No such thing as a free lunch: Trade-offs of trees in grassy ecosystems

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Teacher's Notes:

Summary:
This case study explores environmental decision making in a complex socio-environmental system, the Great Plains grassland biome. We use an interrupted case method, where students explore how over the course of a century a native tree, Eastern redcedar, has transitioned from rare to invasive. In part 1, students are presented with the motivations that led to a biome-wide afforestation program and the first consequence that emerged. In part 2, students are presented with more complexity as Eastern redcedar becomes biologically invasive leading to the loss of native grasslands and a suite of socio-environmental tradeoffs. Students use concept maps, stakeholder analysis, and ecosystem service assessments to help understand and navigate the socio-environmental dimensions of the cedar issue. This case study emphasizes grasslands and cedar woodlands as alternative stable states supported by different stabilizing feedbacks that are strongly influenced by stakeholders and the environmental decisions that are made. This two-part case can be used for a wide range of courses in a few class periods (total class time approximately 4-5 hrs.)

Topic Areas: Agriculture, Ecology, Environmental Science, Policy, Management, Socio-environmental synthesis

Education level: Upper level undergraduate and graduate

Case Type/Method: Interrupted case and discussion case

Acknowledgements: This work was supported by the University of Maryland and NSF Award # DBI-1052875 to the National Socio-Environmental Synthesis Center.

Socio-Environmental Synthesis learning goals:

1. *Understand the structure and behavior of socio-environmental systems.* Specifically, students will identify the environmental and social components of the system, their interactions, and feedbacks.

2. *Consider the importance of scale and context in addressing socio-environmental problems.* Students will demonstrate that ecological and social processes vary across differing contexts relative to space and condition (e.g. economic or political), and will understand that ecological and social processes interact across different scales.

3. *Co-develop research questions and conceptual models in inter- or trans-disciplinary teams*. Students will identify disciplines relevant to the problem and communicate across disciplinary boundaries. Students will consider the value of different knowledge sources and ways of knowing.

Specific Learning Objectives:

By the end of this case study students will be able to:

1. Identify the environmental and social components of a system and their interactions
2. Build system maps that consider both social and ecological interactions and feedbacks
3. Describe how social and ecological processes vary and interact across scales and condition
4. Contrast alternative view-points as they relate to a specific problem
5. Conduct a stakeholder analysis to contrast alternative view-points across multiple stakeholders within a system
6. Describe how viewing a system from a single perspective can undermine system function and persistence
7. Develop alternative solutions to a management problem with multiple trade-offs using system maps
8. Work in interdisciplinary groups to communicate alternative values and sources of knowledge
9. Conduct an ecosystem service assessment based on alternative decision making

Introduction/Background:

This case study highlights the importance of environmental decision making and how maximizing yield of a few resources can lead to unexpected and undesired long-term consequences. In this case study, we explore socio-environmental dimensions of the Great Plains to illustrate how Eastern redcedar, a native tree, has transitioned from a rare species in a hostile environment to one that is biologically invasive. Eastern redcedar is widely planted in windbreaks throughout the southern and central Great Plains to provide wind protection for people, livestock, and crops. Decisions to plant trees and suppress fire across the Great Plains were initially perceived as a win-win solution for improving quality of life. However, these decisions had long-term consequences. Today, Eastern redcedar invasion is perceived as the greatest conservation threat in several Great Plains states. Drawing from more than a century of research, this case study synthesizes social and ecological data using concept maps, stakeholder analyses, and ecosystem service assessments. In light of global efforts to plant trees in non-forested ecosystems, this case study provides unique insights from one of the world's oldest afforestation programs.

A rare species in a hostile environment

Early European American settlers on the North American Great Plains found weather and resource availability extreme and unpredictable. One of the most noticeable differences between Great Plains landscapes and those of eastern North America and Europe was the plains lacked trees. Trees provided fuel, lumber, food, windbreaks, and shade. Settlers liked trees, but they were rare, and those that did grow huddled along streams and in areas with rough terrain—areas that did not burn. Prairie fires set by Native Americans and lightning strikes were common up until the turn of the twentieth century. Fires supported grass dominance to the point of making most of the plains virtually treeless (Wells 1970; Ratajczak et al. 2014). Therefore, it was believed tree planting could make life better (Bessey 1894). Orchards yielded both fruit and shade, and shelterbelts of Eastern redcedar shielded people, buildings, and livestock from strong Great Plains winds. For these reasons, government programs incentivized settlers to improve their properties through tree-planting (Pool 1953). In addition, putting out prairie fires helped ensure that planted trees would survive to maturity and continue to provide benefits, so a culture of tree planting and fire-suppression developed.

The cedar-apple rust problem

Some of the European-American settlers who moved into the Great Plains planted orchards in the hope that fresh fruit could become a viable commercial industry for the region. Settlers who planted apple orchards followed their neighbors' common practice of planting Eastern redcedar for windbreaks. In the orchardists' case, these windbreaks were planted specifically around the orchards to protect them from the cold, wind, and snow of the Great Plains. As the orchards and the windbreaks that protected them grew, however, the orchardists experienced the first serious

drawback to tree planting that their neighbors had not: a type of fungus called cedar-apple rust (Bessey 1904).

Cedar-apple rust is heteroecious, which means it requires two different species in order to complete its lifecycle (Ziems 2009). You will not be surprised to learn that this particular rust requires cedar trees and apple trees in order to complete its lifecycle. Without both species in proximity to each other, the rust will not affect the trees. For the first stage of the lifecycle, the fungus creates “cedar galls” - hard, nut-like spheres - on the branches of the cedar trees. The galls then bloom into “cedar flowers,” which extend long tendrils that allow the wind to blow the fungus to the apple trees for the second stage of the lifecycle. Unlike with cedars, the fungus has a much more adverse impact on apple trees. Leaves form lesions, and apple production is stunted. The apples that are produced have orange or brown lesions themselves, and are commercially unsalable. Extreme infestation can dramatically stunt tree growth or even lead to tree mortality.

While the cedar-apple rust affected apple orchards from the east coast to the Great Plains, Nebraska orchardists in particular suffered heavy infestations because they had intentionally planted both types of trees next to each other. Faced with the collapse of their industry, orchardists removed the windbreaks from around their apple trees. Unfortunately, it was not enough. Even with the windbreaks removed, the rust was able to use cedars from neighboring properties to maintain its lifecycle. For the neighbors, these cedar trees held value as windbreaks for their own properties, or were a source of cultural pride, and were reluctant to take them down.

Faced with the extinction of their industry, the orchardists turned to the state legislature for help. For its part, the legislature realized that if it let cedars grow unregulated, apple production would not be a viable commercial industry in the state. To address the cedar rust problem, the legislature passed a law requiring the removal of all cedar trees within two miles of apple orchards of 1,000 trees or more. At first, the law provided compensation for the loss of the cedar trees, but when it became apparent cedar owners could allow their trees to grow freely and then be paid for their removal, the law was amended. Instead of compensation, cedar owners were fined if they did not remove their cedars within the two mile cedar-free zone. With the cedar law in place, orchardists were able to continue apple production. The cedar rust policy remained in place until fungicides arrived in the market at the start of the 1950’s and allowed, with persistent spraying, cedar trees and apple trees to coexist in close proximity.

From rare to invasive

It was initially assumed that planted Eastern redcedar would behave as an adventive species, in that they would not spread into adjacent environments. However, it is now clear that this is not the case (Briggs et al. 2005; Engle et al. 2008). Today, Eastern redcedar is an invasive species that is rapidly expanding at the expense of native grasslands leading to unexpected consequences

(Twidwell et al. 2013). Research in the Great Plains has revealed some of the consequences that result when grasslands transitions to a cedar woodland state and include:

- Native biodiversity decreases
- Livestock and forage production decreases
- Water yield decreases
- Public education funding generated from grazing leases on school lands is reduced
- Rural livelihoods are endangered
- Wildfire risk increases
- Risk to endangered and threatened species increases
- Spring allergies are worsened

See www.cedarliteracy.unl.edu for a comprehensive review of Eastern redcedar in the Great Plains (Bielski et al. 2018).

In response to these consequences, stakeholder groups have responded differently. Some ranching communities have come together to create prescribed burning associations to control and reverse trends of cedar invasion (Twidwell et al. 2013). Some landowners are removing cedar windbreaks established by past generations. Certain programs, from local to federal, now incentivize cedar removal on private lands (Roberts et al. 2018). However, other policies and actions that promote a cedar woodland state remain in effect, including incentivized cedar windbreak planting and suppression and restriction of fire (Roberts et al. 2018). Cultural ties to cedar mean that some landowners are reluctant to remove cedar from their properties and still actively plant cedar. Overall, past approaches to managing cedar invasion have proven to be insufficient in sustaining grasslands at broad scales, although examples of successful management are found in communities with strong prescribed burn associations (www.cedarliteracy.unl.edu). Looking ahead, there is much uncertainty surrounding how to better manage properties, working landscapes, and a biome with cedar populations.

Classroom management summary:

Total Estimated Time: 3.5 to 5.25 hours (all times are guesses)

Table 1. Time management suggestions

Class time	**Class one**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**
50 minutes	Section 1A	Section 1B	Section 1C	Part 2: stop after task 1	Part 2: stop after instructor led discussion of task 2-3	Part 2: stop after groups discuss tasks 8-9	Complete part 2; assign essay

1.25 hours	Section 1A-B	Section 1C; Part 2: stop after task 1	Part 2: stop after groups discuss tasks 8-9	Finish part 2; assign essay	Instructor-led discussion of essay question (optional)		
2 hours	Part 1	Part 2: stop after groups discuss task 7	Finish part 2; assign essay	Instructor-led discussion of essay question (optional)			

Part 1: System perspectives during Euro-American settlement
Total time estimate: 1.75-2.5 hours
Student handouts 1-2

- Section 1A. Draw how to make toast (20 minutes) (can be skipped if students are familiar with concept maps)
    - Individual student concept maps (2 minutes)
    - Group concept maps (2-5 minutes)
    - Groups discuss concept maps (5 minutes)
    - Instructor-led discussion (5 minutes)
- Section 1B. Case study introduction
    - Students read narrative (5-10 minutes)
    - Groups complete questions 1-2 (5 minutes)
    - Instructor-led discussion of question 1-2 (10 minutes)
    - Groups complete question 3-4 (15 minutes)
    - Group presentations of questions 3-4 (10 minutes)
    - Instructor-led discussion of questions 3-4 (5-10 minutes)
- Section 1C. Introducing cedar apple rust (30-45 minutes) (can be skipped or assigned as homework if time is limited)
    - Students read narrative and complete questions 1-2 in groups (10-15 minutes)
    - Group presentations of questions 1-2 (10 minutes)
    - Instructor-led discussion of questions 1-2 (5 minutes)
    - Groups complete question 3 (5 minutes)
    - Group presentations of question 3 (10 minutes)
    - Instructor-led discussion of question 3 (5 minutes)

Part 2. Merging multiple perspectives and scales in contemporary landscapes
Total time estimate: 1.5-2.25 hours
Student handouts 3-5

- Students read assigned narrative (handout 3 or 4) (5 minutes)
- Groups complete task 1 on assigned handout (20 minutes)
- Jig saw: groups are rearranged (2 minutes)
- Students complete task 1 on handout 5 (20 minutes)
- Group presentations of task 1 (10 minutes
- Instructor-led discussion of task 1 (5-10 minutes)
- Groups complete tasks 2-3 (5-10 minutes)
- Instructor-led discussion of tasks 2-3, including student explanations (10 minutes)
- Groups complete tasks 4-6 (5-10 minutes)
- Groups discuss task 7 (5 minutes)
- Group presentations of task 7, including student explanations that incorporate responses from tasks 4-6 (10 minutes).
- Instructor led discussion of task 7 (5 minutes)
- Groups discuss tasks 8-9 (5 minutes)
- Group presentations of tasks 8-9, followed by instructor-led discussion (15-20 minutes)
- Instructor-led discussion of question 10 (5-10 minutes)
- Assign synthesis take home essay question

Part 1: System perspectives during Euro-American settlement

Total Estimated Time: 1.75-2.5 hours depending on modifications

Necessary Materials: large easel paper pad, sticky notes, or white boards; note or printer paper; markers or other writing utensils; Student Handout 1

Section 1A. Draw how to make toast (15-20 min)

We begin the case study with an altered version of an exercise developed by Tom Wujec (www.drawtoast.com) to introduce the idea of mental models, team work, and systems thinking.

Step 1: Divide students into small groups of about 4-6 students. Give each group a large piece of paper and markers. Make sure each student also has a piece of note paper and a writing utensil.

Step 2: Without talking or discussing with their neighbors, ask each student to draw how to make toast in 2 minutes on their note paper. Once they are finished drawing, they should hide their paper away, without showing any of their neighbors.

Step 3: Ask the students to complete the same exercise, but this time, working as a group. Students should use the large easel pad paper and markers provided at the start of the exercise.

Again, don't let students talk to one another, but just draw their map as a group. Provide students between 2 to 5 minutes to complete their drawings as a group.

> *Expectation:* Groups will produce multiple drawings connected by arrows that diagram the different stages of making toast.

Step 4: Now have students compare their personal drawings with their group's drawing. Ask students what they notice about the differences in how the picture emerged when they thought about the problem on their own compared to as a group.

> *Expectation:* Group drawings will have more information and complexity than individual drawings.

Step 5- Assessment: The instructor should ask the class what they noticed about their drawings and what they feel this exercise demonstrates. During this brief discussion, the instructor should emphasize the importance of teamwork and integrating multiple points of view to better capture the process of making toast. Moreover, highlight how they have drawn system process by using links (arrows) and nodes (the pictures). More complex drawings might represent multiple processes interacting. Their drawings reflect a simple concept map resembling a system that results in the creation of toast.

Modification Option: If class is familiar with concept mapping consider skipping this section.

Section 1B. Introduce case study (1-1.25 hours)

This section introduces part I of the case study beginning in the Great Plains grasslands in the late 1800's. Students will be asked to consider a common problem among Euro-American settlers of the Great Plains during this time period: increasing their quality of life in such an arid system. Students will be asked to extract relevant system components from the case study description and create a system map to represent interactions among multiple social, ecological, and economic components.

Step 1: Provide each student 'Student Handout 1', which gives an overview of a problem Euro-Americans were faced with in the late 1800's and the motivations that led to one of the world's largest afforestation programs. This can be assigned as homework or done in class (5-10 minutes).

Step 2: In small groups (3-5 students), provide students 5 minutes to complete questions 1 and 2 on Student Handout 1:

1. *Use the above scenario (1.1 A rare species in a hostile environment) to create a list of key components related to how you will decide whether or not to plant trees.*

2. *From your list identify which components are related to grassland ecology and which components are related to social benefits/consequences.*

Step 3: Discuss as a class what each group determined to be important system components and why (10 minutes). Student groups may identify different concepts, this is okay. However, if groups are missing some important components (below) introduce them at this point. These components will be used later to create concept maps that will be built on as we move further into the case study.

Student groups can include many additional components but important ones include:

- Grass/grasslands community
- Fire
- Trees
- Tree planting
- People
- Benefits associated with trees

TIP: If students are new to concept mapping it may be helpful to limit the number of components in this initial exercise to 15-20. Using too many components may be overwhelming to students that are unfamiliar with using concept maps. More components will be added later in the case study.

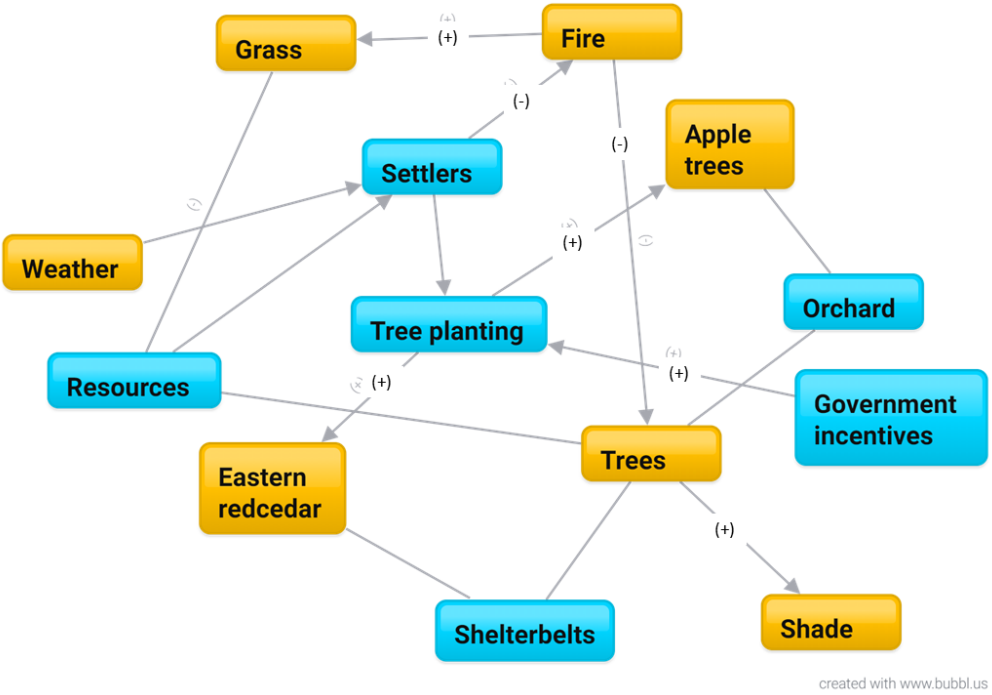
Step 4: In small groups provide students with markers and large easel paper and allow them ~15 minutes to complete question 3 and 4 on Student Handout 1 (below):

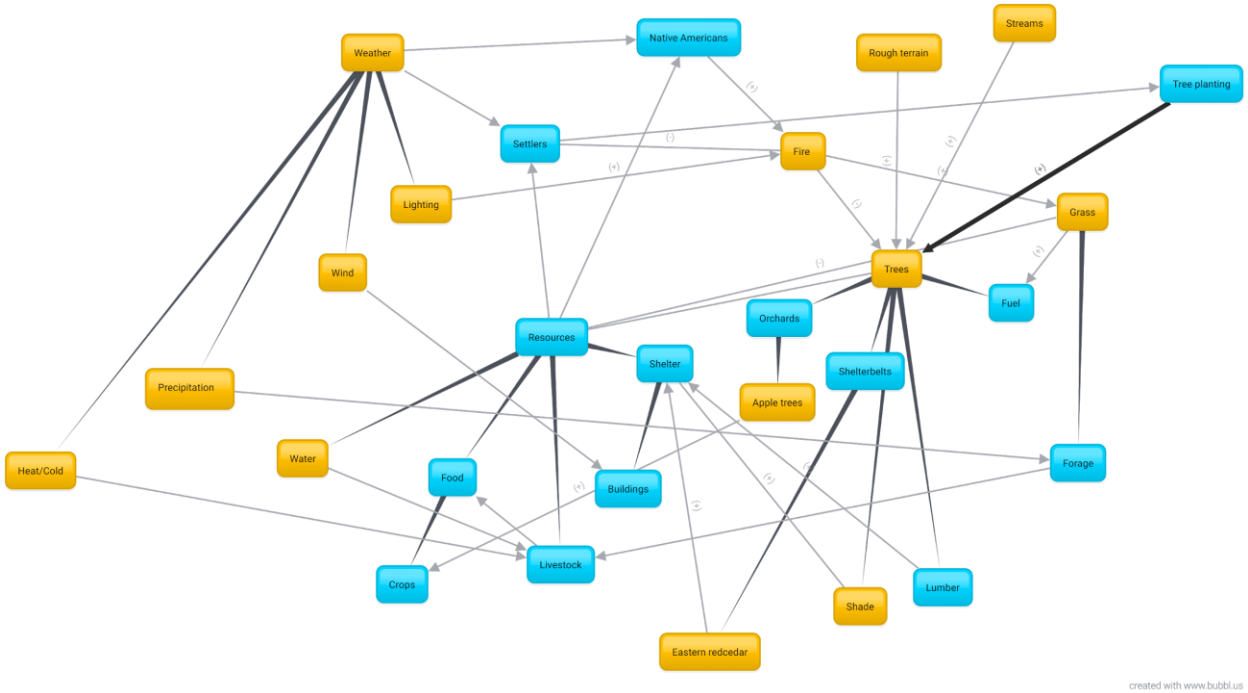
3. *Create a concept map using these concepts to understand* ***how you will decide whether or not to plant trees.*** *In your maps, label the arrows (+/-) to show the nature of relationships.*

4. *Using your concept map, does planting trees appear to be a win-win solution to improving quality of life or do trade-offs exist? Explain your reasoning in groups.*

Students should use arrows to draw positive and negative interactions between different system components. Positive arrows should represent an interaction where one component increases the other, while negative arrows should represent an interaction where one component decreases the other.

Expectation: below are examples of a relatively simple concept map with important concepts and a more detailed example with many concepts.





NOTE: The example concept maps are provided for the instructor to help evaluate student maps. Social components are colored blue and ecological components are colored orange. Student maps will be very different, this is okay. Students can modify their maps throughout the case.

TIP: Teach by wandering around. Observe students work and ask them to explain their ideas and the maps as they develop them. Keep pointing them back to the intent of the map so that maps do not become overly complicated.

Step 5- Assessment: Ask each group to select one representative to stand and give a 1-2 minute presentation to the class on the system map that they made, emphasizing differences between their maps and those of other groups. In their presentation, they should also state what action will likely best increase the quality of life for settlers of the Great Plains based on the information that they have.

> *Expectation:* Students may have different interactions among different system components, but the general interactions will likely be similar, as they are emphasized in 'Student Handout 1' narrative (1.1 A rare species in a hostile environment**)**. Most or all groups should highlight tree planting as the solution to the current problem of improving quality of life based on the information given.

Step 6: Discuss with the class how social and ecological components interact to guide decision making. Emphasize how under the provided perspective, tree plantings appears to be a win-win solution (5-10 minutes).

OPTIONAL: The instructor can discuss some of the decisions that were actually made and how they were implemented with policies. Examples include:

- **1873 Timber Culture Act:** granted homesteaders 160 acres of land with the requirement that they plant trees on 40 acres within 10 years.

- **1902 Forest reserves and nurseries established:** President Theodore Roosevelt designates forest reserves in treeless regions of Nebraska for tree planting experiments, timber production and later the dissemination of trees to private landowners.

- **1912 Kinkaid Act:** resulted in the free distribution of trees to landowners in regions of western Nebraska.

- **1926 Clarke-McNary Act:** authorizes and directs states to encourage tree planting on private lands. Results in incentivized tree planting programs in the Great Plains.

- **1934 Great Plains Shelterbelt Project:** a response to the dust bowl that aimed to establish a 160 km shelterbelt zone along the 99th meridian from North Dakota to Texas.

- **1873-present, local to national level tree planting incentives**: many tree-planting incentive programs exist today and are offered through local conservation districts, state forestry agencies, and the USDA Natural Resource Conservation Service.

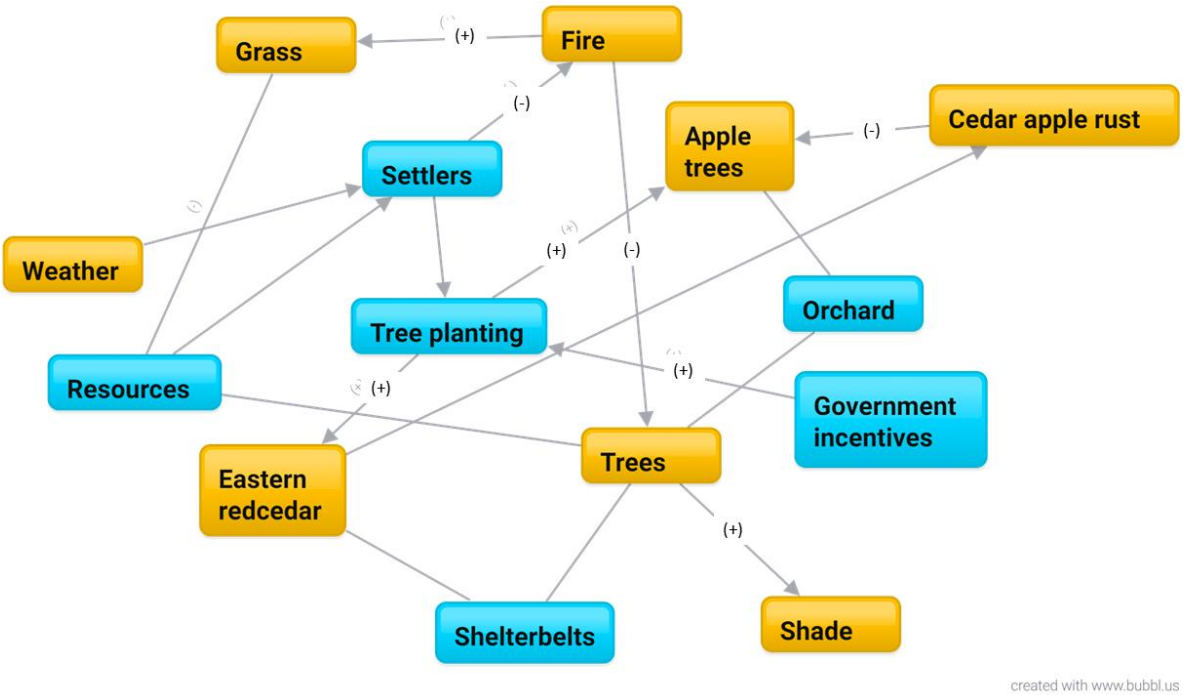
Section 1C. Introducing cedar apple rust (30-45 min)

This section emphasizes the introduction of a new component to the system, cedar apple rust, which began to emerge in the early 1900's. Cedar apple rust is the first unintended consequence of tree planting in the Great Plains. The emphasis of this section is to highlight trade-offs caused by various interactions among system components. In this instance, tree planting negatively influences apple production, thus leading to negative outcomes for some landowners' quality of life.

Step 1: Distribute 'Student Handout 2' to students in small groups and give them 10-15 minutes to complete questions 1 and 2:

1. *Incorporate key components from the cedar-apple rust problem into your concept map.*
2. *How does incorporating cedar-apple rust into your concept map change how you will decide whether or not to plant trees? Do win-win or trade-off scenarios emerge?*

   Expectation: Apple production and cedar-apple rust are the key components students should extract and incorporate into their concept maps.



Step 2- Assessment: Ask each group to select one representative to stand and give a 1-2 minute overview of the changes to their concept map and how this simple addition may have changed their assessment of win-win or trade-off scenarios of planting Eastern redcedar. Presentations by small groups can be followed by a short class discussion on differences among group assessments of the cedar-apple rust problem.

> *Expectation:* Students should identify that a trade-off scenario emerges, complicating how to decide whether or not to plant trees.

Step 3: In the same small groups students will discuss question 3 (~2-5 minutes) from Student Handout 2:

> *3. What actions or policies could be implemented to address the cedar-apple rust problem?*

Emphasize that they are not expected to come up with clear solutions when trade-offs exist, but instead identify how this problem could be addressed to minimize trade-offs. Students should consider the perspectives of both apple producers and nearby landowners with planted Eastern redcedar.

Step 4: Student groups present their answers to question 3 of Student Handout 2 to the class (1-2 minutes), followed by a discussion on differences among groups. Students are then presented with the actual historical policy changes and outcomes that emerged as a response to cedar apple rust problem:

Faced with the extinction of their industry, the orchardists in Nebraska turned to the state legislature for help. For its part, the legislature realized that if it let cedars grow unregulated, apple production would not be a viable commercial industry in the state. To address the cedar rust problem, the legislature passed a law requiring the removal of all cedar trees within two miles of apple orchards of 1,000 trees or more. At first, the law provided compensation for the loss of the cedar trees, but when it became apparent cedar owners could allow their trees to grow freely and then be paid for their removal, the law was amended. Instead of compensation, cedar owners were fined if they did not remove their cedars within the two mile cedar-free zone. With the cedar law in place, orchardists were able to continue apple production. The cedar rust policy remained in place until fungicides arrived in the market at the start of the 1950's and allowed, with persistent spraying, cedar trees and apple trees to coexist in close proximity.

<u>Modification Option:</u> If you have a shorter course period consider assigning 'Student Handout 2' as homework to be completed outside of class. Once students submit their answers, the actual responses to cedar apple rust problem provided in *Step 4* can be posted on the class website or discussed at the beginning of the next class.

Part 2: Merging multiple perspectives and scales in contemporary landscapes

Total Estimated Time: 2-2.5 hours

Necessary Materials: large easel paper pad, sticky notes, or white boards; markers or other writing utensils; Student Handout 3, 4, & 5; Group concept maps developed in 'Part 1' of the case study

Part 2 of this case study introduces greater complexity into the system students modelled in Part 1 of the case study using a role play/jigsaw exercise. Students will be presented with the current issue of Eastern redcedar invasion across contemporary grassland landscapes. Students will consider perspectives of different stakeholders relative to the problem of cedar invasion to gain an understanding of how differing perspectives that vary across scales can interact to shape a complex system.

Step 1: Ask students to re-join their small groups from Part 1 of the case study and provide students with their concept maps developed in Part 1.

Step 2: Assign half of the small groups to the rancher's perspective and provide them with Student Handout 3. Assign the other half of the students to the Federal Grassland Management Service's perspective (fictional; FGMS) and provide them with Student Handout 4. Each hand out describes the current issue in this system as cedar invasion into grasslands, and provides the system components most valued and understood by each stakeholder group. Students should spend 5 minutes reviewing the description of their stakeholder's view of the cedar problem.

NOTE: The Federal Grassland Management Service is a fictional agency created to better represent all resources in a grassland socio-environmental system. Other stakeholder groups are focused on a relatively narrow set of resources, which likely contributes to current disagreement over how to navigate the cedar issue. This point can be illustrated following stakeholder assessments towards the end of the case study.

Step 3: Allow small groups a maximum of 20 minutes to complete question 1 from their assigned Student Handout:

1. *Use the Federal Grassland Management Service's/rancher's perspective to modify your concept map. Note that cedar's context has changed socially in the system. Your concept map will now be used to* ***understand how to navigate cedar invasion.***

Modifying concept maps should include both the addition of new system components relative to their stakeholder's perspective, as well as any changes to system interactions in the contemporary system. Important alterations concept maps should include are: (1) cedar planting

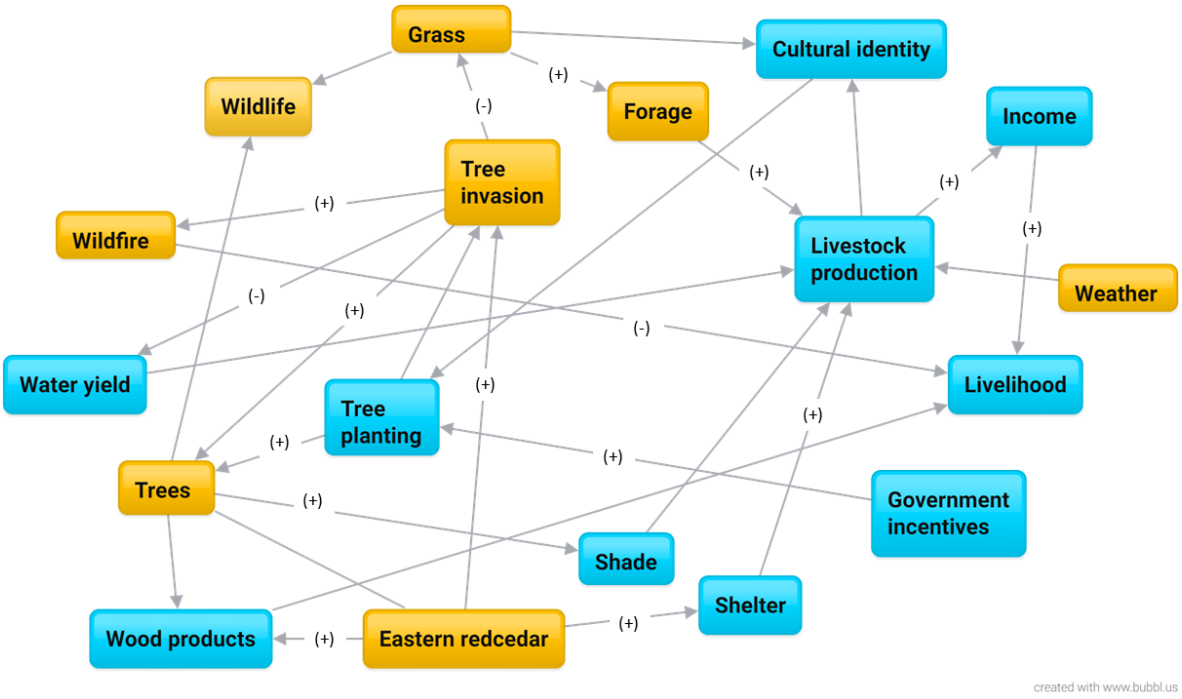
contributes to invasion which promotes woodlands; (2) tree invasion/woodlands negatively influence grasslands; (3) consequences of tree invasion emerge.

Expectations:

Important components from the rancher's perspective include:

- Aesthetics (may also be captured in cultural identity)
- Cultural identity (to ranching, grasslands and/or planted cedar)
- Income
- Livelihood (ability of ranch to support a family)
- Water yield
- Wildlife
- Tree invasion
- Tree removal
- Other benefits and consequences associated with cedar

Example concept map to help evaluate student maps for the rancher's perspective:

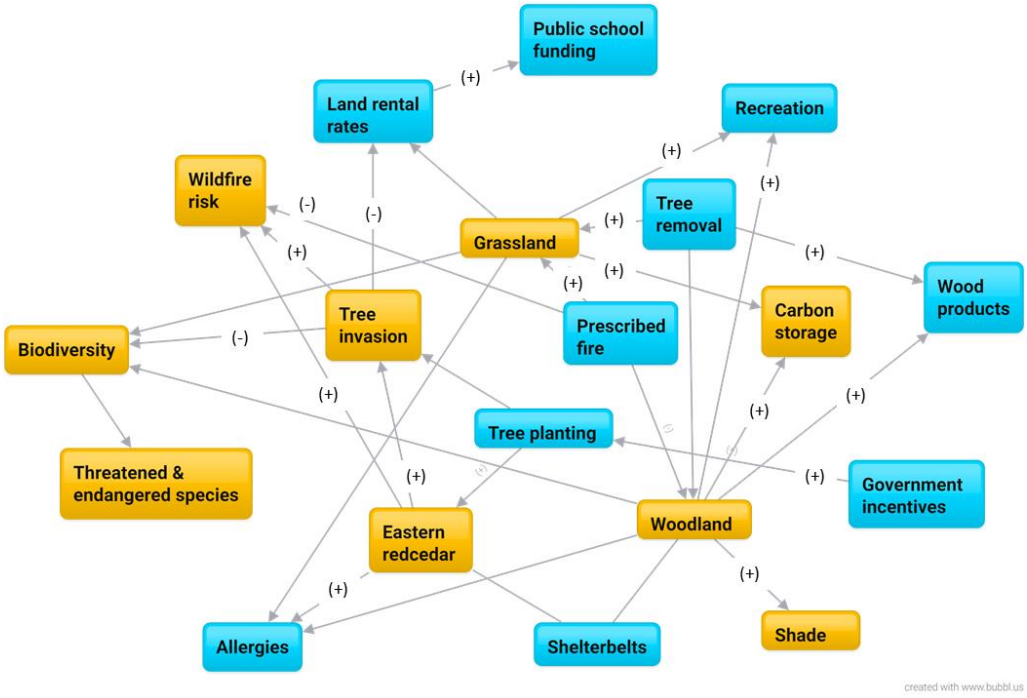


Important components from the Federal Grassland Management Service's perspective include:

- Allergies
- Biodiversity
- Carbon storage
- Livestock

- Public land school funding
- Recreation
- Threatened and endangered species
- Wildfire risk
- Woodland
- Wood products
- Tree removal
- Tree invasion
- Other benefits and consequences associated with cedar

Example concept map to help evaluate student maps for the FGMS's perspective:



Step 4: Provide students handout 5. Announce that a meeting of stakeholders has been called to address the growing cedar issue, requiring representatives from each stakeholder group to attend and determine how to navigate the cedar issue. Ask half of the students from each rancher small group to trade places with members from an FSGM group. Each small group should now contain 2-3 students assigned the rancher perspective and 2-3 students assigned the FSGM perspective. Ask students to complete question 1 from Student Handout 5:

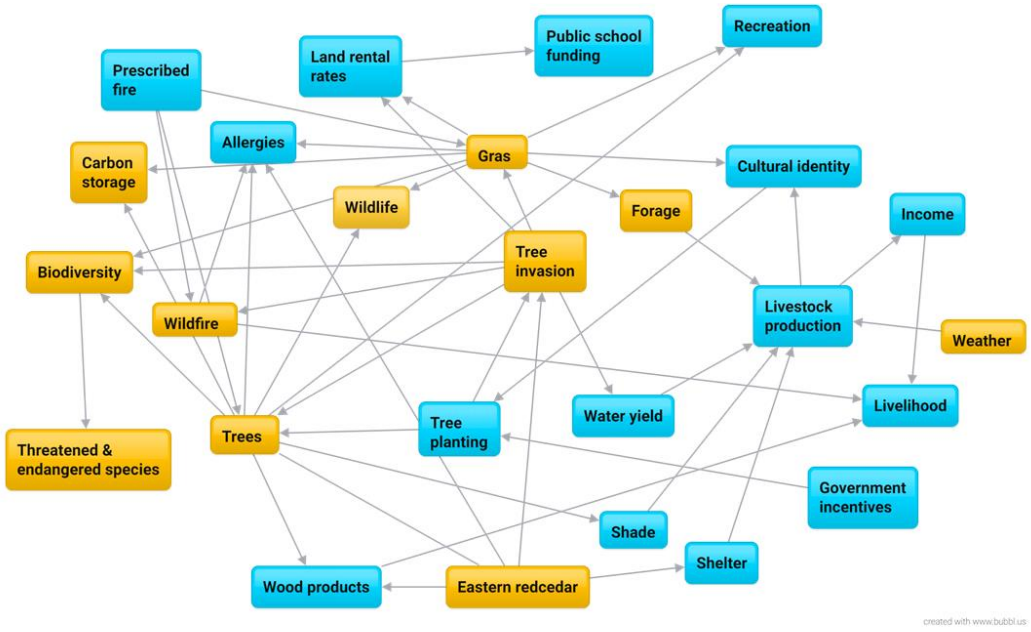
1. *In your new groups merge the rancher's and FSGM's perspectives to* ***understand how to navigate the cedar issue.***

Providing a new sheet of large easel paper may be necessary. It is important to note that each stakeholder group represents a different perspective based on scale and context. Thus students

will need to integrate a multi-scale perspective into their concept maps. Provide students with a maximum of 20 minutes to rebuild their maps.

Expectations:

Example of an integrated concept map:



Step 5- Assessment: Have each group provide a 1-2 minute explanation of their concept map for understanding how to navigate the cedar issue. At this point, the instructor should provide guidance to small groups that have missed key relationships in their concept maps as these maps will help them conduct final exercises.

Expectation: Students will have different looking concept maps. The important part is that they identified appropriate connections between tree planting, tree invasion and grasslands, along with their relationships to social benefits/consequences (i.e., ecosystem services).

Step 6- Discuss as a class why integrating multiple view-points and scales is relevant to understanding the cedar issue. Discussion could be stimulated by asking how independent stakeholder maps look different than maps when the view-points are merged.

Step 7- In small groups, provide students 5-10 minutes to complete questions 2 and 3 on Student Handout 5:

2. Using your concept map identify:

- *What system components support a grassland?*
- *What system components support a cedar woodland?*

3. Using your concept map, determine whether the following policies/actions support a grassland, woodland, or both.

- *Incentivized cedar planting*
- *Incentivized cedar removal*
- *Removal of seed producing cedar trees*
- *Fire suppression*
- *Prescribed burning*
- *Restricting the number of days prescribed fires can be conducted*
- *Doing nothing*

Expectations:

Question 2: Grasslands are supported by interactions between fire and herbaceous fuels. Cedar woodlands are supported by cedar planting, invasion, and fire suppression or restriction.

Question 3:
Policies/Actions that support grasslands

- Incentivized cedar removal: promotes recovery of herbaceous fuels
- Removal of seed producing cedar trees: does not necessarily support grasslands but is meant to "freeze" feedbacks that promote a cedar woodland transition
- Prescribed burning: promotes feedbacks that maintain grassland dominance

Policies/Actions that support cedar woodlands

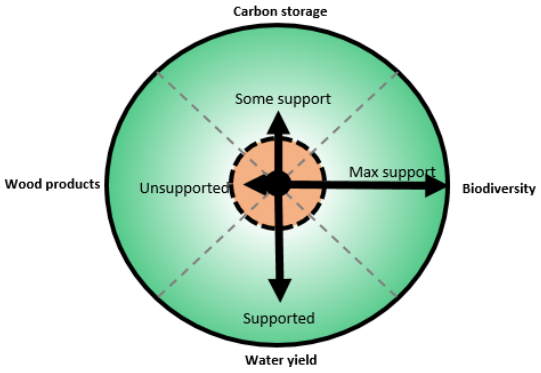
- Incentivized cedar planting: supports feedbacks that promote a cedar woodland transition
- Fire suppression: interrupts grassland stabilizing feedbacks
- Restricting the number of days prescribed fires can be conducted: constrains feedbacks that maintain grasslands
- Doing nothing: In areas with cedar propagules doing nothing erodes the resilience of grasslands leading to cedar invasion

Step 8- Assessment: Discuss with students what they found and how it relates to navigating the cedar issue. Students should be able to use their concept maps to identify that different feedbacks support grasslands versus cedar woodlands, and that specific policies/actions tend to support one of these feedbacks. These questions illustrate socio-environmental connections between

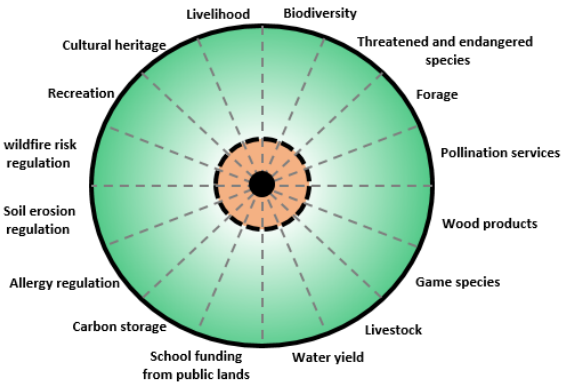
feedbacks that support alternative stable states and how policies/actions can support a stable state or drive a transition to an alternative state.

Step 9: In small groups, ask students to complete questions 4 to 6 on Student Handout 5:

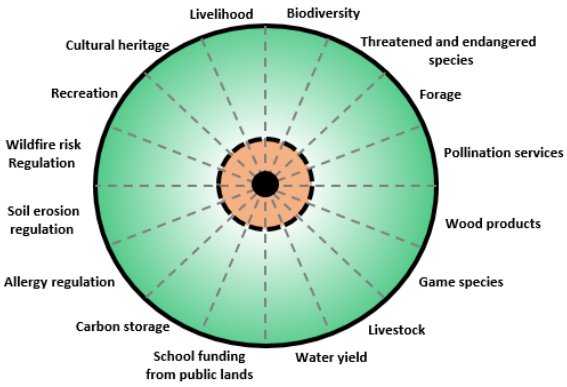
> *4. Use your concept map to create ecosystem service assessments for a grassland and cedar woodland. Populate the **grassland** and **cedar woodland** ecosystem service diagram with arrows to show the relative support (unsupported to maximum support) for each ecosystem service (see example). Arrows in the red zone show no support, arrows in green show varying levels of support.*



Example system



Native Grassland



Eastern redcedar woodland

Stakeholder groups
Ranchers association
Natural Resource Conservation Service (NRCS)
U.S Forest Service
U.S. Fish and Wildlife Service
Board of Education
Environmental Protection Agency
National Parks Service

Ecosystem services
• Biodiversity
• Threatened and endangered species
• School funding from public lands
• Pollination services
• Wood products
• Game species
• Livestock
• Water yield
• Forage
• Carbon storage
• Allergy regulation
• Soil erosion regulation
• Wildfire risk regulation
• Recreation
• Cultural heritage
• Livelihood

5. Conduct a stakeholder analysis using arrows to connect stakeholder groups to their most valued ecosystem service(s). Many stakeholders will value multiple ecosystem services.

6. Different stakeholder groups use different approaches for managing ecosystem services in grassland systems. Use arrows to connect stakeholders to policies/actions you expect them to implement.

Stakeholder groups
Ranchers association
Natural Resource Conservation Service (NRCS)
U.S Forest Service
U.S. Fish and Wildlife Service
Board of Education
Environmental Protection Agency
National Parks Service

Policies/Actions
• Do nothing
• Incentivized cedar planting
• Incentivized cedar removal
• Removal of seed producing trees
• Fire suppression
• Prescribed burning
• Restricting the number of days prescribed fire can be conducted

MODIFICATION OPTION: If students are unfamiliar with the listed stakeholder groups these questions can be modified to better suit your classroom. Figures for questions 4-6 can be downloaded from the following link: https://drive.google.com/file/d/1Og1C945O-o0fhyZzwg7h4oFaU9MHuOkc/view?usp=sharing

Expectations:

Question 4: The student's ecosystem service diagrams should clearly illustrate that that grasslands and cedar woodlands support ecosystem services differently. This introduces the concept of ecosystem service "bundles" or "suites", which shifts the importance from single ecosystem services to bundles of services supported by a socio-environmental system. For more on ecosystem service bundles see Raudsepp-Hearne et al. (2010).

Question 5: Students should identify that stakeholder groups identify with different ecosystem services and that no single agency mission encompasses all ecosystem services of an ecosystem service bundle. Most agencies/stakeholders are focused on a single or few ecosystem services, not ecosystem service bundles that represent a socio-environmental system. The Federal Grassland Management Service (FGMS) is a fictional agency created by the authors to better represent all ecosystem services in a grassland socio-environmental system.

Question 6: Students should identify similarities and differences in the policies/actions used by stakeholder groups. Another point that should emerge is that a single agency may use contradictory policies/actions that support grasslands and others that may support a cedar woodland.

Step 10: Provide 5 minutes for groups to discuss question 7 from Student Handout 5. Emphasize that questions 2-6 should be used to help guide this discussion.

7. *Using what you have learned in the case study, describe potential points of conflict and agreement in determining how to navigate the cedar problem. Think about ecosystem service tradeoffs versus win-wins and how these relate to socio-environmental feedbacks (i.e., questions 2-6).*

Step 11-Assessment: Have each group provide a 1-2 minute explanation of their response to question 7. Group presentations should be followed by an instructor led discussion (10-15 minutes). The following key points can be used to help facilitate discussion:

1. Grasslands and cedar woodlands are supported by different socio-environmental feedbacks that negatively influence each other. That is, cedar woodland transitions occur at the expense of grasslands.

2. Grasslands and cedar woodlands are associated with different social benefits and consequences. This creates complex socio-environmental trade-offs.

3. Not all ecosystem services can be maximized, some increase at the expense of others. Policies and actions that support opposing ecosystem services can erode the resilience of a socio-environmental system (and the associated ecosystem service bundle) and lead to unexpected and undesirable transitions.

4. Stakeholder's values tend to be associated with a few or single ecosystem services, not with ecosystem service bundles. The Federal Grassland Management Service is a fictional agency that was created to better represent all grassland ecosystem services for the purpose of this case study.

5. Traditional policies and actions focused on a single or few ecosystem services can lead to conflicting policies among and within stakeholder groups, in that some policies support grasslands, while others support a cedar woodland. This can lead to disagreement in deciding how to navigate the cedar issue.

Step 12: Provide groups 5 minutes to discuss questions 8-9 from Student Handout 5:

8. *What assumptions did Great Plains citizens make in part 1 of the case study that led to a biome-wide afforestation program? Did these assumptions prove to be true in part 2? Explain your reasoning.*

9. *What assumptions are made in part 2 of the case study to help us understand how to navigate the cedar issue? Explain.*

Step 13-Assessment: Have each group provide a 1-2 minute explanation of their responses to question 8-9. Group presentations should be followed by an instructor led discussion on the similarities and differences among groups (15-20 minutes). Important points to help facilitate discussion include:

An assumption from part 1 was that planted cedar trees would not become invasive (referred to as casual, adventive and naturalized species in invasion biology). Moreover, widely held assumptions were that planting cedar trees was a win-win solution to increasing human well-being. In other words, it was assumed that tree planting could be used to increase specific ecosystem services (e.g., wind protection) without compromising other ecosystem services.

Assumptions from part 2 are a little trickier. In some regions stakeholders are still making the above assumptions. An important (and contradictory to above) assumption today is that cedar invasion will not stop until grasslands have transitioned to a cedar woodland state or until all propagules have been removed. There is plenty of evidence across the

Great Plains to support this assumption and the consequences that result from cedar invasion. Looking ahead, where we assume cedar invasion is possible and where it is not will be a critical assumption for influencing land management decisions and environmental outcomes. For example, it is widely regarded that cedar invasion is not possible in large regions of South Dakota and North Dakota, yet cedar is commonly planted in these states.

Step 14: As a class discuss question 10 from Student Handout 5 (5-10 minutes):

10. *What information would you want to know in order to make policy and management decisions regarding the cedar issue on a property, county, and state?*

Questions to help facilitate discussion:

- Is cedar invasion occurring now, and is it possible?
- How far along is the cedar invasion process?
- What are important ecosystem services in the area of interest?
- How effective are different management actions/policies?
- How much of the area is invadable (e.g,. grasslands versus corn fields and parking lots)?
- What are public perceptions of planting cedar and cedar invasion?
- What are the relevant stakeholders?
- What are the potential tradeoffs/consequences?
- How much do "solutions" cost, and who will pay?
- How much control do stakeholders have at property, county and state levels?
- How much uncertainty exist at property, county and state levels?

Step 15-Assessment: Assign take home essay question:

A recent study published in Science (Bastin et al. 2019) predicts that the world can support more than 2 billion acres of trees in addition to the current 8.6 billion acres. Adding this many trees to the planet is predicted to lower atmospheric carbon pool by about 25%, but would require converting many grasslands into woodlands and forests. Many countries are in the early stages of afforestation, planting millions of trees in grass dominated ecosystems. Using what you have learned from this case study, write an elevator pitch (no more than 200 words) that you would use to help a manager understand how to decide whether or not to plant trees in a grassland dominated ecosystem.

Modification Option: If you have a shorter course period (~1 hour) consider assigning questions 2-6 of 'Student Handout 5' as homework and then discuss questions 7-10 at the beginning of the next class. If this modification is used skip steps 7-9.

Assessment:

Students will be graded for participation in class discussions throughout the case study. Instructors can require a different student to present their group's summary to encourage participation from all students; there are 7 points in the case study where students are required to summarize their group's discussion. The elevator pitch students are required to prepare for their take home essay will be used as a summative assessment of student learning. Students can also be asked to turn in written responses following class discussions. We recommend written responses to the following discussion points:

- Part 1B, step 5: explain the system map [how to decide whether or not to plant trees] your group created and indicate how this was used to determine what actions could be used to increase quality of life for settlers of the Great Plains.

- Part 1C, step 2: explain the changes to your group's concept map [with the addition of the cedar apple rust issue] and how this simple addition altered the assessment of win-win versus trade-off scenarios of planting Eastern redcedar.

- Part 2, step 8: explain the feedbacks that support grasslands and cedar woodlands (question 2 from student handout 5) and how the listed policies (question 3 from student handout 5) influences these feedbacks.

- Part 2, step 11: describe potential points of conflict and agreement in determining how to navigate the cedar problem. Think about ecosystem service tradeoffs versus win-wins and how these relate to socio-environmental feedbacks.

- Part 2, step 13: explain your responses to the following questions.

    - What assumptions did Great Plains citizens make in part 1 that led to a biome-wide afforestation program? Did these assumptions prove to be true in part 2?

    - What assumptions are we making today in regards to the cedar issue?

Suggested readings

Part 1:

Fischel, W. A. (2007). The law and economics of cedar-apple rust: State action and just compensation in Miller v. Schoene. *Review of Law & Economics*, *3*(2), 133-195.

Pool, R. J. (1953). Fifty years on the Nebraska National Forest. Nebraska History 34, 139-179.

Ratajczak, Z., Nippert, J. B., Briggs, J. M., & Blair, J. M. (2014). Fire dynamics distinguish grasslands, shrublands and woodlands as alternative attractors in the Central Great Plains of North America. *Journal of Ecology*, *102*(6), 1374-1385.

Wells, P. V. (1970). Postglacial vegetational history of the Great Plains. *Science*, *167*(3925), 1574-1582.

Part 2:

Bielski, C. H., Twidwell, D., and Allen, C. R. The Eastern Redcedar Science Literacy Project. Retrieved from www.cedarliteracy.unl.edu (Last updated: 17 September 2018).

Briggs, J. M., Knapp, A. K., Blair, J. M., Heisler, J. L., Hoch, G. A., Lett, M. S., & McCarron, J. K. (2005). An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. *BioScience*, *55*(3), 243-254.

Engle, D. M., Coppedge, B. R., & Fuhlendorf, S. D. (2008). From the dust bowl to the green glacier: human activity and environmental change in Great Plains grasslands. In *Western North American Juniperus Communities* (pp. 253-271). Springer, New York, NY.

Holling, C. S., & Meffe, G. K. (1996). Command and control and the pathology of natural resource management. *Conservation biology*, *10*(2), 328-337.

Roberts, C. P., Uden, D. R., Allen, C. R., & Twidwell, D. (2018). Doublethink and scale mismatch polarize policies for an invasive tree. *PloS one*, *13*(3), e0189733.

Twidwell, D., Rogers, W. E., Fuhlendorf, S. D., Wonkka, C. L., Engle, D. M., Weir, J. R., ... & Taylor Jr, C. A. (2013). The rising Great Plains fire campaign: citizens' response to woody plant encroachment. *Frontiers in Ecology and the Environment*, *11*(s1), e64-e71.

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Bessey, C. E. (1894). The re-foresting of the sand hills. Annual Report, Nebraska State Board of Agriculutre.

Bessey, C. E. (1904). The Distribution of the Native Forest Trees of Nebraska.

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Ratajczak, Z., Nippert, J. B., Briggs, J. M., & Blair, J. M. (2014). Fire dynamics distinguish grasslands, shrublands and woodlands as alternative attractors in the C entral G reat P lains of N orth A merica. *Journal of Ecology*, *102*(6), 1374-1385.

Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences*, *107*(11), 5242-5247.

Roberts, C. P., Uden, D. R., Allen, C. R., & Twidwell, D. (2018). Doublethink and scale mismatch polarize policies for an invasive tree. *PloS one*, *13*(3), e0189733.

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Ziems, A. Z. (2009). Cedar-apple and related rusts of apple and ornamentals. University of Nebraska-Lincoln Extension, NebGuide, G1907.