THE EFFICACY OF AERIAL PHOTOGRAPHY ANALYSES FOR DETERMINING DISTURBANCES IN AQUATIC ECOSYSTEMS

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Katherine E. Lanspery
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Major Professor: Ronald Robberecht, Ph.D.

AUTHORIZATION TO SUBMIT

THESIS

This thesis of Katherine E. Lanspery submitted for the degree of Masters of Science with a major in Rangeland Ecology and Management and titled "The efficacy of aerial photography analyses for determining disturbance in aquatic ecosystems" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ______________________ Date 12·14·05
Ronald Robberecht

Committee Members ______________________ Date 12/16/05
Jay J. O'Laughlin

______________________ Date 12/15/05
Timothy E. Link

Department Administrator ______________________ Date 15Dec05
Karen L. Launchbaugh

Discipline's College Dean ______________________ Date 16Dec05
Steven B. Daley Laursen

Final Approval and Acceptance by the College of Graduate Studies

______________________ Date __________
Margrit von Braun

Abstract

Large ungulate herbivory can significantly affect the ecological status and habitat of salmonid fish species. Instruments and methods such as aerial photography and GIS analyses, may allow disturbance such as grazing to be remotely detected in stream and riparian habitat over a broad temporal scale. We examined ecological changes in two components of aquatic habitat: riparian vegetation structure and channel morphology for the years 1977, 1986, 1999, 2002 and 2004. Field data and historical aerial photographs were used for the analyses of a 500-m section of the Upper East Fork Salmon River located in central Idaho. Analyses of aerial photographs were performed in ERDAS Imagine 8.7 and Leica Photogrammetry Suite, consisting of orthorectification, measurement, and qualitative interpretation. Our results indicated that mean channel width has significantly decreased over the observation period, but fluctuations occurred in the area of depositional features, resulting from the maintenance and recovery of frequent flooding events. Significant improvements in habitat condition did not occur after the decrease of grazing intensity in 1999, however significant changes in habitat occurred from 1977 to 2004. Remote sensing analyses using aerial photography proved to be an efficient, user-friendly method to detect long-term ecological trends in aquatic systems in relation to disturbance.

Keywords: aquatic disturbance, herbivory, stream and riparian habitat, remote sensing, aerial photography interpretation, livestock grazing

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Introduction

Riparian areas and stream channels are interconnected through numerous biotic and abiotic ecological processes including nutrient cycling, sedimentation, and temperature regulation (Wetzel 2001, Brooks et al. 2003). Salmonid species such as *Oncorhynchus tshawytscha* (Chinook salmon) are sensitive to modifications of temperature and sedimentation in their spawning and rearing habitat, which is located in the upper portions of drainages in low gradient channels (Allen and Hassler 1986, Bauer and Ralph 1999, Poole et al. 2001). Riparian vegetation provides canopy cover to the stream and thereby regulates water temperature, and root structures stabilize banks during high discharge events (Platts 1981, Neary and Medina 1996). Large ungulate herbivory can significantly affect the structure and function of fish habitat in aquatic ecosystems (Platts 1981, Murray et al. 2004)**.** Detecting and evaluating changes in the long-term function and structure of stream and riparian habitat is essential for understanding alterations caused by herbivory and/or natural disturbances. The analyses of historical aerial photography with current remote sensing techniques provides a potentially useful tool to track changes in stream and riparian habitat in response to disturbance (Laliberte et al. 2001, Mount 2002, Covington and Hubert 2003, Mount 2003).

Large herbivores such as cattle use the abundant vegetation available in riparian areas and concentrate in high numbers to forage, especially in the spring in semi-arid and arid ecosystems (Platts 1981, Roath and Krueger 1982, Kauffman and Krueger 1984). For example, the removal of riparian vegetation represented 81% of utilization in 2% of the total grazed area in eastern Oregon (Roath and Krueger

1982). The loss of riparian vegetation because of cattle can accelerate erosion. Subsequent increases of sediment input into the stream can alter the geomorphic processes and riparian vegetation structure, composition, and distribution (Platts 1981, Kauffman and Krueger 1984, Marlow 1987, Trimble and Mendel 1995, Clary et al. 1996). If riparian vegetation is partially or fully removed, stream banks can lose their resistance to flow at bankfull discharge and may become unstable (Trimble and Mendel 1995, Rosgen 1996).

Domestic livestock may also alter the streambank directly through hoof sheering and trampling (Armour and Elmore, 1991, Platts 1991, Trimble and Mendel 1995, Cowley 2002). Bank trampling occurs mostly in the spring when the streambank soils are saturated and susceptible to the action of hooves. This disturbance has the potential to directly alter stream width and increase susceptibility of the riparian zone to further bank erosion and instability (Kauffman et al. 1983, Kauffman and Krueger 1984, Marlow 1987, Armour and Elmore, 1991, Platts 1991). These alterations to channel morphology directly impact the amount of spawning and rearing habitat available to salmonid species (Knapp et al. 1998). Flooding can also have these effects on streambanks. For example, no significant accelerated streambank erosion occurred under a two-year period of moderate grazing intensity; erosion was attributed to high discharge events during the winter (Buckhouse et al. 1981).

Habitat alteration from herbivory can not be examined as a single factor in a watershed due to the confounding unknown effects of natural disturbances**.** In particular, semi-arid watersheds are characterized by their high flow variability and non-cohesive alluvial soils, which render streams relatively susceptible to channel alterations (Bendix and Hupp 2000, Kershner et al. 2004). Alterations from natural disturbances and herbivory often can not be separated. The effects of large wild herbivores such as moose are also unknown and uncontrolled. Thus, an examination of the long-term changes in riparian zones may clarify the effect of livestock management on the structure and function of stream and riparian habitats. In response to habitat alterations caused by herbivory, other land use activities, and the listing of several fish species under the Endangered Species Act, the US Forest Service and Bureau of Land Management developed and implemented livestock use standards. These standards were implemented in 1999 with the goal of reducing the potential impacts of grazing on critical habitat.

A potentially useful approach to the detection and long-term monitoring of disturbance in riparian zones uses the analyses of field measurements and historical aerial photography through image processing software such as ERDAS Imagine and Leica Photogrammetry Suite (McCullough 1999, Bureau of Land Management 2001, Laliberte et al. 2001, Mount 2002, Covington and Hubert 2003, Mount 2003). Although these studies used analyses of aerial photography to examine changes in stream and riparian habitat, there are few studies that have examined the accuracy of measurements and scale problems presented in such analyses.

The advantages of using aerial photography analyses include time efficiency and low cost (Laliberte et al. 2001, Mount 2002, 2003). Computer-based image analyses with software such as the ERDAS measurement tool allows on-screen measurements of stream and riparian habitat variables such as stream width, areas of deposition, and riparian vegetation structure and composition. However, important and potentially problematic parameters such as image resolution, availability, distortions, and image to image error are often not addressed. Thus, our study examined how long-term changes in stream and riparian structure and function can be evaluated through the analyses of historic aerial photography with the different resolutions, film and camera types. Our primary objectives were to determine: (1) how remote sensing and geographic information systems (GIS) could be used to evaluate long-term changes in habitat altered by disturbance, (2) if long-term trends and significant relationships could be determined through these analyses, and (3) how varying image resolutions affect the measurements.

Methods

Study area

The study area was located on the East Fork of the Salmon River, located in the Sawtooth National Recreation Area of central Idaho (44º 268’ N lat., 114º 326’ W, Figure 1). This river is the largest tributary to the Salmon River in the Upper Salmon River Basin, encompassing an area of 1430 km^2 (US Forest Service 2003a). The drainage flows north with the right bank oriented on the western slope and the left bank to the east. Upper portions of the channel with a low gradient (less than 1.5%) provides spawning and rearing habitat for several fish species listed under the Endangered Species Act; *Oncorhynchus tshawytscha* (Chinook salmon), *Salvelinus confluentus* (bull trout), *Oncorhynchus mykiss* (steelhead), and historically *Oncorhynchus nerka* (sockeye salmon). In addition to cattle, moose also utilize the upper portions of the drainage for winter habitat. Historical alteration of stream and riparian habitats in the study area has resulted from the combined effects of herbivory and natural disturbance such as debris flows and hillslope failures.

Typically, this region receives 254 mm of precipitation at lower elevations and up to 1270 mm in higher elevations. Precipitation occurs predominantly as snow during the winter months and as brief intensive events associated with convective storms in the summer (US Forest Service 2003a). This region has a semi-arid climate where the rainfall is less than the potential evaporation, as shown in the climate diagram (Figure 2). Stream flow regime was dependent on snow melt in late spring and was highly variable with frequent high discharge events (US Geological Survey 2004a). The geology of the drainage was dominantly Challis Volcanics and subdominantly glacial deposits at high elevation, which results in highly erosive soils, typically not suitable for the disturbance from activities related to herbivory (US Forest Service 2003a). Multiple debris flows have occurred in the past decade in tributaries to the East Fork Salmon River, including Big Boulder Creek, Germania Creek, and Slate Creek. All of these tributaries are located downstream of the study site, and none were documented upstream.

Our study focused on the Bowery Creek and East Fork pastures within the Upper and Lower East Fork Salmon River Horse and Cattle Allotment. Historically, the predominant land use included sheep grazing, which was changed to cattle grazing in the 1950s (US Forest Service 2003a). Deferred rotation is a method where a pasture is fully utilized one year and unutilized the next season (cattle are deferred to another pasture). This method was used among five pastures on the East Fork Salmon River Allotment (US Forest Service 2004) over an observation record period from 1967 to 2004. The recommended use of this allotment in these years was 250 cow/calf pairs for 130 days, unless the allotment did not comply with management goals (US Forest Service 2004). Non-compliance occurred in 1978, 1993, 1999, and 2003, which reduced the number of cattle allowed to graze the following year. The number of days grazed was reduced in 1999 to remove cattle prior to the spawning season of threatened Chinook salmon and bull trout.

Subalpine and alpine vegetation communities dominated the drainage at elevations between 1600 and 3350 m. Woody riparian vegetation communities were dominated by *Salix bonplandiana (*Bonpland willow) and *Pseudotsuga menziesii* (Douglas-fir). Three percent of the land within the allotment was classified as riparian zones and was grouped into tree, shrub, and graminoid dominated communities (US Forest Service 2003a). *Poa pratensis* (Kentucky bluegrass) is the dominant grass species in disturbed riparian communities.

Experimental design

Our 500-m sample stream reach was delineated in an unconfined, alluvial channel with a gradient of less than 1.5%. The sample stream reach and transects were used for collection of field data and analyses of aerial photography. A stratified pseudo-random design was used to determine the location of the 40 transects. These transects were established perpendicular to the thalweg, which extended 10 m into the riparian area beyond the top of the bank. Transects were established every 25 m throughout the stream reach. Between these transects, a new transect was randomly established at intervals between 5 and 20 m. This selection method ensured that no transects were within 5 m of each other, preventing pseudo-replication of the sample transects.

Statistical Analyses

Statistical analyses to detect significant differences between stream width measurements for each year utilized tests between the means. Normality plots were used to confirm that the data were normally distributed. An F-test was used (under the assumption of a normal distribution) to determine if the sample variance was equal for all populations (Personal Communication, Everson, 2004). Depending on the outcome of the F-test, a two sample Student's t-test for the means was then used to determine significant changes between the years. A least squares regression analysis was used for detecting relationships between greenline width as the dependent variable and woody species structure as the independent variable. A dichotomous variable taking the value of 1 for transects 1-20 (area of channel migration), and 0 for transects 21-40 was used to control for a hypothesized structural difference between the transect groups. Significant differences in the structure of woody riparian vegetation between each year at a specified distance interval were determined using ANOVA. An alpha value of $P < 0.05$ was used for all tests unless otherwise specified.

Field data

Field measurements including bankfull and greenline width, reach gradient, thalweg location, and woody species were collected with manual measurements and with a global positioning instrument (GPS) (Trimble Navigation Inc., GPS Pathfinder Pro XRS) in October 2004. Bankfull width was determined by using three primary indicators: (1) the highest depositional features within the active channel, (2) slope breaks on the streambanks, and/or (3) the line of riparian vegetation (Rosgen 1996, Overton et al. 1997). Greenline width was measured at the first linear grouping of perennial vegetation near water's edge (Winward 2000). A 10-m transect was subsequently established perpendicular to the thalweg on the right and left banks, looking (upstream). Woody vegetation greater than one meter in height was recorded with species, distance from stream bank, and height class (class 1, 0 - 0.1 m; class 2, 0.1 - 0.5 m; class 3, 0.5 - 1.5 m; class 4, 1.5 - 3.0 m; class 5, 3.0 - 6.0 m; class 6, >

6.0 m) (McCullough 1999). The ground photography collected from positions on the east and west banks of the channel, upstream, and downstream.

Aerial photography analyses

Aerial Photography used in analyses varied in image resolution, distortions, and camera type (frame or digital) (Table 1). Non-digital aerial photography was scanned and imported into ERDAS Imagine 8.7 and Leica Photogrammetry Suite (Leica Geosystems). A separate block file was created for each image using a standard projection (UTM Zone 11 N, WGS 84). The images were then orthorectified using a 1-m digital orthoquad of the Galena Peak Quad and a 30-m digital elevation model. Triangulation reports were evaluated and the resolution recorded (see Table 1).

Each image was analyzed for channel width, depositional areas, and vegetation structure (e.g., the distance of woody species from the streambank) using ERDAS measurement and area of interest (AOI) tools. Transects on each image were established using GPS points collected in the field and channel widths measured. Three repetitions of each width measurement were performed to assist in eliminating observer error while selecting pixels that represented channel width.

The area of each feature and their change in position and formation was compared between years among transects. Aerial photography interpretation (visual interpretation of images upstream) was used to determine the potential of debris flows and hillslope failures in the headwaters of the drainage. To measure sinuosity of the channel for each year, a line was drawn from the start to the end of the reach, and was geographically located in the same position over all images.

The total length of this line was measured and divided by the length of the thalweg (McCullough 1999). Channel migration was measured by using the same geographically located line, but the distance to the thalweg was measured to determine where the channel has shifted through the valley. Along each transect, pixels were identified as being vegetated (1) or non-vegetated (0) at 0, 1, > 2 - 4, and > 5 - 10-m intervals for the right and left banks for each year and transect.

Results

Stream width and depositional features

Bankfull and greenline width decreased over the observation period (Table 2). Significant decreases in width were not observed in years 1999 to 2004 for mean and sample variance (Figure 3). Mean stream width and variance for 1977 and 1986 were significantly different from all other years. The data for all years indicated that mean bankfull width was significantly different than the mean greenline width.

The GPS instrument was not as accurate as the manual measurements. Bankfull width measurements taken manually with stakes and measuring tape were not significantly different from the measurements taken with the GPS instrument. The manual and instrument measurements of greenline width were not significantly different in the variance, but were significantly different in regard to the means of greenline width.

The area of exposed gravel bars significantly decreased until 1992 (Figure 4), and increased in subsequent years. Fine particle (less than 3-mm) deposits in the channel were less than 15% on the exposed gravel bars. Sinuosity over the observation period was not different, ranging from 1.37 to 1.47.

Qualitative interpretation of the aerial photography in the headwaters indicated several hour glass patterns representative of hillslope failures. Scoured channels were also present indicating debris flows. Photographs from 1986, 1992, and 2002 indicated hillslope failures and debris flows that contributed to coarse sediment loads downstream (Figures 6a and b). The aerial photographs from 1977 and 1999 were the last in the flight line, and did not show the headwaters. Interpretation of images also showed a lateral change in the channel from 1992-1999.

Riparian Vegetation

Riparian vegetation on the right and left streambanks were structurally different. The left bank (oriented east) was dominated by Douglas-fir and willow communities and confined by a terrace in the valley floor. The right bank (oriented west) was more accessible to herbivores, more exposed and dominated by willow, Kentucky bluegrass, and *Artemisia* spp. (sagebrush) on banks with terraces. Subdominant species present included *Cornus sericea* (redosier dogwood), *Ribes* spp. (currant), *Rosa* spp. (rose), *Picea engelmannii* (Engelmann spruce), and *Potentilla fruticosa*.

The presence of woody species and greenline width were significantly correlated at all distance intervals for the right and left bank (except the left bank at 1 m and the right bank at 0 m). Regression analysis with the dichotomous variable showed a structural difference between transects 1-20 and 21-40 ($P < 0.0001$). Significant differences in the structure of riparian vegetation existed at the 0-m distance interval (vegetation on the streambank) between the years 1977/2004, 1999/2004, and 1986/2004. Riparian vegetation structure at this distance was not significantly different during the intervals of 1977/1999 and 2002/2004. Results for the 1-m interval indicated changes in structure for years 2002/2004, 1999/2004, and 1986/2004 ($P < 0.0001$). Significant structural changes in woody species did not occur for the other distance intervals farther from the bank.

Discussion

Aerial Photography Analyses

Our study showed that using aerial photography of different resolutions and overall image quality provided broad analyses of important physical and ecological characteristics of the study area. Some confounding factors included variation in resolution, film type, and distortions. The analyses of aerial photography allowed for the rapid collection of historic data in a remote location, although field verification of remotely-sensed data was still required. Stream widths, depositional features, and riparian vegetation alterations were detected over time, thereby providing historical habitat conditions not available prior to this study.

Our study suggests that image resolution, as well as image quality and film type, increased the accuracy of on-screen measurements. The sample variance of the width measurements was due to the image resolution, distortion, and film type used to produce the digital orthoquad from aerial photography. Image quality, pixel size, and film type such as color infrared provided easier identification of habitat features. For example, the 1986 (1:60,000) measurements had a lower sample variance than the 1977 (1:40,000) image. The 1986 color infrared photograph contained no distortions, which are dependant on the angle that the aircraft was flown. The 1977 natural color image was distorted and at the end of a series of photographs, resulting in a higher sample variance than the 1986 image.

The accuracy of bankfull measurement both in the field and through aerial photography analyses can be influenced by observer variability and inherent errors associated with on-screen pixel selection representing a habitat feature (Mount

2003, Archer et al. 2004, Coles-Ritchie et al. 2004). Identifying pixels that indicate the location of bankfull width is more complex than identifying greenline. Locating the pixel that represents bankfull width on varying resolutions of imagery presents difficulty because of tree shadows and small topographical differences in the bank obscure the correct pixel location. Sample variance of the width measurements was relatively high because of image resolutions and distortions, as well as the natural variability within an aquatic ecosystem. The relationship between the precision of measurements such as bank erosion, and the scale of the aerial photography was an important consideration for our study (Figure 8). This concept illustrates that as the scale gets larger, the precision of measurement becomes higher. For example, bankfull width and measuring tree height required large scale imagery, while channel migration, hillslope failures and debris flows can be identified on small scale imagery. However, the hypothesized relationship is limited at a certain scale where the precision of the measurements do not increase.

Even with a high precision instrument such as the Trimble Pro XRS global positioning system (GPS), variability in the measurements obtained manually versus by this instrument indicated that GPS collection was a consistent method for reliable measurements of bankfull width, but not greenline. Sources of errors for measuring greenline width with the GPS included the degree of forest canopy cover and narrow canyons with steep slopes.

Stream width and depositional features

The ability to detect alterations in stream and riparian characteristics provided useful information in the changing patterns of habitat in the upper East Fork Salmon River. Although analyses over several years could be rapidly produced, these provided little insight into the cause of changes in habitat condition. Unlimited supply and delivery of coarse sediments from headwater habitat constantly alter habitat conditions, and the effects of livestock grazing can not be isolated for evaluation. It is likely that livestock grazing may have loosened the riparian vegetation through utilization, thereby facilitating the loss of vegetation and removal of bank materials during periods of high discharge. Improvements in grazing practices have been partially directed at improving bank stability through decreased use by domestic livestock (Hall and Bryant 1995, Cowley 2002, US Forest Service 2003b, Cowley and Burton 2004). However, the number of utilization days by herbivores was not reduced until 1999; no significant changes in stream width were observed from 1999 to 2004. Analyses did not allow for the detection of small alterations in habitat through these years. Thus, we cannot determine if the livestock use standards implemented in 1999 were indeed improving habitat condition.

The increase in the area of exposed gravel bars, overall decrease in stream width, and recent changes in riparian structure in the 1990s were due to high discharge events (stream discharge greater then 70 $m^3 s^{-1}$) that transported sediment downstream. Peak stream flow data shows high variability in stream discharge throughout the upper Salmon River Basin. Figure 5 illustrates how high discharge events are a characteristic of the disturbance regime of this semi-arid system. Flooding in 1996 and 1997 may have caused the channel to move laterally. New maximum February mean flows were recorded throughout the region including the Salmon River at White Bird, Idaho, which experienced 189% of median flow (US Geological Survey 2003). High discharge events in 1996 and 1997 relative to previous years were recorded at the USGS gauge station downstream on the Salmon River (US Geological Survey 2004b). Stream flow data were not available for the East Fork Salmon River gauging station for the observation period.

The channel moved laterally in the floodplain because of frequent high discharge events and unstable stream banks (see Figure 9). The new channel location had increased canopy cover and decreased stream width. The abandoned channel location was in an exposed location with no canopy cover at the edge of a slope change in the valley floor. In contrast to its prior location, the left bank of the new channel has the potential for large wood recruitment and increased pool availability for fish. Multiple channels throughout the meadow dominated by willow and Kentucky bluegrass were a result of the channel migration.

Frequent high discharge events and potential impacts from the 1996-1997 floods accompanied by an unlimited coarse sediment supply create a highly dynamic system during this time period. Riparian vegetation in the low gradient channels were critical to maintain bank stability during high discharge events (Trimble and Mendel 1995). Herbivory in this area has altered riparian vegetation composition through foraging and the introduction of shallow rooted species such as Kentucky bluegrass (US Forest Service 2003a). Loss of root structures has altered the banks and valley floor characteristics. During high discharge events, stream banks lose their resistance to flooding, thereby causing habitat alterations due to bank stability and stream width alterations (Trimble and Mendel 1995, Rosgen 1996). This may have removed the vegetation from the surface of historical-vegetated gravel bars and created newly exposed surfaces (see Figure 7). The resulting bank structures were layered with coarse sediments on vegetated and exposed depositional features.

A decrease in stream width also occurred between the years 1977 and 1986, but the cause is unknown. Grazing intensity did not change during these years, except for in 1979, when the number of cattle was reduced due to non-compliance with use standards. High flow variability may have altered habitat during these years as well. No significant decreases in stream width from 1999 to 2004 were recorded and may be related to the timing of riparian vegetation establishment. We predict that the stream width will decrease after the establishment and development of vegetation on the stream banks based on our data from 1999 to 2004. The accuracy of width measurements as a result of image distortion and resolution may have been too high (greater than 1:10,000) to detect small alterations (less than 1-m) in stream width or riparian vegetation characteristics. Thus, we could not relate the changes in grazing intensity in 1999 to changes in habitat between the years 1999 to 2004.

Although we predicted that the sample variance of the means of the bankfull to be greater than the greenline width measurements, bankfull width defined by exposed gravel bars had a smaller sample variance than the disturbed riparian vegetation representing greenline width. Frequent channel migration throughout the valley, as well as herbivory (cattle and moose) may have prevented the establishment of riparian vegetation. Also, high discharge may not have allowed the deposition of fine particles on the gravel bars as shown by our field observations. This relatively small amount of fine particle deposits on gravel bars suggests that these habitats were unsuitable for the establishment of riparian species.

Riparian vegetation

The significant positive correlation between greenline width and the presence of woody species may be counterintuitive. However, the presence and type of vegetation on the streambank directly affected the stability of the channel and stream width (Neary and Medina 1996, Abernethy and Rutherfurd 1998), thereby resulting in a time delay between the establishment of vegetation and a decrease in stream width (Hupp 1991). Furthermore, the presence of gravel bars with coarse sediment and frequent disturbance may not allow the establishment of species such as willow that would develop in these zones. Large herbivores such as domestic livestock may use the right bank (oriented west) more frequently due to accessibility, creating less dense woody species and more altered soils and vegetation than the left bank. This may explain the lack of significant differences in the riparian structure and presence of woody species among years 1977 and 1999. This is consistent with the grazing practices throughout this period, maintaining 250 cow/calf pairs at 130 days for 30 years. The number of days grazed was reduced in 1999, but changes in aquatic habitat could take years to respond.

Changes in the area and composition of riparian vegetation structure were examined in past studies through a supervised classification (Bobbe et al. 2001, Bureau of Land Management 2001, Congalton et al. 2002). Varying image resolutions and film types prohibited the use of supervised and unsupervised classification. Natural color images had small pixel sizes (> 2 m) and incorporated only one spectral band. The color infrared photography for 1986 and 1999 showed the most promise for the use of classification to determine the areas of each vegetation type. However, the pixel signature for the stream channel and the shadows created by conifers overlapped and could not be separated. The use of band ratios was unsuccessful because the imagery was scanned into the three spectral bands, but not considered spectral like satellite imagery (Personal Communication, A. Smith, 2004). As an alternative to this approach we used the ERDAS viewer with geographically linked transects to determine the presence or absence of vegetation at distance intervals. Consistency in the availability of color infrared imagery and satellite imagery at low resolutions could further the analyses of riparian vegetation structure and composition.

Aerial photography analyses provided baseline data and insight into further investigations. Further studies that use enclosures in the riparian area to examine habitat alterations such as channel width and riparian vegetation composition remotely are warranted. In addition, incorporating the use of high resolution satellite imagery such as IKONOS (1-m pixels) would provide a more detailed examination into the vegetation structure and composition of riparian habitat. To specifically investigate how the channel morphology changes in response to flooding events, the use of green LIDAR (green wavelengths transmitted from an aircraft that can detect sub-meter topography) that examines the depth contours of the channel and deposition would be an appropriate analysis over a particular observation period.

Conclusions

Aerial photography analyses determined historic habitat conditions with a small spatial (500-m reach) and long temporal scale (27 years). Due to the variation in image resolution, distortion, and film type, we could not isolate the impacts of herbivory and/or natural disturbances. These two factors were the driving variables for alterations in habitat. Without aerial photography between the study years, it was not possible to determine the cause of the modifications to stream and riparian habitat. Habitat suitable for native salmonids did improve from 1977 to 2004, but could not be related solely to the decrease in grazing intensity. However, changes in livestock grazing management are expected to improve bank stability through the regeneration of riparian species and overall habitat condition. Increased resistance to frequent change in habitat conditions from high discharge events should also be expected as the vegetation colonizes the streambanks. The abundance of coarse sediments and bank erosion present at this site impede the function of native salmonid habitat. Understanding the natural disturbances in the headwater habitat and bank erosion caused by grazing is essential to evaluate the amount and quality of sediments delivered each year that alter the habitat for salmonids and other aquatic organisms. Studies that isolate the causes of habitat alterations may be useful for additional remote sensing analyses of riparian zones under natural and managed situations.

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Table 1. Aerial photography used for analyses are summarized. The resolution, film, and camera type vary for each year. Each image was processed and analyzed separately in ERDAS Imagine for stream width, depositional features, sinuosity, channel migration, and woody riparian vegetation structure along a 500-m reach with 40 transects

Year	Resolution	Scanned resolution (dots per inch, dpi)	Film Type	Camera Type	Source
2002	1:20,000	400	Natural color	Frame	USFS, Sawtooth National Forest
1999	1:5,000	n/a*	Color infrared	Digital	USFS, Sawtooth National Forest
1986	1:60,000	400	Color infrared	Frame	Aerial Photography Field Office
1977	1:40,000	600	Natural color	Frame	USFS, Sawtooth National Forest

*Original image was digital.

Table 2. Key statistical parameters are shown for the analyses of mean of bankfull and greenline width. The variance is related to both the natural variability in the system and errors that occur from the measurements at different image resolutions and quality. The change in depositional areas over the years shows variability, initially decreasing and then increasing again in the 1990s. Changes in these features may have resulted from frequent high discharge events that supply coarse sediment downstream to the study reach.

Year	Pixel resolution	Bankfull width (m)		Greenline width (m)		Depositional area	Pixel error
	(m)	Mean	Variance	Mean	Variance	(ha)	(pixels)
1977	2.2	29.12	159.76	38.38	302.88	0.4691	61.60
1986	2.5	16.72	25.26	29.58	114.73	0.3693	12.60
1999	0.5	13.94	10.79	18.81	27.55	0.4026	2.52
2002	1.0	12.62	12.86	18.15	22.34	0.4463	3.73
2004	field data	12.95	12.35	17.75	41.30	na	field data

Figure 1. The study site was located on the East Fork of the Salmon River, a semi-arid region of central Idaho on the Sawtooth National Recreation Area. The 500-m study reach was located 900 m upstream of the confluence of Ibex Creek.

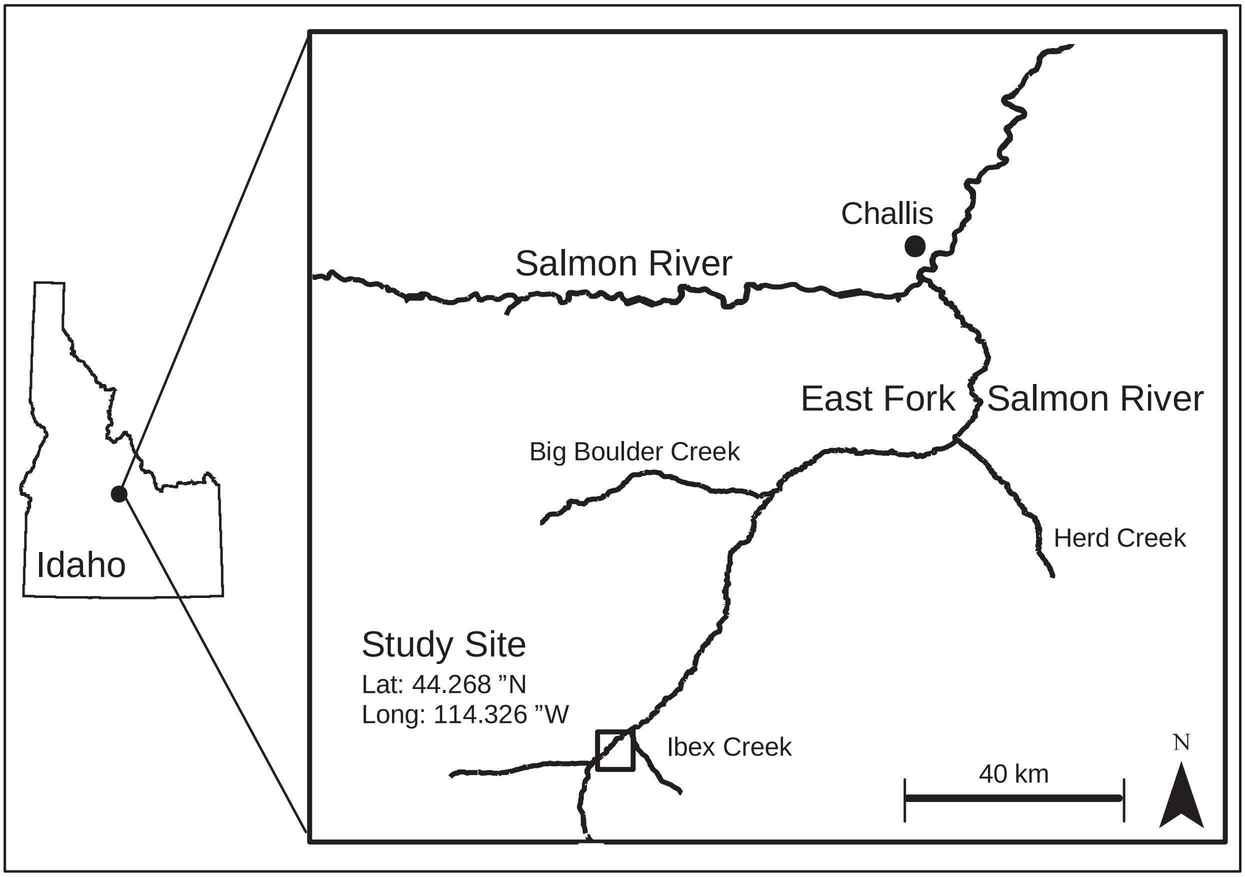

Figure 2. Climatic diagram in the format of Walter and Leigh (1960) for Galena, Idaho located 4 km southwest of the study site. The x-axis represents the 12 months starting in January. At the top of the diagram the climate station name, site elevation, mean annual temperature, and mean annual precipitation are shown. The climate of the study site is characterized by precipitation dominated by snowfall, with dry summers and occasional high intensity rain in the spring and fall.

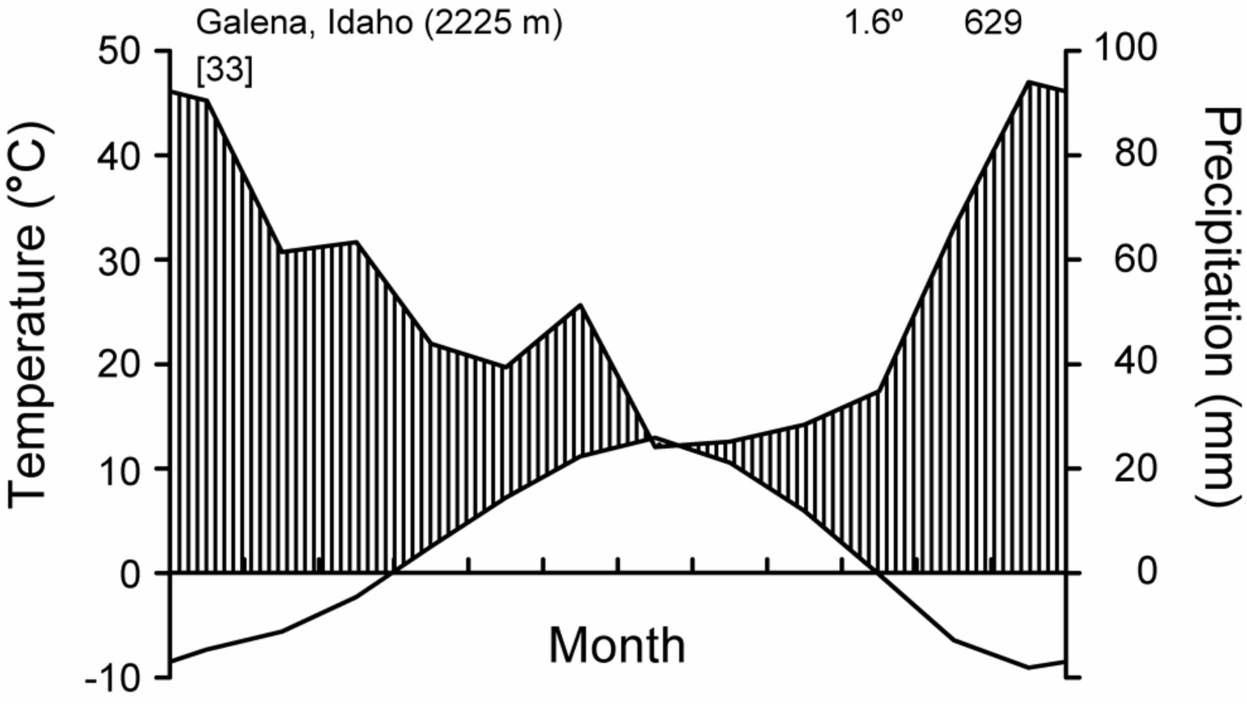

Figure 3. The sample variance of each width type differs based on image resolution, distortions, and overall image quality. Bankfull (n = 40) and greenline (n = 40) width decreased over time. The box and whisker plot represents second quartile median (the center line), the third quartile (top and bottom of plot), high and low observations (at the top and bottom bar) and outliers.

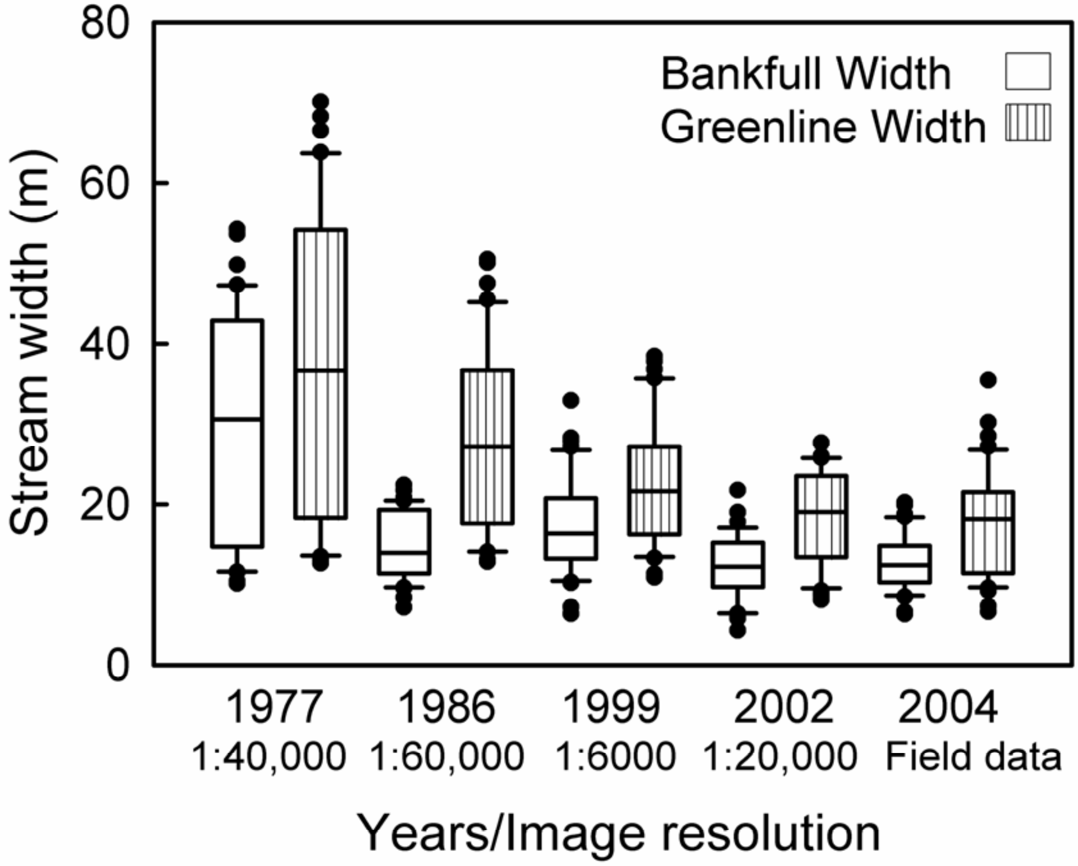

Figure 4. The area of exposed gravel bars within the floodplain fluctuated over time. The initial decrease in area may be related to management changes, but flooding events may have initiated debris flows in the headwaters, altering stream and riparian habitat.

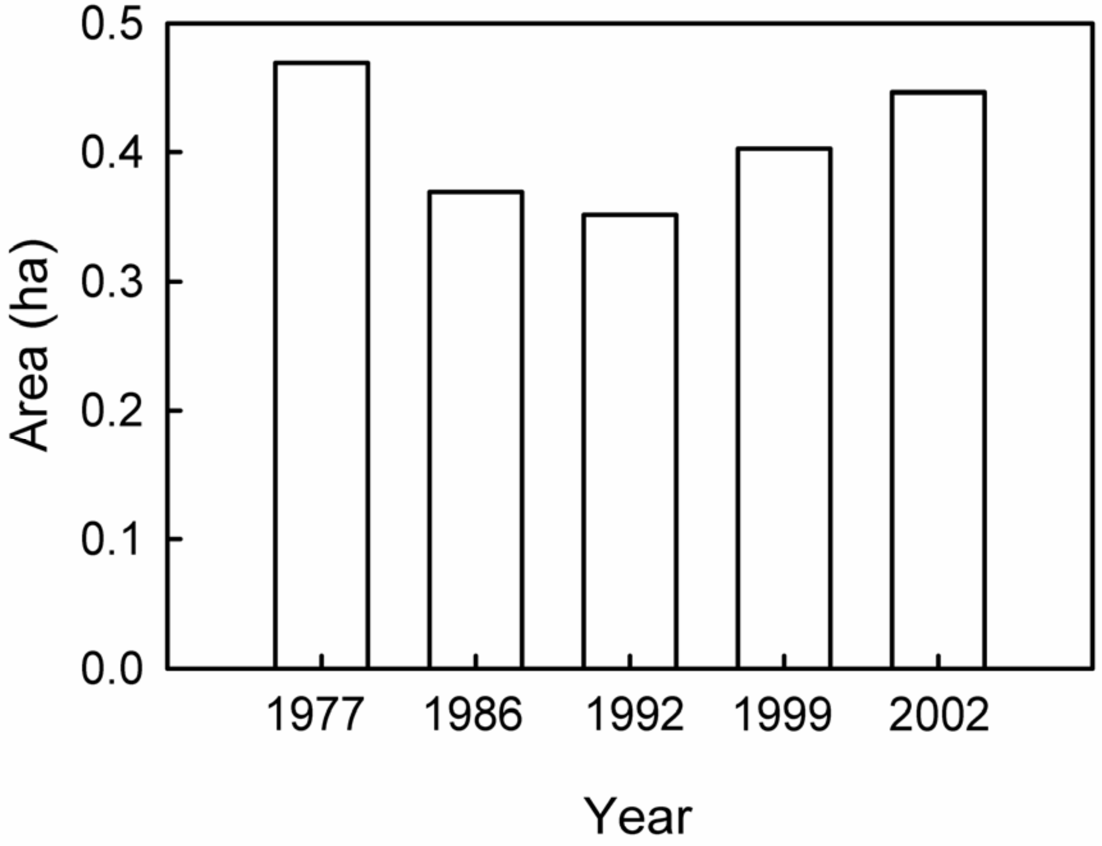

Figure 5. Peak stream flow was variable as shown on the Salmon River over the period 1905 to 2005. Two peak flow events in the 1990s may have played a role in channel migration, altering stream widths and the areas of exposed gravel bars.

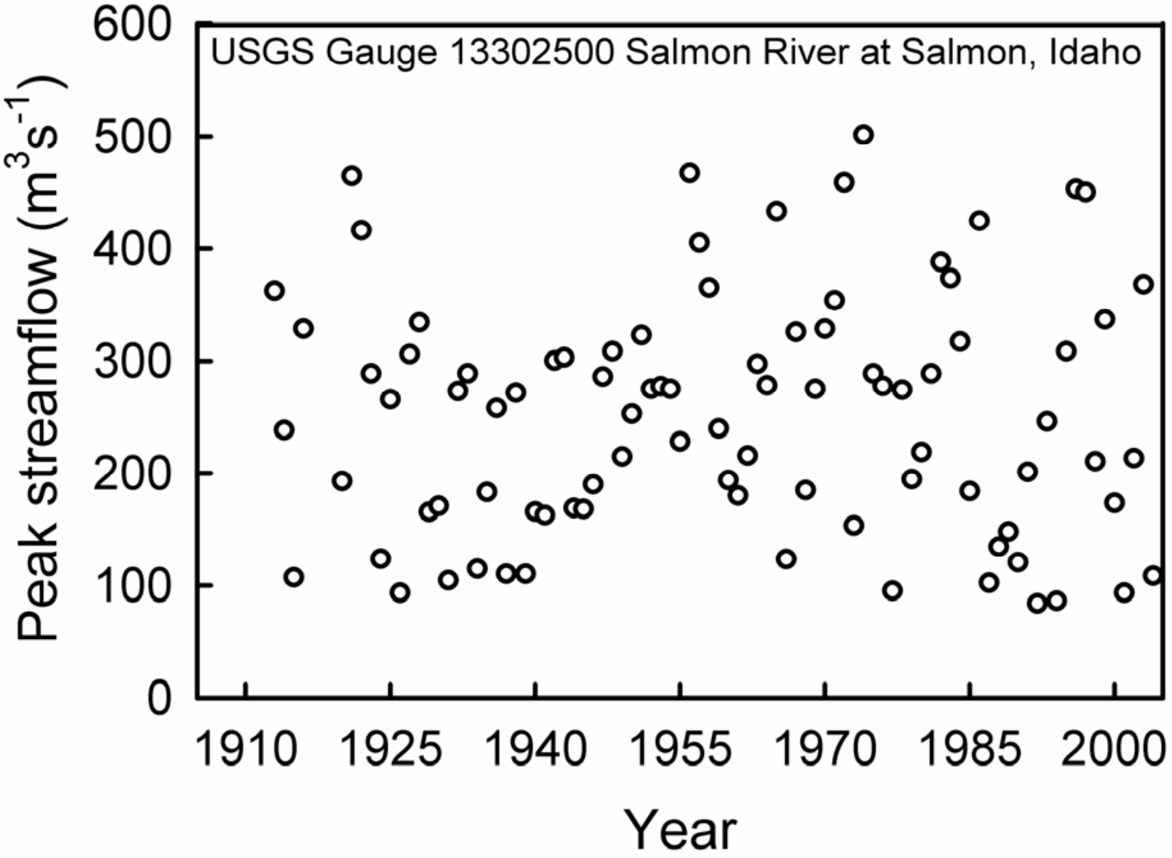

Figure 6. Hillslope failures and debris flows were prevalent in the headwaters above the study site as shown in images (a) 1986, (b) 1992, and (c) 2002. The two processes shown here are debris flows (dashed arrows) and hillslope failures (solid arrows).

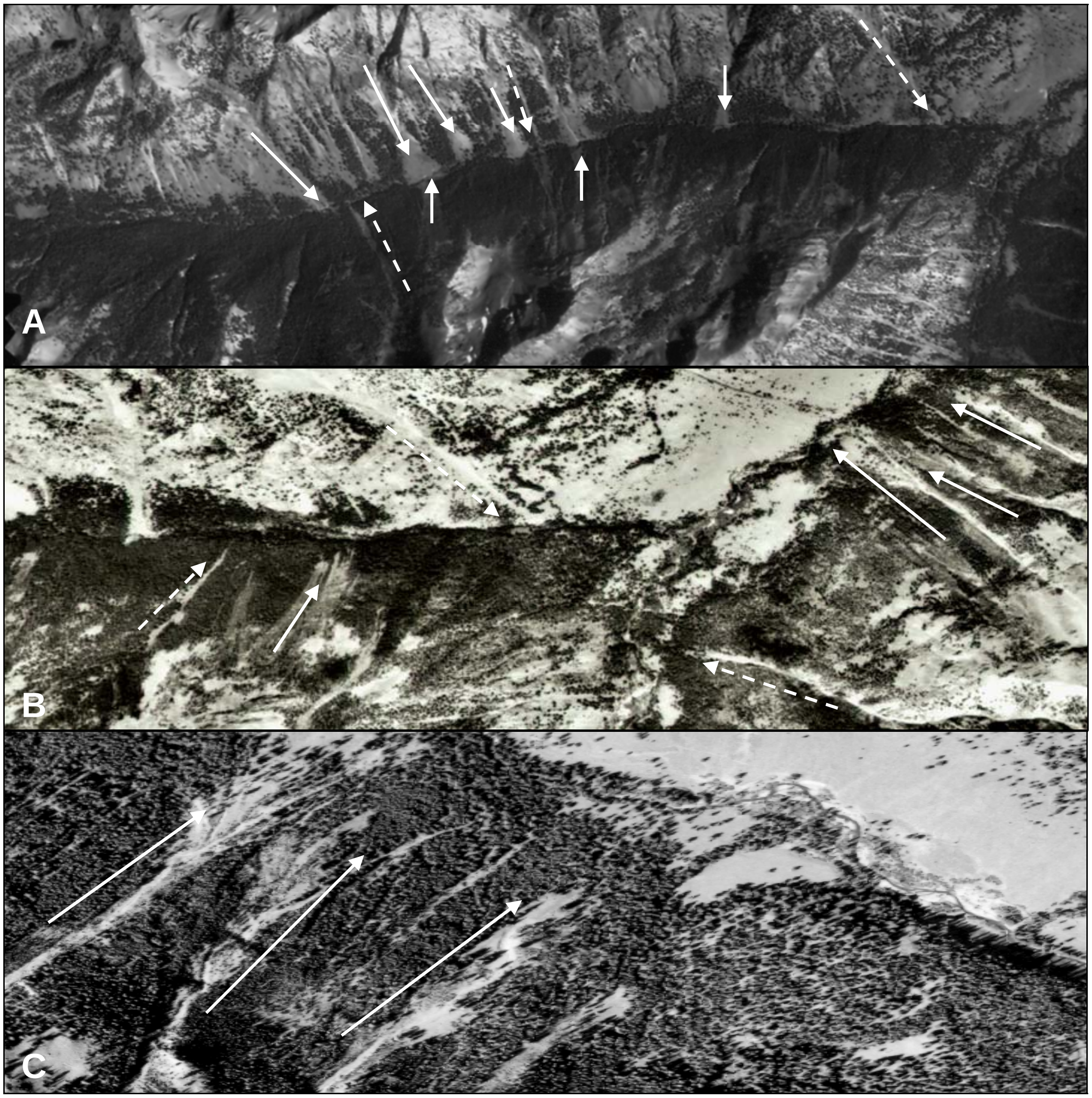

Figure 7. Layers of deposition on this 10-m section of exposed stream bank suggested that natural processes such as flooding were part of the historic range of variability. Streambank alteration may be aggravated by the conversion of the riparian vegetation from woody species such as deeply rooted willow to shallow rooted Kentucky bluegrass.

Figure 8. A conceptual model of the relationship between measurement precision and image scale. Different variables can be measured more precisely depending on the scale of the aerial photography.

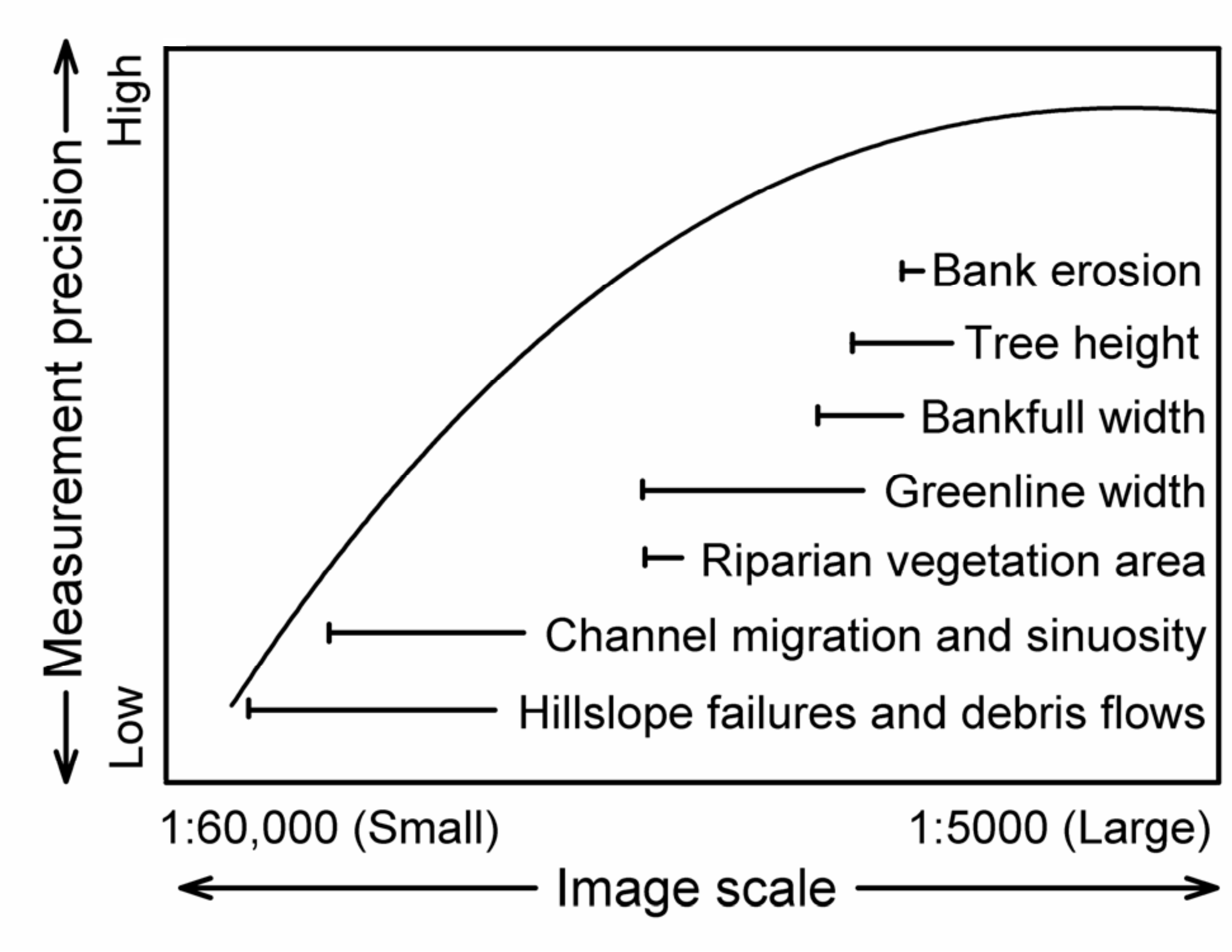

Figure 9. The interaction between frequent high discharge events and riparian vegetation affected by large ungulate herbivory may have caused this channel shift. This may explain the decrease in stream width as the channel migrated.