Study of the Impact of Snow Avalanche on Vegetation Using Geographic Information Systems

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Abstract

John F. Stevens Canyon is located in the southern boundary of Glacier National Park, Montana, United States of America. Snow avalanches are very common in the Stevens Canyon often threatening and injuring people and property. This research uses Geographic Information Systems (GIS) to study impacts of snow avalanches on vegetation in the avalanche paths of John F. Stevens Canyon. The study incorporates historic avalanche data from the years 1986 through 2005 in avalanche paths Shed 7, Shed 8, and Shed 9 in the Stevens Canyon. Landsat 5 Thematic Mapper satellite imagery was utilized to examine vegetation changes over the period. By employing Tasseled Cap Transformation greenness method, vegetation amounts were obtained. Vegetation was classified using a Supervised classification method and subjected to Maximum Likelihood Classification to acquire total vegetation acreage per year. Finally, the impact of snow avalanches on vegetation was analyzed by comparing vegetation existence before, after, and the year of avalanche occurrence. Since snow avalanches have a strong influence with climatic conditions, a statistical correlation test was exercised on the Snow Water Equivalent (SWE), precipitation, and vegetation information of the avalanche year. Results demonstrate a decrease in vegetation in places with frequent avalanches and minimal correlation between climatic data and vegetation.

Introduction

Glacier National Park (GNP) in the United States and Water Lakes National Park in Canada were announced as the world's first "International Peace Park." GNP was also declared as Mountain Biosphere Reserves (MBR) in 1976, by United Nations Educational, Scientific and Cultural Organization (UNESCO), which explains the uniqueness of the mountain's ecosystem.

Fredston and Fesler (1984) define, a snow avalanche as a rapid movement of snow along a sloped terrain, as seen in Butler (2001). Mountain regions in the North America experience dangerous snow avalanches demolishing property, and even death at times (Voight, Armstrong, B., Armstrong, R., Bowles, Ferguson, Fredston, Kiusalaas, McFarlane, and Penniman, 1990). Most of the snow avalanche paths of Glacier National Park disturb people and trees (Butler, 1979).

Frequency of avalanches is determined by the terrain and climate (Voight *et al*., 1990). Butler and Walsh (1990); Keylock (1997) indicate that snow avalanches usually follow a similar path from the source through the run-out

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region, as mentioned in Butler (2001). Avalanche paths in the park occur mainly on slopes with diverse forest (Reardon and Fagre, 2006). Vegetation indicates a slope's stability by showing the amount of trees on a slope (McCollister and Birkeland, 2006). Fagre (2003), reports conifers, and deciduous trees occupy about 60 percent of GNP. An occasional large avalanche has the ability to extirpate old trees and leave gaps; the slow growing vegetation are affected by frequent small avalanches but fast growing trees remain unaffected (Reardon and Fagre, 2006).

According to Butler and Malanson (1985a), trees damaged by an avalanche are tilted, broken, or scarred. Researchers use the tree's direction of tilt to understand the source of previous avalanches (Butler and Malanson, 1985b). Earlier photographs of the paths and overall vegetative conditions indicate avalanches happen in the paths every year (Butler, 1979).

Stevens Canyon in GNP has about 40 avalanche paths affecting transportation along US Highway 2 (Reardon, Fagre, and Steiner, 2004). Sawyer and Butler (2006) state Burlington Northern Santa Fe Railway (BNSF) located near the Stevens Canyon also gets obstructed and damaged by snow avalanche debris.

In order to understand the behavior of snow fall and snow packs in GNP, the United States Geological Survey (USGS) have been exploring archival records of GNP avalanches on Going to the Sun Road (GTSR) and Stevens Canyon (Reardon and Fagre, 2006). Knowledge of historical avalanches helps in understanding avalanche-climate relationships (Reardon and Fagre, 2006). Vegetation trauma marks avers avalanche occurrence, benefitting park development and providing avalanche mitigation planning techniques (Pederson, Reardon, Caruso and Fagre, 2006). Avalanche hazard mitigation programs are seeking new techniques; one of the techniques is natural reforestation. Understanding the cause and the impacts of snow avalanches, may also help in finding new hazard mitigation techniques and ways to sustain mountain ecosystems.

With this research, the primary focus is to use GIS in studying the amount of vegetation affected by snow avalanches in the John F. Stevens Canyon. Study objectives also included comparing vegetation response to snow avalanches over a period of time.

Study Area

The study consisted of three avalanche paths: Shed 7, Shed 8, and Shed 9 of Stevens Canyon. All three sheds are located within a mile between each other. These three sheds are considered for study based on previous avalanche occurrences and their damaging impacts on timber and local transportation. Additionally, avalanches paths Shed 7 and Shed 8 have distinctive branches: Shed 7 is classified as Shed 7 East and Shed 7 West; Shed 8 is categorized as Shed 8 and Shed 8 Low. The primary branch of Shed 9 is considered for study – the additional Shed 9 branch was not mentioned in archival records and therefore was not used. The study area with all branches is displayed in Figure 1.

As inferred from Hamre and Overcast (2004), all three avalanche paths are unique in their size, shape, elevation, slope, and aspect pertaining to snow avalanches. Table 1 contains characteristics of all three avalanche paths.

According to Hamre and Overcast (2004), avalanche paths are classified into distinctive parts: start zone, track zone, and run-out zone. Start zones are regions

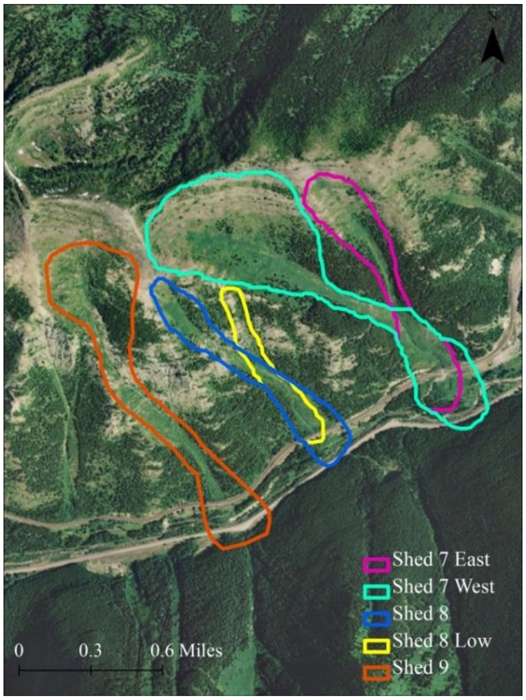

Figure 1. The study area Shed 7 East (Pink), Shed 7 West (Green), Shed 8 (Blue). Shed 8 Low (Yellow) and Shed 9 (Orange) is displayed over an aerial imagery of Stevens Canyon.

at higher elevations where snow avalanches originate. Track zones are regions with enough steepness to sustain the flow of avalanches. Terrain with less than ten degree of slope contributes to the run-out zone; here snow tends to slow down.

Table 1. Avalanche path attributes. Adapted from Hamre and Overcast (2004).

Path name	Starting zone elevation in Feet	Aspect	Shed length in Feet
Shed 7	6760	South to Southeast	1000
Shed 8	6520	Southeast	650
Shed 9	6800	South to Southeast	400

The archival records indicated seven snow avalanches occurred in Shed 7 between 1996 and 2005, and five snow avalanches in Shed 8 between 1986 and 2005. In contrast, Shed 9 reported only three snow avalanches between 1990 and 2003.

Methods

Data Collection

Historical Avalanche Data

The historical avalanche data was collected from USGS (data prepared by B. R., 2006). Historical information was dated from 1910 to 2006 with the date, month, year and place of every natural avalanche occurrence in Stevens Canyon compiled from earlier photographs, newspapers reports and personal observations of avalanche specialists.

For the study, data was organized and sorted in Microsoft Excel in a yearly manner starting from year 1985 for each avalanche path. This helped in understanding the number of avalanches that occurred in each path, the seasonal relationships, and the frequency of the avalanches.

Satellite Imagery Collection

According to McCollister and Birkeland (2006), data acquisition period matters while using vegetative cover for analysis, since vegetation is prone to change by disasters. As a result, satellite imagery was chosen for studying vegetative changes.

Landsat 5 Thematic Mapper (TM) images were collected from 1985 to 2006 from United States Geological Survey (USGS). Imagery for the study area was chosen based on coverage availability of the time period and the quality of multispectral images. Landsat 5 imagery contains 7 bands: Band 1 (Blue-Green), Band 2 (Green), Band 3 (Red), Band 4 (Near Infrared), Band 5 (Mid Infrared), Band 6 (Thermal Infrared), Band 7 (Mid Infrared) with a 30 meter resolution except for Band 6 with 120 meter resolution (Short, n.d.).

The Landsat 5 TM scenes for the study area were identified in Path 41 and Row 26 as per the Worldwide Reference System (WRS). The best quality images with no haze were downloaded and separated for each year.

Imagery Selection for Study

Avalanches in the Shed 7, Shed 8, and Shed 9 occurred in the winter and spring seasons. To monitor the effect of snow avalanche on vegetation, imagery was used during the growing season from June to September. The analysis methodology for every avalanche occurrence involved calculating acres of vegetation during the year before an avalanche, the year of avalanche occurrence, and year after the avalanche. This type of vegetative comparison was selected to learn whether vegetation was disturbed by snow avalanches and also helped to infer any amount of vegetative re-growth.

Climatic Data Collection

Climatic data like Snow Water Equivalent (SWE) and precipitation were acquired from Snow Telemetry (SNOTEL) from the Pike Creek SNOTEL center near Stevens Canyon.

The data was distinguished based on avalanche occurrence for every avalanche path. Data was available on a daily basis. As a result, an average value of SWE and precipitation was calculated. The SWE and precipitation readings were recorded from the day of snow fall in the previous year until the avalanche occurrence. The average was calculated for every avalanche occurrence year and correlated against vegetation acreage during the avalanche year. The method helped to learn about relationships between climatic data and vegetation gain or loss.

Data Preparation

Initially, the United States topographic base imagery was added through ArcGIS. Then, Stevens Canyon Avalanche Atlas images of Hamre and Overcast (2004); Scott (2009) were added for geo-referencing Atlas images to the base imagery. Latitude and longitude values in the Atlas images were in Degree Minutes and Seconds (DMS). The DMS values were converted to Decimal Degrees (DD) using the formula below:

$$DD = \text{Degree} + (\text{Minutes}/60) + (\text{Seconds}/3600)$$

Using the Geo-Referencing Toolbar in ArcGIS, control points were added to the Atlas image. By using the Input XY option, DD values were entered for each control point. The Atlas image was geo-referenced with Root Mean Square error value of less than one.

Polygon shapefiles were created for each avalanche path through on-screen digitizing over of the geo-referenced Atlas image. The attribute table was updated with name of each polygon in each avalanche path.

Data Derivation

Thirty meter Digital Elevation Models (DEMs) covering GNP region were obtained from the Montana Geographic

Information Clearinghouse website. In order to cover the extent of the study area (Shed 7, Shed 8 and Shed 9), two raster DEM layers were mosaicked together. Next, DEM values for each avalanche path were clipped using the digitized polygons. Slope and Aspect values were then derived for each avalanche path.

Tasseled Cap Transformation

Tasseled Cap Transformation is used to retrieve brightness, greenness and wetness of an image (Aufmuth, 2001). Tasseled Cap Transformation provides a favorable technique to extract vegetation details from a multispectral image (Crist and Kauth, 1986). Crist and Cicone (1984) state Tasseled Cap Transformation Greenness is a comparison between near infrared and red bands in the image. As plant cells with high chlorophyll content absorb visible radiation and emit infrared radiation, dense vegetative regions appear dark green with the rest in lighter shades of green. Crist and Cicone (1984); Crist and Kauth (1986) convey Tasseled Cap Transformation is performed by multiplying a specific constant to the digital number of the band's pixel and summation of indexes of the bands as seen in Aufmuth (2001). Toomey (n.d.) states the formula used for calculating greenness includes the following:

$$\text{Greenness} = (-0.2728 * \text{TM Band 1}) - (0.2174 * \text{TM Band 2}) - (0.5508 * \text{TM Band 3}) + (0.7221 * \text{TM Band 4}) + (0.0733 * \text{TM Band 5}) - (0.1648 * \text{TM Band 7})$$

Using the formula in the ArcGIS Raster Calculator Tasseled Cap Greenness was generated for all images.

After generating Tasseled Cap Greenness of each image, study areas (Shed 7, Shed 8, and Shed 9) were clipped using the digitized polygons. The compression was uniformly set to "none" for the images during raster analysis.

Supervised Classification

The bright pixels from Tasseled Cap Transformation Greenness indicate thick canopy of vegetation. Since Landsat imagery of 30 meter resolution was used for the study, it was difficult to segregate vegetation based on their types. Thus, trees and shrubs with dense canopy were used as vegetation for the study. Moreover, values displayed were floating point. To obtain vegetation discrete value counts, the images were subjected to Supervised Classification.

For every image considered for analysis, training samples were collected using the Training Sample Manager Tool. To create a training sample, tiny polygons were drawn on pixels with similar appearances. The raster images were then classified based on training samples by utilizing Interactive Supervised Classification Tool. This tool was used as a test to check if the samples were treated properly. The Swipe Tool in the Effects Toolbar confirmed the classification. Upon satisfactory results, a signature file was created for the samples. The signature file holds statistical information for the created classes. The final image classification was completed using the Maximum Likelihood Classification tool with the raster image and signature file as inputs. The tool computes the likelihood of a cell belonging to a certain class with the help of a signature file and allocates the cell to the class with maximum likelihood. Finally, counts of the bright vegetation in the study were obtained. The acres of vegetation were obtained from the formula:

Acres = 30 * 30 * Count * 0.0002471

Statistical Analysis

The prominent attributes of a snow avalanche are referable to the region's climate and the weather preceding the event (Mock and Birkeland, 2000). The climatic factor responsible to induce an avalanche corresponds to the magnitude of an avalanche, which has the possibility of affecting vegetation. Thus, correlating weather parameters of every avalanche occurrence to vegetation availability during the year may help to further understand climate-vegetation relationships.

Pearson Correlation test was used with SPSS (Statistical Package for Social Sciences) with Snow Water Equivalent (SWE) and precipitation variables compared to vegetation data. Snow cover in a region is represented as SWE (Fierz, Armstrong, Durand, Etchevers, Greene, McCLung, Nishimura, Satyawali and Sokratov, 2009).

Classification Results

Shed 7

This section includes analyses performed on Shed 7 (Figure 1). Table 2 includes vegetation availability (in acres) for the year prior, after, and the year during avalanche occurrence. Table 2 shows three comparisons of vegetation changes in percentage: the year prior and the year during an avalanche, the year during an avalanche and the year after, and lastly the year before and year after an avalanche.

Avalanche Year 1996

A snow avalanche occurred in February of 1996. When comparing years 1995 and 1996, vegetation was found altered in the start zone region of the path resulting in four percent loss. Vegetation decreased another 4 percent the year following (1996-1997). The archival records (B. R., 2006) indicate snow avalanches occurred in various avalanche paths of Stevens Canyon during 1997, yet Shed 7 was not mentioned explicitly. Still, Shed 7's track zone region had vegetation loss, so there could have been an avalanche in Shed 7.

Avalanche Year 2002

After a six year period, another avalanche occurred in Shed 7 in February of 2002. This led to an 8.7 percent loss in vegetation from the previous year of 2001. Missing vegetation was noticed in the western part of the Shed. Records from B. R. (2006) also state the avalanche actually occurred in Shed 7 West. Further, records (B. R., 2006) confirm the avalanche knocked down trees of six inch diameter. Still, vegetation growth increased by 4.3 percent by 2003.

Avalanche Year 2003

Two avalanches occurred in March of 2002 in areas of Shed 7 West and Shed 7 East. Records from B. R. (2006) indicate the avalanches cleared many trees and a 25.7 percent loss was noticed from 2002 - 2003. The vegetation increased by 31.6 percent in the year 2004.

Avalanche Year 2004

With a 25.7 percent loss of vegetation, the January and March 2004 avalanche removed trees in the eastern and center region of Shed 7 coinciding with the records (B. R., 2006). Shed 7 East endured profuse vegetation damage during this event.

Table 2. Shed 7 variations in vegetation acreage and percent change.

Year before avalanche (Left). Vegetation in Acres (Right)		Year during avalanche (Left). Vegetation in Acres (Right)		Year after avalanche (Left). Vegetation in Acres (Right)		Percent change (before and during avalanche year)	Percent change (during and after avalanche year)	Percent change (before and after avalanche year)
1995	28.4665	1996	27.1321	1997	26.0201	4 Loss	4 Loss	8.5 Loss
2001	30.6904	2002	28.0217	2003	29.3561	8.7 Loss	4.7 Gain	4.3 Loss
2002	28.0217	2003	29.3561	2004	21.7946	4.7 Gain	25.7 Loss	22.2 Loss
2003	29.3561	2004	21.7946	2005	28.6889	25.7 Loss	31.6 Gain	2.2 Loss
2004	21.7946	2005	28.6889	2006	25.7978	31.6 Gain	10 Loss	18 Gain

Avalanche Year 2005

Shed 7 West and Shed 7 East experienced avalanches in January of 2005. Besides the 2004 trauma and avalanches in 2005, vegetation responded with growth of 31.6 percent in year 2005.

Overall Shed 7 Analysis

From 1995 to 2006, the majority of the observations indicated there was a loss in vegetation due to avalanche occurrences, but there was an occasional re-growth in the area (Table 2). However, 28.4665 acres of vegetation was reduced to 25.7978 acres by the end of 2006 (Figure 2). In Figure 2, vegetation in 1995 is displayed in green while 2006 vegetation is displayed in red.

Shed 8

This section includes analyses performed on Shed 8 (Figure 1). Table 3 includes vegetation availability (in acres) for the year before, after, and the year during an avalanche occurrence. Table 3 shows three comparisons of vegetation changes in percentage: the year prior and the year during an avalanche, the year during an avalanche and the year after, and lastly the year before and year after an avalanche.

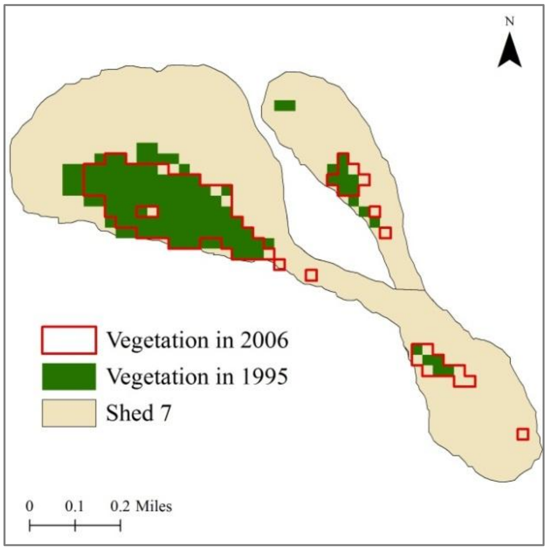

Figure 2. Changes in vegetation between years 1995 and 2006 in Shed 7. Results find a 9.3% vegetation loss between years 1995 and 2006.

Avalanche Year 1986

A small avalanche occurred in Shed 8 on February of 1986. Vegetation in 1986 displayed minor changes in the start zone region and many changes in the track zone region when compared to 1985. There was less than a two acre loss in 1986 and vegetation re-growth occurred in 1987 filling the track zone of the path.

Table 3. Shed 8 variations in vegetation acreage and percent change.

Year before avalanche (Left). Vegetation in Acres (Right)		Year during avalanche (Left). Vegetation in Acres (Right)		Year after avalanche (Left). Vegetation in Acres (Right)		Percent change (before and during avalanche year)	Percent change (during and after avalanche year)	Percent change (before and after avalanche year)
1985	5.5598	1986	3.7807	1987	8.0062	32 Loss	111 Gain	43 Gain
1989	9.5629	1990	6.0046	1991	6.4494	37 Loss	7 Gain	32 Loss
1995	5.3374	1996	5.3374	1997	4.2255	No change	20 Loss	20 Loss
2003	4.2255	2004	3.7807	2005	5.5598	10 Loss	47 Gain	31.5 Gain
2004	3.7807	2005	5.5598	2006	5.1150	10 Gain	8 Loss	35.2 Gain

Avalanche Year 1990

Snow avalanches in 1990 ended with 37 percent loss of vegetation primarily in the track zone region. According to reports from B. R. (2006), the slide was small. vegetation re-growth was noted in the year 1991.

Avalanche Year 1996

As an avalanche occurred in December of 1996, two pre-avalanche imagery comparisons of July 1995 and September1996 were analyzed. Results showed no change in the 5.3 acres of vegetation. However, in the year 1997, vegetation was reduced to 4.2 acres. Vegetation changes were noted in the track zone region.

Avalanche Year 2004

After the February 2004 avalanche, the track zone region was devoid of vegetation. Re-growth was noted in 2005 with 47 percent gain in vegetation.

Avalanche Year 2005

Although, the path experienced two avalanches in January 2005 and an occurrence in the previous year (2004), vegetation increased from 2004 to 2005 by ten percent. Furthermore, the presence of vegetation decreased by 8 percent in 2006 and displayed fewer losses in the track zone.

Overall Shed 8 Analysis

During the years from 1985 - 2006 with five snow avalanche occurrences, results showed an eight percent loss of vegetation in 2006 when compared to 1985. The findings suggest there is a vegetation loss in an area with frequent avalanches. Vegetation alteration in the year 1985 and 2006 is displayed in Figure 3. In Figure 3, vegetation in 1985 is displayed in green while 2005 vegetation is displayed in red.

Shed 9

This section includes analyses performed on Shed 9 (Figure 1). Table 4 includes vegetation availability (in acres) for the year before, after, and during avalanche occurrences. Table 4 shows three comparisons of vegetation changes in percentage: the year prior and the year during an avalanche, the year during an avalanche and the year after, and lastly the year before and year after an avalanche.

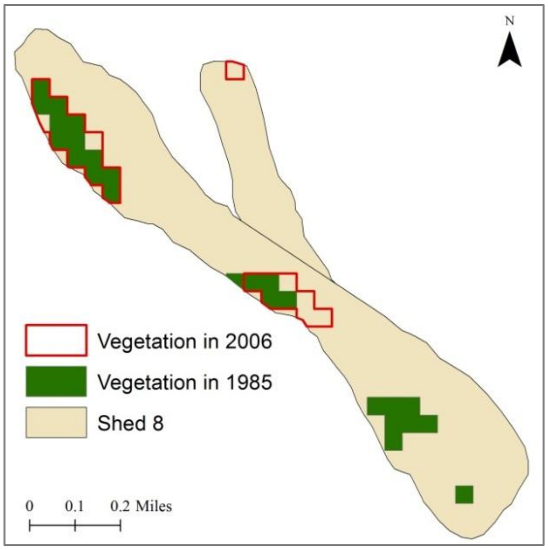

Figure 3. Changes in vegetation between years 1985 and 2006 in Shed 8. Results find an 8% vegetation loss between years 1985 and 2006.

Avalanche Year 1990

A small avalanche occurred in January of 1990. The avalanche did minimal damage according to reports (B. R., 2006). Comparing years 1989 and 1990, images indicated few alterations in the start zone region of the path with 7.4 percent loss of vegetation. Yet, vegetation growth was substantial the following year (1991) with a 38 percent gain.

Avalanche Year 1996

Like Shed 8, an avalanche occurred in December of 1996. In the year prior (1995), July imagery of the shed had dense vegetation which was reduced dramatically in September of 1996 even before the avalanche occurrence. Still vegetation appeared in the track zone region during the year 1996. The total disappearance of vegetation in the track zone in the year 1997 affirms the avalanche could have removed vegetation in the zone. Vegetation was reduced to 21.9 percent between 1996 and 1997.

Avalanche Year 2003

In March of 2003 an avalanche occurred and left six inches of debris near railroad tracks (B. R., 2006). In 2002, 13 acres of vegetation decreased to 9 acres in 2003. Changes were mainly noticed in the track zone facing southeast. Yet vegetation re-growth in 2004 was increased by 39 percent.

Overall Shed 9 Analysis

With the record of only three avalanches over a 13 year period, results indicate a gain in vegetation in the avalanche path. The amount of vegetation in 1989 was 12.0093 acres. Vegetation increased to 12.6765 acres in 2004 resulting in a 5.5

Table 4. Shed 9 variations in vegetation acreage and percent change.

Year before avalanche (Left). Vegetation in Acres (Right)		Year during avalanche (Left). Vegetation in Acres (Right)		Year after avalanche (Left). Vegetation in Acres (Right)		Percent change (before and during avalanche year)	Percent change (during and after avalanche year)	Percent change (before and after avalanche year)
1989	12.0093	1990	11.1197	1991	15.3452	7.4 Loss	38 Gain	27.7 Gain
1995	15.3452	1996	11.1197	1997	8.67339	27.5 Loss	21.9 Loss	43.4 Loss
2002	13.1212	2003	9.1181	2004	12.6765	30.5 Loss	39 Gain	3.3 Loss

percent increase. This perhaps helps show that vegetation was diminished in a place with frequent avalanches. Figure 4 shows vegetation in Shed 9 during 1989 (displayed in green) and 2004 (displayed in red.

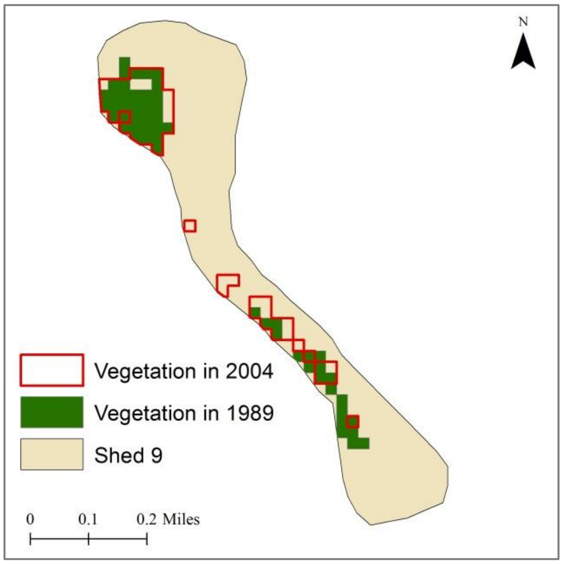

Figure 4. Changes in vegetation between years 1989 and 2004 in Shed 9. Results find a 5.5% vegetation gain between years 1989 to 2004.

Statistical Analysis Results

Correlation analysis involved the Snow Water Equivalent (SWE), precipitation, and vegetation acreage of avalanche years in the avalanche paths for Shed 7, Shed 8, and Shed 9.

Table 5, Table 6, and Table 7 display correlation results for Shed 7, Shed 8, and Shed 9 respectively.

Table 5. Pearson Correlation results for Shed 7 where N = 7.

	*SWE	Precipitation	Vegetation
*SWE	1	0.927	-0.488
Precipitation	0.927	1	-0.250
Vegetation	-0.488	-0.250	1

* Snow Water Equivalent

Table 6. Pearson Correlation results for Shed 8 where N = 5.

	*SWE	Precipitation	Vegetation
*SWE	1	0.786	0.171
Precipitation	0.786	1	-0.118
Vegetation	0.171	-0.118	1

* Snow Water Equivalent

Table 7. Pearson Correlation results for Shed 9 where N = 3.

	*SWE	Precipitation	Vegetation
*SWE	1	0.696	-0.429
Precipitation	0.696	1	-0.947
Vegetation	-0.429	-0.947	1

* Snow Water Equivalent

The test considered values in between 0.70 to 1.00 showing a strong correlation between variables. Table 5 displays the correlation matrix for Shed 7. The correlation coefficient for vegetation versus SWE resulted in a value of -0.488; for vegetation versus precipitation resulted in a value of -0.250. The result showed no strong correlation between variables. Shed 8 (Table 6) shows the correlation coefficient for vegetation against SWE resulting in a value of 0.171. Although, the value is positive, it is not a good correlation. Vegetation and precipitation displayed no correlation with a correlation coefficient of -0.118. This shed also demonstrated a negative relation between the variables. The correlation coefficient of Shed 9 for vegetation versus SWE was -0.429, which was not statistically significant. The correlation coefficient for vegetation versus precipitation was -0.947; showed a strong negative correlation between the variables. The probability of correlation between precipitation and vegetation had a 95% confidence. Thus, during an avalanche event, variations in vegetation acreage exhibit minimal correlation to SWE and precipitation values. In addition, it should be noted the sample size for the study was relatively small due to data inaccessibility. Further research into greater samples may help to reaffirm or increase accuracy if this process is replicated.

Research studies of Cain (1944); Parsons (1990); Saetersdal and Birks (1997); Siikamaki and Lammi (1998), found vegetation in Glacier National Park (GNP) were expected to change due to environmental stress, as viewed in Lesica and McCune (2004). Moreover, Reardon, Fagre, and Steiner (2004) suggest avalanche cycles in Stevens Canyon occur oftentimes in spite of climatic fluctuations. In general, climate influences vegetation and induces avalanches. From the analysis, it could be conjectured that snow avalanche causes more peril to vegetation regardless of the underlying climatic factors.

Conclusion

The study conducted a GIS analysis to monitor impacts of snow avalanches on vegetation in Shed 7, Shed 8, and Shed 9 of Stevens Canyon, Montana. The study used historical records and satellite imagery to aid in exploring patterns in vegetation changes in avalanche paths. Climatic components influencing avalanches has little correlation with vegetation gains or losses.

Over periods of time, findings support diminution in vegetation in avalanche paths with frequent snow avalanches, such as Shed 7 and Shed 8. Furthermore, some findings depict re-growth in vegetation in the year following an avalanche. Alternatively, Shed 9 experienced a low snow avalanche frequency and responded with a gain in vegetation. Therefore, findings support greater avalanche frequencies result in greater loss of vegetation in the study area of Shed 7, Shed 8, and Shed 9.

Data Limitations

Snow avalanches are one type of hazard that can be natural or human triggered. Therefore, for assumed security reasons, detailed accounts of data collection and accuracy of avalanche path areas were limited and generally inaccessible when attempts were made to acquire the data for study. Moreover, historical records of snow avalanches were inconsistent and do not include intricate details.

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