Understanding Fire Regimes

Image from: https://pixabay.com/photos/wildfire-bushfire-fire-forest-4755030/

NGSS

- MS-ESS3-2: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

NGSS Crosscutting Concepts

- Stability and Change: Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

NGSS Practices

- Analyzing and Interpreting Data*:* Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. Analyze data using computational models in order to make valid

Teacher Guide

Credits: This mini-unit was developed by Joshua Rosenberg, Brooke Carter, Ryan (Seth) Edwards, Alex Edwards, and Michael Camponovo as part of a National Science Foundation-seed funding supported project led by Arthur Palisoc and STEMEd, LLC. Though we developed the materials for this lesson, this lesson was inspired by extant lessons related to sunspots, including some materials developed by NASA.

and reliable scientific claims.

Investigation Overview

Students will work to record, analyze, and interpret data to answer a novel question about what happens after a forest fire in areas that are not traditionally prone to fires (or fire-adapted). To do this, they will need to learn about what we know about fire's role in the ecosystem: fire regimes, fire adaptation, and ecological succession. This lesson can be adapted to make assumptions about local/recent fires that may have affected an area near them but will use the Chimneys 2 Fire (near Gatlinburg, TN, in the Great Smoky Mountains National Park, the United States' most-visited) of 2016 as the model. After learning about a natural disturbance, students will learn about how publicly remote-sensed data can be easily collected. There is a wealth of publicly available data that is regularly recorded by sensors—in this case, satellite imagery). Next, hypotheses can be made (what happens to a forest after a fire) and can be tested after students access this data and analyze it. They will then use interpolation (filling in the gaps in between data), and extrapolation (filling in gaps outside of the data range) to make inferences beyond the data. To test the accuracy of their model, they can compare it to older data of a similar nature and see how it fits. While this mini-unit is very detailed, as we note later, this Story Map can be used to provide students with opportunities to understand fire regimes.

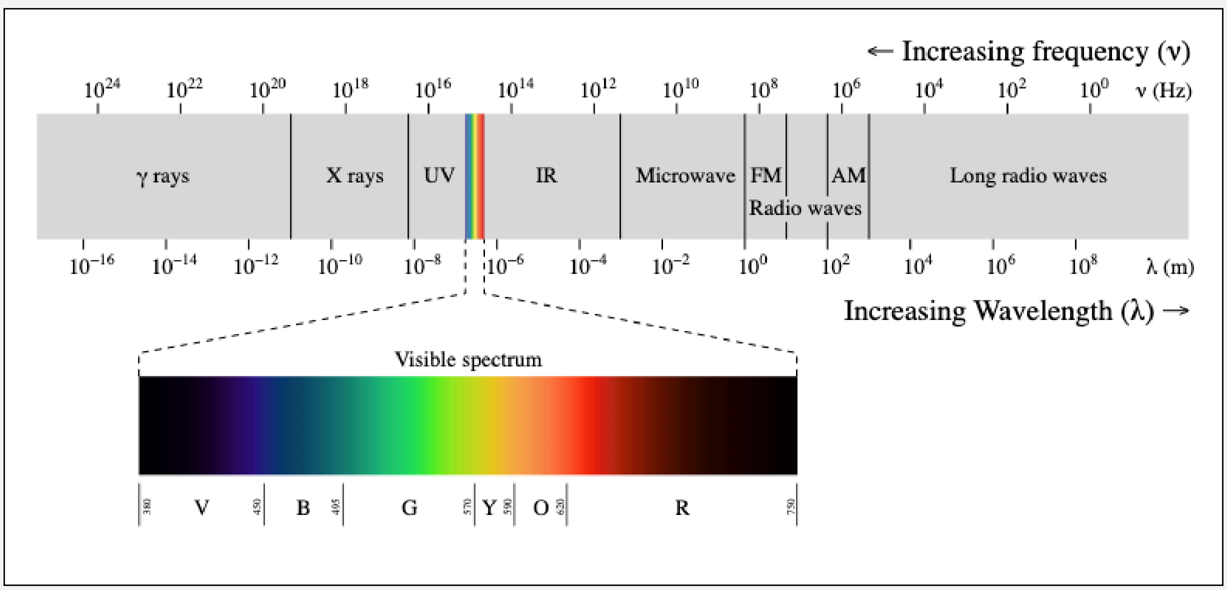
Understanding Fire Regimes & Succession

Background

Remote sensing involves the use of tools that can help us to understand things that we can't see or measure with our eyes and hands. One kind of remote sensing involves using satellites, which can be used to measure a wide range of events and phenomena on Earth, from the spread of wildfires to the area covered by glaciers.

These lessons involve using remote sensing to understand where there is (and where there is not) disruption from fires. Before we dive into remote sensing, a bit of background can be helpful. We have compiled a lot of the following information in this "Story Map", a webpage with maps and other interactive elements that you can use to teach about remote sensing and understanding fire regimes and succession is available [here](#).

Our eyes use different cells to absorb light energy. Two of the most important cell types in your eyes are rods and cones. Rods help us see light and motion, while cones help us see color. While the cones in our eyes help us to see reds, greens, and blues (and the colors in between these), these colors make up a small part of the electromagnetic spectrum.



The electromagnetic spectrum.

Image used with permission from Wikimedia Commons:
https://commons.wikimedia.org/wiki/File:EM_spectrum.svg

While our human eyes cannot see the electromagnetic radiation outside of what we call the visible part of the spectrum (with red, green, and blue), instruments that we create can. Scientists and engineers build sensors to collect data about all this energy. Then they take those sensors and put them on different platforms to collect data. Sometimes they hang sensors from kites and weather balloons, while other times, they attach them to drones, planes, and helicopters. They even attach them to satellites so they can study energy around the entire world. Anytime we collect electromagnetic data about something without touching it, we call that remote sensing.

We use remote sensing all the time. *When was the last time you took a picture with a digital camera, smartphone, or tablet?* The picture above represents the spectrum of the electromagnetic spectrum. *Did someone use a touchless thermometer to take your temperature during the Covid-19 pandemic*? Thermal energy is another component of the electromagnetic spectrum seen in the infrared part of the spectrum. Remote sensing can be really low-tech too. *When is the last time you held your hand near a stove to see if it was warm*? Yep, you used your hand to collect remote sensing data about heat energy.

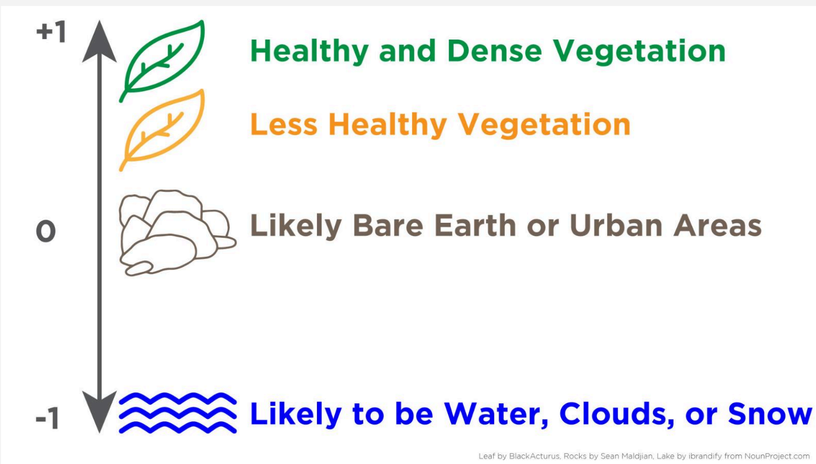
In this lesson, we use remote sensing to understand fire regimes and succession with a real-world data-focused approach. Specifically, we use imagery (or data) collected from a satellite, the Landsat 8 managed by the United States Geological Survey. One feature of the Landsat 8 satellite and other satellites in the Landsat series of satellites is that the imagery they collect is made available to anyone in the world to use. Notably, Landsat 8 records imagery using parts of the electromagnetic spectrum beyond those that are visible to us, especially the near infrared part of the electromagnetic spectrum—-the part of the infrared (IR) spectrum closer in wavelength to visible light (see the image above), as we consider next.

Since we are interested in the regrowth of plants after the Chimney Tops 2 wildfire, we want to focus on the bands of the electromagnetic spectrum that provide us with the most information about healthy vegetation. It turns out that healthy vegetation has a unique interaction with several different bandwidths of the electromagnetic spectrum.

- Healthy vegetation with lots of chlorophyll reflects more near infrared and green light compared to other wavelengths. This is why we see healthy vegetation as green. If we could see near infrared, then that wavelength would be strong for healthy vegetation too.
- Healthy vegetation absorbs more red and blue light. As a result, it reflects

much more near infrared energy than red energy.
- Vegetation that is stressed or unhealthy reflects much more red energy compared to healthy vegetation.
- Since Landsat 8 collects red, green, blue, and near infrared energy, we can compare the ratio of these different bandwidths to find healthy vegetation. The math formula for calculating the difference between near infrared and red light is called the Normalized Difference Vegetation Index but is often abbreviated NDVI.

We simply take the amount of near infrared energy (abbreviated NIR) and subtract the amount of red energy. Then we divide that by the amount of NIR energy plus the amount of red energy. How to interpret the NDVI values is presented in the image below.



The NDVI value between -1 and +1 gives us clues as to what type of material is on the surface of the earth. Adapted from Earth Observing System.

More on this, including the mathematical formula for this equation, is in the story map for this mini-unit here.

Lastly, we briefly describe the Chimneys 2 fire, one that occurred in the Great Smoky Mountains National Park in the fall of 2016. It was the largest fire to occur in recorded history in this national park—and the most deadly fire in the Eastern United States since one in the 1940s. The fire is believed to be caused by arson. Much more on the fire is available here. More on fire regimes is available here.

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Materials

- Story Map to help facilitate understanding of remote data monitoring using satellite imagery. https://storymaps.arcgis.com/stories/dec53e95ea5a4cdf94248848e9a12972
- ArcGIS (pre-formatted) map of Gatlinburg/Chimney Tops area in years before and after the Gatlinburg Fire.
- ArcGIS (pre-formatted) map of Shenandoah National Park in years before and after the Old Rag and Pinnacles Fires.
- Student final product from this investigation: Forest Fire Example.pdf

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Student Thinking & Assessment

Most questions listed below are intended to be asked to students and answered by them, with assistance and guidance when necessary.

The driving question for the study is: **What happens after a forest fire in areas not adapted to regular fires?** Where the other questions can be teacher-assisted, this driving question is intended to be student-driven. The novelty is that neither the students nor the teacher, are likely to know this answer with any precision at the outset.

Lesson 1 : Fires in the ecosystem

- What typically happens after a forest fire?
- How and why are organisms adapted to fire?
- What kind of biomes are adapted to fires?
- Do fires only happen in fire-adapted places?
- Why might these areas experience fires (why might this be occurring with increasing frequency [climate change/invasive species])?
- What happens after a fire occurs in areas not adapted to fire?
    - How long will it take to heal (revegetate)?
    - What things might affect how long this takes (size of fire, type of environment, if there are more fires)?

Lesson 2 : Remote sensing using satellites and ArcGIS

- How can we test a question like our driving question?
- How can we use existing (remote sensing) data to answer this question?
- How does near-infrared imaging work?
- Why do we need to use quantitative data?

Lesson 3 : Collecting data

- How can we turn visual/qualitative data into quantitative data?
- What controls are needed?
- What are dependent and independent variables?

Lesson 4 : Organizing and analyzing data

- How can the way we organize/collect data affect how we can use it?
- How/why can we "trust" our data?
- What can we do to make it more accurate/reliable?

Lesson 5 : Extrapolating from the findings

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- What else can our data tell us (in between and outside of data range)?
- What are the limitations of our model?
- How could we test the reliability of our model?

Implementation

Lesson 1: Fires in the ecosystem

Introduce the driving question, **What happens after a forest fire in areas not adapted to regular fires?** Discuss fire regimes (the natural frequency/tendency of fires to occur in an area and the intensity that they have) and biomes that are adapted to fire (e.g., grasslands, pine barrens, and boreal forest/taiga). Discuss how fires start (probably lots of input based on a human cause which is a big issue and is the cause of the Chimneys 2 fire, but it is important to note that fire is often caused by natural phenomena, including lightning strikes).

After establishing fire as a natural phenomenon (not just anthropogenic), talk about what normally happens after a fire (ecological succession). Ecological succession is the natural progress/change over time in an environment (often after a disturbance). Succession can be divided into Primary succession (immediately after the disturbance when there is no plant life) and Secondary succession (when plants begin to revegetate the area). Secondary succession can then be broken into 3 further divisions: pioneer species (ones that come back right after a fire), intermediate species (ones that come back next after the ground is stabilized), and climax species/community (ones that represent what a non-disturbed area would look like).

After students have a background and understanding of “normal” fire regimes, it is time to present the novel problem: The Great Smoky Mountain National Park experienced a fire (in the Appalachian Mountains) in 2016. This is not an area that is prone to frequent fires. But, areas like the Appalachian Mountains are experiencing fires more frequently due to climate change and invasive species. So, we know what happens to areas that are fire-adapted, but much less about what happens to a non-fire-adapted ecosystem after a fire and how long will it be before the forest is healed.

Lesson 2 : Remote sensing using satellites and ArcGIS

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Help guide them through how they would design this experiment. Have them hypothesize the kind of data they will use (this will be very interesting to see what they think is important and how they would use this to answer the question). Remind students to recall the driving question and their hypotheses. Also remind them that we cannot time travel and that we must thus use data that already exists (this is a hint that they will need past data, not just new data). After brainstorming, hopefully, students will have realized that they need data from before the fire and after the fire (all the way up to the current time). Explain and give them the resources to view the data they will collect. This will be in the form of satellite imagery. It is available in two places: the Story map, which also contains resources for teaching this mini-unit, and this ArcGIS map. Explain what remote sensing is and how we can use/mine data that has already been taken and how there are systems/infrastructure out there that take constant or periodic readings of environmental parameters (e.g., water level gauges, precipitation, temperature, and even pictures). The data we are using are satellite images taken at around the same time each year.

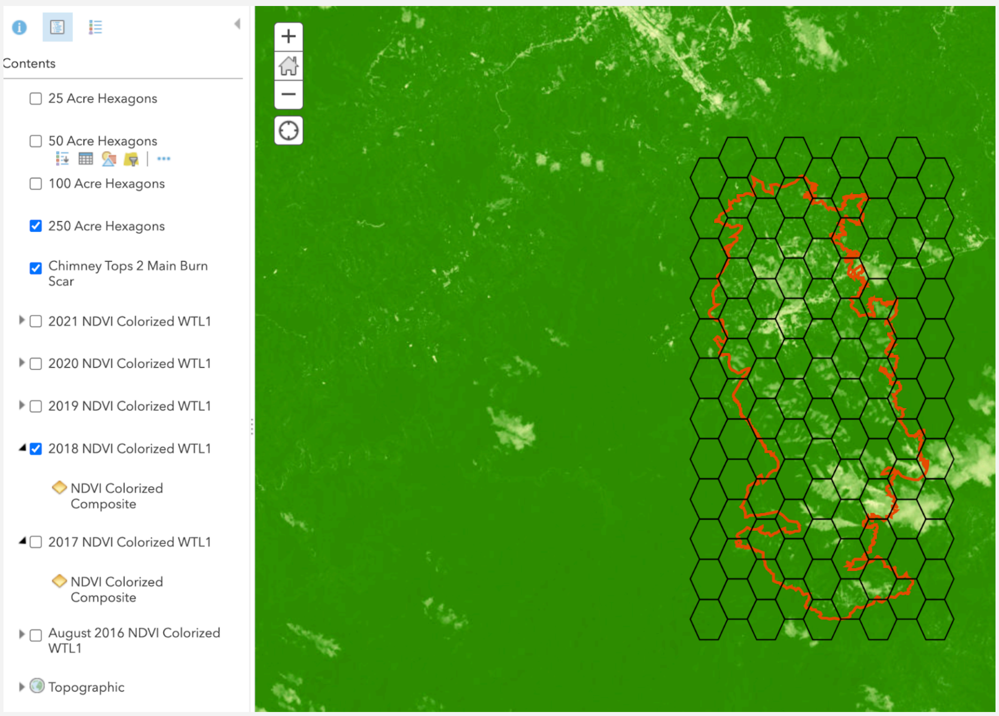
Have students brainstorm what we would be looking for with satellite images (keep in mind the question, how could this answer it?). We are looking at revegetation from year to year. Have them state this in a more simple way (ask them to say it if they were explaining it to a younger child). With this, they should recognize that they need data from not just after the fire but also before (so they know how green it was). Ask them what color trees look like from above (green). Ask if anything else could look green from above (rivers, rocks, rooftops, etc.). Explain how we need to be able to separate what is and isn't a plant (and that color isn't the best way to do that- or at least not green). Explain that plants use light for photosynthesis and that blue and red light is used most often. And because red is used and infrared is not (it is heat and can't be seen by us), we will look at the absorption/reflection of near-infrared (NIR) light and red light. This will allow us to see what things are healthy plants (lots of absorption), unhealthy plants (less absorption), non-plant structures (no absorption), or bodies of water (reflection). This can be presented in red or image reversed to turn it back into green (which makes the most sense)

As noted above, we use imagery of the burned area that had been converted to reflect the amount of vegetation on an ArcGIS platform—this ArcGIS map. This allows students to view the different sample years as layers (can look at different amounts of burn through the years). The program allows many other viewing options and this time provides them with the opportunity to explore these programs.

Students will be challenged to come up with a hypothesis of what they think they will find and how they would turn the obviously qualitative data into quantitative data, and why they should.

Lesson 3 : Collecting data

Students will work to create a protocol to collect (or record) data using satellite imagery using either the ArcGIS map.



Using a 250-acre hexagon grid to measure vegetation in the area of the Chimneys 2 fire (red outline).

Discuss necessary controls (time of year of image) and the dependent (amount of vegetation present) and independent variables (number of years after the fire). How can we make sure our method is "free" from error (consistency, repeatability, and sample size)? What are ways we could affect the outcome by our "interpretations"? After considering these, students will create a detailed method for collecting data using the percent of vegetation indicated by green coloration in a hexagonal grid (grid provided). An example of a protocol developed by a student is here; this contains a great deal more detail on the data collection methods than provided in this teacher guide.

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Lesson 4 : Organizing and analyzing data

Data collection: Review the protocol so that all students are collecting data the same way (this way, it only has to be done once). Remind them that 1=all vegetation (green) and 0=no vegetation (brown/yellow). Depending on class size, each student should be responsible for collecting tw sets of data from two different years. Students will estimate the amount of green (100, 75, 50, 25, or 0) in percent. Sample data collection sheet.

It is very important that they use the numbered grid provided (1-68). This way, data can be checked for consistency (so that someone's grid 5 isn't a 1 for someone and a 0 for someone else). After data is collected, we will work out any issues with data entry and make sure all data has been entered completely and accurately. Students will then be tasked to summarize the data (in this case we had multiple areas [hexagons] within the burn scar and students estimated the % that was green [0, 0.25, 0.5, 0.75, or 1]; all hexagons were then totaled; and lastly, each total was averaged for that same year). Students will then turn their data into a model to "test" their hypothesis (in this case, it should show how much burn is remaining [or how much vegetation is present] each year after the fire). By the end of the class, students should have their model (graph) built.

Sample	2016	2017	2018	2019	2020	2021
1	16000	10812.5	14062.5	15750	15812.5	16062.5
2	16500	11937.5	13937.5	15500.75	15687.5	15625
3	16500	10880	14187.5	16000	15937.5	16125
4	16375	10625	13625	15750	16000	16125
Average	16343.75	11063.75	13953.125	15750.1875	15859.375	15984.375

Sample of compiled data: Values represent unburned areas in acres

If time permits: Students should organize the project into a single document, including: Driving question, hypothesis, methods, data summary, graph/model, and a statement about whether their hypothesis was supported or rejected.

Lesson 5 : Extrapolating from the findings

If not finished the day before, finish graphing/modeling and organizing their project (Driving question, hypothesis, methods, data summary, graph/model, and a statement about whether their hypothesis was supported or rejected). Students will share their models and see how their peers chose to represent the data. If not covered the previous day, we will talk about what else can be done with the data. In order to make a prediction about being healed (if not fully healed in the given data set), they will need to use extrapolation. And if healed during the data set, they may need to use interpolation.

Student generated model showing how much burn is remaining after five years of data and indicating that the burn area should be gone in seven-eight years.

Finally, students will be challenged to go beyond and discuss how they could verify these answers. After the obvious answer of continuing taking data/monitoring and increasing the accuracy of measurements, fish for more. If not intuited by a student, explain how we could use an older fire to compare to our model's predicted data? This could answer whether or not our model can predict future patterns and work outside of the specific disaster.

Simplifications and Extensions

- A key simplification is that [the Story Map] can be used to teach the entirety of this lesson; instead of students formally measuring fire extent, they can use the interactive features of the Story Map. Doing so, students can develop an informal (rather than a mathematical) understanding of fire regimes measured using remote sensing (and NVDI electromagnetic radiation bands) in the context of the Chimneys 2 fire.

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- These lessons can be taught independently; you may wish only to involve students in measuring using satellite imagery (lesson 3), for example.

- This can be extended by analyzing the data for lessons 4 and 5 in other software, such as the Common Online Data Analysis Platform (CODAP).