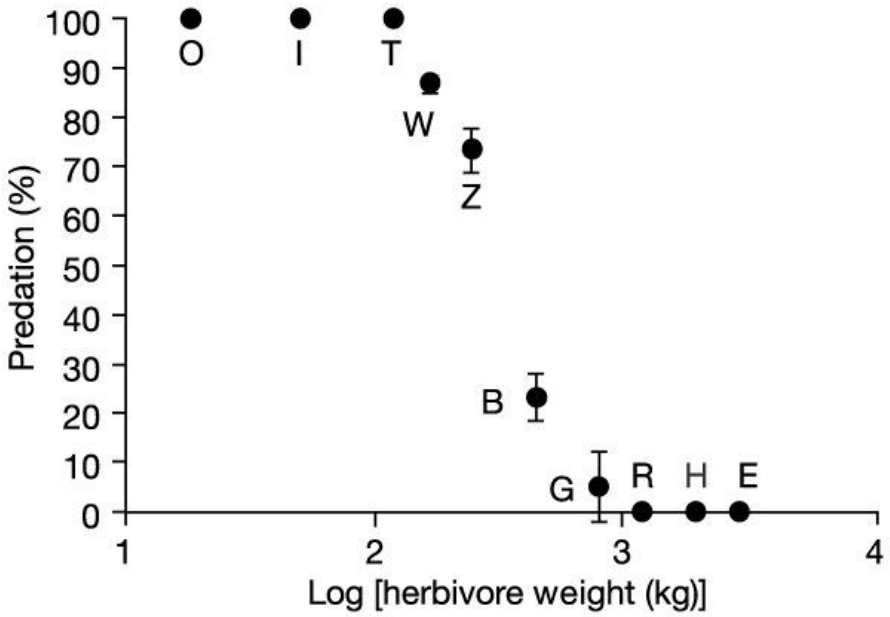
HOW TO USE THIS RESOURCE

Show the following figure and caption to your students. The accompanying Student Handout provides space below the image caption for Observations, Notes, and Questions and space next to the "Background Information" for Big Ideas, Notes, and Questions. The "Interpreting the Graph" and "Discussion Questions" sections provide additional information and suggested questions that you can use to prompt student thinking, increase engagement, or guide a class discussion about the characteristics of the figure and what it shows.



Caption: *Percentages of adult herbivores in the Serengeti that die due to predation. The herbivore species shown are the oribi (O), impala (I), topi (T), wildebeest (W), zebra (Z), African buffalo (B), giraffe (G), black rhino (R), hippo (H), and African elephant (E). Error bars represent 95% confidence intervals.*

BACKGROUND INFORMATION

All populations have limits to how large they can grow. As a population grows larger (population density increases), its size may be limited by the availability of food and other resources, which is known as bottom-up regulation. Alternatively, the size of the population may be limited by predators, which is known as top-down regulation. Ecologists have investigated bottom-up and top-down regulation in many ecosystems. However, most studies have focused on only one or a few species at a time.

In this study, scientists examined the factors that regulate the population sizes of multiple species in the diverse Serengeti ecosystem of East Africa. This ecosystem is home to many different species of predators and herbivores. The predators include 10 species of large carnivores, such as lions, hyenas, and cheetahs. The herbivores include 28 species of mammals, such as elephants, hippos, giraffes, and antelope.

To determine whether the population sizes of these herbivore species are regulated by bottom-up or top-down factors, the scientists analyzed 40 years of data on the causes of death for members of each species. In particular, the scientists looked at the percentages of adults in each herbivore species that died due to predation. They compared these percentages to the adults' body sizes (as measured by weight) to see if there was a relationship between an herbivore's size and its chance of being killed by predators.

INTERPRETING THE GRAPH

The figure demonstrates a nonlinear correlation between the adult herbivores' body sizes and their vulnerability to predators. Predation is the main cause of death for most of the smallest herbivores, such as the oribi (18 kg), impala (50 kg), and topi (120 kg). In contrast, predation plays a minimal part in the deaths of the largest herbivores, such as the giraffe (800 kg), rhino (1,200 kg), hippo (2,000 kg), and elephant (3,000 kg).

The figure also indicates a threshold at around 150 kg where the main cause of adult mortality shifts. Adult herbivores whose body size is below this threshold typically die due to predation, but adult herbivores whose body size is above this threshold typically die from other causes. This result suggests that population sizes of smaller herbivores in the Serengeti are generally regulated by predation (top-down regulation), whereas population sizes of larger herbivores are generally regulated by other factors, such as resource availability (bottom-up regulation). This difference may be due to the fact that smaller herbivores are preyed upon by a greater number of species (see Figure 2 in the original paper for additional data), because they are easier for a range of predators to eat.

The scientists further explored this idea by studying areas of the Serengeti where predator numbers had been reduced by poaching and poisoning. They found that, after the predators were removed, the population sizes of five smaller herbivores increased, but the population size of a larger herbivore, the giraffe, did not (see Figure 4 in the original paper for additional data). These results suggest that the smaller herbivores, but not the giraffe, were indeed regulated from the top down by predators.

Teacher Tip: Prompt your students to explain the parts of the graph as applicable:

- Graph type: Scatter plot
- *X*-axis: Logarithm of herbivore weight in kilograms, which is used as a measure of body size
  - Logarithmic scales like this are often used to compare data that cover a large range.
  - Increments on a logarithmic scale represent relative changes, rather than absolute ones. In this case, each subsequent increment on the *x*-axis represents an increase by a factor of 10.
  - A value of *n* on this *x*-axis corresponds to a body weight of 10^n kg. So a value of 1 on this *x*-axis corresponds to a body weight of 10^1 = 10 kg, a value of 2 corresponds to a weight of 10^2 = 100 kg, and so on.
- *Y*-axis: Percentage of annual adult mortality accounted for by predation
- Labels: Each of 10 Serengeti herbivore species: oribi (O), impala (I), topi (T), wildebeest (W), zebra (Z), African buffalo (B), giraffe (G), black rhino (R), hippo (H), and African elephant (E)
- Error bars: 95% confidence intervals. The data points for the smallest and largest adult herbivores have no error bars. This is because they were observed to either all die from predation, or all die due to other causes, during this study.

DISCUSSION QUESTIONS

- Describe the trends you see in the figure. Based on this figure, what is the relationship between herbivore body size and death due to predators?
- What kinds of herbivores have their population sizes most controlled by predators? What kinds of herbivores have their population sizes least controlled by predators? Use evidence from the figure to support your answers.
- At what herbivore body size (as measured by weight) would predation no longer be a major factor in population regulation? Use evidence from the figure to support your answer.

- Why do you think the scientists chose to show the herbivores' weights using logarithms in the *y*-axis of this figure?
- Would you predict that predators prey on all herbivores equally, or that some predators have a preferred herbivore size range? Use evidence from the figure to support your answer.
- What are some factors other than predators that could regulate herbivore population sizes?
- Based on the figure, which herbivore populations would you expect to be regulated by top-down factors? By bottom-up factors?
- What are some factors other than body size that could affect whether a population is regulated by top-down or bottom-up factors?
- Could different populations in the same species vary in whether they are regulated by top-down or bottom-up factors? Think of an example to support your answer.
- If predators were removed from the Serengeti ecosystem, what do you think would happen to the herbivore populations? Would the sizes of all the herbivore populations change? Why or why not?
    - What might happen to these populations if predators were later reintroduced to the ecosystem?
- How might ongoing losses in biodiversity affect population regulation in the Serengeti?
- Do you think the patterns of predation and population regulation observed in the Serengeti would apply to other terrestrial ecosystems, such as a forest ecosystem or a tundra ecosystem? What about aquatic ecosystems?
- Can you think of other examples of populations regulated by top-down or bottom-up factors? How do those examples compare to the ones shown here?

KEY TERMS

bottom-up regulation, carnivore, error bar, herbivore, logarithmic scale, predator, prey, scatter plot, Serengeti, top-down regulation

SOURCE

Figure 3 from:

Sinclair, A. R. E., Simon Mduma, and Justin S. Brashares. "Patterns of predation in a diverse predator–prey system." *Nature* 425, 6955 (2003): 288–290. https://doi.org/10.1038/nature01934.

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