ABSTRACT: What are effects of trees and shrubs on interception of snow? Interception of falling snow by conifer trees and sagebrush shrubs can increase loss of snow through exposure to sublimation, thus decreasing potential water supply. As many drought afflicted areas are predominantly vegetated by conifers and sagebrush, snow interception by these plants in various stages of drought and maturity is noteworthy.

The project extended over two winters. During the first winter, conifer branches from two species, Lodgepole Pine (*Pinus contorta*) and Subalpine Fir (*Abies lasiocarpa*) were dried to varying wood moisture contents to simulate branch resistance in various drought stages. The force needed to bend the branches at subzero temperatures was measured, as the branch resistance affects snow retention and unloading. Retained intercepted snow is exposed to loss by sublimation, while unloaded snow is contributed to dense ground snowpack.

Fir data supported all hypotheses, because as moisture content decreased, branch resistance increased, and sapwood temperature fluctuated less. Yet, the pine had mixed results, supporting differences between the genus’s. Drier, more resistant fir trees intercept and expose more snow to sublimation, while pines, more flexible when drier, unload more snow to be retained for water supply.

The second winter's research investigated interception of snow by sage (*Artemisia tridentata*) in various stages of maturity, and the force needed to bend branches at subzero temperatures. All sagebrush hypotheses were supported. As shrub maturity increased, branch resistance to bending increased, and percent of intercepted snow increased. T-tests showed that young sage (5-6 yrs) did not intercept significant amounts of snow; therefore sage kept at this maturity would provide maximum water conservation.

These results will help scientists better understand snow interception and retention on conifer branches and sagebrush for better prediction of winter’s snow as water supply during drought and better planning of vegetation communities.

KEYWORDS: vegetation, branch resistance, interception, sublimation, water conservation

1. INTRODUCTION

Snow is a vital consideration as potential water supply during drought. As many drought afflicted areas are predominantly vegetated by conifers, Lodgepole Pine (*Pinus contorta*) and Subalpine Fir (*Abies lasiocarpa*), and sagebrush (*Artemisia tridentata*), snow interception by these plants is noteworthy. However, interception of falling snow by vegetation can increase loss of snow through sublimation, thus decreasing potential water supply (Figure 1).

![Figure 1. Vegetation such as conifers (left) and sagebrush (right) intercept snow.](image-url)
third winter project investigated sage interception in relation to maturity and ambient air temperature. The results can be used to more closely estimate spring water supply according to air temperature and maturity of sage in drought afflicted areas.

The results can be used by scientists and land managers to more economically manipulate snow and vegetation for enhanced water supply during drought.

Questions and hypotheses were developed. The Conifer Branch Resistance aspect had three questions/hypotheses. 1A. Does the moisture content of a conifer branch affect the branch’s resistance to bending in subzero temperatures? It was hypothesized that as moisture content decreases, branch resistance to bending will increase. 1B. Does the moisture content of the sapwood affect the branch’s temperature fluctuation? It was hypothesized that as moisture content decreases, sapwood temperature will fluctuate less. 1C. Does the genus of a conifer branch affect the branch’s resistance to bending in subzero temperatures? It was hypothesized that the genus of the conifer will affect the branch’s resistance to bending.

The second aspect, Interception by Sagebrush, had two questions/hypotheses. 2A. Is branch bending resistance of Big Sage (Artemisia tridentata) during subzero temperatures affected by the shrub’s maturity? It was hypothesized that as maturity of Big Sage (Artemisia tridentata) increases, branch resistance to bending during subzero temperatures will increase. 2B. Is interception of snow by Big Sage (Artemisia tridentata) affected by the shrub’s maturity? It was hypothesized that as maturity of Big Sage (Artemisia tridentata) increases, the percent of intercepted snow will increase.

2. METHODS
2.1 Conifer Branch Resistance

Preparation of Branches and Test Area: 1. Select four conifer trees, two Lodgepole Pine (Pinus contorta) and four Subalpine Fir (Abies lasiocarpa), each approximately 6-8 meters tall, growing in similar environmental conditions. 2. From each tree cut three branches, 80 cm long, and similar in shape and age (Figure 2).

3. Use a 2-pin moisture meter to measure actual moisture content of sapwood of one branch from each tree to establish the “high moisture level” for that tree Calculate 66% and 33% to establish the medium and low moisture levels, respectively. (Figure 3).

4. Use a household oven (150º F) to dry the remaining branches for medium and low moisture to their calculated moisture levels (Figure 3).

5. Mark a “pull point” on each branch with flagging and a loop of string to attach the scale, 10 cm from the branch tip, to avoid over-flexible new growth or extremely rigid older growth. 6. Drill a 1.0 mm hole diagonally into sapwood of each branch, 40 cm from the tip to insert hypodermic temperature probe. 7. Secure ends of branches between two boards where branches will be free of obstruction when pulled down 10 cm (Figure 4).
Collection of Temperature and Resistance Data:
1. Begin data collection immediately after branch drying to avoid further drying. 2. Test should cover both a warming and cooling period for a 24 hour period. 3. Collect data every 1-2 hr for sapwood temperature, ambient air temperature, and force to flex branches 10 cm.

2.2 Experiment 2 – Interception by Sagebrush
Preparation of Sagebrush: 1. Identify the study area by selecting a zone that is: dominated by Big Sage (Artemesia tridentata), affected by similar environments - aspect, elevation, soils, and, contains a variety of burn regimes: (Figure 5)
   o Burned in 1996 (referred to as 96 Burn)
   o Burned in 1988, but not 1996 (referred to as 88 Burn)
   o Not burned in recorded past (referred to as No Burn)

2. Select two Big Sage (Artemesia tridentata) shrubs from each burn regime that are representative of the size and structure of the Big Sage (Artemesia tridentata) shrubs in that area.

Collection of Branch Resistance Data: 1. Select three representative branches on each shrub for measurement of bending resistance; 2. Measure circumference at base of each representative branch. 3. Mark “pull point” on each branch with a loop of string to attach the scale, at the base of this year’s new growth, to avoid over-flexible new growth and extremely rigid older growth. 4. Stabilize shrubs in a natural upright position, so trunk does not move when branches are pulled down 10 cm for bending resistance measurements. 5. Collect data every 1-2 hr for ambient air temperature and force to flex branches 10 cm, every 3 hours through 24 hours with a cooling and warming period (Figure 6).

Collection of Snow Interception Data: 1. Secure shrubs by hanging in natural upright position on suspended wires, slightly above ground. Secure clear plastic tarps on ground below each shrub, each the size of square surface area of largest shrub, to catch falling snow that reaches ground rather than being intercepted (referred to as Ground). 2. Secure 2 tarps also in the open, not under shrubs, as Controls. 3. Collect intercepted snow immediately after snow storms to avoid loss due to wind, sublimation, melting, or unloading. 4. Bag snow from each tarp and each shrub into its labeled bag, and record mass. (Figure 6)

3. DISCUSSION OF RESULTS
3.1 Summary of Results
In the conifer experiments, the fir data supported all hypotheses. As moisture content decreased, branch resistance increased and sapwood temperature did fluctuate less. The pine had mixed results. As the pine’s moisture content decreased, branch resistance also decreased. Yet as the moisture content decreased, the sapwood temperature did fluctuate less. There was a difference between fir and pine.

In the sagebrush investigation, all of the sagebrush hypotheses were supported. As the shrub maturity increased, the branch bending resistance increased, and the percent of intercepted snow increased.

This current research can be used to emphasize the need to capture snow in a dense snow pack wherever additional stored moisture is needed in the spring. Closer estimations of spring water supply can be made based on shrub maturity and wind patterns throughout winter.

These results will help scientists use vegetation type and maturity to more accurately predict interception of snow and loss by sublimation.

3.2 Discussion of Conifer Results:
Lodgepole Pine (Pinus contorta) and Subalpine Fir (Abies lasiocarpa) branches were dried to decreasing moisture levels to represent increasing stages of drought. The resistance was measured in grams every hour for 24 hours. Both the Pine and the Fir showed distinctive patterns in the branch resistance between different moisture contents. All branches also showed a close relationship between the branch resistance and sapwood temperature. As the temperature decreased, the branch resistance increased, and...
as the temperature increased, the branch resistance decreased.

Conifer Branch Resistance Results:
The High, Medium, and Low Moisture Pine all followed a similar pattern of increase and decrease in branch resistance; the High Moisture had the highest resistance level, while the Low Moisture had the lowest (Figure 7).

![Figure 7. Comparison of Pine Branch Resistance to Sapwood Moisture Content](image)

While all moisture levels of the Fir followed the same correlation of temperature and resistance as the Pine, the difference between moisture content was quite different. The highest moisture in Fir branches had lowest resistance, and lowest moisture had highest resistance (Figure 8). This was the opposite of the Pine, thus supporting Hypothesis 1C, because the genus of the conifer did affect the branches’ resistance to bending.

![Figure 8. Comparison of Fir Branch Resistance to Sapwood Moisture Content](image)

The resistance data for the Fir supported the Hypothesis 1A, because as the moisture content decreased, the branch resistance increased. However, the Pine data did not support Hypothesis 1A, because in the Pine branches, as the moisture content decreased, the branch resistance also decreased.

Conifer Sapwood Temperature Results:
Sapwood temperature was measured using a hypodermic needle temperature probe, inserted into a 1.0 mm hole drilled into the sapwood of each tree branch. Temperature was measured every hour for 24 hours, for both a warming and cooling period.

Sapwood temperature followed a close negative correlation to resistance measurements, having a gradual decrease followed by a gradual increase. Pine High Moisture temperatures ranged from 6.5 degrees Celsius (°C) to -13 °C. When a trend line was generated, the results showed the R² value at 0.1313, which showed that the variation off the trend, or the overall fluctuation of sapwood temperature, was 0.1313.

The Pine Medium Moisture branches showed a similar overall pattern in the sapwood temperature. The branches ranged in core temperature from 2 °C to -15°C. The trend line showed the R² value to be 0.1321.

The Pine Low Moisture branches temperatures ranged from 1°C to -12°C. The results from the trend line showed that the R ² value for the Pine Low Moisture was 0.1252.

These Pine results did support Hypothesis 1B, because as moisture content decreased, the sapwood temperature did fluctuate less.

The Fir High Moisture branches sapwood temperature ranged from 3°C to -13°C. The trend line showed the R² value to be 0.114.

The Fir Medium Moisture branches ranged from -0.5°C to -13°C. The trend line demonstrated an R² value of 0.1092.

The Fir Low Moisture ranged from 0°C to -12°C. The R² value for the Fir Low Moisture branches was 0.1046.

These Fir results support Hypothesis 1B, because as moisture content decreased, sapwood temperature did fluctuate less.

Statistical Analysis Results for Conifer Branch Temperature and Bending Resistance:
The R² values of each moisture type were charted to determine the difference between the fluctuations of temperature. For the Pine branches, the Medium Moisture Content had the highest R² value, and the Low Moisture Content had the lowest. Nevertheless, the trend line showed that the slope was a -0.0031; meaning that for every one Moisture Content level decreased, the R² value, or fluctuation of temperature, would decrease 0.0031 (Figure 9).
The R² values for Fir branches followed a similar trend to those of Pine. In Fir, the High Moisture Content had the highest R² value, and the Low Moisture Content had the lowest R² value. The trend line showed a slope of -0.047, demonstrating that for every one Moisture Content level decreased, the R² value, or fluctuation, would decrease -0.047 (Figure 10).

The Resistance Coefficients were calculated for all branch types. This number represents the % of resistance change per one degree Celsius. It was found that both the genus of the tree and the moisture content affected the resistance coefficient. Pine had consistently larger coefficients than the fir. The High Moisture Content had the highest resistance coefficient, and the Low Moisture Content had the lowest coefficient. The trend line for the Pine had a slope of 6.8625, a y-intercept of -22.991, and an R² value of 0.9498. The trend line for the Fir had a slope of 3.1907, a y-intercept of -10.694, and an R² value of 0.8489. This data showed that the Pine was much more responsive to a change in environmental factors (Figure 11).

The resistance coefficient data supported Hypothesis 1C, as the genus of the tree did affect the resistance coefficient.

3.4 Discussion of Sagebrush Results:
Big sagebrush (Artemisia tridentata) was selected from three age groups distinguished by burn areas. The three age classes were: No Burn – no record of recent burning, 1988 Burn – large fire in 1988, and 1996 burn, large fire in 1996. Each of these was later measured for maturity by counting rings for age in years; No Burn averaged 23.5 yrs, 1988 Burn averaged 13.5 yrs, and 1996 Burn averaged 5.5 yrs.

Sagebrush Branch Resistance Results: The resistance was measured in Newtons (N) every hour for 15 hours. There were distinctive patterns in the branch resistance between different maturities. All shrubs also showed a close relationship between the branch resistance and ambient air temperature; as the temperature decreased, the branch resistance increased.

The highest branch resistance occurred in the No Burn branches and the lowest resistance occurred in the 1996 Burn branches. In a resistance over temperature scatter plot, the No Burn branches started on the x-axis at -3.7ºC with a resistance of 23 N, and then gradually increased in resistance to an ending point of 29.5 N (Figure 12).

The 1988 Burn branches started on the x-axis at -3.7ºC with a resistance of 16.5 N, and gradually increased in resistance to an ending point of 26 N. (Figure 12).

The 1996 Burn branches started on the x-axis at -3.7ºC with a resistance of 5 N, and gradually increased in resistance to an ending point of 26 N.
increased in resistance to an ending point of 8.5 N (Figure 12).

Regression Analysis - Sage Maturity (yrs) vs. Branch Bending Resistance

\[ y = 1.0396x + 4.0225 \]
\[ R^2 = 0.8581 \]

Figure 12. Percent Coefficient: Sage Maturity (yrs) versus Branch Resistance

A regression analysis of maturity in years vs. branch bending resistance was run, which led to a percent coefficient. The percent coefficient stated that for every 1 year increase in maturity, the resistance of the sage branches to bending would increase 25.84%. This supported Hypothesis 2A, because as the maturity of the sage increased, the branches' resistance to bending also increased.

Sagebrush Snow Interception Results:
Snow was intercepted over three separate storms by the sage of various maturities. Each sage was suspended upright in a natural position. After each storm, both non-intercepted snow from non-intercepted snow tarps' on the ground below the sage, and the intercepted snow in the sage was collected and massed to determine the percent of interception each sage achieved. The first storm produced moderate snowfall, the second storm produced very little snowfall, and the third storm produced a very large amount of snowfall.

The Control, a No Sage area where all snow fell directly onto the non-intercepted snow tarps' intercepted a mean of 3021 g of snow. This was used as a base of comparison for the sage brush interception percentages.

The total percentage of interception by each sage was calculated by dividing the amount of snow intercepted by the amount of total snow fallen in that area. Therefore, the Control – No Sage always intercepted 0% of the fallen snow.

The No Burn sage intercepted 60% of snow during the first storm, 8% during the second storm and 27% during the third storm, therefore produced a mean of 29% of intercepted snow.

The 1988 Burn sage intercepted 25% of snow during the first storm, 4% during the second storm and 12% during the third storm, therefore produced a mean of 12% of intercepted snow.

The 1996 Burn sage intercepted 6% of snow during the first storm, 1% during the second storm and 4% during the third storm, therefore produced a mean of 4% of intercepted snow.

Statistical Analysis Results for Sagebrush Bending Resistance and Snow Interception:
A regression analysis was conducted comparing maturity, by burn zones, to the percent of snow interception over each storm. This showed that for all storms, regardless of the severity, as the maturity of the sage increased, the percent of interception also increased. For the Mean of All Storms data, the trend line had a slope of 0.0969, a y-intercept of -0.1288, and a R² value of 0.9129. This supported Hypothesis 2B, because as the maturity of the sage increased, the percent of snow interception also increased (Figure 13).

A percent coefficient was generated that described the amount for every 1 year increase in the maturity of sage that the percent of interception would increase on a percentage basis. This concluded that for every 1 year of increase in maturity, the percent of interception would increase 17.37% (Figure 14).
Regression Analysis - Sage Maturity (yrs) vs. Percent Snow Interception

\[ y = 2.4968x - 14.371 \]
\[ R^2 = 0.9192 \]

Figure 14. Percent Coefficient: Sage Maturity (yrs) versus Percent Snow Interception

T-tests were run to determine if amounts of snow being intercepted by sage were significantly different from a non-intercepted area, and if maturity of the sage caused a significant difference in the percent of interception. In the t-test comparing Control-No Sage area to No Burn Sage, there was within a 99% confidence level a significant difference in the snow intercepted by No Burn sage and that intercepted by the No Sage area.

In the t-test comparing Control-No Sage area to 1988 Burn Sage, there is within a 99% confidence level a significant difference in the snow intercepted by 1988 Burn Sage and that intercepted by the No Sage area.

In the t-test comparing the Control-No Sage area to the 1996 Burn Sage, there is within a 99% confidence level a significant difference in the snow intercepted by the 1996 Burn sage and that intercepted by the No Sage area.

In the t-test comparing the No Burn Sage to the 1988 Burn Sage, there is within a 99% confidence level a significant difference in the snow intercepted by the No Burn sage and that intercepted by the 1988 Sage area.

In the t-test comparing the No Burn Sage to the 1996 Burn Sage, there is within a 99% confidence level a significant difference in the snow intercepted by the No Burn Sage and that intercepted by the 1996 Sage area.

In the t-test comparing the 1988 Burn Sage to the 1996 Burn Sage, there is not a significant difference in the snow intercepted by the 1988 Burn Sage and that intercepted by the 1996 Burn Sage area.

This supported Hypothesis 2B because as maturity of the sage increased, the percent of interception of snow increased significantly.

4. CONCLUSION

The applications of the current research focus on the need to preserve water in drought. Today much of the Western United States is still in a drought, which in many areas is predicted to increase in the upcoming years. The use of snow as a water resource, or ‘snow harvesting’ is becoming very popular. Understanding the interception of snow by vegetation, and potential loss of that intercepted snow by sublimation, is important for scientists and land managers. Interception of falling snow by vegetation can increase loss of snow through sublimation, therefore decreasing potential spring water supply.

As many drought afflicted areas are predominantly vegetated by conifers, Lodgepole pine (*Pinus contorta*) and Subalpine Fir (*Abies lasiocarpa*), and the shrub sagebrush (*Artemisia tridentata*), interception of snow by these types of vegetation is noteworthy. The branches’ resistance to bending determines how much snow will be unloaded into the dense snow pack, and how much will remain intercepted, therefore exposed to loss through sublimation. Warming periods allow branches to become more flexible, which causes them to unload their intercepted snow. Unloaded snow then becomes part of the denser snow pack on the ground, rather than being lost to sublimation.

The conifer investigation looked at the varying branch resistances in conifers of different moisture contents, signifying the effects of drought on branch resistance. It was found that moisture content, or drought severity, did have an extreme effect on the branches’ resistance. With fir trees, as the moisture content decreased, the branch resistance increased, yet with pine trees, as moisture content decreased, branch resistance also decreased. If more water were needed in a drought condition, it would be best to plant pine trees, as they would have less branch resistance, thus unload more snow. For example, in Canada a great amount of damage occurs through flooding. The government is replanting areas with conifers that have a high branch resistance, to try to use interception and sublimation to eliminate this water, and decrease the floods. In contrast, in the western U.S., trees with low branch resistance should be planted, as they will allow the snow to unload into the dense snow pack for a spring water supply.

The sagebrush research focused on the varying branch resistances and snow interception percentages in sage from different burn zones, signifying the effects of maturity on branch resistance and snow interception. It was found that
the maturity of the sage did have an extreme effect on branches' resistance, and therefore percent of snow interception.

To increase water availability in the spring, a lower level of maturity is needed. The 1996 burn sage, approximately 5.5 years of age, intercepted the lowest percentage of snow, therefore would be the ideal ground coverage to retain snow as a potential water supply. These results encourage controlled burning to maintain a low maturity of sage, which would in turn increase potential water supply by increasing the amount of snow unloaded into the ground snowpack.

This current research can be used to emphasize the need for closer estimations of spring water supply based on vegetation type, maturity, temperatures, and wind patterns throughout the winter.

These results will help scientists use conifers and sagebrush, to more accurately predict interception and sublimation, and more economically manipulate snow and vegetation for enhanced water supply during drought.

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6. REFERENCES


