Nutrient Cycling in the Serengeti

hhmi | BioInteractive

Activity
Educator Materials

OVERVIEW

This activity uses an example from the Serengeti ecosystem to illustrate the exchange of nutrients between plants, animals, and the environment. Many ecological concepts can be taught using the Serengeti as a case study. It is a rich and diverse habitat where much research has been done to explain how organisms interact with each other and their environment. This activity focuses on the cycling of carbon, nitrogen, and phosphorus using a typical savanna grass and wildebeest as examples. After a brief introductory video, students use a card activity to engage with some processes at play in nutrient cycling in the Serengeti. They then reflect on those processes through group discussion and by completing an additional handout. There are two versions of the handout that are differentiated by the amount of prior knowledge required from students.

Additional information related to pedagogy and implementation can be found on [this resource's webpage](), including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Nutrient cycling involves the movement and exchange of nutrients through biotic and abiotic reservoirs of ecosystems. Different processes move various forms of nutrients between reservoirs.
- Microbes are essential to the cycling of nutrients. For example, many species of bacteria transform nutrients in the soil into forms that can be taken up by plants.
- Nutrients that are harder for a plant to obtain often limit the plant's ability to grow. These nutrients are referred to as limiting nutrients.

STUDENT LEARNING TARGETS

- Identify essential nutrients that organisms need — specifically carbon (C), nitrogen (N), and phosphorus (P) — and their major organic and inorganic forms.
- Describe major reservoirs of C, N, and P, and identify the processes that move the nutrients between these reservoirs.
- Articulate the concept of a limiting nutrient.
- Describe the role of microbes in nutrient cycling.

PRIOR KNOWLEDGE

The introductory video and regular "Student Handout" do not require much formal background knowledge. The card activity can also be done without extensive background knowledge, though it includes several terms that students may need prior background to fully understand. For these terms and the advanced "Student Handout," students should be familiar with:

- organic versus inorganic compounds
- biotic versus abiotic reservoirs
- photosynthesis and cellular respiration
- key processes in the nitrogen cycle (e.g., denitrification, ammonification, nitrogen fixation)
- decomposition

MATERIALS

For each group of students:

- a printed, cut-out set of cards from the "Cards" PDF
- "How Savanna Plants Get Nutrients" graphic

For each group or individual students:

- "Card Activity Instructions" document
- either version of the "Student Handout" (to be completed after the card activity)
- (optional) "Nitrogen Cycle Diagram" graphic

BACKGROUND

Although rainfall is important for plant productivity, nutrient availability is what allows plants to flourish. Some nutrients are harder for plants to get; they are referred to as limiting nutrients because they limit a plant's ability to grow.

Nutrient cycles involve the movement of certain nutrients — such as carbon, nitrogen, and phosphorus — between biotic and abiotic reservoirs in the ecosystem. In this activity, the abiotic reservoirs are the atmosphere (a source of carbon) and soil (a source of nitrogen and phosphorus), and the biotic reservoirs are the plants and animals that live in the ecosystem.

Nutrient cycling keeps ecosystems functioning and productive. This activity provides multiple examples of how nutrients cycle in the Serengeti specifically. As shown in the activity, herbivores take in nutrients by eating plants and return them to the environment through processes such as defecation, urination, and decomposition. Microbes and decomposers, such as detritivores, transform the nutrients into forms that plants can take up. For example, some microbes convert atmospheric N_2, which cannot be directly used by plants, to NH_4^+ (ammonium) or NH_3 (ammonia), which *can* be used by plants.

TEACHING TIPS

- The card activity can be used with groups of any size. The number of students in a group does not affect the activity, since they are jointly completing one model.
- Each group may experience the activity differently based on how they shuffle their cards. For example, some groups may draw a microbe card that enables nutrient uptake early. Others may not and have more limited nutrient uptake. Allow groups to compare their experiences during the discussion after the card activity.
- You may need to emphasize that although only carbon, nitrogen, and phosphorus appear in this activity, other nutrients (iron, sulfur, etc.) are also needed to support ecosystems and also undergo nutrient cycling.
- The card activity is intended to introduce students to and engage them with the concept of nutrient cycling. Every process depicted on the cards is more complex in reality than it is portrayed in this activity. You should be aware of, and may also wish to discuss with your students, some of the simplifications or caveats of the card model. For example:
  - C:N:P ratios in plants are highly variable and can even vary based on growing conditions. The ratio used in the card activity is that of *Panicum maximum*, a typical savanna grass.
  - In reality, microbial communities are highly diverse, and different groups of bacteria are responsible for different stages of decomposition and nutrient release. (For more details, see the short BioInteractive video *Solving Crimes with the Necrobiome*.) The goal of this activity is for students to understand that microbes play an essential role in the cycling of many nutrients. A rigorous review of microbiology is beyond the scope of the activity.
  - The activity includes multiple cards to represent different components of the nitrogen cycle, and the effects of some components are greatly simplified for ease of use. For example, the denitrifying bacteria cards do not have a direct impact on the card activity. However, denitrification does have an important role in nitrogen cycling and is included for the sake of completeness.
- Two options are provided for the accompanying handout. The regular "Student Handout," which requires minimal prior knowledge, is recommended for a general high school audience. The advanced "Student Handout," which requires more prior knowledge (see the "Prior Knowledge" section above for details), is recommended for AP/IB or undergraduate students.

- The downloads for this activity include a diagram of the nitrogen cycle, which students may be less familiar with. They can use this diagram as a reference for processes mentioned in the cards and advanced "Student Handout."

PROCEDURE

1. Engage students with the brief (about 2 minutes) video *Introduction to Nutrient Cycling*. This video introduces the Serengeti and the role of nutrient cycling in this ecosystem.
2. Separate students into working groups of any reasonable size.
3. Give each group one set of cards, the "How Savanna Plants Get Nutrients" graphic, and copies of the "Card Activity Instructions." Each group should shuffle their cards and place them face down on their work surface.
4. Have the groups read through the "Card Activity Instructions" and then do the card activity (about 10–15 minutes). Monitor the groups as needed, making sure they are following these instructions in particular:
   - Some cards should be discarded at the end of each turn, and others should be kept on the plant graphic. Students should read the instructions on the bottoms of their cards carefully to determine what to do.
   - If the students run out of cards before they fill in all the bubbles on their graphic, they should reshuffle their discard pile and use it to continue drawing cards.
5. When all the groups have completed the card activity, have a class discussion (about 10–15 minutes) to compare their experiences. Some suggested discussion questions are as follows:
   - What was your limiting nutrient (the nutrient it took the longest to complete the requirement for)?
     - In most cases, students will say nitrogen. In rare situations, they may say carbon. (This can happen if they get the nitrogen-fixing microbe card early, allowing them to fill up their nitrogen requirement before carbon.) If this happens, emphasize to students that the card model is a simplification and that, in real life, the limiting nutrient is practically never carbon.
   - What are the examples of respiration in the activity?
     - Students should say that both animals and plants respire. Students sometimes miss that plants respire CO_2 in addition to using CO_2 in photosynthesis.
   - How do processes of urination and defecation differ in terms of nutrient cycling?
   - What is the difference between nitrogen fixation and denitrification in terms of nitrogen availability to plants?
   - How do plants in the Serengeti sustain large herds of grazing herbivores, as shown in the introductory video?
6. Ask students or student groups to complete your selected version of the "Student Handout" (about 20 minutes), either in class or as homework. The handout will allow students to reflect on the card activity and explore nutrient cycling in more depth.
   - For the advanced handout in particular, you can recommend that students use the "How Savanna Plants Get Nutrients" graphic and "Nitrogen Cycle Diagram" as references, as some of the information in these documents is helpful for answering the questions.

ANSWER KEY (REGULAR HANDOUT)

PART 1: Nutrients and Their Roles

1. The "How Savanna Plants Get Nutrients" handout from the card activity describes the nutrients carbon, phosphorus, and nitrogen and some of their common forms.

a. Name **one** compound that is a form of the nutrient phosphorus.
phosphate (PO_4^{3-})

b. Name **two** compounds that are forms of the nutrient nitrogen.
ammonium (NH_4^+) and nitrate (NO_3^-)

2. List **three** biological functions or processes that these nutrients are needed for in plants.
Answers may include building essential molecules or structures, growth, development, reproduction, metabolism, photosynthesis, and cellular respiration.

3. Which of the following statements best describes where plants get these nutrients? (*Hint*: Review your "How Savanna Plants Get Nutrients" handout.)
   a. Carbon from the soil, nitrogen and phosphorus from the air.
   b. Carbon, nitrogen, and phosphorus from the soil.
   c. Carbon, nitrogen, and phosphorus from the air.
   d. Carbon from the air, nitrogen and phosphorus from the soil.

PART 2: Nutrients in the Serengeti

4. Briefly describe **two** ecological factors that affected how quickly your plant was able to get nutrients.
Factors include the availability of microbes or detritivores to enable or accelerate uptake from certain processes. Some processes that release nutrients also take longer than others. For example, defecation, urination, and decomposition deliver nutrients quickly (these cards allowed students to fill in more bubbles when drawn), whereas leaching from rocks and bones delivers nutrients more slowly.

5. Which nutrient requirement (carbon, nitrogen, or phosphorus) was the most difficult for your group to complete? (This nutrient is called a "limiting nutrient" because it limits growth of the plant.)

   Most groups will probably say nitrogen. In real life, the Serengeti ecosystem is almost always nitrogen limited. However, it is possible for some groups to complete their nitrogen requirement quickly if the nitrogen fixation microbe card is one of their first draws. If this happens, use it as an opportunity to discuss the assumptions and limitations of modeling ecological systems with a card activity. This is also an opportunity to discuss heterogeneity within ecosystems and how leguminous plants (plants that can fix nitrogen) can have a profound impact on ecosystems.

6. The **process cards** showed ways in which nutrients can be taken up by plants. Choose **two** different process cards that describe plants getting nutrients from **wildebeest**.

   a. Do your two cards differ in the amount of carbon (C), nitrogen (N), and phosphorus (P) they make available to a plant? If so, how?
   Student answers will vary depending on the cards they chose to compare. Wildebeest defecation and decomposition both make 6 C, 1 N, and 1 P available. Wildebeest urination makes 1 C and 2 N available. Leaching from wildebeest bones makes 2 P available.

   b. Why do you think your two cards differ (or do not differ) in the way you described?
   Student answers will vary depending on the cards they chose to compare. They may mention potential differences or similarities in the compositions of the nutrient sources (soft tissue, feces, urine, or bones), the role of soil microbes, etc.

   c. Do you think the processes on your cards would apply to animals other than wildebeest? Explain your answer.
   Students may say that these processes would apply to other animals because other animals undergo similar things (they defecate, urinate, die and decompose, etc.). The exact amounts of C, N, and P made available, however, could vary depending on the animal and its environment.

7. The **soil microbe** cards represent microorganisms such as bacteria. Based on the activity, summarize how microbes help cycle nutrients in the Serengeti.
   Based on the card activity, students may say that microbes enable plants to take up nutrients from multiple sources. More generally, microbes convert nutrients into different forms that can cycle through different parts of the ecosystem (e.g., from decomposing matter into the atmosphere, from the atmosphere into forms used by plants, etc.). In summary, students should build towards the concept that microbes are essential for nutrient cycles to function.

8. The **detritivore** cards represent organisms that eat decomposing matter and feces (dung). Based on the activity, summarize how detritivores help cycle nutrients in the Serengeti.
   Based on the card activity, students may say that detritivores increase nutrient uptake for plants. More generally, detritivores break down complex organic matter (dead organisms, feces, etc.), allowing nutrients from the organic matter to cycle to other parts of the ecosystem.

9. Do you think other ecosystems cycle nutrients using similar processes or organisms? Explain your answer.
   Students may say other ecosystems would be similar because many of the same processes also apply to other organisms (as discussed in Question 6c). Students could also give examples of other ecosystems with similar processes or organisms.

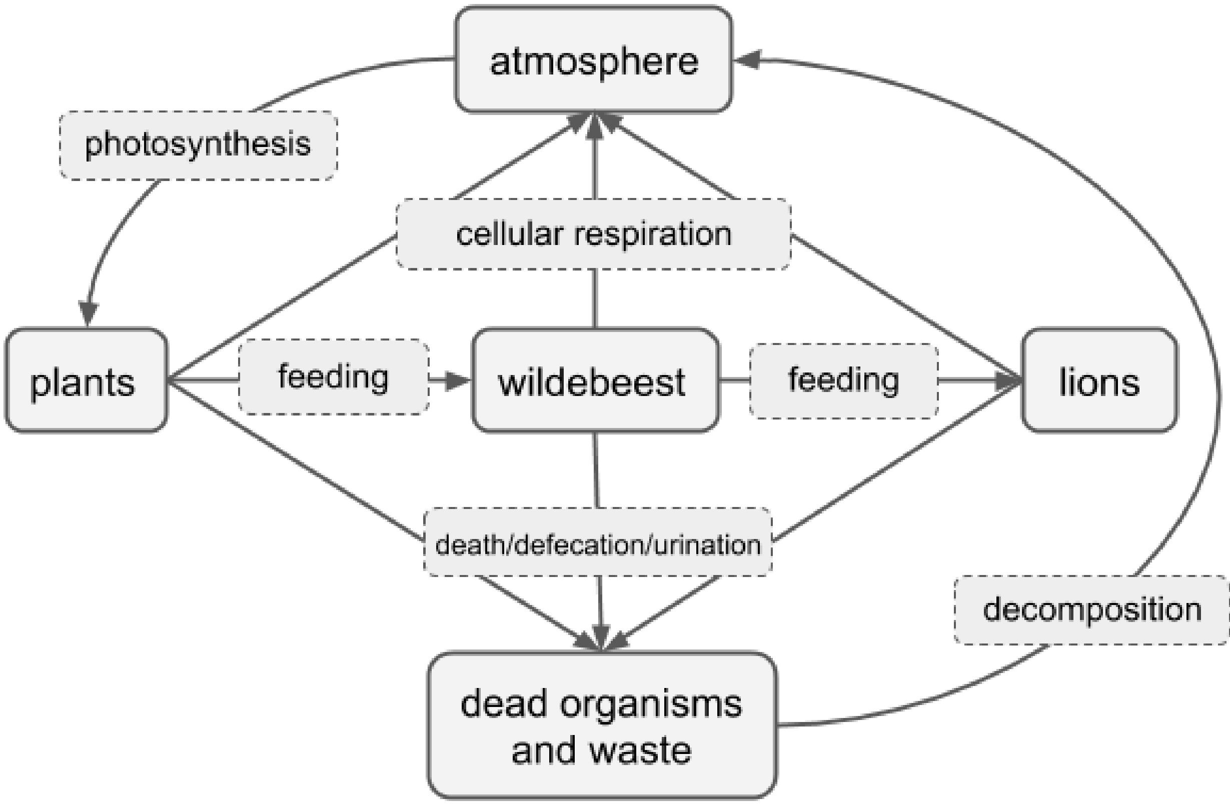
PART 3: Carbon

10. One process that moves carbon between organisms and the environment is **cellular respiration**.
    a. In the card activity, which **two** process cards directly represent cellular respiration?
       The card with a lion ("Animals eat organic compounds for energy and respire CO_2.") and the card with a tree ("Plants use organic carbon for energy and respire CO_2."). In general, students should build toward the understanding that plants, and not just animals, respire.
    b. Describe how cellular respiration moves carbon in particular. Where, and in what form, does the carbon used in cellular respiration come from? Where, and in what form, does the carbon end up after cellular respiration?
       The carbon used in cellular respiration comes from food (eaten by animals or produced by plants through photosynthesis), and it is in the form of organic compounds, such as sugars/carbohydrates. After cellular respiration, the carbon ends up in the atmosphere in the form of carbon dioxide (CO_2).

11. Another process that moves carbon between the environment and organisms is **photosynthesis**. Photosynthesis does not appear in the card activity, but you can learn more about it by watching the *Photosynthesis: Overview* animation.
    a. Summarize photosynthesis in one or two sentences, indicating the inputs and outputs.
       Photosynthesis is a process that converts light energy from the sun into chemical energy. It uses water and carbon dioxide (inputs) to produce carbohydrates and oxygen (outputs).
    b. Describe how photosynthesis moves carbon in particular. Where, and in what form, does the carbon used in photosynthesis come from? Where, and in what form, does the carbon end up after photosynthesis?
       The carbon used in photosynthesis comes from the atmosphere in the form of carbon dioxide (CO_2). After photosynthesis, the carbon ends up in the plant (or other organism that is doing photosynthesis) in the form of sugars/carbohydrates.

12. The following diagram summarizes how carbon moves through the Serengeti ecosystem. Fill in the missing labels with the following processes: **cellular respiration**, **photosynthesis**, **decomposition**, **death/defecation/urination**, and **feeding**. Some processes may be used in more than one label. (*Hint*: Most of these processes are represented in the card activity, so you can refer to the cards for help.)

The completed diagram is shown below.



13. Predict how a decrease in the number of predators — due to hunting, for example — might affect the cycling of carbon in the Serengeti. Use your diagram from Question 12 to support your answer.
Student answers may vary. For instance, they could argue that fewer predators (e.g., lions) might lead to more herbivores (e.g., wildebeest), which might lead to overconsumption of plants. Fewer plants could then lead to less photosynthesis, which could cause carbon to build up in the atmosphere instead of cycling back to organisms. Also, if humans take away the bodies of the predators they hunt and kill, instead of letting them decompose, the carbon from those predators may not be able to cycle back into the ecosystem.

ANSWER KEY (ADVANCED HANDOUT)

Nutrients and Compounds

1. Which nutrient's requirement was the most difficult for your group to complete? (This nutrient is called a "limiting nutrient" because it limits growth of the plant.)
Most groups will probably say nitrogen. In real life, the Serengeti ecosystem is almost always nitrogen limited. However, it is possible for some groups to complete their nitrogen requirement quickly if the nitrogen fixation microbe card is one of their first draws. If this happens, use it as an opportunity to discuss the card model's assumptions and limitations, and why it may not fully reflect what happens in nature. This is also an opportunity to discuss heterogeneity within ecosystems and how leguminous plants (plants that can fix nitrogen) can have a profound impact on ecosystems.

2. Describe some of the ecological factors that influenced how quickly each nutrient was obtained.
Factors include the availability of microbes or detritivores to enable or accelerate uptake from certain processes. Some processes that release nutrients also take longer than others. For example, defecation, urination, and decomposition deliver nutrients relatively quickly (these cards allowed students to fill in more bubbles when drawn), whereas leaching from rocks and bones delivers nutrients more slowly.

3. Plants get essential nutrients from their environment. Which of the following statements best describes where plants get carbon, nitrogen, and phosphorus?
   a. They get carbon from the soil, and nitrogen and phosphorus from the air.
   b. They get carbon, nitrogen, and phosphorus from the soil.
   c. They get carbon, nitrogen, and phosphorus from the air.
   d. ***They get carbon from the air, and nitrogen and phosphorus from the soil.***

4. Carbon, nitrogen, and phosphorus rarely exist as single atoms in nature. They are typically found in compounds. Some of these compounds can be taken up by plants from the environment, and others are produced by plants. Sort the following compounds into the two columns below.

Compounds plants take up from the environment	Compounds produced by plants
ammonium (NH_4^+) *carbon dioxide (CO_2)** *nitrate (NO_3^-)* *phosphate (PO_4^{3-})*	*amino acids* *glucose ($C_6H_{12}O_6$)* *carbon dioxide (CO_2)** *nitrogenous bases* *phospholipids*

****CO_2 is correct in either or both columns; the first column reflects the process of photosynthesis and the second column reflects the process of respiration, both of which occur in plants.***

5. Compounds can be categorized as organic or inorganic.
   a. What is the difference between an organic compound and an inorganic compound?
   Answers may vary depending on students' backgrounds. They may say organic compounds are much more associated with living organisms and life processes than inorganic compounds are. Students may also point out that organic compounds always contain the element carbon, and most inorganic compounds do not. However, because there are carbon-containing inorganic compounds, the presence of carbon alone is not sufficient to classify a compound as organic. With very few exceptions, organic compounds contain carbon atoms bonded to hydrogen atoms to form C-H bonds. Many organic compounds also contain oxygen atoms.
   b. Label each of the following compounds as organic (O) or inorganic (I).

ammonium (NH_4^+) ***I***
amino acids ***O***
carbon dioxide (CO_2) ***I***
DNA/RNA ***O***
glucose ($C_6H_{12}O_6$) ***O***
nitrate (NO_3^-) ***I***
nitrogenous bases ***O***
phosphate (PO_4^{3-}) ***I***
phospholipids ***O***
water (H_2O) ***I***

Carbon Cycling

6. Think about the metabolic process that breaks down organic compounds and produces carbon dioxide.
   a. What is this process called? ***Respiration***
   b. The carbon dioxide produced by this process is released into the ***atmosphere***.
   c. Which of the following organisms perform this process? Select all that apply.

☒ plants ☒ animals ☒ decomposers (fungi and some bacteria)

Nitrogen Cycling

7. Summarize three major roles of microbes in nitrogen cycling in the Serengeti.
   - Bacteria decompose complex organic matter from defecation, urine, and soft tissue. This releases nitrogen that can be taken up by plants.

- Ammonifying and nitrogen-fixing bacteria convert nitrogen into forms that can be used by plants, such as ammonia and ammonium.
- Denitrifying bacteria convert organic nitrogen (in the form of nitrate) into inorganic nitrogen (in the form of N_2), which cycles nitrogen back into the atmosphere.

8. Nitrogen gas (N_2) makes up 78% of the atmosphere. Why are so many ecosystems limited by nitrogen even though it is so abundant?
Although nitrogen is abundant in the form of nitrogen gas, plants cannot take up and use atmospheric nitrogen. Microbes can convert nitrogen gas into a form of nitrogen that can be taken up by plants, which makes microbes essential to nitrogen cycling.

9. Describe one way in which the cycling of nitrogen (and phosphorus) might be affected by human agriculture.
Answers will vary. Some examples are as follows:
   - ***When crops are harvested, nutrients are removed from the ecosystem. This can cause the soil to run out of nutrients over time (which is why people use fertilizer).***
   - ***Runoff and fertilizer from agriculture can increase the amount of nutrients in surrounding soils and waterways.***
   - ***Native plants may be removed so that crops can be grown. Crop plants may have different nutrient requirements and cycle nitrogen/phosphorus differently compared to the native plants.***

Putting It All Together

10. Based on everything you've learned about nutrient cycling in the Serengeti, circle the term in each pair of parentheses that best completes the statements below.
   a. Wildebeest consume (***organic***/inorganic) carbon by eating plants.
   b. Wildebeest obtain energy by breaking down (***$C_6H_{12}O_6$***/CO_2) and releasing ($C_6H_{12}O_6$/***CO_2***) into the atmosphere in a metabolic process known as (***respiration***/photosynthesis).
   c. Some soil bacteria can transform (organic/***inorganic***) nitrogen from the atmosphere into a form that plants can then use to build compounds such as (ammonia/***amino acids***).
   d. Plants take in (organic/***inorganic***) carbon in the form of (***CO_2***/$C_6H_{12}O_6$) from the atmosphere. They then convert it into (***organic***/inorganic) carbon in the form of (CO_2/***$C_6H_{12}O_6$***) in the process of (decomposition/***photosynthesis***).
   e. When plants and animals die, nitrogen is returned to the soil by the process of (nitrogen fixation/***ammonification***). Carbon is returned to the atmosphere as ($C_6H_{12}O_6$/***CO_2***).

CREDITS

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