

Sagebrush Ecosystems in a Changing Climate: Key Opportunities for Adaptive Management

Emily Fort: Hi. Thanks to everyone for joining. I'm happy to introduce Matt Germino. He's a Supervisory Research Ecologist with the U.S. Geological Survey Forest & Rangeland Ecosystem Science Center in Boise, Idaho.

Before then, he was a Professor in the Biology Department at Idaho State University. His specialization is plant ecology and ecophysiology with emphasis in plant-soil relationships, ecohydrology, fire, invasives, and restoration.

He also serves the Great Basin Landscape Conservation Cooperative on special assignment as a scientist. With that, I'll turn it over to Matt. Thanks.

Matthew Germino: Thank you very much for the opportunity to present and for everybody for attending.

Sagebrush steppe is an excellent context to think about climate adaptation because these ecosystems are strongly impacted, both by climate and also the human hand. There's opportunities to stem, prevent, or mitigate the impacts.

Sagebrush steppe, as this map shows, is one of the most widespread vegetation types in the Western U.S. Low sagebrushes are also common.

Here, I've mapped out, using USDA data, big sagebrush, *Artemisia tridentata*, *Artemisia arbuscula*, and other low sagebrushes also coincide with this range and overlap and expand it into different areas.

For the most part though, I'll be focusing on big sagebrush as it's one of the focal species for conservation at the moment.

These ecosystems are declining due to the expansion of agriculture and increases in fire and exotic plants. I'll describe those impacts because they are so important for understanding our vulnerability to climate in these ecosystems.

Conserving or restoring sagebrush ecosystems is a high priority now for states NGOs, and especially federal agencies, ranging from the field office to national program levels. The uses of these ecosystems include grazing of livestock, management of fire, and exotic plants.

Restoration is occurring over extensive and intensive areas. Restoration is occurring intensively over extensive areas. There's also now considerable development occurring for energy. There's other human uses, such as recreation.

The point is that all of these uses, which impact nearly every corner of the domain of big sagebrush, have important links to climate. Thus, they offer key avenues for climate adaptation.

I have geared this talk for a national audience and presumed that relatively few of you would have a strong background in sagebrush. I'm going to describe some of the basics of: what is a sagebrush ecosystem and what's the climate like in these environments?

Then I'll describe some current, recent insights on climate impacts that are gleaned from modeling or from field experiments. Then I'll dive into some surveys of past seeding success in these environments, which offer a key window into a warmer world.

A key message of this talk is that there's a lot of diversity in these ecosystems that doesn't readily meet the eye.

That diversity, both structural and genetic, is very important for thinking about climate adaptation and, more importantly, managing for resilient landscapes that can endure climate variability.

Let's get started here. Many of you have heard this term, "sea of sagebrush." It comes from people that are driving down the highways through the great Western U.S. and hours and hours of observing these flat landscapes that are dominated by sagebrush.

It does look like a sea, in that it seems homogeneous at one scale.

For the purposes of this talk and for thinking about climate variability, it's almost more important to look more closely to see the heterogeneity within these systems. It's at that scale that the vulnerabilities become most obvious, at least, in my mind.

Here, for example, you can see patches of bare soil in the lower left-hand corner, over here. Then over on the right, you can see bunchgrasses.

Bare soil is oftentimes covered with cryptobiotic soil crusts that are comprised of fungi and algae. They're photosynthetic. They take up carbon, and they strongly affect the fertility of soils.

There's actually quite a bit of diversity, especially when you consider the forb or wildflower communities that occur in these habitats. When I see a photo like this, I can see a variety of types of sagebrush intermingled into this scene.

The sagebrush here is semi-evergreen. It's got an evergreen component, but it's also drought deciduous and drops a lot of its leaves during summer drought.

It has both shallow and deep roots -- shallow roots that are connected to recent moisture/rainfall, and deep roots which are obviously tapping moisture that arrived in rains from previous winters.

There's a lot of diversity within an individual sagebrush, but also within the subspecies or populations within a subspecies of big sagebrush.

Bunchgrasses -- and I'll talk a little bit about exotic annual grasses -- tend to use soil resources in a very different way than do sagebrushes.

These species tend to green up in the spring. Then they are senesced come mid-summer. They spend most of their year in a senesced state. They see a very different climate than does sagebrush.

The important thing here is that in its native condition, big sagebrush communities are, for the most part, dominated by perennial species that are relatively long-lived.

In fact, having lived in sagebrush steppe for over two decades now -- that includes many drought years and wet years, dry years and wet years -- the one thing I've noticed is that, in its intact condition, these perennial plant communities can endure lots of climate variability.

Paleoecologists who have studied pollen in soil cores have told us that sagebrush pollen has been dominant on many of the Great Basin landscapes over tens of thousands of years of wild climate variability.

Ranging from little ice ages to hypsithermals, it's always been there.

More recently, we're seeing that sagebrush is becoming locally extirpated, due to the co-occurrence of climate stress with fire and invasives.

These plant communities have also had strong interactions with animal communities. There's many specialized wildlife species, such as greater sage-grouse and pygmy rabbits that are very tuned to using sagebrush for forage and shelter.

In fact, the charismatic aroma of sagebrush relates to either antiherbivory compounds, as well as palatability compounds. There's a lot of variability in those compounds within and among big sagebrush subspecies. I'll talk more about that in a little bit.

What's the climate of big sagebrush? This is one of our principal focuses of the talk. Let's see if we can understand what climate is all about in these systems.

Usually when people talk about climate of an ecosystem, they tend to focus on a mean annual temperature or mean annual precipitation. In my opinion, those terms are not very useful for helping us understand climate of big sagebrush.

Here's some data for the Boise airport, which is located in the Southern or low-elevation range for the big sagebrush biome. Mean annual temperature is around 10 degrees, and it has a little bit less than 300 millimeters per year of precipitation.

Again, those terms aren't so useful. It's more useful to think about how growing season precipitation, or annual precipitation, overlaps with temperature.

Scaled on the left here, you see increments of temperature going with the red line. On the right, for every 10-degree increase in temperature, there's a 20-degree increase in precipitation.

When you scale temperature and moisture this way, you can get an idea of which months of the year precipitation will be stored as soil moisture, and which months of the year there will be a net deficit, or net loss, of precipitation.

This is critical for several reasons. First of all, most plant growth occurs in the springtime when temperatures are still relatively low. At night, most plants can have freezing or near freezing temperatures, even during their principal growing phase.

For species, like big sagebrush that are evergreen and also have deep roots, much of their growth relies on moisture received by these ecosystems during winter, but stored for use in deep soils for the warm summer period.

Now I'll talk a little bit about exotic annual grasses. They do almost their entire lifecycle during these shoulder seasons, thereby not using any stored moisture. Instead, trying to make a go of it when temperatures are relatively cool.

These are pretty important factors when you try to think about climate vulnerability. Speaking of variability, it's almost more important to think about the year-to-year fluctuations in climate. In other words, weather, than it is long-term climate in these systems.

Now I'll explain a little bit more about this, but for now I just want to show you the data for 2013, which was a remarkable year for the entire Northern Great Basin.

In this year, many landscapes barely greened up, if at all. They remained brown almost the entire year, even though the annual precipitation wasn't all that low compared to the 30-year average.

Why was it so brown in these landscapes? Well, we had a little bit of a drought over a few months, during that period when moisture is so critical in spring. This led to an inhibition of plant emergence and germination.

Even though we had moisture later in the season, the developmental phase wasn't coinciding with that moisture. Furthermore, it was too hot and dry when the moisture came.

These year-to-year variabilities are super important. To emphasize this further, I'm drawing a graph here from Stuart Hardegree, a colleague of mine. He studies weather variability.

He took the long-term climate records and extracted out just the variability for March and May in this graph.

You can see the variability. It's just astounding. If you were to plot out the variability for months of September or July or January, there's much less variability.

In arid environments, you both have less precipitation but more importantly the precipitation is very unpredictable or increasingly unpredictable with aridity from year-to-year.

That's a key factor for both restoration as well as the way the basic plant ecosystem functions.

Variability is also a problem for land management programs. People, in general, have a hard time dealing with variability.

We like things to be predictable, but a key part of our adaptive management is coming up with ways to cope with variability. I'll talk more about that later.

For now, though, what do climate modelers tell us about climate impacts in big sagebrush ecosystems? John Bradford, a colleague of ours at USGS, has a nice program running on doing species distribution models to assess the entire range of big sagebrush.

You can see here under the A2 doubling of CO₂ scenario by year 2100. They're predicting using standard, traditional species distribution models, which simply correlate sagebrush with existing climate. Then try to map it forward.

You can see sagebrush, as a species, is predicted to be lost from its southern range, and it's predicted to increase in the interior northern range.

Now if we take a slightly different approach, and instead of just using standard climate metrics, you try to model how much water will actually be available to this desert species.

To do this, you need to take into account soil maps, soil depth, and it's a more analytical approach. The model predictions are roughly in agreement with standard species distribution model.

However, notice how much more patchy the outcome is. This patchiness is important for several reasons. Number one, management decisions are usually occurring at these smaller pixel levels.

This prediction that's mapped here is probably a lot more relevant to management decisions, but more importantly from my perspective this graph on the right, which takes into account the mechanisms by what sagebrush grows, is a lot more akin to what we see from field simulations of warming effects or of climate change effects.

For example, here's some data that I published recently from a 25-year-long irrigation study that I did with a colleague of mine.

We added water in either the winter, shown in black symbols, or during the summer, shown in gray symbols, to very large plots replicated in the Snake River plain. We did this on deep soils that were about six feet deep or shallow soils that were about a meter deep.

I want to note that this isn't very shallow, but two meters is obviously quite a bit deeper than one meter. Two meter soils can store a lot of water.

Remember, big sagebrush, is deeper in. It's no surprise that doubling winter precipitation, which I want to point out does not match any forecasted change in climate.

The climate forecasters tell us that we can expect to see about a degree or two increase in temperatures within about a 20 to 50-year time horizon here in our region.

That precipitation should change. We don't know if precipitation will increase or decrease, but what everybody seems to agree is that we're most likely to see more precipitation found in winter than in summer.

Anyways, winter precipitation clearly tends to favor big sagebrush more than summer precipitation, at least, when it's added.

Now in the shallow soils, you see a very different effect. Shifting that precipitation, that extra precipitation, to winter actually inhibited the sagebrush.

If you take these results, which are somewhat surprising, and you map them out onto a landscape that has variable soil depths, it's easy to see that some locations or sites could be winners and some

could be losers of these shifts in the amount of water and seasonal timing of water coming to the site.

Similarly, with warming, we applied the very same passive overhead warming treatments across the climate gradient from the cold high meadows in the basins of Grand Teton National Park all the way down to the much warmer and drier meadows or sagebrush steppe in the lower Snake River plain near Boise.

These chambers increased minimum nighttime temperatures by a couple of degrees. What we found is that in Boise where it's already warm, warming doesn't have much of any effect on the annual growth of established big sagebrush plants.

However, in the very high cold meadows of the Tetons, we saw, in some years, appreciable increases in growth with warming.

Again, this tells us that even though we think of big sagebrush in terms of homogenized seas of plant communities that should respond to the climate in very predictable ways, that couldn't be further from the truth.

There's actually quite a bit of variability in these ecosystems. They differ in climate, and the plants differ, in terms of how they are adaptive to the local climate. Key points to keep in mind.

Now I'm going to shift gears a little bit and address some of the main stressors in sagebrush ecosystems that really need to be considered when you think about climate impacts.

The first and most dominant is fire. We're seeing larger and more frequent fires than these ecosystems are adapted to. That's been in the news. This is a major, major point. Fire, of course, is very closely related to climate.

Warm dry conditions following luxuriant growth periods are the recipe that provides us with wildland fire.

In many ecosystems, like forests, the fire itself is the management concern, but in big sagebrush, while fire itself is important, what happens in the years after fire is almost more important.

During the recolonization, or the reassembly of the plant community, these ecosystems can take wildly different trajectories, in terms of whether they restore themselves to a native perennial condition that's stable over the long-term, or if they are degraded into an exotic plant community, very different.

Another key thing is that, following summer wildfire, these landscapes, once burned, may have bare soil exposed to the air with no protective cover for months, sometimes 10 months, after a fire.

During that period, depending on the climate and weather system, erosion due to water or due to wind, can be a very pervasive and important factor affecting these ecosystems.

Much of the sagebrush steppe is dominated by relatively flat drain. This view in front of you is actually a relatively hilly site.

In much of these flat areas, we've seen a perfect storm of precipitation events followed by very dry, windy conditions, in which wind erosion can sweep off the top few inches of soil, removing precious nutrients as well as the seed bank from sites.

That, obviously, has a huge impact on the ability of these areas to recover. These impacts can affect areas that are sometimes hundreds of thousands of acres in size.

Related to fire are exotic plants invading big sagebrush steppe from the low elevations, the most notorious of which is *bromus tectorum*, known as cheatgrass. At the higher elevations, native invaders, pinyon pine and junipers, are encroaching on sagebrush steppe.

Both these invaders are reducing the effective habitat area for big sagebrush. That comes at the consequence of the wildlife that are dependent on big sagebrush, such as sage-grouse, pygmy rabbits, and other species that are not obligated to spend a lot of time in these ecosystems, such as mule deer.

The most important impact of exotic annuals is that they are good fuel for wildfires. Some of you may have heard of the cheatgrass fire cycle in which cheatgrass may invade open inner spaces and impact plant community.

Sometimes that follows after inappropriate livestock use.

Cheatgrass forms an excellent fuel bed, providing easily ignited continuous fuels across the landscape. Once cheatgrass is in the ecosystem, fires are more likely.

When they happen, the fires are much more likely to become large and uncontrolled and spread over large areas.

Following the fire, cheatgrass has an important establishment advantage over native perennials. With each successive fire, we see that sites become more and more dominated by cheatgrass, as you can see in this photo in front of my truck, here from Southern Idaho.

By the way, these two photos, left and right, were on opposite sides of the highway.

In terms of climate weather, one of the most interesting things about cheatgrass is that, not only does it increase fire, it increases the coupling of fire and climate. Cheatgrass is quite sensitive and responsive to annual weather.

First of all, it's an annual. Secondly, it is tuned into late winter precipitation and the temperature conditions prevailing in the spring. Its growth and abundance can vary widely from year to year.

Following a good growth year, the litter produced by cheatgrass stays on site. That litter then is carried over into subsequent years when we might return back to a warm dry cycle in which fires are more likely to occur.

This strong coupling of climate and fire has been proven in many regressions that have been conducted over the years. It's a very interesting phenomenon.

I'm going to go back one slide. One other impact of cheatgrass is these impacts are very much the hallmarks of desertification. The net outcomes are a loss in biodiversity, both of plants but also of animals.

Also, related to desertification, these sites dominated by cheatgrass do not utilize all of the soil moisture that's available from a year's precipitation. Thus, the site is less productive for the amount of moisture received.

There's a lot of experimental evidence that supports the climate sensitivity of cheatgrass. For example, winter rainout shelters that I've established here in this photo in Pocatello, Idaho.

If we put these up just during the wintertime, we can nearly block out cheatgrass from sites. Thus, it's proved that cheatgrass is sensitive to winter precipitation. Others have irrigated in the winter and increased cheatgrass abundance.

Similarly, warming studies, like the passive chambers that I showed before, or electric heaters, all of them tend to have increased cheatgrass or other exotic annuals, especially when the warming is done during winter or wet spring periods.

Shifting gears a little bit, I want to point out that the climate sensitivity of cheatgrass is something that's currently well recognized by the managers.

In fact, the management paradigm known for its resistance resilience is now becoming well embedded into land management in the Great Basin.

The story starts by first recognizing that there's a gradient of climate vulnerability -- I'm trying to pull up these, there we go -- of vulnerability to annual grasses.

These are different ecosystem types found within the big sagebrush biome. Mountain big sagebrush, Wyoming big sagebrush, and desert scrub at the low elevations.

As you go up in elevation, these sites, obviously, are moister and they're also cooler.

What's most important though is that when we look at where cheatgrass tends to become most abundant, it tends to be not at the lowest elevation but here in Wyoming big sagebrush. A lot less so at the higher elevations.

We think this is due to several factors. One is low temperatures here inhibit cheatgrass directly.

Secondly, these high elevation sites tend to be relatively better endowed with re-sprouting perennial bunch grasses that can quickly rebound after disturbances, such as fire, and provide competitive pressure against exotic annuals that might be invading sites.

These concepts have been ingrained into land management using maps like this. These are different sage-grouse conservation zones. The different colors represent different soil moisture and temperatures. Sorry, this is a low quality image.

Managers, they're using these maps to help prioritize where and when treatments or conservation investments might be applied to have save these ecosystems.

With this concept, we know that the very highest elevation, these cryac or frigid types of sites, they don't need much of an investment because they're naturally resistant to exotic annuals. They can rebound after fire.

On the flip side, the lowest elevations, mesic-aridic, soil climate regimes, are highly vulnerable.

No matter how much investment you put into these ecosystems, you might not see a good return in terms of taking out exotic annuals and increasing desirable perennials that the wildlife need.

Instead, it's these middle climate conditions where the ecosystem needs the assistance, and you're more likely to see a positive outcome with your investment.

I've worked on several fires recently where the managers used this resistance resilience paradigm to actually map out and apply their investments. This is an exciting way that climate is being used in land management.

I mentioned that the human hand is pretty strong in sagebrush steppe. Some colleagues of mine here in the USGS, led by David Pilliod, have a very intensive effort underway to catalogue and record the details of where human impacts, both extractive but more importantly restorative in nature have been applied.

You can see this is six zeros behind this 14. These are the number of acres treated up to about several years ago. Restoration seedings have been applied over many millions of acres across the Great Basin.

Similarly, herbicides and other types of vegetation or soil treatments have been very common. Let's talk a little bit more about these to get an idea of how it is that climate can be used, can be thought of as ways to improve the adaptation of these ecosystems.

I'm going to pick a little bit on sagebrush seeding since sagebrush, of course, is the foundational keystone species of these environments. I forgot to point out that big sagebrush is not very well adapted to fire.

Historically, small patch fires probably prevailed every 30 to hundreds of years, depending on what kind of climate zone you're in in sagebrush steppe. We don't think that there were million acres fire complexes a thousand or so years ago in these environments.

Following the small patch fires, sagebrush can probably reestablish. But following a big fire, big sagebrush is in big trouble. The reason is that big sagebrush cannot re-sprout after fire. More importantly, big sagebrush does not form a good seed bank.

It has tiny little seeds that are only viable for a year or two. They must reside and germinate on the surface. We've seen good evidence that there's seed limitation after fire.

For many decades now, the land managers of this environment have been importing seeds. When I say import, it's important to keep in mind that, when you have a large 500,000 to a million acre burn complex, there really aren't any local seeds left.

Sagebrush is not a plant that's grown on farms to produce farm-yielded seed. The seeds are obtained from wildland seed collections and need very large areas to collect the amount of seed that is needed to cover hundreds of thousands of acres.

Picture an operation in which a train of large trucks are transporting millions of pounds of seeds to a fleet of helicopters which then fly the seeds over periods of weeks to a month over a burn area. It's fairly extensive.

The bottom line here is that seed transport has been and probably will always be a significant part of restoring big sagebrush in an effort to save these ecosystems. To me, it seems almost unavoidable.

Let's take a look at how successful sagebrush seeding has been. Newton, Dave Pyke, David Pilliod, and others in the USGS did a really cool study a number of years ago where they randomly picked about a hundred historic seeding treatments.

They visited these sites across the Great Basin. They quantified how many of the seeded species were abundant or what the cover abundance was.

Here, you're looking at the number of plants of big sagebrush that were on unburnt areas that were unseeded, or areas that were burned and unseeded.

You can see that fire led to a lot less big sagebrush. These are sites that were burned years to, maybe, decades before sampling.

The key thing here is that there's no real distinction in the abundance of sagebrush on burned seeded versus burned unseeded sites. In other words, this isn't a very rosy picture of seeding outcomes.

I want to point out that our land manager colleagues can identify areas that have had a lot more success and also the sampling on each one of these burned areas was necessarily fairly small.

It might have only been a handful of small plots, each less than an acre in size, over projects that sometimes were near 100,000 acres.

Nonetheless, the important thing to know is that it's very challenging to restore sagebrush in these dry environments, not too surprising.

The question is why? Is it just drought or are there other factors that could be controlled? That's what I want to get into in this talk.

The first point hearkens back to this idea that big sagebrush is a very diverse species. That's not surprising. Many widespread species occupy large areas by having a lot of diversity within them.

As I said before, big sagebrush has different subspecies, but also different cytotypes -- plants that differ in their genome size, which affects how they function. Mountain versus Wyoming and Basin big sagebrush, all considerably different, and I'll explain why.

For now, I wanted to point out two things. Wyoming big sagebrush occupies those large flat plains where species like cheatgrass and fire are the worst problems.

Basin big sagebrush has been plowed under because it normally occupies relatively fertile deep soils that are also good for growing potatoes.

Mountain big sagebrush occurs in areas that have high resistance resilience, and there's fewer problems up there. These subspecies all differ quite a bit in how they relate to wildlife.

Minty aromas can be gleaned out of mountain big sagebrush, whereas basin big sagebrush has a little bit of a turpentine smell to it.

Animals can detect those differences, too. That really matters for sage-grouse. Keep that in mind as we look at the variability, and their response to climate, and how these species have fared on seeding trials.

We've learned a lot about the variability in these species by growing them together in common gardens. Here's a common garden that Bryce Richardson started near Boise.

It has about 500 plants from 60 different populations of the three subspecies. Its populations are originated from all around the Western United States.

This is one of seven gardens that were established up to 25 years ago in Utah and Idaho. The first one went in by Bruce Welch, and has been carried on since by Alan Sands.

In those two gardens they started, we observed that the local populations, by far, have the most survivorship.

Like I said, using local seed sources is not very practical in big sagebrush. We're always going to have to transport seeds.

Now I want to tell you a little bit about what we've learned from an ecophysiological approach, comparing the physiology, the cold stress, cold tolerance, cold response of these different sagebrush types.

Here's a plot that shows the temperature at which the leaves freeze in these different varieties, mountain big sagebrush, basin big sagebrush, and Wyoming big sagebrush shown here, and the different cytotypes broken out.

This Y-axis shows how the difference in the temperature which will kill the leaf compared to the temperature at which it freezes at.

There's some key findings here. First is that there's a tremendous amount of variability within big sagebrush, about as much a variation as you might see among tree species, for example.

Basin big sagebrush, the tetraploid type, is very good at depressing its freezing temperature by using an antifreeze-like mechanism. Literally, it increases the amount of sugars in its cell fat to decompress freezing temperatures.

However, once it begins to freeze, it's in big trouble. Unsurprisingly, we've seen these subspecies cytotypes be knocked out of our common gardens following cold snaps. That's a freezing avoider.

These other subspecies are freezing tolerators. Normally, a species is assigned to one of these ranges of tolerance and avoidance. Here, you're seeing a huge gradient within big sagebrush.

Anyways, you can see species, like mountain big sagebrush, freeze really easily, which is counter intuitive on one hand. Then, on the other hand, that freezing temperature is not even close to the temperature at which they can withstand a freezing event.

Some key insights, important take-home message from this graph is that there's a lot of variability in frost response.

With respect to water relations, here I'm using carbon isotopes as a way to gauge how efficient these subspecies are with their use of water. More water use efficiency on this side of the axis usually would equate to a plant that's better apt to deal with the desert.

If I were to draw a line across the averages, there's no differences between mountain big sagebrush, or Wyoming big sagebrush, or basin big sagebrush. These different lines are each different populations.

Here, you can see the population variability is tremendous, compared to the variability amongst the different taxa, very important finding.

We can see, most importantly, in these common gardens the differences in survivorship are really insightful. What we've observed is that plants from relatively cooler areas tended to survive.

Cooler areas that have more fluctuation in diurnal temperature tended to fare better in these gardens, at least, the three gardens that Bryce Richardson started.

We can use those results to then map out the differences in climate adaptation shown here. High survivorship shown by blue. Low survivorship shown by red in those warmer, more temperate sites.

Now I'm going to shift gears again and take a look at climate responses, as we can know them from studying historic treatments. I told you before that Newton et al. found a very low success of historic seedings.

I wanted to know whether or not that low success could, in any way, be linked to the types of seeds being used on the treatments.

This is a hard question to answer because most BLM records do not include anything about where the seeds were obtained, which is a problem for allowing us to learn about the treatments for adaptive management.

Cindy Fritz and company in the BLM here locally had some information for 25 sites. We visited those and ran transects.

Here's some interesting results. First of all, on the X-axis here, I'm showing the elevation difference and the geographic distance of the seed origins, compared to where the seeds were planted onto burn areas.

You can see that the origins were about 700 meters higher in elevation on this axis and usually about 300 to 350 miles far away from where the seeds were coming to, which is interesting.

You'd think in a warming trend the ideal strategy would be to move plants from warmer, drier areas. Well, that wasn't really an option for the BLM because seeds aren't available from those warmer areas.

Nonetheless, we have an opportunity to learn from this. We also asked about the subspecies. Here is the different treatments. Here is the abundance of sagebrush on the treatments.

Nine of the treatments had no sagebrush whatsoever. Five of the treatments shown here at the top had a pretty good abundance, a desirable abundance of sagebrush.

This column right here shows the subspecies type that's considered to be native. W stands for wyomingensis where again most of the problems are. V is mountain big sagebrush, vaseyana. T is subspecies tridentata, basin big sagebrush.

This next column shows the type of subspecies that BLM thought they were purchasing, as labeled by the vendors and the seeds' certifying labs.

Then this last column to the right shows the type of subspecies that we detected on the sites, years to decades after the seeding.

What you can see is that we were actually detecting that basin big sagebrush or hybrids between basin and wyomingensis or mountain big sagebrush were dominant on these supposedly Wyoming and big sagebrush site types.

To be fair, it's very difficult in the field to identify these different subspecies types. We've been working hard with Bryce Richardson to come up with ways to better assess what subspecies are present.

More importantly, many people think that the subspecies type, like mixing subspecies, has a negative effect on seeding outcomes. That may be true, but in this data set, there's actually not much evidence to that effect.

These data are yet to be published, but there's a preliminary indication getting the wrong subspecies surprisingly did not have too much of a negative effect on the seeding outcomes.

Instead, we found a strong indication that getting the right climate of origin, the right population, matters a lot. There again, on this Y-axis, I'm showing different kinds of parameters. The numbers are the difference between the seed source and the seeded site.

This column right here is all 25 or 24 treatments. The far right column is the totally unsuccessful treatments where there was absolutely no sagebrush. Then inside this blue line on the right are the most successful treatments.

A few simple points from this complex graph. Number one, the most unsuccessful sites tended to get their seeds from really warm sites that had high minimum temperatures.

The most successful sites got their seeds from areas that had almost an identical mean temperature of the coldest month.

Interestingly, again, over these decades that these seedings were occurring, the background temperatures were increasing due to climate oscillations as well as potentially some directional change, some warming.

Also, I'm not going to show data on this, but we also found that weather after seeding, among other variables like whether or not drill seeding or other co-treatments were applied and whether or not the seed was applied on snow, all those were important.

Weather, after the fire, is indeed important. We were very surprised though that there were no correlations yet with the weather within a year after seeding.

Instead, you had to wait about three to four years to look at the weather to find a good correlation between that weather and seeding success.

This began to make a lot of sense to me when my colleague, David Pilliod, discovered that these weather cycles in which cool, wet conditions produce a lot of fuels, grass fuels, but then fires don't happen until a drought cycle begins.

He also discovered that that drought cycle tends to persist for several years after the fire when restoration treatments have typically been attempted.

Traditionally, land managers have only had a year to apply their treatments after a fire, and then they would monitor for two years after with no additional actions. Now that has changed quite a bit, and I'll show you how in the Soda fire which is in the slider here.

Point being though that seeds have been transported from relatively cool, wet areas into these very warm, dry flat areas. That probably explains some of the low success. This is something that could be changed to increase climate adaptation for sure.

Now in those plots that we studied, those treatments, we weren't really sure where...We had been given the polygons, hand-drawn maps, in some cases, where the seeds were flown.

More recently, the land managers have been asking that the contractors that fly the seeds to use GPS to mark exactly where different seed lots are put down.

After the 35,000-acre Preacher fire in 2014, just south of Sun Valley, the different seed sources were stripped and mapped. We went out and measured each individual seed source in these areas and found some interesting results.

First was that, of all the seed sources, only two of them had seedlings that were seeded. That was really surprising to us. The two that were successful happened to come from areas that had a good match of minimum temperatures to the seeded site.

The Soda fire, I just mentioned, is very significant. This is probably the first real example of adaptive management.

This follows on the tails of Secretarial Order 3336 in the Department of Interior, which asks the land managers to change the way we restore landscapes burnt and also how we manage for fire.

This is now called the Integrated Rangeland Fire Management Strategy. Anyways, this new policy direction gave land managers five years to do their treatments and to monitor.

What we're finding is that we've monitored 2,000 points, and we're seeing that we're learning quite a bit from them.

No surprise, at higher elevations that are cooler, we're seeing more sagebrush, particularly the basin big sagebrush types.

We can map out many of the variables from these models, and we can actually predict where and when the sagebrush are more likely to establish successfully.

Just like in the Preacher fire, stripping is now occurring in this where different seed sources are flown individually. We're studying those and learning things, like seed sources from relatively dry areas or relatively warmer areas, are having greater performance.

These are preliminary data subject to improvement, but the important thing is that the land managers are now able to use these findings to tune up both the management of the Soda fire as well as seed zone criteria for enhancing the general program of restoration.

Here, for example, you can see that just recently land managers are now putting seed zone information on seed tags, a very important way that we're adapting to the environment.

Now let me finish up with a couple of take-home messages regarding this. Climate impacts will involve fire and invasives for sure.

We're lucky in the sagebrush steppe that management has a heavy hand affecting much of the area. This provides opportunities to increase climate resistance and resilience.

What we need though is to continue the direction of increasing flexibility to tune management treatments, such as what's seeded, where, when, and how seedings occur, and to have these people doing restoration work more closely with researchers as we're doing on the Soda fire.

Learning from these actual management trials is about the only way we're going to come to grips with learning about and managing for climate resilience across these huge landscapes.

I think I've come to the end of my time allotment. Thank you for your attention. I'd like to acknowledge many colleagues that I couldn't refer to here, as well as our funding sources. Thank you.

John Ossanna: Thank you, Matt. Do you have some time for a few questions?

Matthew: Absolutely.

John: While we're adjusting these, if you're on the line, feel free to enter some questions into the chat box if you have any. We got a couple coming in right now.

First one, "Has your research given you some idea of how long a fetch is associated with higher wind erosion risk?"

Matthew: Yes, absolutely, Louisa, that's a great question. Two points. Number one, small patch fires are generally not prone to catastrophic wind erosion.

My research has identified that you need to have, at least, about a thousand to 10,000 hectare patch size in order to see catastrophic wind erosion.

The fetch has to be relatively flat. The key thing is allowing soil particles to be able to move freely across the landscape.

One moving soil particle, when it hits the ground, it entrains the movement of additional soil particles and so on and so forth until you have like a literal snowballing, lateral landslide.

That's a really important thing that we're beginning to learn.

John: The next question is, "You showed a map showing probability of ARTR survival based on common garden. It was not clear if it was a single sub or all subspecies."

Matthew: Yes, Chris, that map is for all subspecies combined. That paper, by the way, just came out in "Evolutionary Applications." That was written by a post-doc Bryce Richardson, Lindsay Chaney, and that map is for all subspecies.

Now, our more recent work is focusing more specifically on doing those same maps for Wyoming big sagebrush separately from the other subspecies. I didn't show those data, though.

John: Next question's from Gifford. "What are some areas of focus to bridge the gap with industry and politicians, between what we know and what needs to be accomplished, to move forward?"

Matthew: That's a great question, Giff. Giff actually is an old student of mine that I haven't heard from in about 15 years. Good to hear from you.

I decided to focus on the seeding problem because I believe it's one of the most tractable, important areas where we need to come together on these points.

For example, the BLM buys their seeds from private vendors, wildland seed collectors, they have a relatively large industry amongst themselves. They work very closely with government seed certifiers and these seed buyers within the Department of Interior.

At the other end, you've got the post-fire rehabilitation specialists who are the ones that are actually deciding how much seed to buy and which type of seed, where, and when to apply it.

Right now, there's the Great Basin Native Plant Program, which is attempting to bring all these people together. They also are working on every species in the Great Basin, not just big sagebrush itself.

In the last month, some colleagues of ours from the Forest Service have tried to bring together a focus group just for big sagebrush, to deal with these issues.

That would be one example of an opportunity to bridge the gap between industry and the people that are making decisions.

I don't know that it's really politicians that have a hand in this. I think it's more the individuals in the programs that set policy on seed purchasing, procurement, and the sideboards on that agency purchasing system.

John: Next question, "Is it too soon to begin providing guidance for seed collection, based on the apparent finding of greater seed success for seeds collected from warm or dry sites?"

Matthew: Well we don't have the publications, John. I showed preliminary data on these effects.

We're doing everything we can to get the publications out. Preferably, policy would be enacted on the basis of peer reviewed, published literature that's gone through the full lifecycle.

At this point, there is a very strong indication that using seed from warmer dry sites might be a good idea. However, we, as scientists, would want to see some repeatability in the effects. Continuing to collect data would be essential.

I do want to point out one thing, though. That photo that I showed you of the seed tag that had the climate zones written on it, the National Seed Program Manager chose to begin including that information on those seed tags after seeing a presentation, just like what I gave you, well in advance of publications that proved that those climate parameters were the ones that needed to be listed.

It's not too soon to begin getting a dialogue going and encouraging land managers to branch out a little bit or to put a little bit of their precious time and effort towards trying to work with seed from warm dry sites. But setting a firm policy may be a little bit premature.

John: One last question "Near the end of the PowerPoint, a slide said something about local seed less important than what?"

Matthew: Let's see. Let me find that slide. The issue with local seed...I'm still trying to track where that comment comes from at the top...but the issue with local seed...

Well, local seed is very difficult to come by and may not be practical for the large fires that are receiving most of the sagebrush seeding effort, in which case then we have to import seeds.

Our preliminary data is suggesting that perhaps more focus should be put on matching the climate of seed origin to the seeding site than on getting the subspecies identity well matched between seed source and seeding site, if that makes sense?

In other words, it's more important to match the climate in seed transfer than it may be to match the subspecies type.

Another way to think about this is that here in Boise, Idaho, if I look up the hill, I feel that I can point out to people where Basin big sagebrush is growing versus Wyoming versus Mountain big sagebrush.

However, if I go over to California, the sagebrush in California, the Wyoming big sagebrush there, might be a lot more similar to the Mountain big sagebrush here in Boise.

The message is that local adaptation or local gradients have generated a lot of strong selection on population divergence. That adaptation is relatively strong, compared to the consistency of subspecies diversification across the whole range of big sagebrush.

John: Ok. Matt, thank you for the presentation. Thank you for everyone who participated.

Matthew: Thank you.