

The Dilution Effect: How Biodiversity Can Affect Human Health

by

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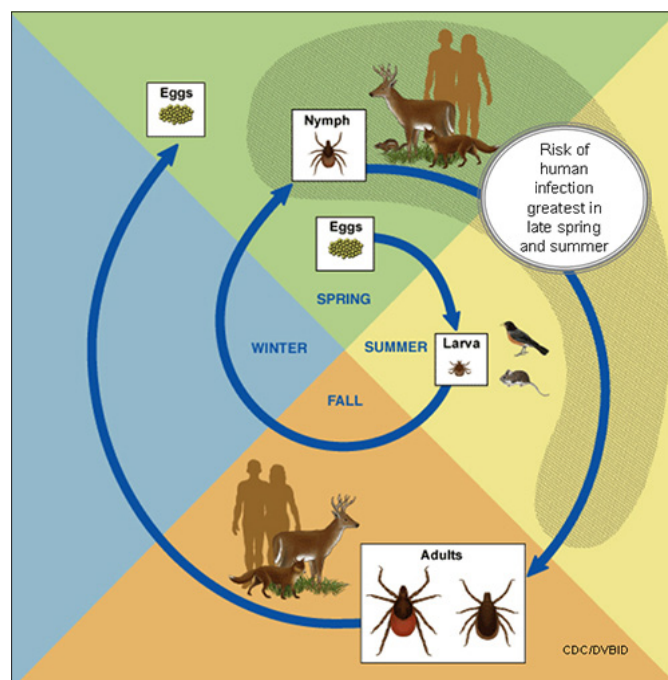


Introduction

Today you will learn information and examine data to piece together a fascinating story of how forest fragmentation and biodiversity loss can seriously affect the risk of Lyme disease transmission to humans. Diseases can be transmitted by biological *vectors*, such as mosquitos, flies, and ticks. Vectors feed on *hosts*, which can vary in their quality as a *reservoir* (their probability of infecting a vector with a pathogen) and in their quality as a host (their probability that a vector attempting a blood meal successfully feeds and survives). In the case of Lyme disease, ticks are the vectors that carry the disease-causing bacterium.

Lyme disease is an infectious disease transmitted via the bite of an infected tick. It is named after Lyme, Connecticut, the town in the United States where the first cases were described in 1975. It is the most frequently reported vector borne disease in the United States. In 2013 there were about 36,000 confirmed or probable cases of Lyme disease. Symptoms of Lyme disease include fever, headache, fatigue, and a characteristic “bullseye” rash. Lyme disease is easily treated with antibiotics soon after infection, but if left untreated, infection can spread to the joints, heart, and nervous system (CDC, 2015). Lyme disease in North America is mainly caused by the spirochete bacterium *Borrelia burgdorferi* that is vectored by the black-legged tick (genus *Ixodes*). Larval ticks are born uninfected, but by taking a blood meal from an infected host they can become infected with the bacterium and transmit the disease to other hosts including humans.

This case study consists of a figure set in which each data figure represents one piece of a puzzle that will fit together to tell the whole story. Different figures will be assigned to different groups, so each group will become an expert on one figure. After becoming experts on the different figures, we will come together as a class to share data and put the whole story together.



The lifecycle of blacklegged ticks generally lasts two years and they go through four life stages. After the eggs hatch, the ticks need a blood meal at each stage of their life cycle to survive. *Source:* www.cdc.gov/lyme/transmission/blacklegged.html.

Part I – Examine the Data Puzzle Pieces

To work on your assigned figure, please follow the directions below:

- To begin, choose one spokesperson and one note-keeper in your group. Each group will be asked to explain some element of your figure to the class during the class discussion. The spokesperson will share a brief explanation of your study's methods and your interpretation of the results with the class.
- First, look at the figure on your own. Read through the figure legend to orient yourself to the study. Then orient yourself to the graph (examine the parameters and scale on each axis, and the symbols). Then examine the overall pattern in the result (i.e., the basic trend, shape, relative values). Then attempt to interpret the results (i.e., determine how the pattern indicated in the results relates to the original hypothesis).
- After each person in your group has finished doing this, carefully discuss each figure together and answer the questions. Talk to make sure that each person truly understands the data, the axes, the symbols, the pattern, and your interpretations.
- Now decide how to explain these graphs to other students who will not have seen them before. What confused you at first? Show and explain these aspects. What are the most important points you need to make? Make sure you can explain these clearly. Anticipate problems and questions other students may have.

References

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Extra Resources

- The Centers for Disease Control and Prevention (CDC) has a comprehensive site with information about Lyme disease transmission and symptoms, preventing tick bites, tick removal, treatment, post-treatment Lyme disease syndrome, and data on incidence: <http://www.cdc.gov/lyme/>
- Learn more about Lyme disease symptoms, tests, and treatments from Mayo Clinic: <http://www.mayoclinic.org/diseases-conditions/lyme-disease/basics/definition/con-20019701>
- The National Science Foundation special report on ecology and evolution of infectious disease has a useful graphic explaining how forest fragmentation is related to Lyme disease risk: http://www.nsf.gov/news/special_reports/ecoinf/lyme.jsp
- The National Science Foundation also has an article on “ten things you always wanted to know about ticks, but maybe were afraid to ask” at: http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=131439
- Post-treatment Lyme disease syndrome (PTLDS) has been controversial. It is not directly relevant to the ecological concepts presented in the case, but it is a subject that has increasingly been in the news media. There is some information about it on the CDC site above. This news article from the *Portland Press Herald* (June 29, 2015) discusses how Maine is dealing with medical treatment of this syndrome: <http://www.pressherald.com/2015/06/29/maine-legislature-clears-way-for-long-term-lyme-disease-treatment/>
- *The New Yorker* published an article (“The Lyme wars,” 2013) about the increasing Lyme disease infection rate and the battle over how to treat it. Some of the authors of the scientific papers in this case study are interviewed. An interesting point highlighted by Dr. Rick Ostfeld is that there are still many unknowns in this area of science, such as the impact of co-infections by multiple tick-borne pathogens, and the way to treat advanced Lyme disease. <http://www.newyorker.com/magazine/2013/07/01/the-lyme-wars>

Figure 1 – Host Quality

Larval ticks feed on a wide variety of vertebrate host species, including mammals, birds and reptiles. To determine if species differ in their quality as a host, Keesing et al. (2009) captured individuals of six different host species in upstate New York, USA and conducted a larval tick feeding experiment in the laboratory. After a 72-hour pre-test period, they infected each individual with 100 larval ticks and then recorded how many ticks fed in a 96-hour period. Feeding success of a tick is defined as a larval tick getting a blood meal from the host and surviving. Feeding success was compared using ANOVA with host species as the treatment and individual hosts as replicates. Examine the data below.

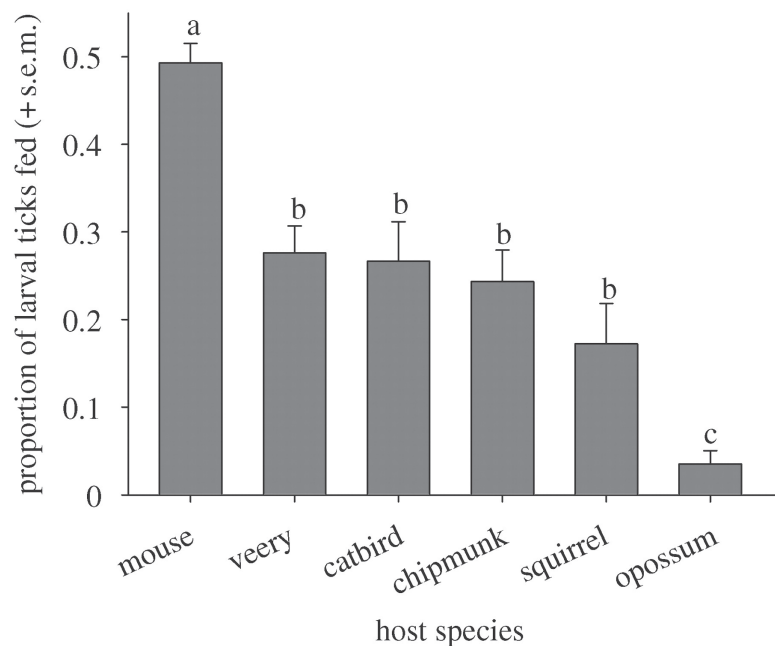


Figure 1. The proportion of larval ticks that fed successfully on six species that are common hosts for larval blacklegged ticks in upstate New York, USA. Hosts were captured in the field and held in the laboratory until ticks naturally feeding on them had fed to repletion and dropped off. Hosts were then reinfested with 100 larval ticks and monitored to determine the proportion of those ticks that fed successfully. Lowercase letters indicate results that were significantly different (ANOVA; $p < 0.05$). *Source:* Figure 1 of Keesing et al., *Proceedings of the Royal Society B* (2009), used with permission of the Royal Society.

Questions

1. Does the feeding success of larval ticks differ among different host species? If yes, how?
2. What are possible reasons why feeding success could differ among host species?
3. Based on this information, what are options to minimize the abundance of larval ticks?

Figure 2 – Species-Specific Effects on Human Exposure Risk

Different host species have radically different roles influencing the risk of human exposure to Lyme disease. This host-specific disease risk is affected by:

- the number of ticks an average individual of each species hosts in a given species,
- how many host individuals per species occur per unit area, and
- the probability a tick feeding from a member of each host will become infected.

The data shown in the figure below shows for different host species how many ticks are supported by each host species, indicated by larvae fed per hectare, and what proportion of those ticks will become infected. The data were collected during the seasonal peak in larval activity (August and September) in Dutchess County of south-eastern New York.

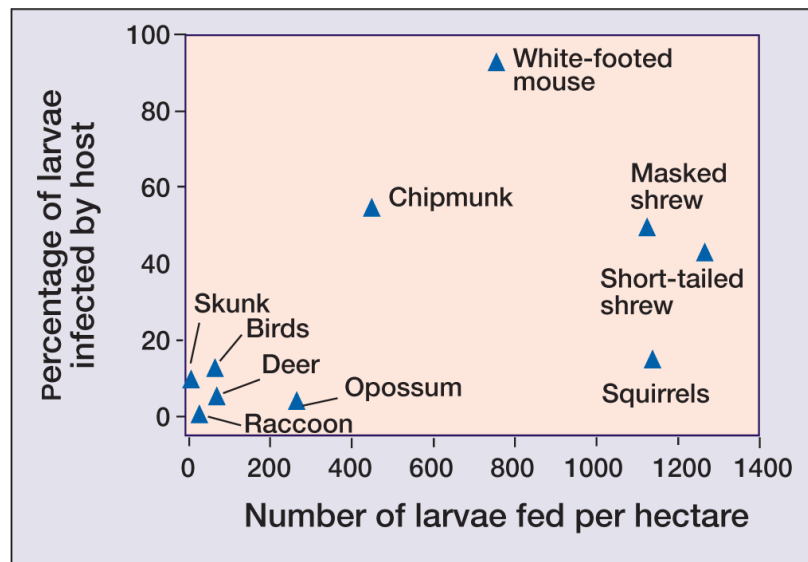


Figure 2. Position of 13 host species or host species groups for Lyme disease in two dimensions of species-specific effects on risk of carrying Lyme disease. The percentage of larval ticks infected by each host species (i.e., its reservoir competence) represents the probability that an uninfected, feeding larval tick will acquire infection with the bacterial agent of Lyme disease (*Borrelia burgdorferi*). The number of larvae fed per hectare represents the average larval burden per individual member of each host species species multiplied by the estimated population density of that species. Source: Figure 6a of Kremen and Ostfeld, *Frontiers in Ecology and the Environment* (2005). © The Ecological Society of America, used with permission.

Questions

- Can you identify where components *a*, *b*, and *c* of host-specific disease risk appear in the axes/variables of the figure?
- Examine the number of larvae fed per hectare per host.
 - Which host species feed the most larvae per hectare?
 - Which host species feed the least larvae per hectare?
- Examine the larval infection rate for each host.
 - On which host species does the highest infection rate occur?
 - On which host species does the lowest infection rate occur?
- How would you classify these species in terms of reservoir competence? Which are the least and most competent reservoirs?
- You are a land manager and you would want to reduce the risk of human exposure to Lyme disease on your land. Which host species would be the focus of your attempts and what actions would you take? Explain your rationale.

Figure 3 – Modeling Removal of Host Species on Exposure Risk

Kremen and Ostfeld (2005) used a computer model to explore the consequences of removing different tick hosts from the system to determine if the order of species loss affects the percent of nymphal ticks infected, one of the species-specific risk factors. The conditions for the three different scenarios they tested (random, mice always present, and empirical) are described in the legend below. The figure summarizes the results of their computer simulation model.

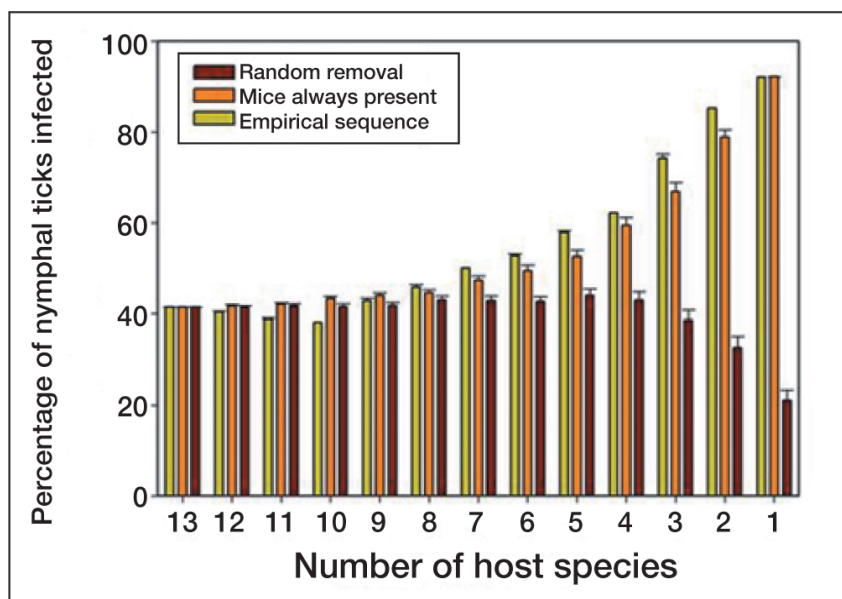


Figure 3. Simulations showing the consequence of three different extinction scenarios in vertebrate communities for the risk of exposure to Lyme disease, as measured by nymphal infection prevalence (NIP). In all cases, initial host communities included 13 species or species groups. In the “random removal” scenario, species were selected for removal in random sequence. In the “mice always present” scenario, mice never went extinct, and all other species were selected for extinction in random sequence. In the “empirical sequence” scenario, species were removed in the empirically observed order in which they are actually lost as forests are fragmented in the midwestern US (e.g. veeries, grey squirrels, flying squirrels, and chipmunks tend to occur only in large forest fragments and were the first to go extinct in the model, while white-footed mice tend to be ubiquitous and reach high densities in small fragments, and went extinct later in the model; see LoGiudice et al., 2003 for references). Error bars represent standard errors from 100 simulations for each extinction scenario. *Source:* Figure 6b of Kremen and Ostfeld, *Frontiers in Ecology and the Environment* (2005). © The Ecological Society of America, used with permission.

Questions

- Reread the figure legend, examine the x-axis, and explain how species richness is altered in each of the three extinction scenarios in your own words:
 - Random:
 - Mice always present:
 - Empirical:
- Does the density of infected nymphal ticks change as host species are lost from the system? If yes, how?
 - Random:
 - Mice always present:
 - Empirical:
- Why do you think you see the resulting pattern for the empirical sequence?
- What is your conclusion from results shown in this figure, i.e., how does species richness influence the risk of Lyme disease in natural systems?

Figure 4 – Effect of Habitat Patch Size on Mouse Density

The white-footed mouse, *Peromyscus leucopus*, lives in forest habitat, including large forests and small, isolated woodlots that are often separated by agricultural fields. Krohne and Hoch (1999) studied the density and dispersal of populations of the white-footed mouse inhabiting forest patches of different sizes in Indiana. Using digital measurements taken from aerial photographs of the region, forest patches of different sizes were selected. In 1989 they sampled mouse populations in 12 patches of forest of various disturbance history, sizes, and distances from other forests. In 1992 they sampled mouse populations in 6 forest patches of different sizes. Mouse densities in each patch were determined using live trapping during a 6-week period in late June and early July, when *Peromyscus leucopus* densities reach their summer peak. White-footed mouse density data for 1989 (a) and 1992 (b) are shown below.

Questions

1. Explain the x-axis. How are patch size and forest fragmentation related to each other?
2. Describe the relationship between mouse density and forest patch size.
3. In what range of forest patch size is mouse density particularly high?
4. What are possible explanations for the relationship between mouse density and forest patch size?

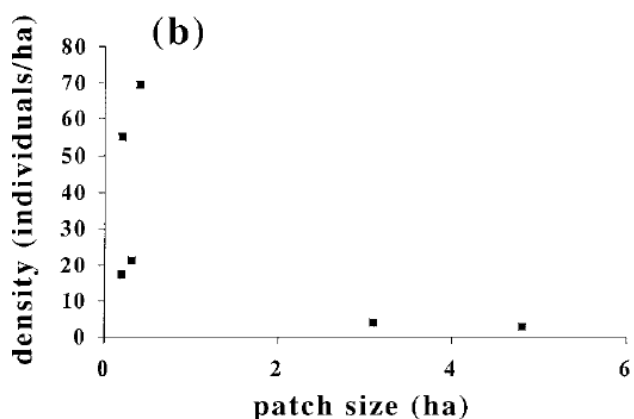
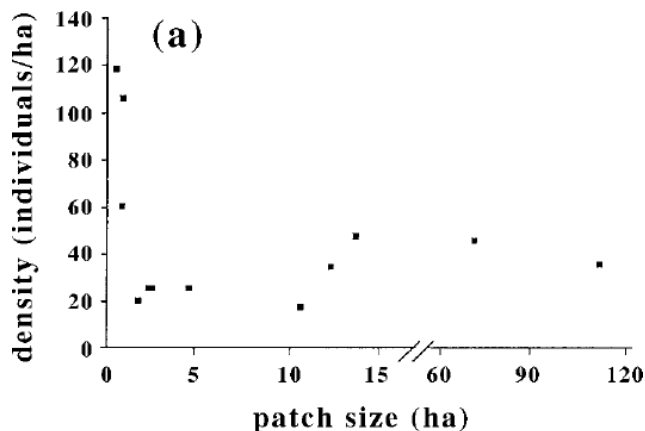


Figure 4. Relationship between *Peromyscus leucopus* (white-footed mice) density and habitat patch size in 1989 (a) and 1992 (b). Source: Figure 2 from Krohne and Hoch, *Canadian Journal of Zoology* (1999). © Canadian Science Publishing or its licensors, used with permission.

Figure 5 – Effect of Forest Fragmentation on Lyme Disease Risk

Human Lyme disease risk is related to two things: nymphal infection prevalence (NIP, the proportion of nymphs infected) and density of infected nymphs (DIN). NIP represents the probability one is exposed to Lyme bacterium if bitten by a tick, while DIN represents the probability one is exposed to Lyme bacterium upon walking into tick habitat. DIN is a function of NIP and the total density of nymphs (DON) in the area (i.e., $DIN = NIP \times DON$) (Allan et al., 2003). Allan et al. (2003) hypothesized that small forest patches, which tend to have more white-footed mice, would have a higher DIN for blacklegged ticks (*Ixodes scapularis*) than larger forest patches. To test this, they sampled tick density and *Borrelia burgdorferi* infection prevalence (NIP) in 14 maple-dominated forest patches, ranging in size from 0.7 to 7.6 ha, in Dutchess County of southeastern New York State. Examine their data below.

Questions

1. Identify DON, NIP, and DIN in the figure.
2. Recall the tick life stages. What is a larva? What is a nymph?
3. How is the density of tick larvae related to patch size? Why do you think this is?
4. How is the density of tick nymphs (DON) related to patch size? Why do you think this is?
5. How is the nymphal infection prevalence (NIP) related to patch size? Why do you think this is?
6. Explain the relationship between density of infected nymphs (DIN) and patch size. Compare panels B, C, and D.
7. What are the implications of these results? What do the results indicate about the effect of forest fragmentation on risk of Lyme disease?

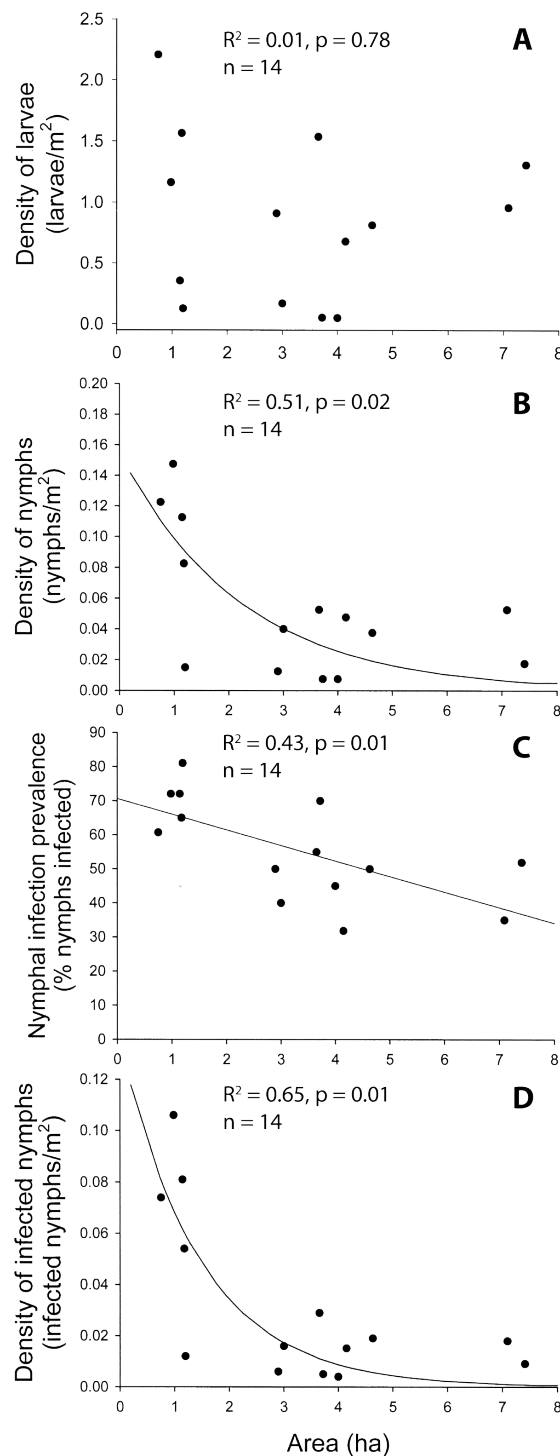


Figure 5. Relationship between measures of Lyme disease risk and forest patch area in a fragmented landscape in Dutchess County, New York. Source: Data modified from Figs. 1 and 2 from Allan et al., *Conservation Biology* (2003).

Part II – Putting It All Together

Based on the information you now have from the five data figures, create two concept maps/box-and-arrow diagrams that explain the relationship among the factors listed below and the risk of Lyme disease (1) without forest fragmentation and (2) with forest fragmentation. Connect items (words/boxes) with arrows to show relationships.

Each concept map should include all of the following items:

- Biodiversity
- White-footed mouse
- Human risk of LD
- Infected nymphal ticks
- Poor reservoir for *B. burgdorferi*

Connect items with arrows and label the direction of each connection with words (e.g. increases, decreases, supports, causes) or symbols (+ or -). Be prepared to present your concept map to the class.

Concept Map 1 (Without Fragmentation)

Concept Map 2 (With Fragmentation)

Part III – Discussion Points

1. What are the implications of this particular case for managing forests and animal populations in eastern and mid-western North America?
2. Some people criticize the growing effort to market conservation actions based on the utilitarian services that biodiversity can provide for human society. Other people say that using scientific understanding to inform policy (about conservation, land management, etc.) is smart practice and should not be considered “marketing.” Which perspective are you more comfortable with and why?
3. An ecosystem function is a biological, geochemical, or physical process that takes place within an ecosystem (e.g., carbon storage in vegetation, water filtration in a watershed). When an ecosystem function benefits humans, we often call it an ecosystem service. This case features reducing human disease risk as an ecosystem service provided by biodiversity. Can you think of other ecosystem services that are valuable to human society and why?
4. A parallel effect may exist in plant-herbivore systems, so that plant diversity inhibits the abundance of herbivores and parasites that attack plants. Given this type of dilution effect, how could biodiversity affect crop production?
5. Some people argue that conserving biodiversity is a good strategy to minimize disease outbreaks. Can you think of any other information you would like to know before you applied this strategy broadly?



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