Mice, Acorns, and Lyme Disease: a Case Study to Teach the Ecology of Emerging Infectious Diseases

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Abstract

Ebola, Zika, the recall of contaminated lettuce – these are just a few recent outbreaks making headlines. Students should be able to connect what they learn in their biology courses to explain these events happening around them. Unfortunately, students do not necessarily make those connections. Therefore, it is important, as instructors, to provide opportunities where students engage with societal issues and problems related to course content and case studies, using headlines from the news are one way to do this.

Here I describe a case study about Lyme disease that engages students in learning about the ecology of infectious disease. Lyme disease incidence has tripled in the last 15 years and is estimated to affect 300,000 Americans annually. This lesson uses an NPR news audio clip containing interviews with two disease ecologists, Rick Ostfeld and Felicia Keesing, who describe predicting Lyme disease incidence by measuring mice populations. The activities in this lesson explore factors that led to the recent surge in Lyme disease. In small collaborative groups, students analyze data figures from publications by the Ostfeld and Keesing labs (along with others) to construct an understanding of the ecology of Lyme disease and predict how changes to the ecosystem could affect Lyme disease incidence. This case study lesson could be relevant to those teaching microbiology, ecology, public health or biology for majors.

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Supporting Materials: S1. Lyme Disease - Reading Assignment and Objectives, S2. Lyme Disease - Reading Quiz with Answer Key, S3. Lyme Disease - Case Study In-Class Worksheet, S4. Case Study In-Class Worksheet Instructor's Key, and S5. Lyme Disease - Case Study PowerPoint Slides.

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Learning Goal(s)

Students will:

- understand human's impact on the environment and the environment's impact on human infectious disease (aligns with ASM Evolution Learning Goal: How do humans' impact on the environment influence the evolution of microorganisms in the context of emerging infectious diseases).
- understand the ecology of Lyme disease and how humans, animals, and the environment impact disease prevalence (aligns with ASM Systems Learning Goal: How do microorganisms, cellular and viral, interact with both human and non-human hosts in beneficial, neutral, or detrimental ways?)
- explore how biodiversity loss impacts transmission of zoonotic diseases.

Learning Objective(s)

Students will be able to:

- outline the life cycle of ticks and explain the transmission cycle of Lyme disease.
- describe factors that make mice a competent reservoir for Borrelia burgdorferi.
- analyze and interpret line and bar graphs of data on the effects of changes to ecological communities on the risk of human exposure to Lyme disease.
- explain how the incidence of Lyme disease is determined by interactions between bacteria, animals, humans and the environment.
- predict how changes in the ecosystem affect Borrelia burgdorferi transmission.
- explain how human activities affect biodiversity and the consequences of those actions on disease outbreaks.

INTRODUCTION

Outbreaks and infectious diseases make headlines all the time. Students hear about these events and need to understand and grapple with their implications. However, students do not always connect what's happening in the world with the science I am teaching in my microbiology course. I want to help students see those connections so that hopefully they can make them for themselves beyond the classroom. Indeed, research shows that experts tend to organize knowledge with a high density of connections versus novices who often learn concepts in isolation, making few connections among concepts and facts (1). To help students see the relevance of microbiology in the world around them and to appreciate the impact of societal behavior on the emergence of infectious diseases and their spread, I developed this lesson to engage students in learning about the ecology of infectious disease and the interconnectedness of humans, microorganisms, animals and the environment and its impact on human health. To achieve this, I developed a case study that focuses on a current infectious disease epidemic.

Case Study Approach

I chose the case study approach because it is student-centered, collaborative, and shifts the focus away from memorizing facts to applying concepts and skills to solve real world problems (2). Furthermore, providing content in the form of a narrative of a real-world event makes the content more relevant to students (3) and since relevance can be a strong motivating factor (4), case studies can engage students in deep and lasting learning (1). The case study approach was particularly appropriate in the context of teaching the ecology of infectious disease because it has been shown to be highly effective in promoting interdisciplinary learning (5, 6).

This case study lesson is anchored by an NPR audio news clip (7) containing interviews with two disease ecologists, Rick Ostfeld and Felicia Kessing, who describe their novel way of predicting Lyme disease incidence by measuring mice populations. The activities in this lesson follow the experiments performed by the ecologists featured in the news report to explore the factors that have led to the surge in Lyme disease. In small collaborative groups, students analyze data figures from publications by the Ostfeld and Kessing labs (along with others) to construct an understanding of the ecology of Lyme disease and predict how changes to the ecosystem would affect Lyme disease incidence.

This news story provided an interesting case study to engage students in examining factors that have led to the surge in Lyme disease and to learn about the ecology of infectious disease.

Intended Audience

This lesson was designed for a class of 20-25 junior and senior-level biomedical science majors in an elective course about Outbreaks, Epidemics and Pandemics. In this course, students learn about both the biological as well as the social/cultural/environmental factors that impact disease spread and how to prevent and control outbreaks. The vast majority of students intend to pursue health professional careers (physicians, dentists and physician assistants) or public health careers.

Required Learning Time

The lesson was completed in 90 minutes using 1 x 75-minute class period and the first 15 minutes of a second class period.

Pre-requisite Student Knowledge

The students should have basic skills in interpreting line and bar graphs and in the process of science, i.e. making predictions based on evidence, testing those predictions against experimental or observational data and modifying one's own understanding in light of evidence. The students should also have basic knowledge of infectious disease and the chain of transmission including the role of reservoirs. If students lack this knowledge, this content could be provided by a brief mini lecture in a preceding class or as an assigned reading prior to class.

Pre-requisite Teacher Knowledge

Instructors should have a basic understanding of the transmission cycle of Lyme disease and the ecology of Lyme disease including the roles of mice, tick, and deer. Instructors should also familiarize themselves with the experiments performed to generate the graphs in the case study worksheet by reading the scientific papers referenced by each graph (Table 1). I suggest instructors read the full scientific papers to familiarize themselves with Ostfeld and Keesing's research in order to field potential student questions that may arise. The instructor does not need to have a comprehensive background in microbiology or ecology to understand these papers or to teach this lesson.

SCIENTIFIC TEACHING THEMES

Active learning

Students read a CDC-produced brochure as well as a scientific article outside of class to gain an understanding of Lyme disease and its transmission cycle as well as a basic introduction to the ecology of infectious disease. Students then spend class time working in teams of four to five students to interpret data from a number of research articles on Lyme Disease and to evaluate potential answers to each question on the case study worksheet. Teams of students are given a single case study worksheet to encourage discussion and debate. During the whole class debrief, students are asked to provide and explain their responses to the case study questions. This whole class debrief allows teams to assess their own responses for correctness. Individually, students will summarize what they have learned by creating a concept map demonstrating connections between the concepts discussed.

Assessment

I assess students' understanding of the background reading by an individual and group quiz (Supporting File S2: Lyme Disease-Reading Quiz). This multiple-choice quiz is initially taken individually. Then the student takes the same quiz with their team using an IF-AT scratch off card (http://www.epsteineducation.com/home/) for immediate feedback. I also informally assess background knowledge by visually inspecting the teams' drawings of the transmission cycle of Lyme disease.

Students can self-assess during the student-led discussions of the case study worksheet questions (Supporting File S3: Lyme Disease In-class Worksheet) as peers can correct each other and/or clarify concepts to one another. I provide formative assessment by interacting with groups during the team discussions and during the entire class debrief. I also collect and assess the team written responses for accuracy. I provide written comments on the worksheets that are returned to students the following class.

Finally, summative assessment occurs when I gauge each team's concept map during class session 2 for accuracy and integration of concepts. Each individual student created a concept map as homework prior to class session 2 and these may be turned in collected and assessed for an individual grade although I did not choose to do that.

Inclusive teaching

The lesson uses multiple approaches to facilitate learning: reading, listening, analyzing data, discussing and creating a concept map. The use of structured small group work allows input and collaboration among all students. Students work with the same team of peers throughout the semester to enable less confident students to become comfortable sharing their ideas in a nonthreatening environment so that they can gain confidence in their knowledge. I provided guidance on effective teamwork at the beginning of the semester to ensure that team expectations were clear, and that group work would be inclusive and productive. Framing the content around a current and real-world event provides relevance to a variety of students. The use of Lyme disease as our case study allowed opportunities to think about environmental issues and public health issues in addition to microbiology and therefore appeals to students' broader interests.

LESSON PLAN

Course Context and Course Situational Factors

This activity is designed as part of a unit on the physical and social environmental factors that facilitate infectious disease spread. This unit is one of 4 units of a 3-credit upper level course on Outbreaks, Epidemics and Pandemics taught by a single instructor. The lesson occurs after basic infectious disease concepts of chain of transmission, role of reservoirs and zoonotic disease have been covered. Fourteen and 22 students enrolled, respectively, during the two semesters I implemented the case study. A course in microbiology was a prerequisite for this course; however, the activity could be adapted for lower division students who haven't taken microbiology yet. The course was designed using a team-based learning model in which students work in groups of 4-5 on class activities throughout the semester. I randomly assigned students to groups and they worked with the same group throughout the semester. Thus, the students had established effective group dynamics and had experienced working on case studies and completing a case study worksheet before this particular activity. The course was taught in both a standard classroom and a collaborative and active learning (CAL) classroom (http://www.marquette.edu/ctl/faculty-professional-development/CallforProposalstoTeachinCALClassroom.shtml). The standard classroom had small moveable desks whereas the CAL classroom had tables large enough for students to work in groups of 4 or 5, moveable chairs and portable white boards. In the discussion, I describe some modifications I made to the standard classroom to implement the collaborative and active learning approach of this lesson.

Timeline of Lesson

<u>Pre-Class Student Preparation</u>

This lesson specifically addresses humans' impact on the ecosystem and how this changes the dynamics between bacteria, animal reservoirs, and human hosts. The students should already be familiar with basic infectious disease concepts such as the chain of transmission, transmission cycles, role and types of reservoirs and zoonotic disease. I covered these concepts in prior lectures and/or prior reading assignments in this course. For example, students have read several scientific review papers about zoonotic spillover events and different types of transmission cycles of vector-borne diseases prior to this lesson (8-10). These additional references may be assigned in preparation for this lesson as well.

Students will also need to understand concepts specifically related to transmission of Lyme disease. I assign a CDC brochure, "Lyme disease: What you need to know," as outside-of-class reading to provide students with this background. In addition, students read a scientific review article about biodiversity loss and the ecology of infectious diseases as homework (11). Reading objectives are provided to the students to guide their reading (Supporting File S1: Lyme Disease Reading Assignment). If students have not yet been introduced to the topics of reservoirs, transmission cycles or zoonotic disease, then additional readings that cover these topics should be assigned. Example resources are provided in the modifications for lower division students in the Discussion.

<u>Pre-Class Instructor Preparation</u>

Instructors should assign the pre-class reading to students before the class period in which you use the case study. Instructors should prepare copies of the reading quiz (Supporting File S2: Lyme Disease-Reading Quiz) for each student, a case study worksheet per student group (Supporting File S3 Lyme Disease In-Class Worksheet) and an IF-AT scratch off card per student group. Instructors should check that the embedded links to the audio files function properly with their classroom equipment. Instructors may choose to download the audio file of the NPR story from: http://www.npr.org/templates/transcript/transcript.php?storyId=518219485.

<u>Individual and Group Readiness Assurance Test</u>

Class begins with an activity to ensure students' understanding of the preassigned reading about Lyme disease transmission. Each student takes an individual readiness assurance test (i.e. a quiz) and submits their answers for a grade (Supporting File S2: Lyme Disease-Reading Quiz). I use the Zipgrade app (https://www.zipgrade.com/) to grade these individual quizzes and examine the item analysis to gauge which quiz questions were challenging to the students. It takes me less than 2 minutes to grade 22 quizzes using Zipgrade. While I grade the individual quizzes, the students work within their small group on the same quiz and submit group responses by completing an Immediate Feedback Assessment Technique (IF-AT) card (http://www.epsteineducation.com/home/about/). The purpose of using the IF-AT card is that the group must discuss the answers and reach consensus before committing to an answer. The IF-AT cards also provide immediate feedback and students are able to make a second attempt at a question is their initial answer is incorrect. The quiz is worth a total of 15 points with the individual quiz making up 5 of the points and the group quiz grade making up 10 of the points. The grading was designed intentionally to emphasize group work.

<u>Introduction to the case</u>

I begin the case study activity by playing the first 2 minutes of the audio file titled, "Forbidding Forecast for Lyme Disease in the Northeast" by Michaeleen Doucleff and Jane Greenhalgh aired on National Public Radio on March 6, 2017 (7), (Embedded audio file in slide 2 of Supporting File S5-Lyme Disease Case Slides). The clip introduces the students to the case: an emerging Lyme disease epidemic is happening in the Northeast and 2017 is predicted to be the worst year for Lyme disease. Why is this happening? The ecologists in the story imply that an increase in the mice population predicts a high number of Lyme disease cases. After the clip, I explain to the students that they will be working through this case study to figure out the relationship between large mouse populations and Lyme disease to understand more broadly how humans' impact on the environment is a driver of emerging infectious diseases.

The individual and group quizzes encouraged retrieval of the students' knowledge of the life cycle of ticks and Lyme disease transmission from the assigned reading. After the case is introduced, the students use their prior knowledge to create a visual flow diagram of the chain of transmission of Lyme disease on a white board, which is essential to thinking through the case. I quickly assess the drawings by looking at each group's white board and address any incorrect concept or any missing factors. Next, we discuss the concept of the epidemiological triangle, and I emphasize that this case study will focus on the environment that increases exposure of the human host to the infectious agent, Borrelia burgdorferi. Then, I play the next minute of the audio file, which reinforces the chain of transmission of Lyme disease and describes the spread of Lyme disease in the U.S. and ends with the reporter asking, "So why is Lyme spreading like this? That question is simple, but the answer is complicated." Student teams then brainstorm ideas for why Lyme cases have tripled in the last 30 years and these ideas are shared with the entire class. I then guide the discussion back to the case study and repeat the prediction voiced in the case study by the featured ecologists, Felicia Keesing and Rick Ostfeld, that large mouse populations lead to increased Lyme cases. I then explain to the students that they will be interpreting data published by Keesing's and Ostfeld's labs.

Discussion of figures

The bulk of the lesson is spent with students working through the case study worksheet (Supporting File S3 Lyme Disease In-Class Worksheet) either interpreting graphs from Keesing and Ostfeld publications or predicting the results of Keesing and Ostfeld's experiments and then verifying their predictions by comparing to published results. Case Study Figure 1 (slide 12 from Supporting File S5: Lyme Disease- Case Slides) is a graph created from the data in Table 1 from LoGiudice et al (12). I explain that the authors sampled various host species by collecting the engorged larvae from animals during a 72-hour captive period and calculating the proportion of engorged larvae that molted into nymphs and the infection prevalence of the resulting nymphs. After students examine Case Study Figure 1, the instructor can prompt them to analyze the figure and use the data to explain why Drs. Keesing and Ostfeld focused on mice. The next discussion prompt is to get students to think about why mice might be a competent reservoir. In a previous lecture, we covered features of reservoir competence and so this discussion serves to reinforce this concepts. However, if reservoir competence is not a critical concept for your students, this discussion prompt can be skipped without affecting the goals of the case study.

Next, the students brainstorm why mice populations increase. Even though none of the students in the course had taken an ecology course, they were able to come up with ecological explanations such as loss of predators, higher birth rate, influx of mice from other areas in search of food, abundance of food, availability of alternative food source, milder weather, etc. I then explain the experiment conducted by Schauber et al., where researchers measured acorn production annually from 1992-2002 by placing baskets underneath mature oak trees in two 2.25 hectare forest plots at the Institute of Ecosystem Studies in Duchess County, New York and counting intact mature acorns collected every month during autumn. They calculated acorn production by dividing the total acorn count by square meter of ground under oak trees (13). The authors also calculated mouse density in the same two 2.25 ha areas by a capture-mark-recapture method to count mice and then divided the number of mice per square meter. Students are asked in question 4 to consider Case Study Figure 2 (slide 17 from Supporting File S5: Lyme Disease-Case Slides) and as a group, write down their conclusion. After a brief discussion of Case Study figure 2, I give a mini lecture about masting events and then ask the students, "Why would an increase of acorns lead to increased mice density the following year?" Possible response may include higher mouse survival, immigration of mice to the area of high food, and higher fitness and consequently better breeding. I then explain that Dr. Ostfeld's group did an experiment that was published in Science, one of the premier science journals (14), to examine this question. Their experiment aimed to characterize the relationship between acorn production and mouse survival and reproduction. The researchers took advantage of the fact that in 1995, acorn production at their research site was exceptionally low (lower by a factor of 18 than in 1994). They added acorns to 3 experimental grids of land but not to three control grids in October- November 1995 and monitored mouse density and reproductive status each month before, during and after the acorn addition. Students analyze Case Study Figure 3 (slide 20 from Supporting File S5: Lyme Disease- Case Slides) and write down their conclusions. Students should be able to articulate that after acorn addition in Nov/Dec, mice densities were greater in the experimental grids than on control grids from March- August. The instructor can then also discuss the mouse breeding data which is consistent with the mouse density data.

After the Case Study Figure 3 discussion, the students predict the levels of tick density in the control and experimental grids after acorn addition in the same experiment. The case study worksheet includes a blank template of a graph (Question 6) that the students should fill in. By providing a template, the students must visualize how the data should appear and commit to a prediction. I find that having the students draw their prediction on the graph allows for a richer discussion of their ideas. This also allows instructors the opportunity to very quickly assess each groups' prediction by quickly glancing at their drawn graphs on their worksheet. After I ask one group to explain their prediction, I then discuss the results published by Jones et al. (14) and students can compare and assess their own predictions. After a brief mini lecture about urban sprawl and forest fragmentation, students then predict the effects of forest fragmentation on mouse density. I then reveal a figure from Nupp and Swihart, "Case Study Figure 4 (slide 27 from Supporting File S5: Lyme Disease- Case Slides) that shows that as woodland size decreases, mice density increases (15). Next, students use knowledge gained from their assigned reading to discuss why mice may be resilient to forest fragmentation. Students then predict the effect of forest fragmentation on tick density, again using a provided graph template. Next, I display the data figure from Allan et al. (16), "Case study Figure 5" (slide 33 from Supporting File S5: Lyme Disease- Case Slides), that shows that as forest size decreases, tick density also decreases. Students compare and assess their predictions to the published data. Subsequently, students predict the effect of a decrease in species biodiversity on Lyme prevalence using a provided graph template. Again, students compare their prediction to published data from Ostfeld et al. (17).

Summarize in a Concept Map

After going through the data that helps explain the ecology of Lyme disease, I ask the students to construct a concept map as homework, using a provided list of terms (Question 14 from Supporting File S3 Lyme Disease In-class Worksheet), to synthesize what they learned.

Concluding the Case

The lesson continues the next class period. The students begin by sharing their concept maps with their team members. Then together as a team, they construct a group concept map and draw it on the white board. I quickly assess the group concept maps and address any errors. Student groups are invited to look at other groups' concept maps and compare to their own. We then listen to the remaining few minutes of the audio file, which explains how urban development of forest areas impacts mice populations, leading to increased tick populations and consequently increased incidence of Lyme disease. As a whole class, we debrief on why one would expect to see a high incidence of Lyme disease cases in a suburban habitat based on the interactions in the concept map. This leads into a broader discussion of strategies to control the Lyme disease epidemic and prevent its further spread. The lesson is completed in about 15 minutes of this second class period, leaving time to cover a new topic.

TEACHING DISCUSSION

This case study activity is an engaging, adaptable lesson that effectively gets students thinking broadly about infectious disease and the interplay between animals, humans, microbes and the environment in disease emergence. Examining disease ecology data helps students see the connections among the multiple determinants of disease outbreaks. The case study format and the use of a current news story make the topics of disease ecology, epidemics, and emerging infectious diseases approachable and interesting.

Lesson's effectiveness

The Lyme disease epidemic case study provides a framework for students to integrate concepts of ecology, microbiology and epidemiology to construct a rich understanding of how this epidemic emerged. The first question in the handout will typically elicit somewhat superficial responses from students to explain the recent explosion of Lyme disease cases in the US. By following the experiments from Keesing's and Ostfeld's labs, students dive deep into the research to understand the connections between humans, environment, wildlife, and pathogen. At the end of the lesson, students synthesize their knowledge by creating a concept map. My assessment of the groups' concepts maps indicate that the lesson was effective for student learning of how changes in the interactions between bacteria, animals, plants, and humans increased Lyme disease incidence. While students explored the microbiology and ecology behind the case, they also explored the social human factors that impact disease emergence. Exploring these interactions in the context of a case study led to richer discussions of the multiple determinants of disease emergence and establishment of epidemics in subsequent class discussions.

In addition to content, the case study was also designed to encourage students to develop hypotheses and predict the graphical representation of experimental data. I observed that students became more comfortable over the course of the lesson with drawing their predicted graphs. The first time they are asked to draw their prediction in the graph template (Question 6 from Supporting File S3 Lyme Disease In-class Worksheet), the students seem hesitant but as we move through the activity, they seem more willing to take intellectual risks and draw multiple possible outcomes that the group can then discuss to determine the most likely outcome. Asking students to draw their prediction on a graph not only forces them to commit to a clear unambiguous answer as a group, but also requires the students to externally visualize their understanding of the concept. Thus, asking students to draw the predicated data allows the instructor to quickly gauge whether the students understood the experiment and concept.

Students' reaction

The students' response to the case study and small group work format was very positive. In 2017, students completed an anonymous course survey where they were asked to rate on a Likert scale of one through five the usefulness/effectiveness of various course components. 10 of the 12 (83%) students who completed the survey rated the case-based format as "most useful/effective" (score=5) and the remaining students (17%) rated it as "useful/effective" (score=4). In 2018, the class completed a different anonymous survey and in response to the open-ended question, "What worked well for you in this course?" a majority of students (11/20) mentioned specifically the opportunity to work with a group of peers on the worksheets. A representative student comment was: "The ability to collaborate in small groups each class was a great simulation for the teamwork that is required of all professionals." In addition, some (7/20) responded to the same open ended question that the case studies specifically were what worked well for them : "It [case study format] really helped put things into a "real life" and applicable perspective" and "The case studies during class allowed me to conceptually apply the material we would learn in class."

Adaptations and Modifications

Different topic emphasis

While this activity was implemented in a small upper-division infectious disease course, its content touches upon multiple disciplines and therefore could be appropriate for ecology, microbiology, epidemiology, environmental studies, general biology, or (with modifications) biology for non-majors courses. Depending on the course learning goals, different concepts of the case may be emphasized or eliminated. For example, an ecology course may eliminate the discussion of reservoir competence but spend more time discussing oak tree masting events or the impact of biodiversity loss.

Adapting for lower division biology students

The activity could be used with lower division biology students who have not taken a course in microbiology. These students would need to receive instruction in or read as an assigned reading about concepts of transmission, reservoir and infections. A good resource that covers these topics is Lesson 1 Introduction to Epidemiology Section 10: Chain of Infection from Principles of Epidemiology in Public Health Practice, a free online resource published by the Centers for

Disease Control and Prevention (https://www.cdc.gov/ophss/csels/dsepd/ss1978/lesson1/section10.html). Excellent, short video clips are available to introduce students to the concept of zoonoses (https://www.cnn.com/videos/tv/2017/04/07/unseen-enemy-extra-1.cnn). Reading objectives should be modified based on the students' prior knowledge. For example, my students had already been introduced to the topics of sylvatic and urban transmission cycles and therefore were able to answer Reading Objective #5 using their prior knowledge. For lower division students, this reading objective and others may need to be modified. Adapting the activity in the classroom would require more instructor guidance of student-led discussions of the worksheet questions. If enrollment is large, then senior undergraduate or graduate teaching assistants may be needed to facilitate the small group discussions. In addition, more time for whole class debriefs would be needed to articular the process of interpretation of the data and how it supports a particular response.

Whiteboards for group drawing (pathways, concept maps, predicted graphs, etc.)

Because my course emphasizes group work, this exercise (along with others that I use in the course) requires students to generate drawings of predicted graphical data, pathways and concept maps to visually represent students' thinking to help facilitate the discussion of ideas in a group. Because I teach in both a CAL classroom and a classroom that does not have white boards, I have modified the traditional classroom by taping large poster-size pieces of paper to the wall at the start of class on days that involve drawing. In addition, 3M makes easel pad size Post-It adhesive paper, although these can be expensive. Other ways to facilitate drawing for small group discussion are laminated poster boards or cut marker board sheets from a home improvement store that students can write on with dry-erase markers.

Different time frames

While the activity is designed to take ~90 minutes, it could be extended by including further discussion questions. For example, students could be shown a brief news clip about a different epidemic of a zoonotic disease and asked how forest fragmentation may impact it. Some examples include the 2014 West African Ebola epidemic or Rocky Mountain spotted fever in the U.S. In a higher-level course where students have been trained in reading primary literature, students could be assigned to read the original scientific papers and complete the worksheet as a homework assignment and class time could then be used to discuss their answers. Depending on the course objectives, certain worksheet questions or topics may be eliminated to shorten the case study activity to fit a 60-minute class format.

Adapting for a large enrollment class

While the activity was used in relatively small (<25 students) classes, it could be adapted for use in a large enrollment class by allowing more time for the all-class debrief. A subset of groups could be asked to present their responses to the worksheet questions. Teaching assistants could rotate among groups as they work through the worksheet questions guiding students in their small group discussions. Sample concept maps or sample graph predictions could be shared with the entire class by capturing with a cell phone or document camera and projecting to the class.

Alternative systems to grade group quizzes

This instructor used IF-AT cards for the group quizzes however, if an instructor does not have access to IF-AT cards, students could also simply submit a single group answer sheet that the instructor grades immediately. Alternatively, some student response systems have a group quiz function (i.e., Learning Catalytics) or a team mode (i.e., Kahoot!) which would allow immediate feedback to the group.

SUPPORTING MATERIALS

- S1 Lyme Disease - Reading assignment and objectives
- S2 Lyme Disease - Reading Quiz including answer key
- S3 Lyme Disease - Case Study In-class Worksheet
- S4 Lyme Disease - Case Study In-class worksheet/ instructor's key
- S5 Lyme Disease - Case Study PowerPoint slides

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16. Allan, BF, Keesing, F, Ostfeld, RS. 2003. Effect of Forest Fragmentation on Lyme Disease Risk. Conservation Biology. 17:267-272.
17. Ostfeld, RS, Keesing, F. 2000. Biodiversity and Disease Risk: The Case of Lyme Disease. Conservation Biology. 14:722-728.

Table 1. Scientific Articles used in the case study

Reference	Related Question in Worksheet	Notes
LoGiudice, K, Ostfeld, RS, Schmidt, KA, Keesing, F. 2003. The ecology of infectious disease: effects of host diversity and community composition on Lyme disease risk. Proc. Natl. Acad. Sci. U. S. A. 100:567-571	Question 2, Case Study Figure 1	
Schauber EM, Ostfeld RS, Evans AS. 2005. What is the Best Predictor of Annual Lyme Disease Incidence: Weather, Mice or Acorns? Ecological Applications. 15(2): 575-586.	*Question 4, Case Study Figure 2*	
Jones CG, Ostfeld RS, Richard MP, Schauber EM, Wolff JO. 1998. Chain reactions linking acorns to gypsy moth outbreaks and Lyme disease risk. Science. 279:1023-1026	Questions 5 and 6, Case Study Figure 3	
Ostfeld RS, Schauber EM, Canham CD, Keesing F, Jones CG, Wolff JO. 2001. Effects of acorn production and mouse abundance on abundance and Borrelia burgdorferi infection prevalence of nymphal Ixodes scapularis ticks. Vector Borne Zoonotic Dis. 1:55-63.	Question 6	
Nupp TE, Swihart RK. 1996. Effect of forest patch area on population attributes of white-footed mice (Peromyscus leucopus) in fragmented landscapes. Canadian Journal of Zoology. 74:467-472	Question 8, Case Study Figure 4	
Allan BF, Keesing F, Ostfeld RS. 2003. Effect of Forest Fragmentation on Lyme Disease Risk. Conservation Biology. 17:267-272	Questions 9 and 10, Case Study Figure 5	
Ostfeld RS, Keesing F. Biodiversity and Disease Risk: the Case of Lyme Disease. Conservation Biology. 14:722-728	Questions 11 and 12, Case Study Figure 6	
Diuk-Wasser MA, Gatewood Hoen A, Cislo P, brinkerhoff R, Hamer SA, Rowland M, Cortinas R, Vourc'h G, Melton F, Hickling GJ, Tsao JL, Bunikis J, Barbour AG, Kitron U, Piesman J, Fish D. 2012. Human Risk of Infection with Borrelia burgdorferi, the Lyme Disease Agent in Eastern United States. Am. J. Trop. Med. Hyg. 86(2): 320-327.	n/a	Background reading
Keesing F, Holt RD, Ostfeld RS. 2006. Effects of species diversity on disease risk. Ecol. Lett. 9:485-498.	n/a	Background reading
Keesing F, Belden LK, Daszak P, Dobson A, Harvell CD, Holt RD, Hudson P, Jolles A, Jones KE, Mitchell CE, Myers SS, Bogich T, Ostfeld RS. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature. 468:647-652	n/a	Background reading
Ostfeld RS, Keesing F. 2012. Effects of Host Diversity on Infectious Disease. Annual Review of Ecology, Evolution, and Systematics. 43:157-182	n/a	Background reading

Table 2. Lyme Disease Case - Teaching Timeline

Activity	Description	Time	Notes
Preparation for Class			
Background reading	Students read the assigned reading as homework prior coming to class	Outside of class	Reading assignment and reading objectives are provided in Supporting file S1
Prepare materials for class	1. Make copies of case study worksheet for each group 2. Make copies of reading quiz 3. Bring copies of IF-AT cards 4. Bring superstick easel pad and markers if no dry erase boards are available	~15 minutes	1. Case study worksheet is provided in Supporting File S3 2. Quiz is provided in Supporting file S2
Class Session 1- Progressing through the Activity (lecture slides with notes are in Supporting file S5)			
Individual and Group readiness assurance tests	Students take a quiz individually, submit their answers and then take the same quiz as a group using the IF-AT card	15 minutes	
Listen to audio file	Students listen to the first 2 minutes of the audio file of the case study played by the instructor	2 minutes	Audio file is embedded in PowerPoint. Transcript can be accessed from http://www.npr.org/templates/transcript/transcript.php?storyId=518219485
Draw	As a team, the small groups draw a visual diagram of the Lyme disease transmission cycle on a whiteboard that the instructor checks for accuracy. Student teams should complete the table on their worksheet.	5 minutes	Slides 3-6 Worksheet
Mini lecture	Instructor introduces the epidemiological triangle and tells the students that today they'll focus on the environment of Lyme disease transmission	1 minute	Slide 7
Listen to audio file	Students listen to minutes 2:10-3:10 of the audio file of the NPR story played by the instructor	1 minute	Audio file is embedded in PowerPoint. Transcript can be accessed from http://www.npr.org/templates/transcript/transcript.php?storyId=518219485
Brainstorm	Student teams brainstorm ideas for why Lyme cases have tripled	3 minutes	Slides 9-10 Worksheet question 1
Graph interpretation	Team interpretation of the graph of host species and % infected ticks and whole class discussion	3 minutes	Slide 12 Worksheet question 2
Mini lecture on reservoir competence	Mini lecture on reservoir competence	3 minutes	Slides 13-15
Brainstorm	Student teams brainstorm ideas for why mice populations increase	4 minutes	Slide 16 Worksheet question 3
Graph interpretation	Team interpretation of the graph of acorn density and mouse density over time	2 minutes	Slide 17 Worksheet question 4
Mini lecture on masting events	Background on masting events and the Ostfeld and Keesing experiment to look at the effect of acorn supplementation	3 minutes	Slides 18-19

Activity	Description	Time	Notes
Graph interpretation	Team interpretation of acorn and mouse survival and mouse reproduction	5 minutes	Slide 20 Worksheet question 5
Prediction	Student teams predict the levels of tick density in the control and experimental grids after acorn addition, and then instructor reveals data collected by Ostfeld and Kessing and decide if it supports or refutes their prediction	5 minutes	Slides 21-22 Worksheet question 6
Mini lecture	Background on urban sprawl and forest fragmentation	3 minutes	Slides 23-24
Prediction	Student teams predict the effect of a forest fragmentation on mice population and then instructor reveals graphs that students interpret and decide if it supports or refutes their prediction	5 minutes	Slides 25-27 Worksheet questions 7-8
Question	Based on their assigned reading, student teams answer: Why are mice resilient to forest fragmentation? This is followed by whole class discussion.	5 minutes	Slides 28-31
Prediction	Student teams predict effect of forest fragmentation on mouse and tick populations and then instructor reveals a graph that students interpret and decide if it supports or refutes their prediction	5 minutes	Slides 32-33 Worksheet questions 9-10
Prediction	Student teams predict Lyme disease prevalence as species biodiversity decreases and then instructor reveals graphs that students interpret and decide if the data support or refute their prediction. Group discussion of which habitat would Lyme disease most likely occur.	5 minutes	Slides 34-36 Worksheet questions 11-13
Outside of Class			
Concept map	Given a list of terms, individuals construct a concept map as homework		Slide 37
Class Session 2 - Progressing through the Activity			
Concept map	Individuals share their concept maps and together as a team, they construct a concept map on the whiteboard that the instructor checks for accuracy.	6.5 minutes	Guide on how to read scientific literature in S4
Listen to audio file	Students listen to minutes 3:00-6:29 of the audio file of the audio file of the NPR story played by the instructor.	3.5 minutes	Audio file is embedded in PowerPoint. Transcript can be accessed from http://www.npr.org/templates/transcript/transcript.php?storyId=518219485
Discussion	Discuss and summarize why higher levels of Lyme disease occur in suburban areas relative to rural and urban areas. Discuss strategies to control or prevent the current Lyme disease epidemics.	5 minutes	Slides 41-42