Learning the Landscape: An Active and Applied Lesson on Landscape Ecology for General Ecology Courses

Erin G. Rowland-Schaefer†, Brianna Negrete McGinley†, and Heather E. Bergan-Roller†

†Department of Biological Sciences, Northern Illinois University

Abstract

Landscape ecology is an important subtopic of ecology. As a field, it is inherently interdisciplinary and provides opportunities to teach not only content, but transferable ecological and geographical skills. Given the broad spectrum of topics in general ecology courses, landscape ecology is often relegated to a single lecture or not covered at all, meaning that there is a need for concise, effective lesson content for teachers. Here, we present an adaptable, active lesson on landscape ecology that can be implemented to help address this gap and support student engagement and the application of content knowledge to local systems. Students are presented with an active lecture that introduces key concepts of landscape ecology, then presented with opportunities to apply and reinforce these concepts. First, students work in groups to solve applied challenges about a real environment. These group challenges support greater understanding, content retention, and engage students in collaborative creative problem-solving with their classmates. Second, students apply the concepts of the lesson to a natural space that they are familiar with to increase personal connections to the content and again reinforce the topics. This lesson has been implemented a total of three times in two courses across two universities with distinct student populations. Student feedback has been largely favorable, with students reporting increased understanding of the subject and enjoyment of the lesson, especially the group problem-solving challenges. We provide avenues for instructors to localize the content to help students connect to the topics using examples with which they are familiar.

Learning Goals

Students will:

◊ understand the key concepts of the field of landscape ecology and the scope and role of the field in ecological research.
◊ understand the applications of landscape ecology in conservation and restoration.
◊ appreciate the significance of the impacts of urbanization and other anthropogenic activities on the landscape context of an ecosystem.

◊ From the Ecology Learning Framework:
  » How do species interact with their habitat?
  » How are living systems interconnected and interacting?
  » What impacts do humans have on ecosystems?
  » What can or do humans do to mitigate negative impacts they have on ecosystems?

Learning Objectives

Students will be able to:

◊ define landscape ecology and key tenets of the field such as habitat fragmentation, edge effects, and scale.
◊ apply the concepts of habitat fragmentation, edge effects, scale, and connectivity in a conservation management challenge.
◊ make applied management decisions using landscape ecology concepts.
◊ communicate about and justify management decisions.
◊ describe a natural area in terms of landscape features.
◊ consider the impacts of human activity on landscapes and ecosystems across scales.
INTRODUCTION

Landscape ecology is a relatively young field that bridges ecological theory with geographic concepts to allow for a greater understanding of broad patterns across spatial scales (1). This field is inherently interdisciplinary, which strengthens ecological theory by combining evidence-based methods of ecology with multi-scale inquiries of geography, allowing an understanding of how processes at multiple spatial scales operate together and influence each other. No single scale or aspect of ecology exists independent of the surrounding landscape processes. Landscape ecology is a constantly evolving field and is growing in prominence due to the constant change to landscapes from human activity such as deforestation or increasing urban expansion. Thus, effective teaching of landscape concepts is increasingly important. Furthermore, given the increasing value of collaborative and interdisciplinary work, bridging the gap between geographic and ecological concepts will better prepare students for their future careers.

Incorporating landscape ecology into general ecology coursework provides students with critical interdisciplinary and transferable skills such as spatial reasoning. Given the surge in geographic technology in recent years, including unmanned aerial vehicles (UAVs) and geographic information systems (GIS), these skills are highly desirable on the job market (2). Furthermore, since it is a niche topic, many students complete an entire undergraduate degree in ecology without ever studying the subject. Incorporating landscape ecology efficiently and effectively into general ecology coursework can provide an introduction to the field and may spark passion and interest for students who otherwise would not have known the field existed.

Targeting this topic is a priority for geography and biology educators alike. Geographic skills and spatial reasoning are crucial to ecologists and can be strengthened through training and application in the biology classroom in addition to the geography classroom. In 2013, the Association of American Geographers published the Road Map for 21st Century Geography Education Project (3), a document that outlined the history and future of geography education research. It specifically highlighted two charges: “What areas of research will be most effective in improving geography education at a large scale?” and “What strategies and methodologies can relevant research communities develop and adopt to maximize the cumulative impact of education research in geography?” Within the first charge, the report included a call for consideration of education research in related fields, such as biology. The report also identified four key research questions that are high-priority, big-picture topics in the field, including identifying what supports or promotes the development of geographic knowledge, skills, and practices, as well as the needs for implementing the development of these concepts.

The Road Map for 21st Century Geography Education Project was released nearly simultaneously with the final draft of the Next Generation Science Standards (NGSS), which identify core concepts or ideas, competencies or skills, and cross-cutting themes that underlie science (4). These K-12 standards reflect a transition in thinking about science education and a prioritization of skills and multidisciplinary ideas in addition to content knowledge. These priorities were further mirrored in the undergraduate biology community with the Vision and Change in Undergraduate Biology Education: A Call to Action report, which outlines specific actions that can improve undergraduate science education and defines key concepts and competencies for undergraduate biology programs (5). In the wake of this publication and its follow-ups, a number of tools have been developed to support implementation of these core concepts and competencies, including the BioCore Guide (6) and the BioSkills Guide (7), as well as the development of the Four-Dimensional Ecology Education (4DEE) Framework by the Education Committee of the Ecological Society of America (8). The 4DEE framework takes on the ideas of the NGSS, integrating core concepts, competencies, and cross-cutting themes specific to ecology, while adding the fourth dimension of human-environment interactions. Similarly, socioscientific issues center the development of scientific reasoning skills through using these skills to solve localized problems with connections to cultural or societal issues (9). Research has shown that implementing socioscientific issues in the classroom can improve students’ civic engagement and self-efficacy (10). Together, these keystone documents all informed the decisions we made in the development of this lesson plan, helping to address the need for concise and effective landscape ecology lessons for use in general ecology classrooms. A number of other lessons published in CourseSource have integrated the themes of socioscientific issues and human-environment interactions through techniques like place-based learning, further cementing the need for and benefits from applying these ideas in lesson content (11, 12).

Here, we present a lesson designed for use in two class periods that introduces the major concepts of landscape ecology through an active lecture and reinforces those concepts through group problem-solving challenges and a reflection. These active techniques are designed to be engaging and to reinforce key lesson topics and critical ecological skills such as collaboration, research design, and communication with stakeholders. This lesson is adaptable, able to be modified for use across a longer set of lecture periods or for laboratory exercises. Also, we provide avenues for instructors to localize the content to help students connect to the topics using examples with which they are familiar.

Intended Audience

This lesson is intended for intermediate-level undergraduate courses in biology, ecology, or environmental science. It has been implemented a total of three times. We taught the lesson twice in the general ecology course (n = 29 and n = 26) at a diverse, regional comprehensive, four-year public R2 institution serving a number of students from a peri-urban setting and many first generation, commuter, and returning students (hereafter University 1). We also implemented the lesson in an ecology and field biology course (n = 15 students) at a private, rural, primarily undergraduate institution with a much smaller student population composed largely of residential college students aged 18–24 (University 2). Students in these courses have varied levels of experience in ecology and most have limited coursework on the subfields of ecology.
Required Learning Time
This lesson was designed for two lecture periods of either 50 or 75 minutes. However, if an instructor chooses to have groups solve more than one challenge together, the lesson can easily be extended to cover one shorter lecture period and a longer (2–3 hour) laboratory period. See Teaching Discussion for more information on how these challenges may be differentially implemented.

Prerequisite Student Knowledge
Students should be familiar with basic ecological concepts of community structure, as well as disturbance. Specifically, students should understand how disturbance can modify an ecosystem and have impacts on the community within. A basic understanding of biogeography concepts such as range, distribution, and dispersal of species is beneficial, but not necessary. Depending on the group problem-solving challenges used, students may also need a basic understanding of the scientific method, including how to develop hypotheses, predictions, and basic methods for ecological research.

Prerequisite Teacher Knowledge
Instructors should be familiar with the field of landscape ecology and have a strong grasp of the concepts of habitat fragmentation and connectivity, land cover, edge effects, and disturbance, as well as the impacts of scale on the community within. There are multiple assessments in this lesson, including group problem-solving exercise summaries, a written reflection, and informal check-in questions during the lecture. Students work in groups to prepare a summary of their solution to the group problem-solving challenge (Supporting File S2). This summary can take various forms depending on the time available, including a short verbal presentation, a more formal slide show presentation, or a written report. This lesson was initially assessed with short verbal presentations during the class period. In our applications, students received points for participating in group discussions and presentations, but these presentations and reports could be graded, either individually or as a group. Additionally, students are asked to submit a written reflection applying key concepts from the lesson to a real-life problem using the ideas from the lecture. This activity challenges them to think collaboratively, think creatively, and apply new concepts in a practical setting, thus engaging students behaviorally, cognitively, and emotionally.

To further encourage students’ emotional engagement, the group problem-solving challenges are derived from the real world about a local ecosystem to help increase their interest and value in learning the content. By sharing their solutions and rationale with the class, students are asked to engage agentially, demonstrating how they applied the topics to the class and asking questions of each other. Finally, the reflection assignment asks students to connect lesson concepts to a space personal and familiar to them, providing another opportunity for them to take the ideas out of the classroom and into their world. This step is the most engaging within the emotional dimension by bringing the content into a space that is familiar, comfortable, and relevant to students. The reflection also asks students to think about what questions they have about their own surroundings and how they might go about answering them. By encouraging students to ask their own questions, this can facilitate agentic engagement and can prompt curiosity-driven exploration of the topic by students on their own.

Active Learning
This lesson uses multiple forms of active learning designed to support student engagement and attainment of learning objectives. Engagement can be framed through a lens of four dimensions: behavioral, emotional, cognitive, and agentic engagement (14–16). Specifically, behavioral engagement includes actions such as attendance and in-class participation. Emotional engagement involves students’ feelings, such as interest and excitement. Cognitive engagement encompasses behaviors where students seek out deeper learning through their own motivation and seeking out more information (17). Finally, agentic engagement is defined as students contributing to the instruction by asking their own questions and participating in the teaching of the course (18). Below, we identify the portions of the lesson that address each of these dimensions of engagement.

The lecture portion of this lesson is designed to be conversational, with several points designated for think-pair-share. Students are presented with a conceptual question and given time to formulate their thoughts before discussing with classmates and sharing with the class (19). This is a form of behavioral engagement as students are asked to participate in discussion with one another, as well as cognitive engagement as students are asked to think about ideas before they have been introduced completely to them. In the second component of the lesson, students are asked to work in groups to develop solutions to a real-life problem using the ideas from the lecture. This activity challenges them to work collaboratively, think creatively, and apply new concepts in a practical setting, thus engaging students behaviorally, cognitively, and emotionally.

Agentic engagement could be further attained by inviting students to share their reflections and what they learned with the class, giving students the opportunity to participate in the teaching of the lesson.

In addition to creating multiple opportunities for forms of engagement, this lesson creates opportunities for collaborative construction (20). The think-pair-share checkpoints during lecture allow for students to develop responses on their own and further develop their ideas with a partner before sharing with the class. The group problem-solving challenges ask students to work together to apply the concepts from lecture and create solutions together. This gives the students the opportunity to not only refine their own knowledge, but work to support each other in filling in the gaps in their understanding.

Assessment
There are multiple assessments in this lesson, including group problem-solving exercise summaries, a written reflection, and informal check-in questions during the lecture. Students work in groups to prepare a summary of their solution to the group problem-solving challenge (Supporting File S2). This summary can take various forms depending on the time available, including a short verbal presentation, a more formal slide show presentation, or a written report. This lesson was initially assessed with short verbal presentations during the class period. In our applications, students received points for participating in group discussions and presentations, but these presentations and reports could be graded, either individually or as a group. Additionally, students are asked to submit a written reflection applying key concepts from the lesson to a real-life problem using the ideas from the lecture. This activity challenges them to think collaboratively, think creatively, and apply new concepts in a practical setting, thus engaging students behaviorally, cognitively, and emotionally. Finally, we assessed students formatively during the lesson using think-pair-share checkpoints to adapt to the
content knowledge of the class. These checkpoints gave us insight into where to spend more or less time in the lecture based on student understanding.

**Inclusive Teaching**

We included several elements of inclusive teaching in the lesson. During the lecture period, we integrated think-pair-share not only as an active learning exercise, but also as an inclusive teaching approach. We were very intentional about taking long pauses during these checkpoints, allowing students time to formulate their thoughts individually and share in pairs before asking them to share out loud. This approach aims to increase student comfort with sharing verbally by providing sufficient time to interpret the questions and formulate an answer, as well as by sharing ideas with another person to gain support and confidence before sharing with the class as a whole. We also allowed multiple students to share during this period to increase the amount of voices and opinions being heard in class discussions (21).

This lesson plan involves collaboration and group problem-solving, aiming to foster a sense of community and belonging. It is beneficial to begin discussion time with a statement reminding students about rules for safe and productive conversations and encouraging them to make sure all perspectives are considered (22). When groups are sharing their results at the end of group discussion, we encourage all members of the group to participate in the presentation by sharing their group’s decision or fielding questions, but we also did not force any students to participate.

Some students may not be comfortable or able to share verbally in class discussions with think-pair-share or group presentations. To make sure all students are included in think-pair-share discussions, instructors can consider using tools like Socrative and InfuseLearning, which allow students to submit answers to questions using their computers or mobile devices. Instructors can also make use of resources like online discussion boards through Learning Management Systems or third-party sources like Edmodo for students to share their solutions to group problem-solving challenges. These forums can provide additional opportunities for discussion and debate and may be an especially applicable technique for online courses. Additionally, students with vision impairments may not be able to use the maps and images provided in the group problem-solving challenges. To that end, we have provided image descriptions for each of the maps in these challenges. This lesson plan involves collaboration and group problem-solving, aiming to foster a sense of community and belonging. It is beneficial to begin discussion time with a statement reminding students about rules for safe and productive conversations and encouraging them to make sure all perspectives are considered (22). When groups are sharing their results at the end of group discussion, we encourage all members of the group to participate in the presentation by sharing their group’s decision or fielding questions, but we also did not force any students to participate.

**Pre-Class Preparation**

Prior to the lesson, you should familiarize yourself with and adapt the lecture slides and accompanying lecture script in the notes (Supporting File S1). This script is intended to be a starting point to be adapted and modified based on the instructor and their students.

You should also review the sample group problem-solving challenges (Supporting File S2). Consider adapting the group problem-solving challenges in a space that is familiar to your students. See the spreadsheet of suggested locations by state (Supporting File S3) for examples in your region.

**Lecture**

During the lecture, your goal is to introduce and assess the key concepts of landscape ecology that will be used throughout the lesson. These concepts are scale, fragmentation and connectivity, land cover, spatial heterogeneity, edge effects, and disturbance. The lecture slides (Supporting File S1) provide key examples that will allow students to visualize these concepts. This lecture is designed to be active and conversational, using think-pair-share and other opportunities for student responses. In addition to the think-pair-share checkpoints, you may choose to ask students to sketch or illustrate these concepts during the lecture to further engage with the ideas. It is critical to provide students with clear definitions of the key concepts of this lesson as they are the foundation for the rest of the activities.

**Group Problem-Solving Challenges**

After the lecture, students break into groups (which can be assigned or chosen per instructor preference) to work through
one or more group problem-solving challenges (Supporting File S2). In our applications, students were allowed to choose their own groups, but groups could be assigned if preferred. These challenges are modeled as socio-scientific issues, designed to emulate real-life decisions made by land managers while applying the key concepts of the lesson. The challenges aim to provide students with the scaffolding to participate in high-order reasoning practices and consider sociopolitical dynamics in conjunction with scientific concepts (9). Sample challenges localized to the two universities where the lesson was implemented can be found in the supporting materials (Supporting File S2). The challenges are accompanied by a map and site description of the study area to support the students. Challenge 1 asks students to develop a research question, hypothesis, predictions, and methods related to the topics covered in lecture and tested at the study area. Challenge 2 provides students with a budget, a map of potential purchase parcels, and a table with the price and a description of each of those parcels (Figure 1). They are asked to use their budget to maximize the positive impacts when considering the landscape ecology of the study area. Challenge 3 presents students with a potential commercial development near the study area and asks them to consider the impacts on the landscape, as well as to make suggestions on how to minimize or mitigate the negative effects. Students are encouraged to ask questions as needed and to use any resources, including the internet or their notes.

After discussing solutions in groups, each group is asked to share their solution and how they made their decision. Students are encouraged to all participate in their group’s discussion and to ask questions of other groups. You should ask questions to prompt further discussion and reflection. For example, Challenge 2 asks students to prioritize spending money to maximize benefits when purchasing land. You can ask students to prioritize by telling them that budget cuts have reduced their funds and they need to reduce the land they purchase.

In Challenge 3, students are asked to consider possible impacts of a meat-packing plant being built in proximity to the preserve and to brainstorm methods to mitigate the efforts. You may ask students how they would convince the plant or local community to support their recommended changes. To end the class period, provide a brief wrap-up and explain the reflection homework.

**Reflection Assignment**

The last component of this lesson is a take-home reflection assignment that asks students to apply the landscape ecology concepts from the lecture to a green space they are very familiar with. Students were prompted to visit or visualize a familiar green space such as a local park, the campus lagoon, or their backyards and describe it with the terms that were covered in the lecture. The instructions invite students to use sketches, drawings, maps, photographs, or tactile descriptions if desired. We also provided resources for students to complete this assignment virtually by watching virtual tours of green spaces. We provided resources for a local space to help increase engagement and recommend that instructors localize this piece to somewhere close to their students. The reflection instructions and rubric for assessing the reflection are provided in Supporting Materials (Supporting Files S4, S5).

**TEACHING DISCUSSION**

**Observations from Implementations**

Both our observations in the classroom and the reported experiences by students affirm that this lesson was engaging and beneficial in both introducing the concepts of landscape ecology and helping students connect the ideas to socioscientific issues that are relevant to them.

During the implementation of this lesson plan in Fall 2021 and Fall 2022, we observed student responses to the activities by taking notes during and after each lecture period. In addition...
to observations drawn from the lesson implementation, we also asked students to participate in a survey about their impressions of the lesson. This research was reviewed and approved by the Northern Illinois University Institutional Review Board (IRB) Protocol #HS22-0128. We used a pre- and post-survey to assess student knowledge of the lesson content and opinions about the lesson. This survey was designed not to assess student performance for a grade, but to assess the lesson for efficacy. The questions are provided in the Supporting File S6. The pre-survey asked students to provide short-answer definitions of various terms associated with landscape ecology (landscape ecology, habitat fragmentation, edge effects, and disturbance), as well as how familiar they were with the concepts (5-point Likert scale ranging from Extremely Familiar to Not Familiar at All) and how confident they were in the definition that they had provided (5-point Likert scale ranging from Completely Confident to Not Confident at All).

The post-survey included the same questions as the pre-test, as well as a second set of questions evaluating students’ experiences with the lesson. Students were asked to rank the components of the lesson (lecture, reflection assignment, group problem-solving) from favorite to least favorite and explain why they ranked them as they did. We also asked if students had observed any of the concepts covered in the lesson since class and to describe what they had observed. Finally, students were asked what suggestions they had to improve the lesson.

The survey was administered to the students from the two universities in Fall 2022. Surveys from students were excluded from this data set if they did not consent to participate in the research, did not attend both days of the lesson, or reported in the survey that we should not include their responses in our study because they did not pay attention to the survey questions (i.e., validity check). After exclusion, we had 28 participants in the pre-survey (n = 19 from University 1 and 9 from University 2) and 16 participants in the post-survey (n = 8 from University 1 and 8 from University 2). The survey questions are included in Supporting File S6.

**Lecture**

The lecture was generally well received, though considered less engaging than the other components of the lesson by some. In the post-survey, the lecture was most frequently ranked as students’ second-favorite activity (50%, n = 8). Students who ranked the lecture as their first favorite (n = 3) expressed that they preferred to learn from lectures and found it informative. Those who ranked the lecture as their least favorite component (n = 5) noted that they either generally prefer activities to lectures or that it was just less engaging than the other two components (i.e., group problem-solving challenges, reflection assignment).

Based on the classroom observations, students generally engaged well with the active learning components of the lecture, though there was some difficulty getting all students to be willing to share during the think-pair-share checkpoints. Nearly all students actively participated in paired discussions, but most of the whole-class sharing came from a few students. We observed all students actively discussing with their partners, with conversations often taking up all the allotted time. You may address this by selecting groups to share their thoughts rather than waiting on volunteers to share. We also found that diffusing the tension of prolonged thinking time in think-pair-share was beneficial in encouraging students to take their time before engaging in paired discussion (24). Students at University 1, the large R2, had used think-pair-share regularly in class before this lesson and seemed generally comfortable with the process, but students at the smaller University 2 were less experienced and seemed less comfortable. We recommend using statements such as “lean into the discomfort and really take your time to think quietly on your own,” to help slow down the process for students who are less accustomed to formal think-pair-share in the classroom.

**Group Problem-Solving Challenges**

The group problem-solving challenges were the most popular component of the lesson with students. In the post-survey, the majority (73%, n = 12) of students rated the group problem-solving challenge as their favorite component of the lesson. Many students described enjoyment of collaborative problem-solving and real-life applications, and reported that they felt it benefited their understanding of the subject matter. In class, students actively participated in the exercise. Group conversations were largely on topic throughout the class period. Additionally, students were animated and often laughing. This indicated to us that students were comfortable discussing in their groups and were presumably having fun. Groups developed solutions for each challenge that we anticipated and also some that were unexpected, demonstrating both a grasp of the material and creativity. For example, when addressing Challenge 3 (suggesting solutions to mitigate the negative impacts of a new meat-packing plant near the preserve), one group recommended that the preserve suggest that the plant be built on stilts or otherwise elevated to allow a wildlife corridor connecting the two parts of the prairie that would be fragmented by this new construction. Additionally, some groups had disagreements but worked to find compromises or negotiate for a desired solution. For example, one group had some members who had very different ideas about how to handle the development of a meat-packing plant in close proximity to a nature preserve (Challenge 3) but discussed together and landed on a compromise where both sides presented their ideal situation, and they also shared a middle-ground solution. Sample solutions for the challenges are available in Supporting File S7.

Student responses to Challenges 1 and 2 were overall similar between the two universities. However, there were marked differences in the ways students from the two universities responded to Challenge 3, which dealt with the impacts of commercial development on neighboring preserved land and suggestions for how to mitigate the damage. Students at University 1 (the R2 with many commuter students from peri-urban areas) largely focused their solutions on persuading the developers to move the site of their project to another location or to cancel the project altogether. They placed a high priority on protecting the nature preserve from the impacts of noise and water pollution and reduced connectivity. At University 2 (the residential rural university), students were more reserved in their suggestions and focused on making adjustments and compromises regarding the development, such as changing the locations of planned road expansions and suggesting ways that the preserve itself can work to address these changes. When others in the class expressed concerns with this approach, the group in question raised the issues of economic benefits to the community. This may reflect different perspectives held by students in a more rural setting, where
economic concerns and garnering investment from job creators could be strong motivators (25). These different perspectives allowed us to engage students directly in thinking about these priorities. When students expressed that the planned development should be moved, we questioned them on how the surrounding community may feel about that decision and how they would convince the stakeholders. Students struggled with how to clearly and succinctly argue their perspective against business interests. When the students who argued on the behalf of the commercial development were confronted with the environmental perspective, both from the instructor and other classmates, they were able to stand their ground firmly and make convincing arguments about the economic needs of a rural community. This demonstrates the importance of discussing localized issues that students relate to, as well as the need for instructors to be prepared to argue for alternatives in the discussion period to help further student learning.

**Reflection Assignment**

The reflection assignment was less well-received than other components of the lesson, with 69% (n = 11) of the students ranking it as their least favorite component. Many students stated that they perceived this activity as busywork or yet another assignment during a busy part of the semester. Explaining the purpose of this exercise explicitly (e.g., “This activity asks you to apply the concepts we discussed in class to somewhere you are familiar with. The goal is to help you put these ideas into practice and increase your awareness of how they relate to our community”) may improve student perception. To reflect this, we have added a purpose statement to the assignment document for this component. Another tactic may be for students to do this activity as a class, visiting a green space together and making observations, or to regroup after writing their reflections to share with partners or groups, and then the class as a whole to discuss trends in observations.

Generally, students expressed a clear understanding of the key components of the lesson and correctly applied the ideas in their observations. Another question on our survey expanded on this exercise by asking the students to describe any observations of the concepts we covered in their daily lives. Many students described observing details about their campus structure that caused fragmentation, such as the arrangement of campus buildings or placement of sidewalks. Several students at University 2 described the effects of an ongoing campus construction project, noting increased disturbance.

**Attainment of Learning Objectives**

Student attainment of learning objectives were assessed through the pre- and post-survey on key concepts, as well as observations during the implementation. Pre- and post-surveys were scored by two coders using a rubric, assigning points based on the completeness and accuracy of student responses. Students could score a maximum of 15 points on the surveys. This rubric was designed for research purposes to assess lesson efficacy, not for instructors to grade answers, but is available as a template upon request.

There was a significant increase in score from the pre-survey (M = 6.6, SD = 2.30) to the post-survey (M = 9.1, SD = 2.31), t(31) = 3.49, p = 0.0015, (Figure 2) suggesting that students had a grasp of the concepts after the lesson. On the pre-survey, students scored 0s on a few questions by answering “I don’t know” or something similar. There were no instances of this on the post-test. We also observed university-specific differences between pre- and post-survey scores (Figure 3). These scores were compared using a two-way ANOVA (Type II) with an interaction and showed a significant difference in score between the two universities (F(1,40) = 4.583, p = 0.0384) and pre/post condition (F(1,40) = 7.396, p = 0.0096), but no interactive effect (F(1,40) = 0.0239, p = 0.8779). We then repeated the two-way ANOVA (Type II) excluding the interaction, which also showed significant difference between the universities (F(1,41) = 10.568, p = 0.0023). The effect size eta squared was 0.158, indicating a strong effect. There was also a significant difference between the pre- and post- scores.
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(F(1,41) = 19.196, p = 0.00008), with the eta squared of 0.225 also indicating a strong effect. The university differences could be attributed to a number of factors. University 2 had lower scores on the pre-survey with a smaller range of scores, while University 1 averaged higher and with a wider range. This may reflect the broader range of preparation for students at University 1, which has a student population from a variety of pre-college backgrounds, including some students who may have had AP Biology or Environmental Sciences coursework and previous exposure to the concepts of landscape ecology. On the post-survey, University 1 scored overall higher, with a smaller range, while University 2 had a wider range of post-survey scores with a lower average, closer to but higher than the post-survey score of University 1. This may be attributed to the shorter instructional period for University 2. Since lecture content at University 2 was covered in 50 minutes instead of 75 like at University 1, content was covered more briefly and some examples were skipped or condensed.

On the surveys, students were also asked to report their confidence in the definitions that they submitted on a 5-point Likert scale from “Not Confident at All” to “Completely Confident.” Student self-reported confidence increased on the post-survey for every question (Figure 4). Of particular note is the question asking students to define edge effects. Students were the least confident about this question on the pre-survey, with over 50% identifying as “Not Confident at All.” On the post-survey, confidence on this question was in line with all other questions, despite the lower starting point.

Student presentations and reflection assignments demonstrated a strong understanding of the key concepts of landscape ecology. Students correctly applied the concepts of the lecture to the challenges, making decisions and crafting arguments to defend their choices based on the content we covered. They also collaborated well, sometimes through disagreements, to come to a solution as a group, demonstrating effective use of problem-solving skills and communication.

In the reflection assignment, students once again successfully applied the concepts of landscape ecology to green spaces in their lives. They described the impacts of disturbance and habitat fragmentation on the ecosystem appropriately. Many students focused on edge effects caused by roads, trails, or boundaries between habitat types (such as a park being bordered by agricultural fields). One student referenced in-class examples in their reflections, recalling that “we talked about how a small path of 1m was too long for a shrew, or some other small mammals to cross, and in these woods, there are many different bike paths and a few roads.” Many students also reflected on human impacts, both at the landscape scale and otherwise, reflecting on the role of human foot traffic, litter, and run-off from nearby agriculture or athletic fields. Discussions of landscape heterogeneity were largely less thorough, largely focusing on biotic factors such as plant diversity. Few students discussed the role of abiotic factors such as small ponds or other bodies of water in creating a heterogeneous habitat.

Finally, through think-pair-share checkpoints, group problem-solving challenges, and reflection assignments, students demonstrated clear thought about the impacts of human activity on landscapes. They were readily able to identify examples of land cover change caused by humans and the impacts of habitat fragmentation. In the final checkpoint, students were asked to describe a familiar space on campus in terms of some of the terms we discussed as a setup for the reflection exercise. Overall, students were very successful here, appropriately applying the concepts and specifically reflecting on the role of human activity. In all aspects of the lesson, students frequently reflected on the direct and indirect impacts of human activity through habitat change and the creation or maintenance of artificial edges. This lesson provided students the opportunity to reflect on human impacts at different scales and through different mechanisms than they may be familiar with.

Adapting this Lesson
 Localization

We recommend localization the lecture and challenges to the community where the lesson is being taught to enhance engagement. Using local examples can help students better picture concepts and draw connections to the material and can serve as a form of cultural competence (26). By forging connections between the material and ideas or locations with
which students are familiar, students may feel better equipped to
learn the material and experience a greater sense of belonging in
the classroom (27, 28). This localization can be integrated into
the lecture by using photos, maps, and examples of local natural
spaces that students may already be familiar with. For example,
when discussing habitat fragmentation, we used paired examples
of Yellowstone National Park, a common touchstone that many
people have at least some familiarity with, and aerial imagery
of the community where each college is located. This imagery
should be accompanied by verbal or written descriptions of the
imagery and the differences that are represented.

Additionally, localizing the group problem-solving
exercises may help increase student emotional engagement
with the assignment. We presented the same group problem-
solving exercises to two groups of students, one group
who was familiar with the preserve in the exercise and one
group who was not. Because of their greater knowledge of
the preserve, the more familiar group generally produced
more nuanced and specific solutions to the challenges. The
instructor had familiarity with the location and was therefore
able to field questions for the class that was not familiar with
the location, but this was not equivalent to students having
personal experience with the location. We recommend that
instructors adjust the group problem-solving challenges to a
site their students have experience with. This should include a
map, a site description, and any revisions to the questions to
make them more appropriate for the chosen location. See the
file on localization (Supporting File S3) for recommendations
on how to make this lesson relevant to your audience.

Different Presentations of the Lesson

The original implementation of this lesson was in two
75-minute class periods at University 1 with lecture on the
first day and group problem-solving challenges on the second
day. We also implemented this lesson in two 50-minute
class periods at University 2. We found that two 50-minute
periods made the lecture component a little rushed and
forced us to condense down the content, leading to less
comprehensive coverage of the topics. The effects of this may
also be demonstrated by the smaller improvement on post-
survey scores in students in this treatment (Figure 3). We
recommend that for classes with 50-minute periods, the lesson
be expanded to three days, with lecture content covered over
two class periods. Remaining time on the second lecture day
should be designated for fielding questions and introducing
the reflection assignment, or perhaps starting the reflection
exercise as a class. The third day can then be solely dedicated
to the group problem-solving challenges.

To enhance the impact of the reflection exercise, it may be
beneficial to provide an example of this reflection assignment
as completed by the instructor. Additionally, to more
completely incorporate agentic engagement into this exercise,
consider using any additional class time for students to share
their reflections with the class, giving them the opportunity
to participate in teaching by demonstrating how the lesson
concepts applied to their chosen space.

This lesson is also well suited to adapt to a single lecture
period and a longer lab session. Students can work in groups
to solve multiple group problem-solving challenges in a longer
lab period and present their solutions either in a subsequent
lecture period or at the end of lab. This would allow students
to face multiple challenges and deepen their understanding of
the lesson content through multiple applications.

For instructors with more subject-level expertise and
available resources, an opportunity exists to expand this
lesson further for more advanced coursework. Instructors who
choose to localize the group problem-solving challenges to a
space that students have access to may also choose to expand
this lesson out by having groups conduct a research project
based on the solutions to the first group problem-solving
challenge (which asks students to develop a research question,
hyotheses, and methods related to a landscape ecology topic).
For examples of how to implement in-class experimental
design and assess student responses, see (29). This takes the
application of the topic one step further, allowing students to
come in the process of landscape ecology research. This can
also integrate geospatial research techniques and technology
such as Google Earth, GIS, or unmanned aerial vehicles
depending on the goals and resources available. However, it is
important to note that this will rely on the instructor having the
capacity to lead and develop this research with their students.

SUPPORTING MATERIALS

- S1. Landscape ecology – Lecture slides and script in
  notes
- S2. Landscape ecology – Group problem-solving
  challenges
- S3. Landscape ecology – Localization suggestions
- S4. Landscape ecology – Reflection exercise
- S5. Landscape ecology – Reflection exercise rubric
- S6. Landscape ecology – Pre- and post-survey questions
- S7. Landscape ecology – Sample group problem-solving
  solutions

ACKNOWLEDGMENTS

We wish to thank all the student participants from both
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Hoepner, and Emily Calagro) and Jones Evidence-Based
Restoration Lab (Antonio Del Valle, Jesse Sikora, Lizzy Small,
Samantha Berk, Andrew Drelin, and Regina Francis) for their
feedback and support on this lesson and manuscript.
Table 1. Lesson timeline. A recommended timeline for a presentation of this lesson in two 75-minute class periods. See the Teaching Discussion for recommendations on modifications for different class period lengths.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Estimated Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-Class</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructor Preparation</td>
<td>1. Adapt or create lecture content and active learning checkpoint activities</td>
<td></td>
<td>Supporting Files S1–S4</td>
</tr>
<tr>
<td></td>
<td>2. (Optional) Localize group problem-solving exercises for your student population</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Prepare to be able to distribute the materials during class, either as a printout or online</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Day 1: Lecture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>Introduce the learning objectives, as well as the field of landscape ecology</td>
<td>2 minutes</td>
<td>Supporting File S1</td>
</tr>
<tr>
<td>Active Learning Checkpoint 1</td>
<td>Display first prompt. Encourage students to think on their own, share with a neighbor, and then as a whole class (think-pair-share herein)</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Scale</td>
<td>Introduce the concept of scale, as well as grain and extent</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Active Learning Checkpoint 2</td>
<td>Display second prompt and facilitate think-pair-share</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Landscape Composition</td>
<td>Introduce landscape composition and the subtopics and land cover and land cover change. Provide examples</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Active Learning Checkpoint 3</td>
<td>Display third prompt and facilitate think-pair-share</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Landscape Configuration</td>
<td>Introduce landscape configuration. Discuss the ideas of fragmentation and connectivity, as well as how these ideas are difficult to separate from habitat loss and land cover change</td>
<td>8 minutes</td>
<td></td>
</tr>
<tr>
<td>Active Learning Checkpoint 4</td>
<td>Post fourth prompt and facilitate think-pair-share</td>
<td>5 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Composition vs. Configuration</td>
<td>Discuss the differences between landscape composition and landscape configuration</td>
<td>6 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Edge Effects</td>
<td>Introduce the concept of edge effects. Discuss examples of species that benefit from edge habitat (e.g., brown-headed cowbirds) and those that do not</td>
<td>8 minutes</td>
<td></td>
</tr>
<tr>
<td>Lecture – Landscape Heterogeneity</td>
<td>Introduce the idea of landscape heterogeneity. Describe the role of disturbance in heterogeneity. Outline aspects of disturbance</td>
<td>10 minutes</td>
<td></td>
</tr>
<tr>
<td>Clarifying and Questions</td>
<td>End lesson by asking for any questions, thoughts from students</td>
<td>4 minutes</td>
<td></td>
</tr>
<tr>
<td>Assign Reflection Exercise</td>
<td>Introduce students to the reflection. Encourage students to visit their chosen green space if possible. Remind students that they are free to write, illustrate, make maps, or choose another method to convey their ideas</td>
<td>4 minutes</td>
<td>Supporting Files S4 and S5</td>
</tr>
<tr>
<td><strong>Day 2: Group Problem-Solving Challenge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groups</td>
<td>Split students into groups of 3–5. Students may choose their own groups or groups may be assigned</td>
<td>5 minutes</td>
<td>Supporting Files S2 and S3</td>
</tr>
<tr>
<td>Introduce Problem-Solving Exercises</td>
<td>Give each group one of the three problem-solving challenges. Introduce the study site and explain that students are to work together to come up with solutions to these challenges to share at the end of class. There are no right or wrong answers. Students will also be expected to turn in a written summary of their solution</td>
<td>6 minutes</td>
<td></td>
</tr>
<tr>
<td>Group Work Time</td>
<td>During group work time, float around and answer questions. Listen to student discussions and intervene to help solve problems if necessary. In general, let students discuss together and allow them to have some debate</td>
<td>40 minutes</td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td>Description</td>
<td>Estimated Time</td>
<td>Notes</td>
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<tr>
<td>Group Presentations</td>
<td>At the end of the group work period, introduce each challenge to the class and ask one member of each group to share their solution to their challenge. Ask questions to clarify and prompt further thinking (e.g., “Why is that the decision that you made?” and “Have you considered this alternate perspective?”). Encourage the class to ask questions of each other as well. Collect written summaries from each group.</td>
<td>25 minutes</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Lesson alignment with society learning outcomes. An outline of the alignment of the components of this lesson with the core concepts and competencies of Vision and Change (5–7), 4DEE (8), socioscientific issues (SSI) (9), and other guiding frameworks stated within the lesson (3, 27).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Core Concepts</th>
<th>Core Competencies</th>
<th>Alignment with Other Frameworks</th>
</tr>
</thead>
</table>
| Lecture                       | **Structure and Function,** Systems: Introduce students to the field of landscape ecology and how this field examines large-scale systems and how organisms respond to changes in the environment. | **Interdisciplinarity:** Introduce students to the connections of biology and geography in the field. | 4DEE: Human-environment interaction and understanding human impacts on landscape.  
Geography Education: Interdisciplinarity and spatial reasoning.  
SSI: Connect students to the material through relevant, real-world examples and inviting problem-solving. |
| Group Problem-Solving Challenges | **Structure and Function,** Systems: Encourage students to apply these concepts in action to reinforce understanding. | **Process of Science:** Students are asked to design an experiment to test a question related to landscape ecology.  
Science and Society: Apply these concepts to real-world issues that are relevant and relatable.  
Communication and Collaborations: Students work together in groups and share their results to the class for feedback and discussion. | 4DEE: Human-environment interactions – students are asked to consider how to best implement restoration and to mitigate environmental impacts of a development.  
SSI: Challenge students to solve a relevant, real-world issue by applying the lesson concepts. Frame these local challenges in terms of larger societal issues. |
| Reflection Exercise           | **Structure and Function,** Systems: Encourage students to refine understanding of the concepts by applying them to a space that is relevant to them. | **Process of Science:** Students are asked to think of a question and possible experiments in a familiar green space.  
Interdisciplinarity: Students are asked to apply spatial concepts to biological observations. | Geography Education: Relates to the value of place-based learning and the importance of sense of place in emotional engagement. |
REFERENCES