Let’s talk about some of the methods for measuring fire history.

These are characterized using natural and human archives.
We use many different terms to describe recurring fires – our fire history methods are more useful for characterizing fire frequency and size than for describing other aspects of fire regimes.
When trees are injured by but survive fires, that event is recorded in the annual growth rings. These fire scars are especially well preserved in ponderosa pine because of the way living trees get resinous when injured. Once scarred, the trees are more likely to be scarred again. The triangular shape, the “cat face”, typically extends from the ground up with relatively smooth margins that help to differentiate it from injury caused by other things, such as mechanical damage from other trees falling, or animals.
We can find fire-scarred snags, stumps and logs. Heyerdahl et al. (2008) targeted such trees with many old fire scars in their study of fire and climate across the northern Rocky Mountains. They specifically sought those locations with the most scars and the most well-preserved scars to get the most scars over time.

Their results do NOT meant to represent fire frequency of the surrounding landscapes, but they can tell us much about past fire and climate.

We most often sampled stumps and logs, as shown here, because we wanted the greatest temporal depth possible.
Cross-dating the varying patterns of wide and narrow rings is critical to assigning dates to each ring. This accounts for missing and false rings, and allows us to date trees that died long ago. This temporal accuracy is required if we are to correlate with climate (weather stations or tree rings).
Dendrochronology is the science of dating tree rings. Here, you can see how tree rings found in the beams of old Anasazi ruins were dated by matching the pattern in dead standing and live standing trees. Some particular sequences of very narrow and wide rings can be markers of particular years. Long chronologies can be built from multiple trees; such chronologies are now available for many locations. We can use them to date fire scars in trees.
You are probably most familiar with this sort of data

Not all trees record fire. The fires must be sufficiently severe to partially kill cambium, and the tree must be susceptible (if the bark is too thick or the tree is killed by the fire) and able to survive (the tree doesn’t die).

Season of the fire is interpreted from the position of the damaged cells – are they in the earlywood (the light part of an annual ring) or in the late wood (the dark part of the annual ring).

Cross-dating is important if you want to know what exact year a fire scar formed. This is important both for fire frequency (are fire scars in 1934 on one tree and in 1933 on another really the same fire or different? Why does this make a difference to the calculated fire frequency?)
Part of a large study (Heyerdahl et al. 2008) on the fire-climate relationships in the US northern Rockies based on fire-scar data collected from 21 sites in Idaho and western Montana, the data in this slide are from Heyerdahl et al. (2008) and fire-scarred partial cross section are from Hunter Ridge on the Kootenai National Forest in Montana.

On the fire-scarred section (picture), fire scar dates are shown in white along with the date of the outside ring and the inner-most ring. Data for the 25 fire-scarred trees are shown, but only the intervals between years with fire scars on at least two trees over the 77-acre sampling area during the period from 1650 to 1900 are shown. The pictured fire-scarred partial cross section is the fifth row from the top. Notice that you can pick out some years, such as 1751, when most trees were scarred, and others, such as 1951 when only one tree was scarred. The median fire interval was about 12 (bottom left) and most of the fire scars were in the ring boundary suggesting that they occurred when trees were dormant, in the late summer or fall.

Box plot encloses the 25th to 75th percentiles and the whiskers enclose the 10th to 90th percentiles of the distribution of intervals. The vertical line across the box indicates the median fire interval, and all values falling outside the 10th to 90th percentiles are shown as circles. In the histogram (bottom), the same intervals are plotted in 1-year bins.
Fire history studies of fire-scars in tree-rings have yielded very valuable information about where and when past fires occurred. Dendroclimatology and dendroecology depend on these and other data derived from tree rings.

<table>
<thead>
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<th>Dated fire scars on trees</th>
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<tr>
<td><strong>Strengths</strong></td>
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<tr>
<td>• Extraordinary time depth (often 300-500 yr); these long records encompass extreme events</td>
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<tr>
<td>• High temporal resolution: fires crossdated to year, and often season using dendrochronology (<a href="http://web.utk.edu/~grissino/">http://web.utk.edu/~grissino/</a>)</td>
</tr>
<tr>
<td>• Multiple researchers have analyzed synchrony across dates relative to other independent temporal and spatial data to infer fire-climate, suppression-release, insect defoliation</td>
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</table>
Not all trees scar. Trees that are small and have thin bark often don’t survive fires, and trees of some species seldom survive fires.

These data are very informative but can be limited when we want to infer fire frequency across all landscapes. Baker and Ehle (2000) criticized fire history studies and Van Horne and Fulé (2006) responded. Baker (2006) argues that the uncertainty in fire history from ponderosa pine forests is not reliable enough for management and restoration efforts in Grand Canyon National Park. Fulé et al. (2006) defended the data and the related practices.
Heyerdahl et al. (2001) analyzed fire scars and tree ages across multiple watersheds to infer spatial controls of fire regimes.

- **Top-down vs. bottom-up**

Heyerdahl et al. (2001) used fire scars and tree ages collected at regular intervals across watersheds to examine the degree to which fire frequency varied with topography. These data can be used to infer landscape patterns of fire in similar landscapes. They hypothesized and found that fire frequency responded to both “top-down” controls (e.g. broad climatic patterns over space and time) but also “bottom-up” controls (local topography, aspect and landscape context).

Fire and climate records based on analyzing synchrony across sites – goal is to get temporal depth
Fire-scarred trees are just one of multiple natural archives of fire history data. There are lots of different natural records or “proxies” for fire history. We can interpret fire history from each of these. Each has major strengths and limitations.

You might be interested in checking out the International MultiProxy Database to see what data exists in what form for the areas you’re interested in. This database includes fire-scar data as well as data from lakes and bogs.

You can date the charcoal and sediments in fire-related debris flows. I have an example of such a study from Idaho at the end of the presentation.
Here is an example of dating historical fires and vegetation over millenia based upon cores of lake sediments. Higuera et al. (2009) cored lakes like the one shown here to obtain sediment cores including both pollen and charcoal (shown below the lake with a meter stick for scale, the dark lines are charcoal concentrations) from which samples are taken for examination under a microscope (lower right shows slide for counting density of microscopic charcoal from the lake sediments). In the upper graph, the density of charcoal in the core is graphed and in the lower graph these are used to infer fire return interval for more than 7000 years before present. Higuera et al. (2009) related the plant pollen identified and suggested that once boreal forests established, fires were more frequent and produced more charcoal than when the vegetation surrounding the lakes was dominated by forest-tundra. These data clearly have a strength of providing long-term perspectives for selected sites. When data from extensive networks of such sites are analyzed, researchers can infer the long-term dynamics of fire, vegetation and climate. Such data become very useful for forecasting the potential effects of different climate conditions for the future on the fire-vegetation-climate system.

This is an example of a natural archive. People core bogs and lakes and other locations where sediment and charcoal has accumulated through time.
Our tree ring record is short compared to the long-term records we can obtain from sediments.
Jen Pierce, now a faculty member at Boise State University, examined the alluvial fans created in small streams draining into the South Fork of the Payette River. Here is quite a different example. The data were collected in Idaho from the area around Garden Valley and Lohman, along the South Fork of the Payette River.

Pierce et al. (2004) Nature

She used Carbon 14 dating to date layers of sediment deposited in floods. These often contained charcoal.
Here’s a picture of severe post-fire erosion that could have resulted in debris flow with abundant coarse charcoal, coarse sediments.
Pierce et al. (2004) found lots more small fire events dating to 1200-1900 than to earlier centuries. They attributed this to the Little Ice Age. They conclude that the historical fire frequency we often use from fire-scarred trees (in this region it often dates from 1650-1900) comes from within the Little Ice Age and may not be a good reference to use for the times since 1900 when Little Ice Age conditions haven’t prevailed.

Grant Meyer has similar results from Yellowstone National Park (shown on graph in light gray)
Another natural archive that many people study to infer fire history are time-since-fire maps. This approach works most effectively where we want an area frequency. Best in even-aged cohorts established soon after stand-replacing fire. (Why? What if the stand age isn’t the age of the fire?)

Important assumptions are listed.

It can be challenging to infer past fire dates when trees don’t establish in abundance soon after fires, or when fires are frequent.
We have lots of records people have made of fires – in the next few slides we’ll explore some of them.
These are “flat” files. Many include cause (human or lightning), size class, cost of suppression, location (in general) for fires.
Fire atlases have been relatively little used until recently. They are not available in many locations outside of large wilderness areas and national parks.

As part of our fire-climate research in the northern Rockies (Morgan et al. 2008), we assembled fire atlas data from 10 national forests and 2 national parks. While most of these include maps of large fires occurring since the 1950s, some include fires since the 1930s or 1900s (these latter are interpreted by local experts based on vegetation patterns and aerial photographs). The vary tremendously in quality, and are more reliable for identifying years of extensive fires than they are for saying exactly where those fires burned or exactly how large the fires are. Errors likely vary through time but errors have not been consistently quantified.

Fire atlases have been relatively little used until recently. They are not available in many locations outside of large wilderness areas and national parks.

<table>
<thead>
<tr>
<th>Fire atlases</th>
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<tbody>
<tr>
<td>• Compilations of mapped fire perimeters</td>
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<td>• Paper or digital</td>
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<tr>
<td>• Include date and perimeter of fires, but typically do not include information on fire severity, rate of spread, or perimeters of small fires</td>
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<tr>
<td>• Usually only larger fires (&gt;50 or 100 ac) are included, but they likely to represent a large proportion of area burned</td>
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<tr>
<td>• Errors in spatial location and date of fire occurrence are difficult to assess, likely vary through time and can be severely limiting</td>
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From Morgan et al. (2001) Int. J. Wildland Fire
Here’s an example of the fire atlas for the Gila/Aldo Leopold Wilderness Area. This was compiled by local fire management personnel who knew the area well and were committed to maintaining these maps. They were paper maps that were digitized. This displays the fires by decade.

The Gila Wilderness has one of the most active wildland fire use programs in the US.

Note how the fires are more likely to burn in some areas than others, and that some locations burned multiple times within the last century.
If you’re going to rely on these data to estimate extent or area frequency of past fires, you need to fully aware of the limitations of the data.

Most of the burned polygons included in atlases are fire perimeters, so they often include many unburned islands without identifying those islands as unburned.

### Fire atlases limitations

- Perimeters are often only approximate
- Spatial pattern of burned and unburned areas within the mapped perimeters is seldom known
- Can do spatial analyses of fire location, area burned through time, and frequency
- Typically only larger fires are mapped
- Accuracy likely varies through time
- Accuracy has not been consistently assessed
- Only available for some areas

From Morgan et al. (2001) Int. J. Wildland Fire
Notice that there are many years without any polygon fire records:

- probably long gaps are lack of recording
- but short gaps are likely lack of fire
- but don’t know for certain

Many small fires <40 ha not included, but large fires are probably all here

Note that the fire atlas for the Boise National Forest extends further back in time than noted here.
Rollins et al. (2000) created continuous “wall-to-wall” fire frequency surfaces from the fire atlases, thus taking advantage of the fire location and fire size information.

They did this as part of a research project. They sought to understand the degree to which fire frequency was correlated with vegetation, topography and climate. They compared these two study area not because they are large wilderness areas with long history of fire reflected in fire atlas records. The two areas are not replicates. Instead, Rollins et al. (2000) considered these comparative case studies. They qualitatively compared regression models built for each area and found that fire frequency varied in logical ways with elevation and vegetation in the two study areas.
This is a graph of area burned through time for the two areas:

SBWA follows expected pattern of fire occurrence. Relatively little area burned during the era of modern fire suppression (when the goal was to suppress all fires). Area burned increased in recent decades under Wildland Fire Use management (the policy used to be called Prescribed Natural Fire, now simply prescribed fire), but the area burned was still much less than historically occurred (reflecting that the most common fire management decision here, as in many wilderness areas, is to suppress fires). The lack of fire in the 1930s and 1940s could have been poor detection.

GALWC does not show this pattern, however. This is probably due to the VERY heavy grazing typical of even remote areas in the southwestern US in late 1800s and early 1900s – fires burned less area where cattle and sheep had consumed find fuels. In the Gila Wilderness, this was much reduced in the 1930s. Grass is an important fuel in the dry forest, woodland and grassland ecosystems that dominate the GALWC. Like the rest of the southwestern US, this area experienced drought in the 1950s. This was the deepest drought of the previous 2000 yrs.

1950s in the SBWA were not very dry, so suppression was effective

Conclusion: both fire policy and drought are important influence on area burned as recorded in the fire atlases
Fire perimeters and burn severity are now commonly inferred (at least for large fires) from satellite imagery. These data can be compiled into atlases. Here is burn severity data compiled for the Gila-Aldo Leopold Wilderness (black outline) and surrounding area in New Mexico. These data have been used in multiple research efforts, including Holden et al. (2010).

In this case, four classes of burn severity were inferred from RdNBR the Relative differenced Normalized Burn Ratio derived from Landsat imagery as explained in the next few slides.
Burn severity, the degree of ecological change as a result of a fire, can be inferred from satellite imagery. Often Landsat imagery is used. In a burned forest canopy, incoming radiation from the sun will interact differently with the earth’s surface depending on the characteristics of the vegetation and the ground. Looking at this picture, your eyes will tell you than more radiation in the green portion of the electromagnetic spectrum is being reflected in the unburned area to the right, while more brown is being reflected by the scorched trees at the center of the picture. Light is also being reflected and absorbed in areas of the electromagnetic spectrum that can’t be seen with the human eye.

(Slide courtesy of Zack Holden)
For the last several years, the Monitoring Trends in Burn Severity Program (MTBS) has been mapping fires in the western US using Landsat data. These data are now publicly available via the website (www.mtbs.gov). Briefly, a spectral index called the NBR or Normalized Burn Ratio index has been used to infer the severity for large fires (greater than 1000 acres in the western US and greater than 500 acres in eastern US) that have burned from 1984 to present. The dNBR uses a differenced ratio of near infrared to shortwave infrared radiation in bands 4 and 7 obtained by subtracting a post-fire image from a pre-fire image to infer the amount of fire-induced change relative to pre-fire conditions. RdNBR is calculated relative to the pre-fire image.

This gives us a lot of information beyond what has been available from over traditional fire records like point data, including more precise estimates of area burned and spatially explicit data that we can use to identify the underlying topographic and vegetation characteristics of the burned area. MTBS provides 2 basic products, a continuous dNBR, where each pixel has a value from -1000 to 1000, and a classified product, in which the fire is classified into 5 classes, very low, low, moderate and high severity, and a green-up class, which is essentially a very low severity class.
We’ve used the Fuzzy C-means clustering algorithm to reprocess the MTBS dataset. We’ve done this for more than 2000 fires, in what we’re calling the Pacific Northwest region, an area that include Oregon, Washington, Idaho, western Montana and Northern California.
There are some potential problems associated with using MTBS data in quantitative analyses, especially in interannual comparisons, and comparisons of fires across time and different vegetation types. First, the magnitude of the dNBR distribution can vary significantly depending on the timing of the pre- and post-fire image being used and the vegetation type of the fire. Without some relativity, inferences we might draw about differences in dNBR values between years are suspect. Classified dNBR images might be more appropriate for these types of analysis. However, the thresholds set that define low, moderate and high severity classes were assigned somewhat subjectively and visually by a number of different analysts. This would make publication of results using these methods difficult to defend.
Holden et al. (2010) used random forests, a statistical tool, to relate burn severity from fires of recent decades to topography and vegetation. Based upon the resulting predictive models the produced this map of the probability that fires would burn severely if they occurred. This map is of great interest to managers tasked with managing fires. Dillon et al. (2011) are in the process of expanding this approach to produce a west-wide (contiguous US) map of probability of severe fires. Their maps will include climate as a variable as part of a fire severity mapping system through research funded by the Joint Fire Science Program.
Point frequencies are calculated from fire-scarred trees and so more often apply to fires that were predominantly nonlethal or mixed (many trees survived and some were scarred).

Area frequency is more often calculated from maps of area burned through time or from the size and age of even-aged stands that we assume established after stand-replacing fires.

Explicitly spatial, but represents spatial patterns as aggregates of point samples.
Four fires, each of which burned part of the landscape

Point frequency
--Notice how mean interval at points 1 & 4 are both 50 yr but they have different variability around that mean
--Mean interval at each of the four trees is shown in k.
--Fire frequency at points (j). Mean of the interval between fires is 50 yr. This is annual probability of burning of 1/50 = 0.02

Area frequency
--Number of fires/100 yr is 4. On average, fire visited this landscape 4 times in 100 yr
--Fire rotation for the individual squares is the same as the fire frequency for that quarter when fire visits the whole quarter
--Fire rotation for the landscape as a whole is different though:
  --Mean fire interval for this landscape would be 50 yr
  --Fire rotation = time period / (proportion burned) = 100/(.25+.50+.75+.50) = 100/2 = 50
This is our current challenge – how can we characterize fire regimes across landscapes and through time?

We only know fire history from a few places within a landscape and for a few landscapes, yet we want the information for whole landscapes and all landscapes.

<table>
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<th>Challenges</th>
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<td>Fire is a stochastic, spatially complex disturbance process</td>
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<td>Data are from points or from small areas and often from relatively short time series, or they are from landscapes over short time</td>
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<td>Extrapolation is difficult</td>
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<td>Interpretations are often biased by truncated time series (Finney 1995), which causes us to overestimate fire frequency.</td>
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<tr>
<td>We don’t have fire history studies everywhere we need them</td>
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<tr>
<td>The past may not be useful to forecast the future</td>
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The greatest challenge is that we know fire regimes have changed through time as climate changes, as fires have been influenced by land use (Indians used fires, do we need to figure out how to exclude those fires from our historical fire frequency?), and by history (past fires influence the fuels available for the next fire).
## Key points

- We have many different sources of fire history data, all with different strengths and weaknesses
- Less fire history available for rangelands than forest
Food For Thought

- Why do we understand more about the temporal patterns of fires than we do about the spatial patterns of fires?
- Little empirical data addresses both long time periods and broad spatial scales, but we can use multiple approaches together
- What will we learn?

Thanks!