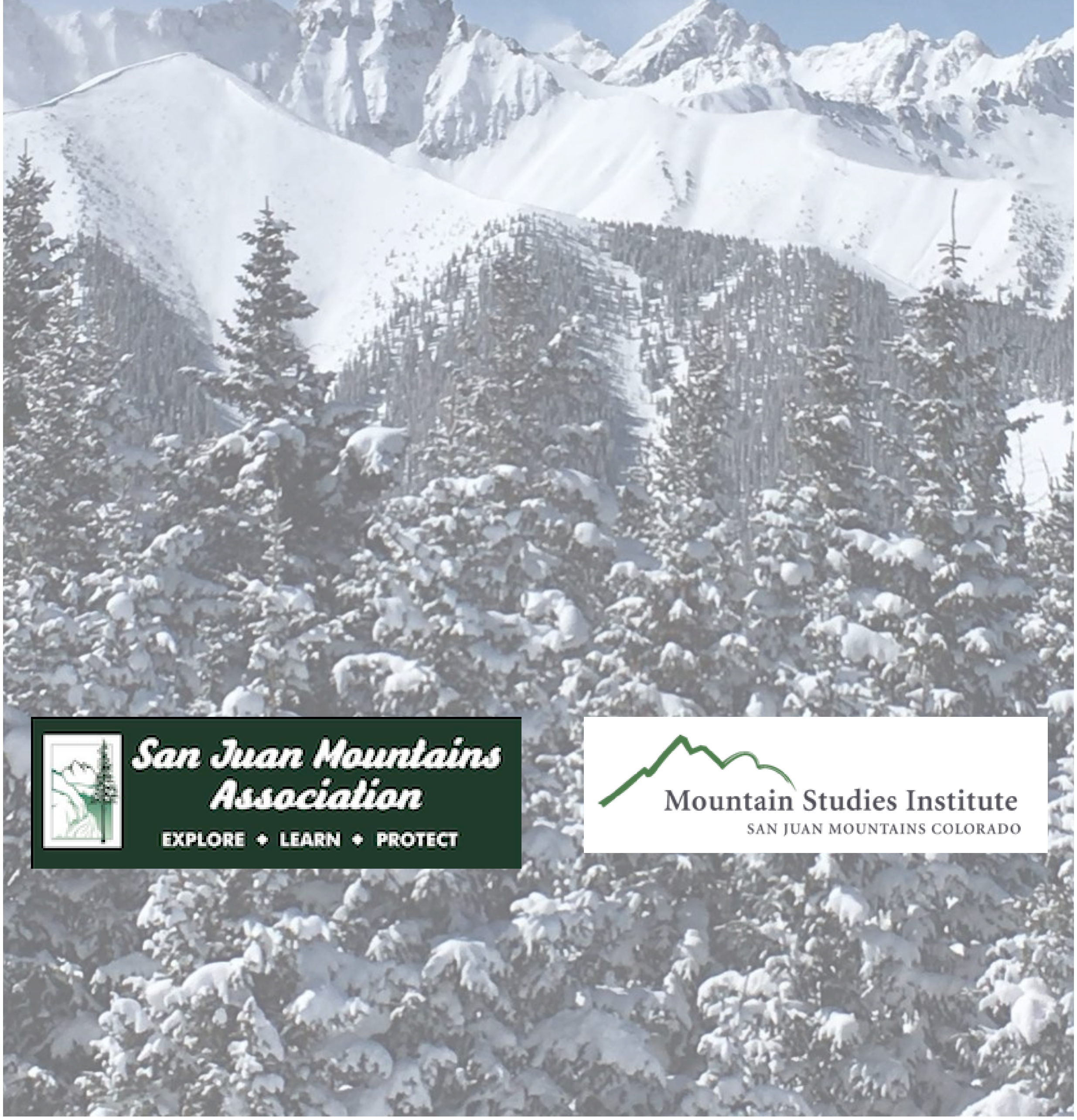
Winter Après-Ski
Science & Social Series

Information and Activity Guide

Climate Change, Forest Health, and the Future of Snow in the San Juan Mountains



San Juan Mountains Association
EXPLORE • LEARN • PROTECT

Mountain Studies Institute
SAN JUAN MOUNTAINS COLORADO

Organizational Information

This booklet is the product of a collaborative effort between two Durango-based non-profits. We hope that by combining our unique expertise in boots-on-the-ground science in the mountains, stewardship, visitor outreach and youth education, we are able to provide a unique educational resource that will add inspiration to your future backcountry adventures. A little bit about us…

Founded in 1988, the **San Juan Mountains Association (SJMA)** promotes the exploration and protection of public lands in Southwest Colorado through stewardship and conservation education for people of all ages. Services to the community include direct outreach at trailheads and at the San Juan National Forest Visitor Center, a bookstore, experiential nature-based youth camps and school programs, and wilderness stewardship. For more information, or to support, donate, or get involved, visit www.sjma.org.

Founded in 2002, **Mountain Studies Institute (MSI)** works to advance mountain research, improve best practices, and promote education that empower communities, resource managers, and scientists to sustain the social, cultural, natural, and economic resources of the San Juan Mountains. You will find MSI staff organizing citizen science data collection, leading on-the-ground ecological restoration, conducting education, and working with students from local schools throughout the San Juans. For more information, or to support, donate, or get involved, visit www.mountainstudies.org.

Introduction

What's Special about the San Juan Snowpack?

While the winter landscape is magnificent, snow in the San Juans is special for myriad reasons beyond its beauty. The uniqueness of the snowpack in the San Juan Mountains stems from our location at the nexus of alpine and desert environments.

Compared to other mountain ranges in North America, the San Juans are drier, sunnier, higher elevation, and more subject to large swings in weather—on both a macro level as intense winter storms drop feet of snow to be followed by long, sunny dry spells, and on a micro-level, as dry air lends itself to large daily temperature swings from the negative or single digits, to the 20s and 30s in the sunshine of midday.

Furthermore, mountains act as storm-makers. By forcing air upward, they squeeze moisture out of the air, causing it to fall to the ground as snow. In this way, the San Juans act as a water source, via rivers, to the arid environs below.

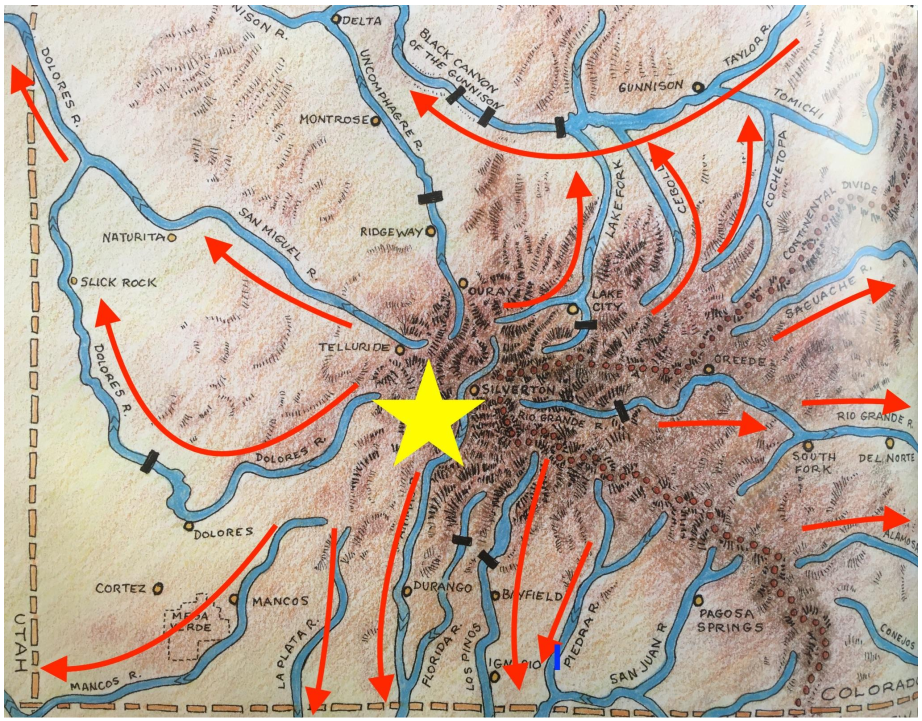
These qualities make the San Juan snowpack an ideal place to study the interaction between climate, snow, forest ecology, and water availability. This booklet is intended to educate public lands lovers on all things snow in the San Juans!

Photo: The jagged South Lookout and V5 peaks viewed from Anvil Mountain, Silveron, CO. Mike Bienkowski.

Colorado: A Western Water Tank

Colorado may be known as the Rocky Mountain State, but perhaps a better nickname might focus on the fact that water originating in Colorado flows outward into 17 different U.S. states, and to Mexico. Here, on the state's Western Slope, all streams lead to the ***Colorado River, which supplies water to some 40 million people!***

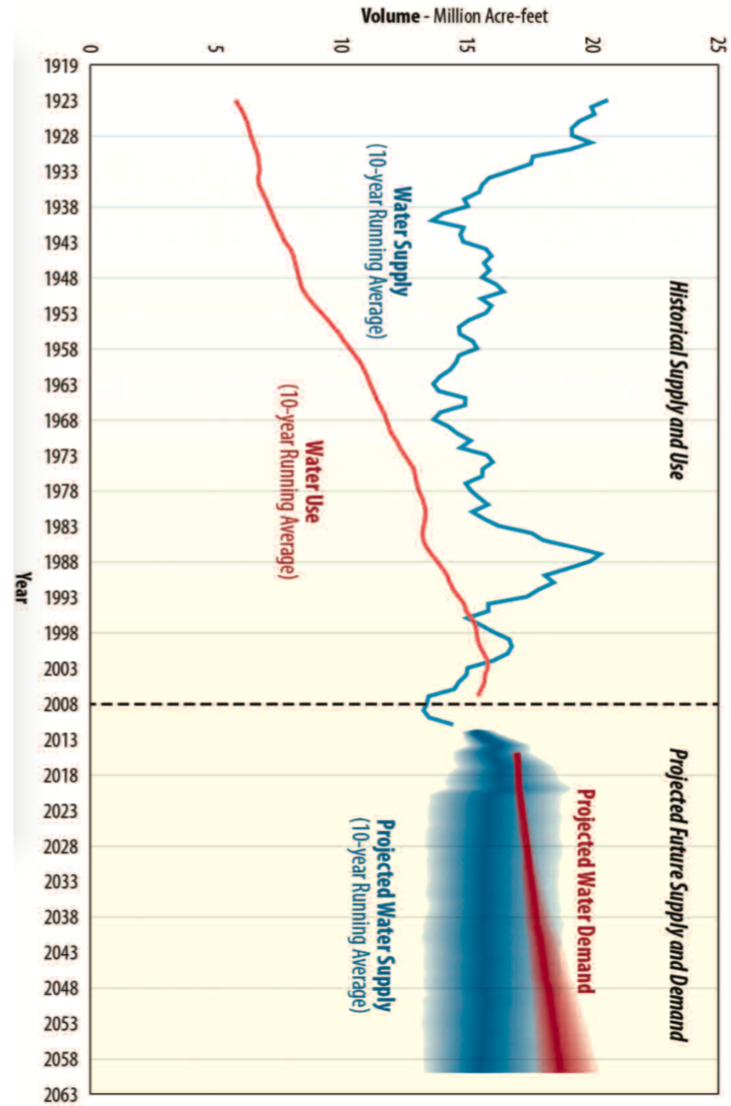
A closer look at the San Juans shows why Colorado is such a "mother of rivers." The range forms a raised "island" that rises far above the surrounding terrain. Since mountains force moisture out of the air, it makes sense that streams and rivers fed by mountain snow will carry water outward in all directions.



Red arrows show direction of river flow, yellow star shows the location of the SJMA tiny house. Source: "My Water comes from the San Juan Mountains" by Tiffany Fourment

Water in the West - The Future

It's clear that the San Juans are one essential water tank for the Colorado River system. But how does water consumption in the Southwest compare to water supply? The graph below tracks 100 year trends in river flows in the basin (blue line) vs consumption, and includes projections for the future (right side of graph). *Source: USDI Bureau of Reclamation*



Snow is Water // Water is Life

A little bit about Snow Water Equivalent (SWE)

If the mountain snowpack is the water storage tank, then ***Snow Water Equivalent (SWE)*** is the measure of just how much water is in that tank…Though snow contains water in the form of frozen crystals, it is mostly actually air, between the crystals. Because of this, snow has a much lower **density** than water does. Below are some rough estimates of the densities of different types of snow compared to water.

Snow type	Density	% Water
Pure liquid water	1.00 grams per mL	100%
Cold, dry powder aka "blower"	0.10 grams per mL or less	10%
Compacted, old snow	0.30 grams per mL	30%

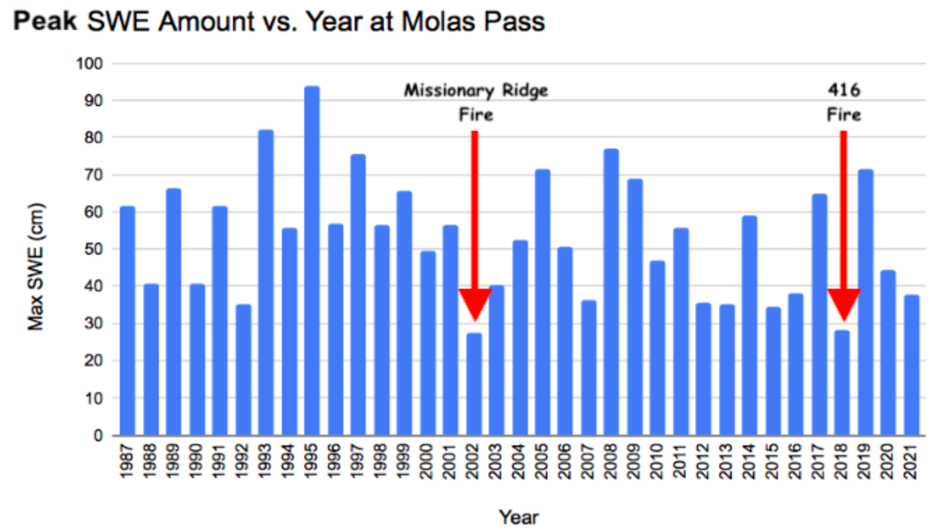
So why does density matter? The more dense the snow, the more liquid water it contains. We can visualize SWE by imagining a jar full of snow, melting it down, and comparing the content of liquid water.

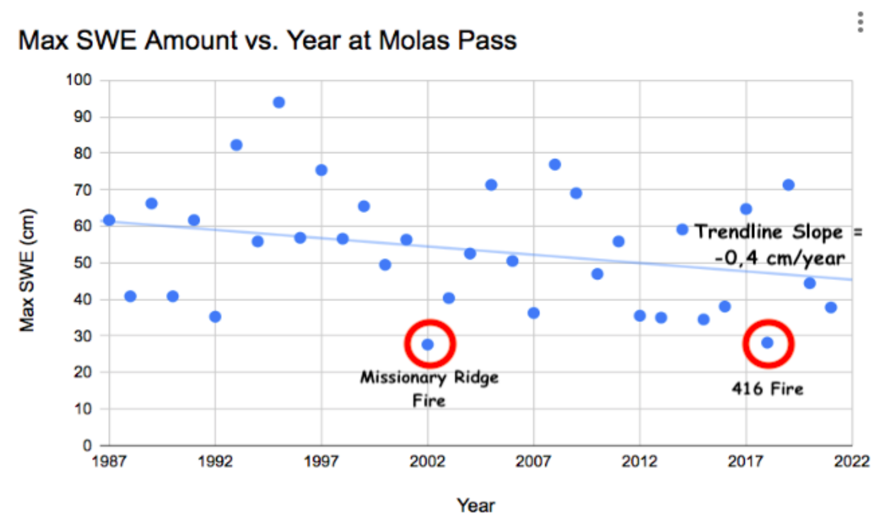
SWE in the mountains is defined as the ***depth, in centimeters or inches, of water that would be on the ground if all the snow turned to liquid***. To determine SWE, we need to know both the DEPTH and the average DENSITY of the snowpack.

SWE is essential for many reasons. A healthy snowpack ensures high river flows and abundant water for wildlife and humans alike. But snowmelt also infiltrates into the soil, effectively watering the plants in the forest. Low SWE years result in drought-stressed trees with dry wood that are more susceptible to wildfire and beetle kill.

SWE Through the Years

The graphs below show the highest SWE attained at Molas Pass each year dating to 1987. The second graph contains the same data, but with a trendline. The slope of this trendline indicates that on average, snowpack has declined by 0.4 centimeters each year over the past 35 years. *Data sourced from USDA SNOTEL*





Peak SWE (timing)

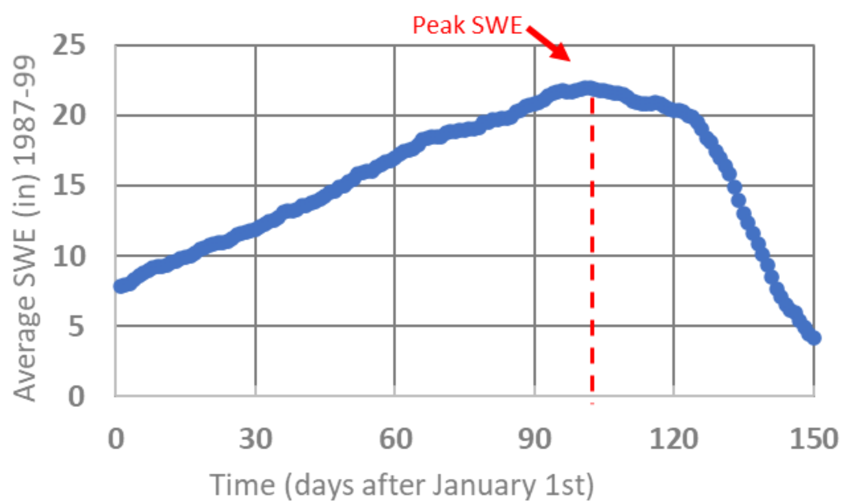
Tracking the start of spring runoff in the San Juans

The timing of peak SWE is a way to record the timing of snowmelt which impacts irrigation scheduling, legal water systems, and wildfire regimes. The formula below shows shows how it is a combination of the amount of SWE and the date of melting that matters:

High snow + late melt = lots of flow

Low snow + early melting = less flow

Average Snow Water Equivalent (SWE) at Molas Lake from 1987 to 1999. The average timing of peak SWE was on April 11 (101 days after January 1st).



USDA Natural Resources Conservation Service
National Water and Climate Center

Sources: https://labs.waterdata.usgs.gov/visualizations/snow-to-flow/index.html#/
https://www.sciencedirect.com/science/article/pii/S2214581821000288

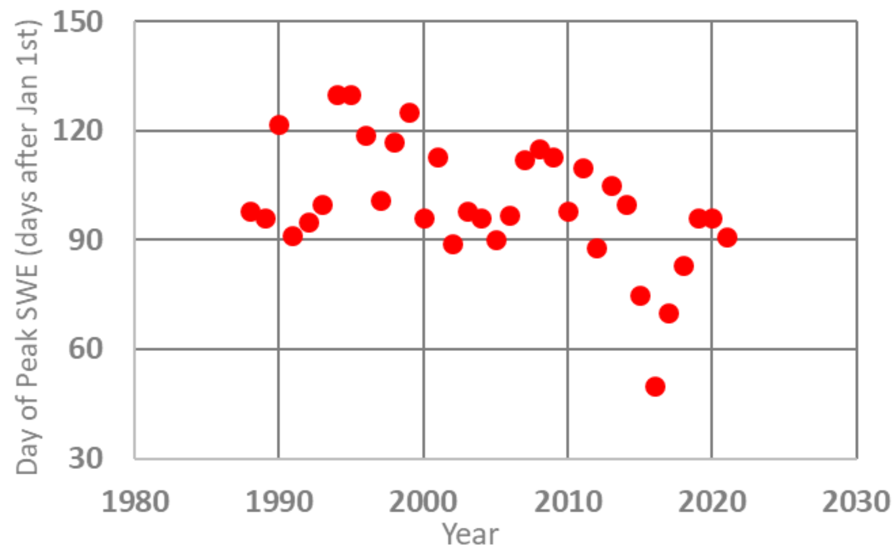
Peak SWE (timing)

Long-term trends in the San Juan Mountains

Looking at the graph below, has the date of peak SWE been getting earlier, later, or no change?

Why?

Date of peak SWE from 1988 to now



The slope of a linear trendline fit to this data is -0.8 (Days/Year). This means that, on average, the timing of peak SWE is getting ~1 day earlier each year.

Snowpack Science – An Introduction

The snowpack can be likened to the sedimentary rock layers exposed in a desert canyon. Because each storm deposits a new layer of snow on top of the older ones, layers are arranged sequentially, with the oldest at the bottom and the newest at the top.

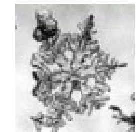
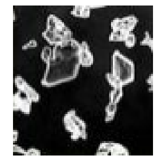
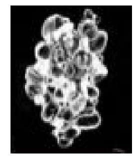
After falling in the familiar shape of fluffy flakes, snow is subject to a variety of processes that create new shapes, including:

- Getting blown and re-deposited by the wind
- Getting crushed by the weight of snow above,
- Melting and refreezing
- A dust layer from the desert dirtying the snow surface
- Sitting under frigid, dry weather for nights on end. .

A close look at the snow in each layer hints at a record of the winter's events. What patterns do you see in the snow layers pictured below?

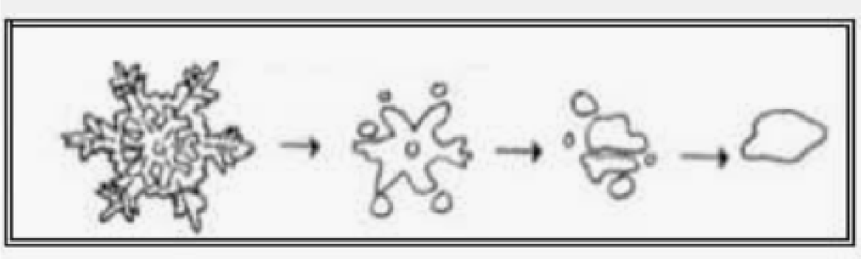
Source: Durango Herald "Climate change taking a toll on mountain towns"

Snow Crystal Types

Type	Shape	Also Called	Looks Like	Where you Find It	How it's Formed
New Snow		Powder, rime, graupel, etc.	No two are alike	On the surface	Falls from the sky
Rounded Snow **AKA equal temperature snow**		Equilibrium snow, ET (equitempera-ture) snow, old snow	Fine-grained, chalky, easy to pack into a snowball	Old layers of snow	Low temp. Gradient (<1 deg. C/10 cm)
Faceted Snow **AKA temperature gradient snow**		Sugar snow, kinetic snow, depth hoar (when near ground)	Sparkly, large grained, hard to pack in a snowball	Anywhere in the snowpack	Large temp. Gradient (>1 deg. C/10 cm)
Depth Hoar		Sugar snow, ground hoar	Sparkly, large grained, feathery, extremely light and airy	On the surface or buried by more recent layers	Winter equivalent of dew on the surface
Melt-freeze Snow		Corn snow, Spring snow, wet snow	Coarse, granular, wet	Snow surface or buried by more recent layers	Repeated melting and freezing of the snowpack

Destructive Processes

How do they affect snowpack qualities and SWE?



Destructive processes are those factors that take snow crystals, which fall from the sky as stellar flakes, and press them down into round, compact shapes. Some of these processes are…

Wind transport Wind moves a lot of snow, especially above treeline. As crystals tumble across the surface, they grind into small, round shapes that fit together tightly in a dense "wind slab." Wind slabs preserved in the snowpack mark a record of past wind events.

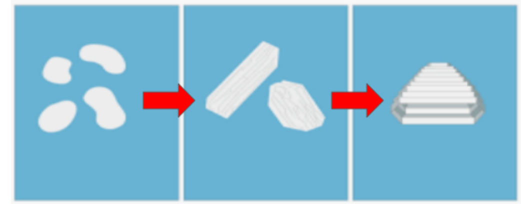
Melt-freeze cycles When snow melts, the outer arms and facets of the crystals are the first to turn to water. Refreezing results in round, shiny, ball shaped crystals. Look for melt-freeze crystals near the surface on sunny slopes. When buried, these crusts preserve a record of past periods of above-freezing weather.

Time, and more snow When the snowpack gets deep, the sheer weight of snow can crush snow crystals in underlying layers down into a compact, rounded shape. This process usually takes a long time (weeks or months), but does result in the snowpack being more dense, cohesive, and stable by late winter and early springtime.

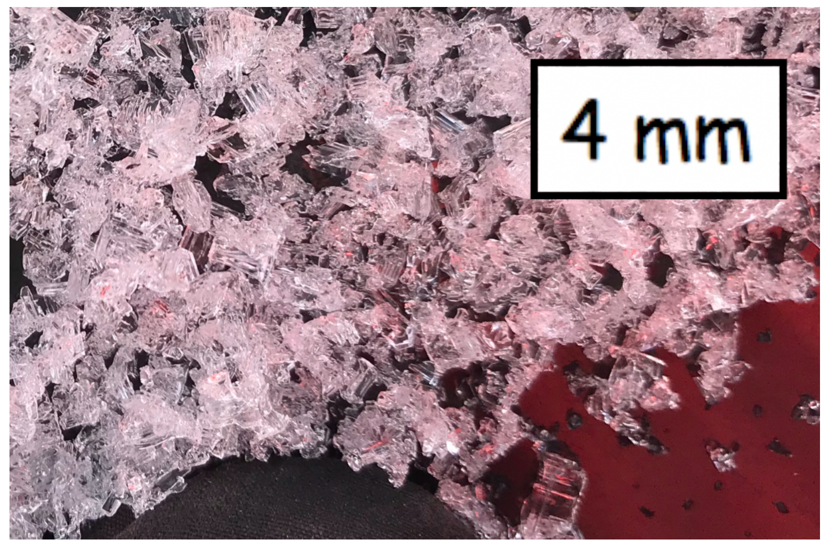
Overall… destructive processes create rounded snow crystals. These crystals give rise to dense, cohesive layers of snow. They usually contain more water (higher SWE) than new or faceted snow.

Constructive Processes

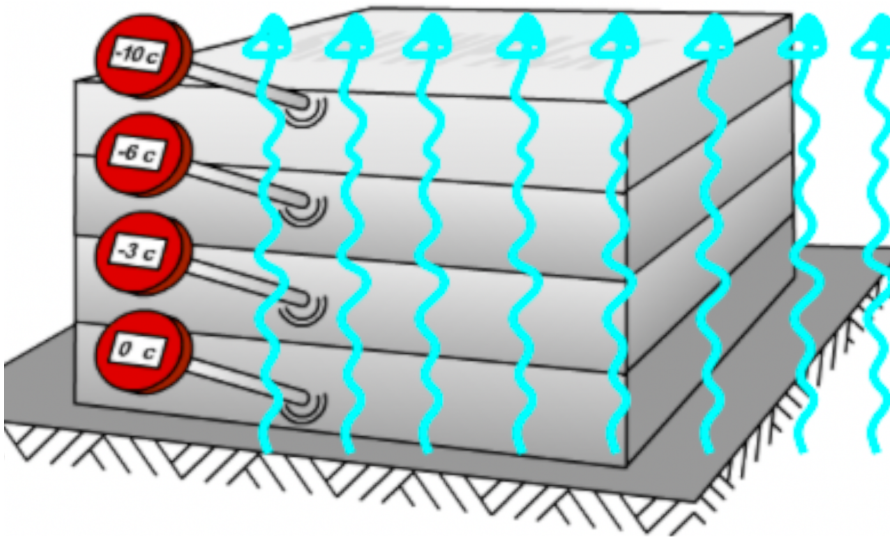
So we know now how snowflakes can get battered and rounded down into little balls. But what on Earth can make these grains grow larger and add new patterns upon them? Constructive processes can, and they are uniquely influential here in the San Juan Mountains.



Constructive processes are also called **faceting**, because they create snow grains that have large, angular faces that build outward like crystals. Uniquely, they grow larger over time. The snow crystals created this way have a variety of names: **facets** and **temperature gradient (TG)** snow more officially, and sugar snow, weak snow, or rotten snow more colloquially. They really all refer to the outcomes of the same faceting process.



Facets. The individual crystals in this photo measure roughly 4mm across. Note the angles and faces; do you think this snow makes a good snowball? (answer: no way!)



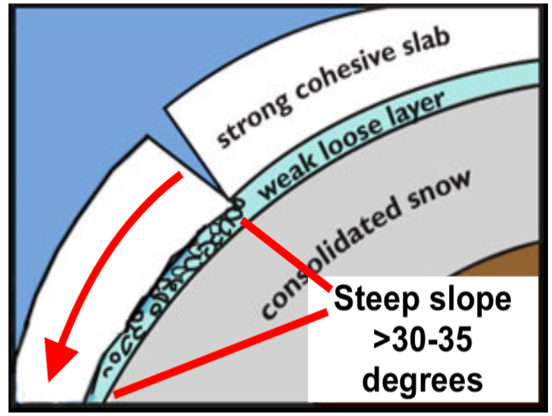
Faceting is driven by a large temperature difference between the surface of the snow, and the ground. While the ground remains warm (close to 32 degrees) the surface fluctuates with the air temperature. Here in the San Juans, shady slopes get seriously cold and dry between storms. When this happens, moisture in the snow and ground ***sublimates*** (turns from solid to gas, skipping liquid), and migrates upward toward the cold dry air to "balance things out." As it does, it leaves empty spaces behind, while depositing frost on the sides of crystals. That's why they grow bigger over time!

Layers of facets buried in the snowpack indicate long dry spells between storms with exceptionally cold, clear, starry nights (in fact, facets are what create that magical "sparkle" beneath a full moon). Faceted snow feels dry, sugar, non-cohesive, and loose. It will not make a good snowball, and usually has a lower density and water content (20-25% water) than rounded snow, which is closer to 30% water.

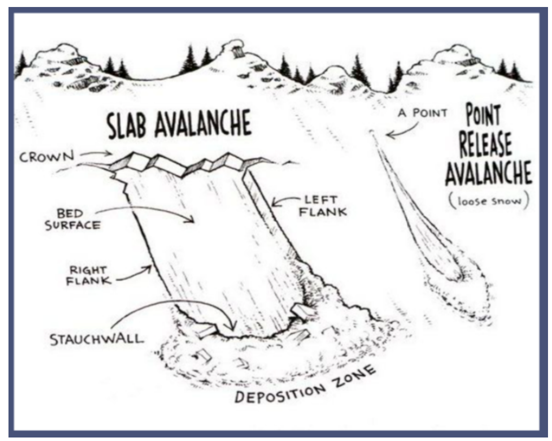
Facets have many implications: when buried, they become weak layers whose lack of cohesion is responsible for most large avalanches. But they are also easier for animals in the subnivean zone to burrow through. Many small mammals thrive in the **depth hoar**, or layer of facets that forms near the ground on shady slopes because of this.

A Little on Avalanches

Using what we now know about layers of rounded vs. faceted snow, let's consider the implications when we tilt these layers on a slope:



Here, the "weak loose layer" is made of facets, probably formed during a long, cold dry spell. The "strong cohesive slab" is rounded snow, probably formed during big storms with lots of wind. When the slope angle hits 30-35 degrees, this setup becomes very unstable, and the dense layer above is liable to break and slide off the weak layer below in one big "slab avalanche."



Slab avalanches are common in the San Juans because of our cold, dry weather, and relatively thin snowpack. This creates a large temperature gradient that drives the faceting process. Big storms overwhelm these weak layers and result in cycles of large avalanches.

Image sources: University of Alaska Fairbanks (top), Wilderness Medical Society (bottom)

Know before you go: if you plan to recreate in the backcountry during winter, rescue gear (beacon, shovel, and probe, and training on using them), and getting the avalanche forecast from avalanche.state.co.us are essential.

What do Animals do in Winter?

Winter poses serious challenges for wildlife. These challenges boil down to three: 1) it's hard to move through the deep snow, 2) food is scarce outside of the growing season, 3) the cold makes thermoregulation for animals more difficult and energetically expensive. With that in mind, animals usually adopt one of three strategies:

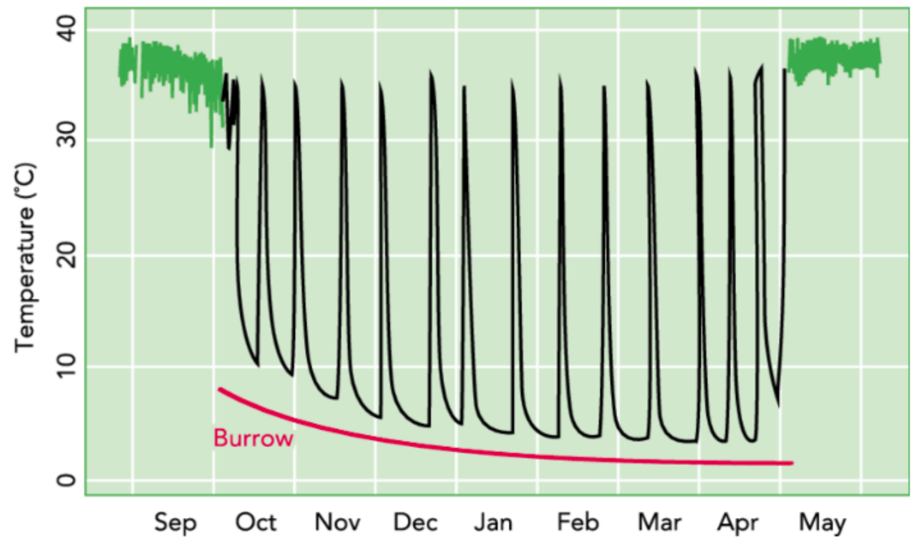
Strategy #1 - Migration If winter's tough, just move somewhere that it's not! Migrators simply travel to avoid the acute challenges of winter. Some migrations are epically long—take a winter trip to Central America and you'll see the Broad-tailed Hummingbirds that visit your feeders in Colorado all summer. Other migrations are more local. White-crowned Sparrows, mule deer, and elk live near treeline during the summer, but migrate to the foothills and river valleys at lower elevations during winter.

Strategy #2 - Hibernation Hibernation is more than just sleep. It is an adaptation to reduce energy consumption to match the reduction in available food. Hibernators in the San Juans include bears, marmots, and chipmunks. Many songbirds go into a short-term hibernation called "torpor" to survive cold nights before becoming active to forage during the day. See the facing page for more information on hibernation.

Strategy #3 - Toleration Many animals don't just survive, but actively thrive in winter! They usually have special adaptations that allow them to stay active all winter long, including thick fur, and either big feet to walk on top of snow (lynx, snowshoe hare), long legs to walk through it (moose), or wings to fly above it all (Grey Jay, Clark's Nutcracker, Raven, Chickadee). Pika, deer mice, and pocket gophers take advantage of the insulating qualities of snow by surviving underneath it (the ***subnivean zone***), where temperatures can be surprisingly mild.

A Winter in Hibernation

A Time-course Look at Body Temperature in a Hibernating Yellow Bellied Marmot



Source: Arnold, Gitroud, Valencak and Ruf. "Ecophysiology of Omega Fatty Acids." Physiology, May 2015.

The above graph tracks the body temperature of a yellow-bellied marmot over the course of its hibernation period in the subalpine zone. The black line shows the marmot's temperature, the red line shows the temperature of the burrow.

Why hibernate? Note that the drop in body temperature makes the gap between marmot temperature and that of the burrow smaller. This means that the marmot is losing less heat to its surroundings, and spending less energy on heating itself. Think of it as turning down the heat in the house to save on your energy bill. Heart rate and respiration also drop. What do the bimonthly spikes represent? These are times when the animal comes out of hibernation, mainly to feed on some stored food and refuel.

Tracking in Winter

Winter provides an amazing opportunity to learn about the lives of animals. Because tracks in the snow degrade quickly, it is easier to discern the age or "freshness" of tracks, and new ones show up every morning!

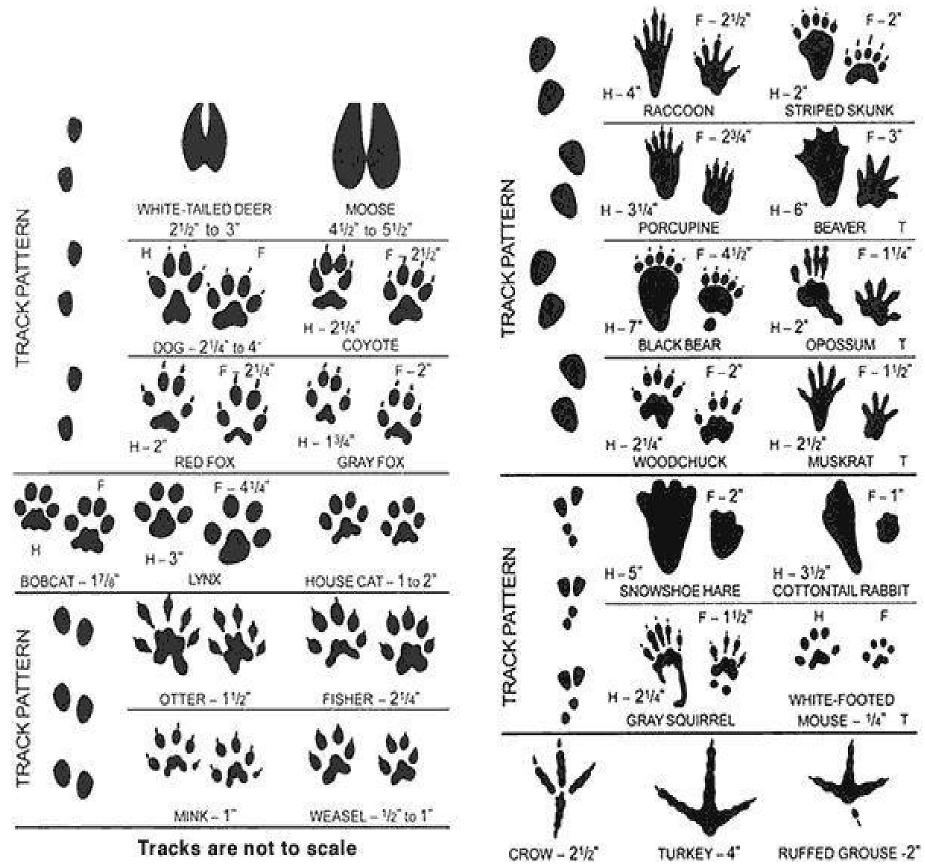
Identification of species is just one part of the tracking story. Tracks also provide a glimpse into the habits, adaptations, and relationships of animals in the San Juan Mountains.

When observing animal tracks in the winter, ask yourself the following questions. You'll be surprised by what you might notice!

Tracking considerations:

- How big or small do you think the track-maker was?
- How was this track-maker traveling? Was it walking? Bounding? Galloping? Running?
- Is there a pattern to the track-maker's movement? Is it in "get somewhere" mode or "poke around and check things out" mode?
- Do you notice signs of other animals with whom the track-maker may have interacted?
- Take stock of the threats or hazards the track-maker may have been aware of—exposure to predators, the elements, etc.
- Take stock of things the track-maker may have been attracted to—food, cover, water, shelter from the elements, etc.
- Which species seem particularly abundant in certain places? Do different animals seem to prefer different "microhabitats" within the area you are exploring?
- Follow a track and see what else you find!

Some Common Winter Animal Tracks



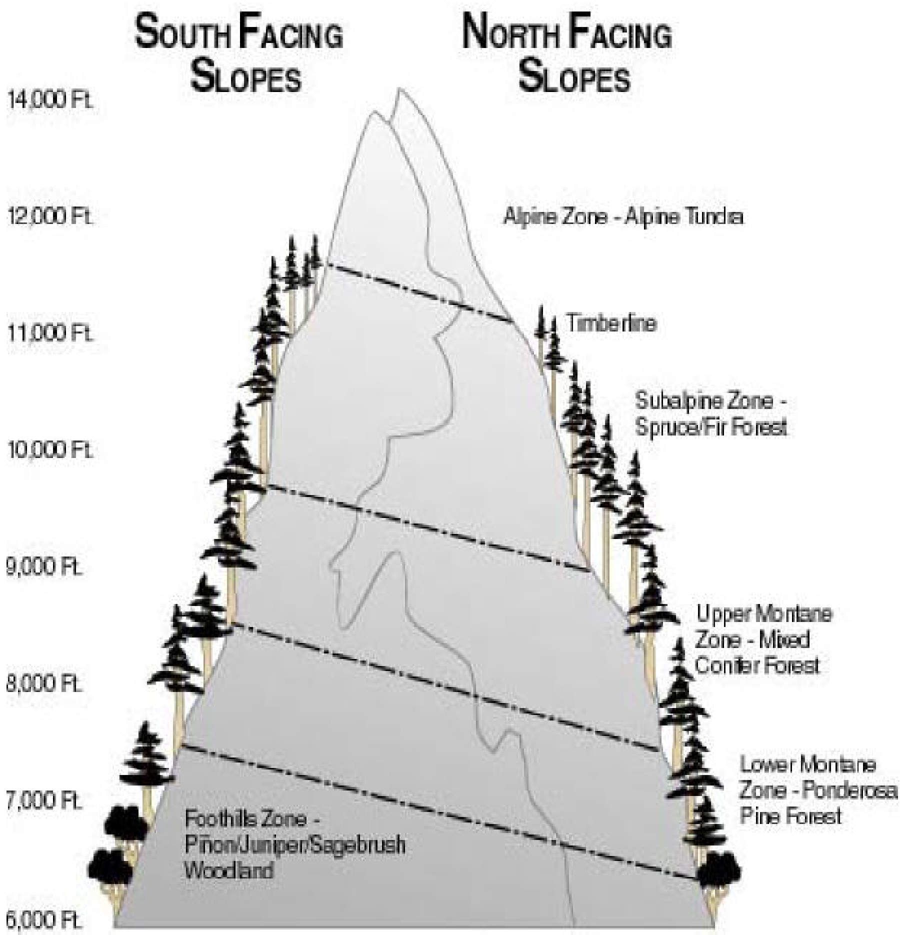
To identify tracks, notice the shape of the print, but also the "track pattern" shown at the left. Animals leave different track patterns depending on their "gait" or walking style.

Clockwise from top left: 1) diagonal walker, 2) pacer, 3) galloper (back legs land forward of front legs), 4) bounder.

Direction of motion for all track patterns shown is from bottom to top

Life Zones in the San Juan Mountains

A drive from Farmington to Silverton will take you through an almost astronomical change in your surrounding ecosystem. In fact, you will pass through five distinct ecosystem types, or "life zones," along the way. Check them out on the diagram below!



Note that the range of each life zone is higher on South-facing vs. North-facing slopes. Why might this be? Hint: it has to do with the Sun!

Life Zones (cont'd)

Alpine Zone: Life up here is harsh due to an extremely short (~3 month or less) growing season, high winds, and despite heavy snowfall, the soils tend to drain rapidly, resulting in a dry growing environment. Small, slow-growing plants with vibrant flower displays to attract pollinators thrive in this zone.

Subalpine Zone (spruce-fir): While intense winter cold, deep snow, and a short (~4 month) growing season limit what plants can grow here, this zone is sheltered enough from the wind, and downhill enough for water to collect abundantly in the soil. Subalpine fir and Engelmann spruce are perfectly adapted to the cool, moist climate of summer and the deep snowpack of winter. Look for osha, leafy Jacob's ladder, Richardson's geranium and monkshood, and subalpine larkspur along the forest floor.

Upper Montane (mixed conifer): Biodiversity reaches its peak in this cool, moist, middle zone with a longer growing season than the subalpine but still with abundant moisture from snowfall.. Here, quaking aspen thrives in sunny openings created by fire or avalanches, with Douglas fir in the shadier spots. Chokecherry, thimbleberry, wild raspberry, and currants provide abundant food for wildlife on the forest floor.

Lower Montane (ponderosa pine): This zone splits its time between cold, snowy winters with hot, dry summers. Trees in this zone must be able to tolerate long periods with little rainfall, intense sun, and rocky, nutrient-poor soils. Gambel oak, serviceberry, Oregon grape, thrive in the open, sunny understory of this forest and provide abundant food for wildlife preparing for winter.

Pinyon-Juniper Woodland: This high desert zone is characterized by scarce moisture and hot summer temperatures. Drought tolerance is key for plants in this zone, and plants are widely spaced and slow growing. Sagebrush fills the openings between the sparse, squat trees.

Mean Fire Return Interval
Understanding natural forest fire cycles

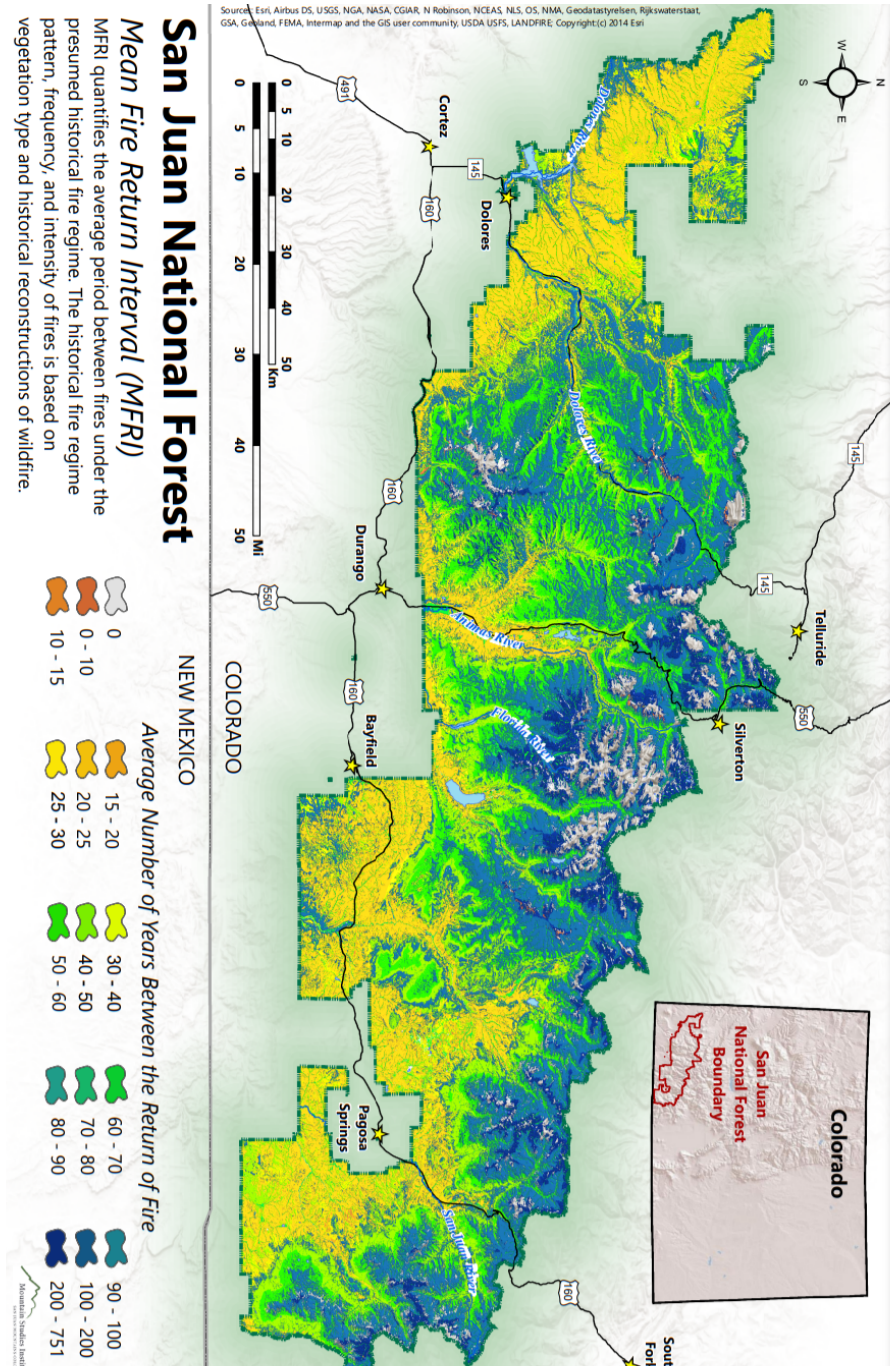
Wildfire is a natural part of many ecosystems, particularly in the west. In fact, many of these ecosystems have co-evolved with fire, and some even rely on it to persist in a healthy state..

One tool to analyze fire’s role in different ecosystems is the Mean Fire Return Interval (MFRI). MFRI is defined as the ***average number of years before fire returns to a place that has already burned***. So if the MFRI is 10 years – then it will be, on average, 10 years before a given place burns again. This average is assumed to be historical, prior to anglo settlement. Below are fire return interva’s associated with different forest types :

Life Zone (forest type)	MFRI
Alpine tundra	0 (too cold/wet, lack of fuel)
Subalpine (spruce-fir)	300+ years
Upper Montane (Aspen-conifer)	50-150 years
Lower Montane (Ponderosa)	5-25 years
Pinyon-Juniper	Rare (lack of sufficient fuel)

Source: Colorado State University “Fire Ecology in Colorado”

The facing-page map shows historic (pre-Anglo settlement) Mean Fire Return Intervals for ecosystems throughout the San Juan National Forest. What trends do you notice from this map? Can you identify the forest types present in each area by their fire return interval?



Fire Debt

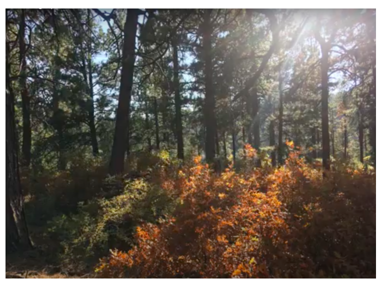
A tool for predicting the next "big one"

Looking at the Mean Fire Return Interval map on the preceding page, were you amazed at how frequent the natural fire interval is on so many lands in our area? Regular fires have many benefits, including but not limited to:

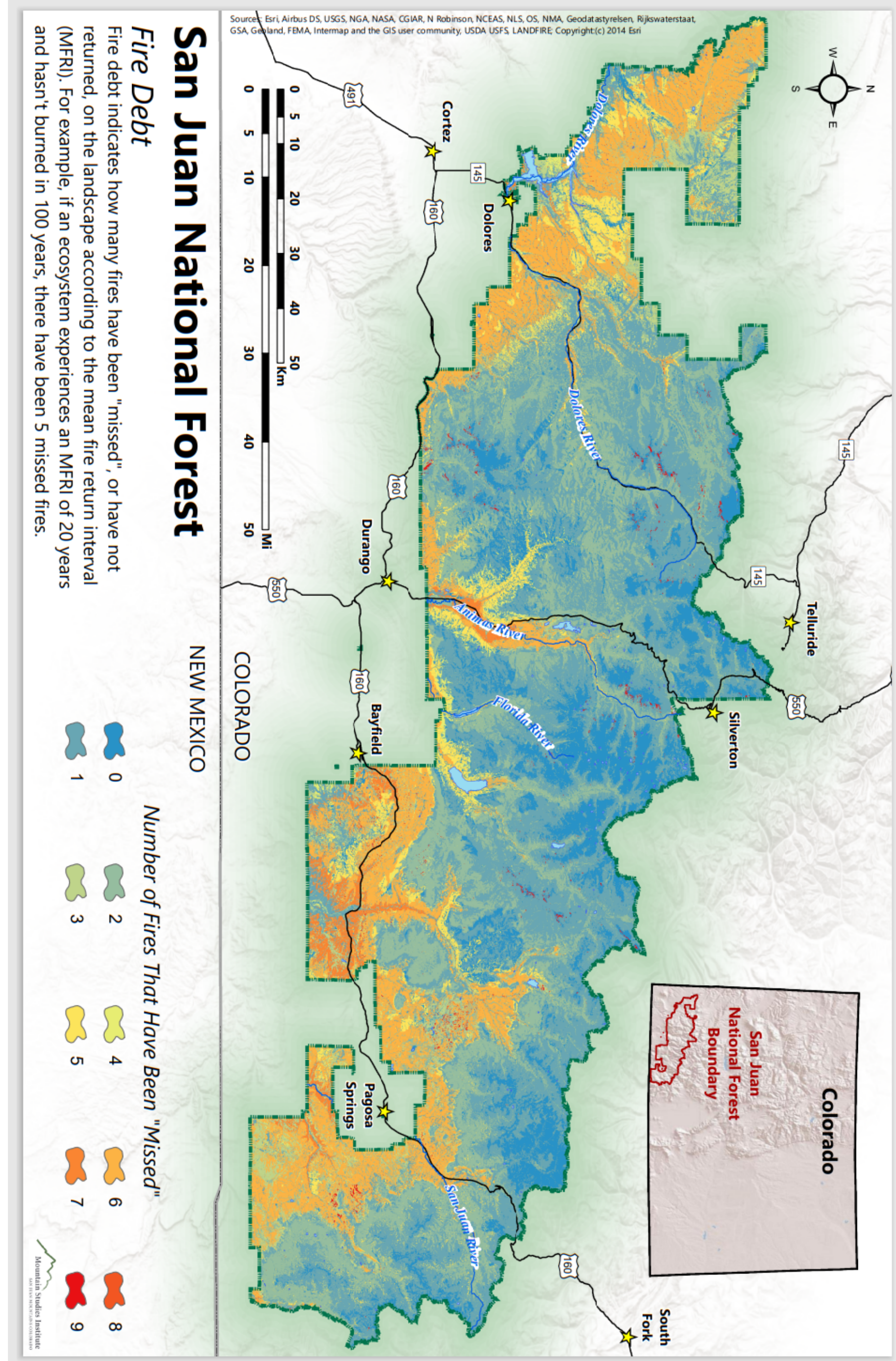
- Clearing out excessive growth that could fuel a larger fire
- Clearing "ladder fuels" or mid-size trees that could bring a fire from the ground, up to the crowns of large trees
- Returning nutrients to the soil to help young plants grow
- Opening up the forest floor to easier travel for animals
- Helping fast-growing, sun-loving wildflowers which provide food for pollinators.

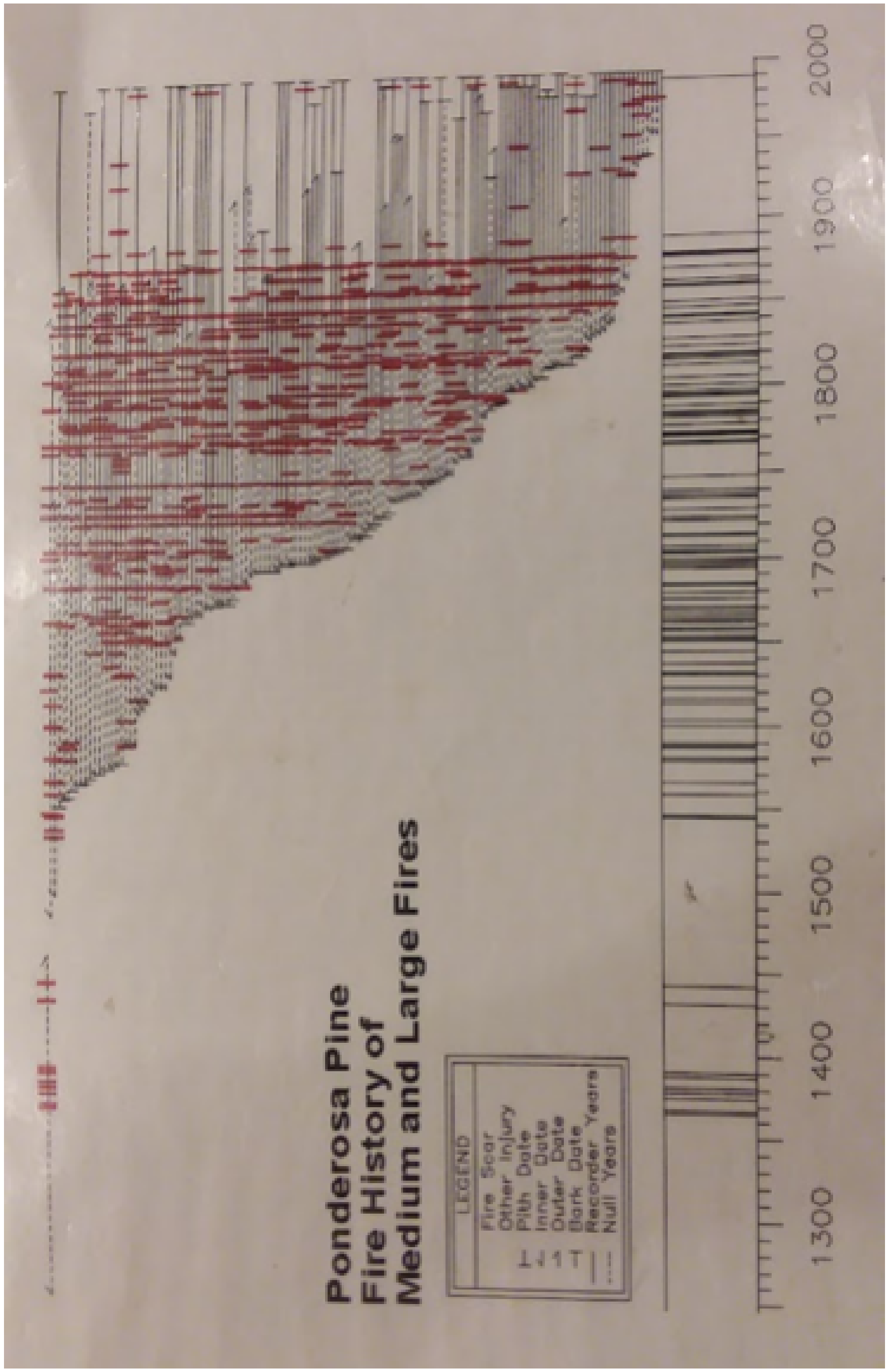
When ecosystems that rely on these fire benefits for health "miss" wildfires, there are consequences that follow. Trees become dense and compete for a limited supply of water in the soil. This increases their susceptibility to disease (beetle kill), and to devastating, high intensity fire when at last it does return.


Ponderosas on a regular burn cycle


Ponderosas with a "missed" fire

The colors on the facing-page map illustrate the number of fires that have been "missed" in an area. For example, a ponderosa forest with an MFRI of 15 years that hasn't burned in 75 years has "missed" five fires. What trends do you notice on the map, and what are the potential implications?





A History of Wildfire

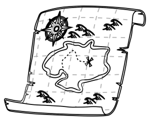
How does our past intervention in fire ecology affect our wildfire future?

Check out the facing-page graph. Each of the horizontal lines shows the life of an individual ponderosa pine, starting at the left, and ending at the right. Wildfires that don't kill the tree leave scars on the tree rings, preserving a record of all the fires each tree experienced during its many (sometimes hundreds!) years of life.

What trends do you notice in the graph? Specifically, what changed around 1900? You may have noticed that the frequency of wildfires (shown by red lines) reduced dramatically. This coincides with the founding of the US Forest Service and a decades long attitude that all fires needed to be suppressed. The result? Lots of "missed" fires in ecosystems that are evolutionarily accustomed to regular, periodic burning.

So what does this mean for the future? In the short term, land managers including the Forest Service are making a widespread effort to reverse the negative consequences of fire debt through programs of prescribed burning to restore ecosystems that rely on fire for health. In the long term, the 2020 Ice Fire called collective attention to the potential for climate change and drought to bring fire to subalpine forests that burn less frequently. What changes do you predict might happen in our forests as summers grow longer, winters shorter, and deep snowpacks arrive less consistently?

The 7 Principles of Leave No Trace



Plan ahead and prepare
Know before you go! Check the weather, local regulations, and avalanche conditions. Know your group's capabilities and how to use your gear (especially avy rescue gear).

Travel on durable surfaces
Stay on deep snow wherever possible. If mud is exposed, walk through the middle of the mud rather than at the edges to avoid trail widening.

Dispose of waste properly
Leave nothing behind - even compostables like apple cores. Pack out all garbage, including human waste and hygiene products.

Leave what you find
Do not collect or move natural items. Don't pick flowers or plants, and return any structures built to their natural state. Help preserve historical or cultural sites.

Minimize campfire impacts
Use only downed wood, and don't break branches off trees, live or dead. Completely extinguish fires by drowning then burying them.

Respect Wildlife
Use the "rule of thumb" - if you can't cover the animal by holding your thumb out at arms length - you're too close! Avoid wildlife during sensitive times. Never feed wildlife.

Be considerate of other visitors
Yield to downhill and faster traffic. Use quiet voices and be respectful of the uses of electronics, music, and drones. Don't hike through ski or snowshoe tracks. Step off trail when stopped. Don't make excessive noise.