect because rats are endothermic, not ectothermic, and species X is most likely ectothermic.

Short Free-Response

11. (a) Algae are producers and are the only member of this ecosystem that can perform photosynthesis. Therefore, algae either directly or indirectly provide organic compounds to the other members of this ecosystem.

(b)



(c) Secondary consumers eat primary consumers. Primary consumers eat producers. The primary consumers are snails, oysters, clams, and fish. Therefore, the secondary consumers are crabs, fish, and birds.

(d) Birds should have the fewest numbers since they are a top predator.

12. (a) The use of the insecticide significantly increased the mean dry weight of crop B. The upper limit of the 95% confidence interval for crop B without the insecticide is 9.13, and the lower limit of the 95% confidence interval for crop B in the presence of the insecticide is 9.44. So there is likely a significant difference between the two groups.

(b) Percent increase in mean dry weight =

$$\frac{\text{mean dry weight in the presence of insecticide} - \text{mean dry weight without insecticide}}{\text{mean dry weight without insecticide}} \times 100$$

$$\text{Crop A} = \frac{14.02 - 12.40}{12.40} \times 100 = 13\%$$

$$\text{Crop B} = \frac{10.02 - 8.63}{8.63} \times 100 = 16\%$$

$$\text{Crop C} = \frac{19.54 - 15.64}{15.64} \times 100 = 25\%$$

Crop C has the greatest percent increase in mean dry weight.

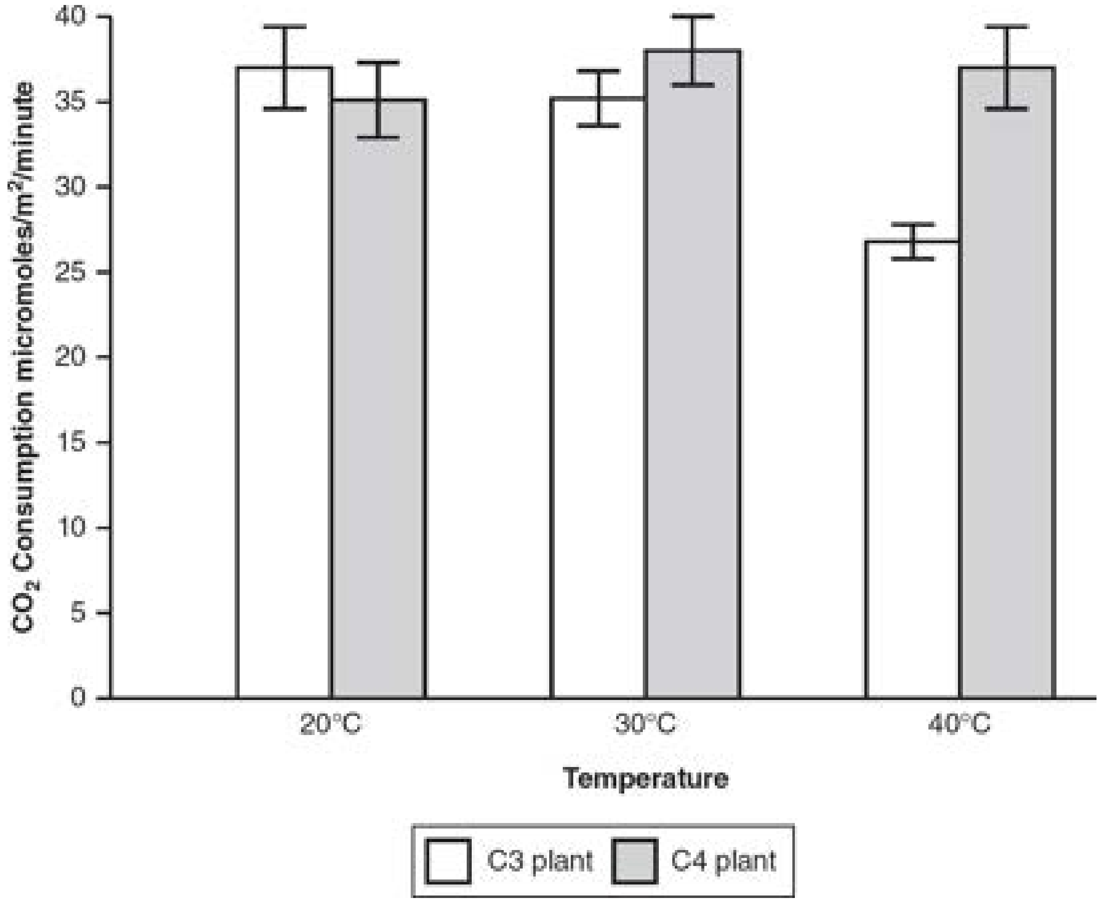
(c) The researcher's claim is *not* supported by the data. This is because the 95% confidence intervals for plants from crop A grown with and without insecticide overlap: the upper limit of the 95% confidence interval for crop A without insecticide is 13.40 and the lower limit of the 95% confidence interval for crop A in the presence of insecticide is 12.90. Therefore, it cannot be concluded that there is a significant difference between those two groups for crop A.

(d) Many insects consume plant material and are therefore primary consumers. The use of insecticides would decrease the number of primary consumers and could thereby increase the crop yield.

Long Free-Response

13. (a) Carbon dioxide is a reactant that is consumed during photosynthesis, so measuring the rate of carbon dioxide consumption could be a good way to compare the rate of photosynthesis between these two organisms.

(b)



(c) There is likely a statistically significant difference at a temperature of 40°C because the 95% confidence intervals for the C3 and C4 plants do not overlap at that temperature, but they do overlap at 20°C and 30°C.

(d) The plant would likely consume less carbon dioxide and would perform less photosynthesis in a 39°C environment than in a 30°C environment. It would have fewer organic compounds with which to supply itself with energy. This is because the data show that a C3 plant will consume less carbon dioxide at 40°C (compared to at 30°C), so it will probably perform less photosynthesis when exposed to heat wave temperatures.