RESPONSE AND RESILIENCE OF RIVERS TO HISTORICAL RESOURCE USE IN THE GREATER YELLOWSTONE ECOSYSTEM: A REPEAT PHOTOGRAPHY ANALYSIS

by

Heidi Martin Clark

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ABSTRACT

Repeat photographs provide a glimpse of the past and thus tell a story of how man and nature have shaped the landscape. With the use of repeat photography based on on-the-ground oblique images, this study investigated how historical natural resource uses (e.g., logging, mining, ranching, and dam building) have affected headwater rivers of the Greater Yellowstone Ecosystem (GYE). These rivers included the Gallatin, Yellowstone, Wind, Gros Ventre, Snake, Madison, and Green Rivers along with several of their tributaries. Oblique photo pairs or series of photos were compared using three types of analyses: quantitative pixel comparisons, rank order statistics, and individual descriptions, in order to identify changes in riparian vegetation cover, sinuosity, bankfull, and flood plain area. Additionally, additional data from a stream reach of the upper Yellowstone River in Paradise Valley, Montana, allowed for aerial comparisons to quantify vegetation cover and sinuosity within photo frame wedges of corresponding oblique photos. The results of the comparisons revealed: (1) increased riparian vegetation where anthropogenic perturbations had ceased, indicating resilience and recovery; (2) decreased riparian vegetation and sinuosity where impacts intensified; and (3) little change in riparian vegetation where human natural resource use continued at a similar intensity. Application of this methodology to more photo points and other regions will provide a better understanding of the extent of previous threats and how river systems have responded or continue to counter ongoing anthropogenic impacts.

INTRODUCTION

Background

Western riparian systems provide key ecological services and are essential links between terrestrial and aquatic ecosystems (Patten, 1998; Webb, Leake, & Turner, 2007). Even though they comprise less than 1-3% of the landscape (Patten, 1998), an estimated 60% of wildlife species rely on them (Harting, Ekey, & Glick, 1994). Intact riparian ecosystems prevent excessive erosion by stabilizing stream banks and trapping sediment, enhance ground-water recharge, improve water quality, modulate hydrologic processes by enhancing sinuosity and counteracting channelization, and provide wildlife habitat (Harting et al., 1994; Patten, 1998).

Utilization and management of watersheds have degraded the structure and function of riparian ecosystems throughout history and continue to impacts these systems today (Patten, 1998, p. 199) making riparian ecosystems among the world's most threatened ecosystems (Helfield, Capon, Nilsson, Jansson, & Palm, 2007). Effects of natural resource development (i.e., mining, forestry, and agriculture), introduction of invasive species, and extirpation of top predators have dramatically impacted the structure and function of riparian ecosystems (Patten, 1998).

Recognizing the impacts of human activity on watersheds and rivers, this study focuses on effects of historical natural resource uses (i.e., exploitation of water, land, and subsurface materials) on rivers within the Greater Yellowstone Ecosystem (GYE) to better understand the extent of these early threats and how river systems have responded or continue to resist ongoing anthropogenic impacts.

As settlement spread across the western United States during the turn of the 19^{th} century, the GYE became a target for natural resource industries seeking areas rich in timber, water, grazing land, and ore. Railroad extension, agriculture encroachment, cattle industry growth, and national need for raw materials fueled this expansion, seriously affecting riverine (i.e., riparian zone and river channel) ecosystems. A series of federal legislation aided in the expansion of western development in the mid-19^{th} century. The Homestead Act of 1862 allowed any 21 year-old male to pay a nominal filing fee in order to acquire 64 ha (160 ac) of federal surveyed land and after five years gain residency and a title. Subsequent land giveaway acts, the Enlarged Homestead Act and Stock Raising Homestead Act, increased and encouraged grazing on these lands. The Mining Law of 1872 legitimized mining on public lands with minimal regulation. Timber Acts further enabled the removal of federal assets, while no national regulation policy existed at the time (Allin, 1982). The Land Revision Act of 1891 designated certain mountainous areas as forest reserves, driving homesteaders to settle in river basins (Strickler, Mistretta, & Historic Crail Ranch Conservators, 2012). The 1877 Desert Land Act gave away arid lands for the purpose of irrigating, which led to the need for federal support and thus the establishment of the Reclamation Act in 1902. In addition to individual giveaways, the federal government granted railroad companies land for expansion into the West to gather resources for railroad infrastructure and towns along the way. From 1850 to 1871, Congress granted these companies more than 38 million ha (94 million ac) (Allin, 1982). These acts encouraged increased logging, ranching, damming and mining in the GYE.

Understanding Change

Interpretation of historical records can provide insight into impacts of previous resource use. Paleoclimatology infers historical climate variation from natural archives, such as tree rings, ice cores, banded corals, laminated speleothems (cave formations), and deposited sediments. The longest records of instrumental data (e.g., hydrographs of stream flow) only extend back to the early eighteenth century from Western Europe; however, most records do not exist beyond the early nineteenth century. Therefore, archival data derived from nature offers a long-term perspective on climate variability (Bradley, 2011). For instance, sediment cores from Loon Lake, Wyoming provide a 12,500-year pollen record, indicating the climate history of the southwestern corner of Yellowstone National Park. These data sets can help to validate environmental reconstruction models (Whitlock, Bartlein, & Van Norman, 1995).

Historical data gathering techniques include stream flow hydrographs, aerial photos, historical land surveys, and historical photographs. Unlike natural archives, these tools can provide more direct glimpses of the past. The U.S. Geological Survey (USGS) began measuring stream flow in 1889 and their aerial photography records date back to 1937 (USGS, 2012). However, oblique photos predate both of these data sets and provide ways to understand whole landscapes at specific sites by capturing on-the-ground views.

In the 1870s, the federal government expanded surveys to document the western U.S. for future expansion (e.g., Washburn Expedition to the Yellowstone and Fire Hole Rivers of 1870 and the Hayden Geological Survey of 1871). Reports from these surveys include topographical, geological, geographical and biological details, which provide a valuable resource for understanding the state of the landscape before settlement. W.H. Jackson took the first photographs of the GYE as part of the Hayden Survey. Additional federal surveys followed, including a trip by President Chester Arthur to Yellowstone National Park in 1883. On this expedition, Arthur and his army escort traveled down the Gros Ventre River, up the Snake River and into Yellowstone National Park accompanied by photographer, F.J. Haynes. Despite the lack of written documentation, Haynes's photos provide an illustrative resource about the condition of this landscape at the time (Gruell, 1980a).

Repeat Photography Application

Early photographers captured images of all aspects of the landscape, thus allowing repeat photography to serve as a tool to evaluate long-term change. Historical photos depict how an area appeared at some point in the past and thus can be used to assess change when one revisits the historical location. Information acquired from aerial photography can also supplement oblique repeat photography analysis.

Repeat photography, first documented as a scientific tool in the 1880s to study glacial change in Europe, is now featured in a variety of publications ranging from scientific articles to picturesque coffee table books (Webb, Turner, & Boyer, 2010). For instance, *The Changing Mile* (Hastings & Turner, 1965) and its sequel, *The Changing Mile Revisited* (Turner, Webb, Bowers, Janice E., & Hastings, 2003), discuss ecological succession across a mile elevation gain in southern Arizona. In S*econd View: The Rephotographic Survey Project* (Klett, Manchester, Verburg, Bushaw, & Dingus, 1990) and its sequel, *Third Views Second Sights* (Klett et al., 2004), Klett along with a group of photographers and historians focus on the mechanical and conceptual aspects of the repeat photography process. Wyckoff (2006) utilized repeat photography from a geographer's perspective in *On the Road Again: Montana's Changing Landscape*, where he retook historical photographs from the 1920s and 1930s taken by state highway engineers to examine physical and cultural geographical change. Repeat photography books have featured rivers (e.g., Webb, 1996. *A Century of Environmental Change in Grand Canyon*), but there has yet to be a book that incorporates this method to describe long-term changes specific to rivers within the GYE.

A few studies have quantitatively compared landscape changes using oblique photos. Munroe (2003) quantified differences in the distribution of vegetation of subalpine tundra communities in the northern Uinta Mountains from 1870 to 2001. He determined change in tree line, quantified density of forest, and measured changes in meadows. His results indicated changes in alpine vegetation due to climate change. Hendrick & Copenheaver (2009) quantified landscape changes in the Southern Appalachian Mountains from 1880 to 2008 through direct pixel comparisons of different cover types (e.g., agriculture, distant mountain, forest, rock outcrops etc.). Their results revealed changes due to patterns of land conversion. Both studies show how repeat photography can be a useful application to reconstruct the ecological and historical profiles of an area, but they also highlight the difficulties of locating historical photo points (i.e., locations where photos were taken) and matching the perspectives of the historical photos. A common perspective among photographs of a given site is necessary for quantitative analytical comparisons across time.

Repeat aerial photography provides not only qualitative visual assessment, but also allows for general quantitative measurement of change over time. Techniques for analyzing aerial photographs in GIS can also serve as a tool to link aerial analyses with oblique photos by examining change in land cover within the fields of view (FOVs) of oblique photo point locations. The combination of repeat oblique and aerial photos taken over a broad span of time can provide a more detailed sequence of the past. Thus, this combination can serve as a valuable tool for understanding dynamics of riverine systems in order to apply current and future management and restoration. When linking these two techniques, one must take into consideration the time gap between historical and recent photos, because historical oblique photos may substantially predate aerial photos.

Riverine Resilience

Riparian species as well as riverine systems exhibit traits that make them resilient after both natural and human-induced disturbances. Resilience is the ability of species or ecosystems to recover to their previous state following a natural disturbance or anthropogenic perturbation (Kauffman, Beschta, Otting, & Lytjen, 1997). Riparian species have developed adaptive traits (i.e., flexible, resilient stems, specialized cells to store oxygen during large flood events, and the ability to sprout quickly from flood damaged stumps) to resist and recover from floods. In addition to surviving floods, riparian plants utilize floods to their reproductive advantage through water seed dispersal, regeneration from branches/shoots, and germination on new surfaces created by flood events (Marston & Anderson, 1991). Certain riparian species can also withstand dramatic human impacts. For example, Bebb's willow is resilient to heavy grazing and thus dominates over-browsed sites (Vance, Newlon, Lemly, Jones, & Agency, 2012).

By analyzing repeat photographs of changes in rivers over time (i.e., vegetation, lateral channel movement, and river bankfull areas), this research was designed to assess resilience of rivers following historical natural resource use. Human activities both directly and indirectly affected and continue to influence mountain streams. Direct impacts alter channel structure, water chemistry, sediment movement, stream flow, and aquatic and riparian communities; indirect activities within the watershed influence the movement of water, sediment, and solutes into the channel. Outcomes of historical natural resource uses can still influence current riverine states. For instance, tie driving (i.e., the process of transporting logs down rivers to use for railroad construction), damming, and agriculture, directly impacted riverine systems in the western U.S. (Wohl, 2006).

Predictions

This study focuses on the influence of three main historical anthropogenic uses on riverine systems in the GYE: tie driving, damming, and agriculture. Tie driving is intentional flooding of waterways for the purpose of moving logs from high elevation harvest sites to lower elevation processing sites. Tie driving exaggerates the disturbance of natural floods due to additional damage caused by a dense collection of floating logs. Damming creates an intentional alteration of the hydrologic regime, typically for the purposes of irrigation storage or flood control. Changes in the hydrologic regime alter the erosion/deposition cycle that would otherwise create dynamic natural channel forms like meanders. Sediment retention in the reservoirs behind dams create sediment-starved downstream flows that will aggressively erode the downstream channel bed. Agriculture (primarily ranching in this study) enhances erosion due to cattle traffic and associated disturbance of riparian vegetation.

We predicted that these uses of riverine natural resources would result in photographic evidence of the following influences on the riparian ecosystem: 1) where former substantial natural resource use had ceased, river reaches would show an increase in riparian vegetation, decrease in river surface area (i.e., channel, bankfull area, or floodplain) and an increase in sinuosity; 2) river reaches where substantial natural resource use had increased would show a decrease in riparian vegetation, increase in river surface area, and a decrease in sinuosity; 3) river reaches where substantial natural resource use continued would show no significant change in riparian vegetation, river surface area, and sinuosity (Table 1). Predictions related to dams apply to reaches downstream of dams and upstream of any major tributaries.

The change over time indicated by photographs is used to evaluate resilience of riverine systems and show how rivers might respond to threats. To address recovery, we predicted that riverine areas where former dramatic natural resource use had stopped for over 50 years would show signs of resilience: increased riparian vegetation and river complexity (i.e., increased sinuosity and floodplain area). Determining full recovery to a pre-disturbance state is difficult, because historical photos do not always identify the natural state of systems before human impact. However, recovery of vegetation and improvement of channel structure following human-induced perturbations indicates resilience.

Table 1. Predictions of natural resource influences on riverine areas. Predicted impacts include the effects of tie driving (TD), damming (D), and agriculture (A) on riparian vegetation (Veg.), river channel or floodplain width (Riv.) and river sinuosity (Sin.).

	Past Impact			Impact Ceased			Continued Impact		
Activity	Veg.	Riv.	Sin.	Veg.	Riv.	Sin.	Veg.	Riv.	Sin.
TD	↓	↑	↓	↑	↓	↑	NA	NA	NA
D	↓	↑	↓	↑	↓	↑	↓	↑	↓
A	↓	↑	↓	↑	↓	↑	↓	↑	↓

STUDY AREA

Greater Yellowstone Ecosystem

The Greater Yellowstone Ecosystem (GYE) is a 5.5 million hectare (ca. 14 million ac) region that includes two national parks (Grand Teton and Yellowstone), six national forests, and three national wildlife refuges extending over three states, Montana, Idaho, and Wyoming (Figure 1). The GYE contains headwaters of three of the nation's major river systems: the Missouri/Mississippi, Snake/Columbia, and Green/Colorado. These headwaters arise in the Yellowstone Plateau and 14 surrounding mountain ranges, and their watersheds form the core of the GYE (Marston & Anderson, 1991). Stream flow generation is typically dominated by snowmelt and rain in the spring, followed by groundwater baseflow generation during a dry summer and early fall (Rood et al., 2008). This precipitation and flow regime produces predictable vegetation communities with respect to elevation and proximity to streams: grasslands or shrub steppe in the lowest elevations, cottonwoods and/or willows in riparian areas, mountain shrub in foothill regions, Douglas-fir in the lowest elevation forests, lodgepole pines at middle elevations, spruce-fir or subalpine forests at higher elevations, and perennial grasses, sedges, and forbs in the alpine tundra community (Marston & Anderson, 1991).

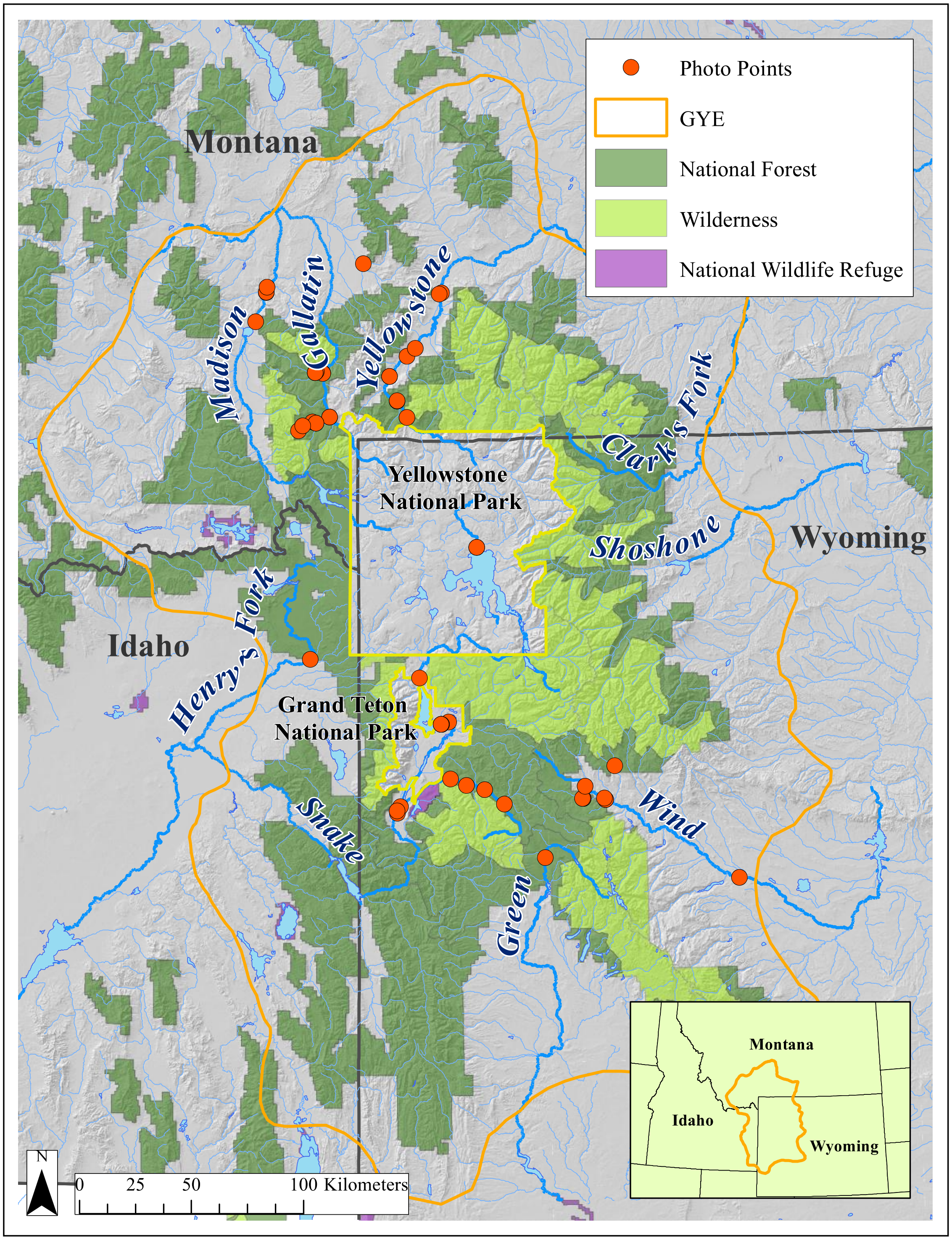


Figure 1. Greater Yellowstone Ecosystem photo points

Within the GYE, repeat photograph comparisons are organized by watersheds and specific reaches or geographical reference points within them. The rivers used for this study include: the Gallatin, Yellowstone, Wind, Gros Ventre, Snake, Green, and Madison Rivers. Gallatin River comparisons are divided into three geographic areas: Taylor Fork, near 320 Ranch, and West Fork. Yellowstone River comparisons are divided into three regions: Yellowstone Lake, Point of Rocks, and Emigrant. Wind River comparisons include the following geographic regions: Upper Wind River and Horse Creek, Warm River, and Wind River Diversion Dam. Snake River comparisons occur in two regions: Jackson Lake Dam and Wilson Bridge. The Green River comparison only includes one area in the headwaters. Madison River comparisons include two regions: Earthquake Lake and Bear Trap Canyon.

Riparian Vegetation

Interpreting changing riverine systems requires an understanding of riparian ecosystem dynamics. Riparian ecosystems include plant species located in valley bottoms that have a competitive advantage in saturated environments attributed to seasonal or permanent inundation and flooding disturbance (Shoutis, Patten, & McGlynn, 2010). Riparian vegetation, particularly willows (*Salix spp.*), cottonwoods (*Populus angustifolia, P. balsamifera,* and *P. trichocarpa*), and alders (*Alnus spp.*), provide terrestrial habitat, create favorable shaded areas for aquatic species, and maintain riverine morphology (Kauffman et al., 1997).

In the GYE, elevation has the strongest influence on vegetation distribution, directly affecting temperature and moisture gradients as a result of fluctuations in precipitation, temperature, landforms, and stream networks. At lower elevations in the GYE, cottonwoods tend to dominate riparian communities, whereas willows are most common in higher elevations (Marston & Anderson, 1991). Merigliano and Polzin (2003) categorized six age classes for cottonwoods reflecting tree conditions as land bird habitat: young (1-10 years), saplings (11-20 years), pole (21-30 years), mature (31 to 70 years), old (71 to 125 years) and very old (125+ years). Further investigation of ecological dynamics within different cottonwood age class communities revealed that mature cottonwood forests had the widest variety of tree sizes, volume of debris, and biomass understory, which supported vast number of birds species and highest total bird abundance, when compared to the other cottonwood classes (Hansen, Rotella, Klaas, & Gryskiewicz, 2003). Aging cottonwood stands provide less desirable habitat, because they become decadent and no longer regenerate. Grasslands will likely replace these stands, reducing the extent of the riparian ecosystem (Hansen et al., 2003).

Floodplain Dynamics

Riverine plant community distributions are dynamic due to fluvial disturbances that limit competitive exclusion through removal of mature trees and enhancement of the potential for higher species diversity (Naiman & Decamps, 1997). Flooding also influences species distribution through sediment and nutrient deposition and by facilitating the dispersal of riparian propagules (Helfield et al., 2007; Naiman & Decamps, 1997). Cottonwood trees are dominant features along the rivers in the GYE and they serve as indicators of flooding events because their life histories represent floodplain age. Turnover period, or time required for a channel to completely erode and re-deposit sediment, is an important concept in floodplain ecology. A dynamic floodplain system with a shorter turnover period will stimulate cottonwood forest regeneration and increase the number of young cottonwood stands. Bank stabilization and regulated flows cause a longer turnover period, which will diminish cottonwood colonization, reduce the number of young cottonwood stands, and increase the number of cottonwood trees that reach maturity (Merigliano & Polzin, 2003).

Resource Use in the GYE

Westward migration of early settlers from the eastern U.S. shaped the culture and landscape of the GYE. The arrival of explorers, miners, and fur trappers ignited the beginning of western society. Railroads embodied the transformation of the West as a vector for harnessing natural resources including, soil, water, forests, minerals, and wildlife. Formerly bison-dominated grasslands became cattle pastures; dam construction and irrigation implementation provided water storage, allowing increased agriculture and settlement in arid western lands. Mining prospects progressed from primarily gold and then to silver, copper, and associated metals and later to oil, gas, and coal. Forestry expanded from initial interests in selectively processing the highest-grade timber to clear cutting forests (Clawson, 1977).

Beaver Trapping

As keystone species, beavers provide a crucial ecological role in regulating movement of water by building low-head dams. However, between 1810 and 1860 in the western U.S., early fur trappers caught tens of millions of beavers, depleting populations and reducing the number of beaver dams. When trappers discovered a new beaver rich area, they only took a few decades to wipe out the majority of the beavers (Wohl, 2006). Beaver extirpation considerably impacted western ecosystems because their dams trap sediment and create pools providing habitat for a wide array of species and serving as a buffer for flood waves (Wohl, 2001).

In ecologically complete riparian systems, willow communities and beaver populations function symbiotically. Willows supply food and dam building materials for beaver and in turn beavers create dams, which provide increased water availability, stimulating willow productivity. Thus, these two organisms are key to riparian disturbance regimes. Consequently, beaver absence promotes stream erosion, leading to incised channels and disconnected floodplains from adjacent streams. These effects create a negative feedback loop by lowering the water table, which decreases willow population and further limits viable beaver habitat (Bilyeu, Cooper, & Hobbs, 2008; Marshall, Hobbs, & Cooper, 2013). The decline of beaver populations resulted in dam destruction, amplifying flood impacts, which then undercut channels and increased sediment transport (Wohl, 2001). However, repeat photography does not capture the extent of early beaver devastation because the fur industry boomed before the age of photography. Additionally, channel changes attributed to beaver removal were probably less substantial when compared to the more direct impacts of human perturbations (Wohl, 2006)

Tie Drives

Development of the Union Pacific Railroad in 1869 and the Northern Pacific Railroad in 1883 created a demand for railroad ties (Allin, 1982; Rosenberg, 1999). Tie hacks, or lumberjacks, stripped conifer forests in the foothills from summer to spring. They dammed upper tributaries, creating holding ponds, or surge dams, to store ties until spring snow melt. Prior to the release of the ties, tie hacks modified river channels by removing large obstacles (i.e., natural wood debris and large boulders) and blocking off overbank areas to create clear channels for tie transportation (Wohl, 2005; Young, Haire, & Bozek, 1994).

During spring high water, tie hacks opened dams, releasing thousands of ties down tributaries and into main river channels (Rosenberg, 1999; Wohl, 2001). Within the GYE, tie drive operations occurred on the Gallatin, Upper Wind, and Green Rivers. Traveling masses of ties would scour riverbanks, rip vegetation, destabilize sediment, and disrupt the natural heterogeneous structure of rivers (i.e., series of riffles and pools) (Wohl, 2001). In steep tributary reaches, tie hacks would build flumes to transport ties (e.g., Warm River Canyon) (Rosenberg, 1999; Young et al., 1994).

In 1902, Walter Cooper began supplying ties for the Northern Pacific Railroad construction via the Gallatin River. After the railroad company completed the transcontinental railroad, the company continued to make feeder lines, including a line to Salesville, known today as Gallatin Gateway. Cooper Tie operations began on Taylor Fork of the Gallatin River and lasted until 1907 upon the completion of most of the railroads in Montana. In 1924, the Bozeman Weekly Corridor estimated that during the five years that Cooper operated, loggers removed 2.5 million railroad ties (Cronin & Vick, 1992).

Between 1914 and 1946, tie hacks logged the Shoshone National Forest in the upper Wind River. Over this span of 40 years, tie hacks produced more than ten million hand-cut ties that floated approximately 160 km (100 mi) down the Wind River to Riverton, WY. The Wyoming Tie and Timber Company began in 1919 and built several dams to hold back ties in the upper Wind River tributaries; one of these was right before the Warm River Canyon. Due to the ruggedness of this canyon, tie hacks built a nine-mile flume and fed ties down the flume where they then met the Wind River, 10 km (6 mi) above Dubois. Trucks replaced the flume in 1942, as a more effective way to transport ties to the Wind River until operations ended in 1946 (Pinkerton, 1981).

In 1867, Charles Delony began a tie driving operation in the headwaters of the Green River to supply ties for construction of the Union Pacific Railroad. Ties floated about 210 km (130 mi) down to the railhead in Green River, WY. In 1919, the Standard Timber Company began operations in tributaries of the Green River and North and South Cottonwood Creeks, later becoming Green River Lumber and Tie Company. However, during the 1930s, sawmills and chainsaws replaced tie hacks and broadaxes and Green River Lumber preferred trucked lumber to water logged ties. Consequently, the last tie drive in this region occurred in the early 1940s (Rosenberg, 1999).

Dams

Dams impact river flows and thus influence habitats upstream and downstream of reservoirs. In 1902, the Reclamation Act authorized the U.S. government to “reclaim,” or install water projects to make arid lands useful for agriculture. As a result, the federal government produced multiple dams within the GYE (e.g., Jackson Lake Dam). Dams disrupt natural flow regimes, which coincide with precipitation events within watersheds. For instance, as snow melts in the spring, river waters rise, providing favorable conditions for stream bank vegetation reproduction, such as willows and cottonwoods. Dams cause an unnatural hydrograph through reduction, augmentation, and timing of river flows, disrupting vegetation life cycles, sediment transport, water chemistry, water temperatures, and stream biota (Wohl, 2001, 2005). Specifically, dams decrease peak flows, often increase baseflows, alter bedload discharge and bankfull cross-sectional area, and affect river depth, gradient, and sinuosity (Petts, 1979).

The Jackson Lake Dam (JLD) and a downstream levee system altered the natural state of the Snake River. In 1906, the Reclamation Service converted a toll bridge at the outlet of Jackson Lake into a log crib dam. However, when this dam failed, the Reclamation Service constructed the current cement dam with earthen dike, completing the project in 1916. JLD raised the water level by about approximately 12 m (3 ft), increasing the lake area by one-third, to provide about one million cubic meters of water to irrigate farmlands in Idaho. In 1909 and 1912, the Teton Irrigation Company secured the water rights to JLD and to this day Jackson Hole, WY is not able to directly use any of the Jackson Lake water (Daugherty, 1999). Additional repairs in 1989 did not affect the lake level or schedule of water releases (Marston, Mills, Wrazien, Bassett, & Splinter, 2005).

After a severe flood in 1950, Teton County landowners prompted the Army Corps of Engineers to build a levee system along a 21 km (13 mi) section of the Snake River near Wilson, WY, completing the project in 1964. As a result, large earthen dikes blocked the natural meandering flow of the river and restricted overbank flows to riparian wetland habitats. Due to negative public reactions, the Corps produced a study examining the affected riverine areas and impacted species in 1993 and identifying potential restoration activities. This restoration study originally considered 12 sites lying between Moose, WY and US Highway 26 Bridge. However, due to high costs, the number of selected sites decreased to four. The goals included wetland and riparian restoration as well as island protection and restoration (Anthony, 1998).

The Wind River Diversion Dam is another large dam in the periphery of the GYE. Initially completed in 1923, this dam diverts water from the Wind River to the Wyoming Canal, flowing into Pilot Butte Reservoir. By the 1940s, the vast majority of this water irrigated 29,513 ha (72,929 ac) (Cohn, 2010).

There are three dams along the Madison River within the GYE, but the photo results only capture the Madison Dam. Built in 1901, this 78 m (257 ft) long and 10 m (35 ft) high dam contains water within Madison Canyon, which then flows through a four-unit hydroelectric plant with a current generating capacity of nine megawatts. With a storage capacity of 3,355 ha-m (27,200 ac-ft), this dam is classified as a "run-of-river" project, generating electricity by water flowing down a natural gradient (PPL Montana, 2014). Due to the limited storage capacity of Ennis Lake, the Madison Dam does not dramatically alter the river's flow (BLM, 1984).

Agriculture

National expansion of railroads along with establishment of the first stockyards in Kansas caused the cattle industry to shift westward (Allin, 1982). Additionally, the Homestead Act of 1862 encouraged western migration by granting settlers 64 ha (160 ac) of public land for a nominal filing fee, which they could then purchase after six months. By 1900, this act distributed about 32 million ha (80 million ac) of public land to individuals. However in 1909, the Enlarged Homestead Act increased the acreage an individual could hold to 130 ha (320 ac) for dryland farming. The federal government then doubled the acreage to about 260 ha (640 ac) for ranching purposes in 1916 (Apple, 2012).

Intensive cattle and sheep grazing occurred throughout the valleys of the GYE and to a lesser extent, grazing still continues today. Even though wildlife, such as bison, elk, deer, moose and bighorn sheep, have grazed the land for thousands of years, their impacts on riverine habitats are temporary, because they are not confined to certain areas. Conversely, impacts of cattle and sheep grazing are extremely concentrated and they often prefer streamside areas with plentiful green forage, water, and shade (Wohl, 2001). In western North America, cattle may consume 20% of their forage diet from riparian areas (Samuelson & Rood, 2011). Large herds of sheep and cattle compact soil, contributing to sediment runoff and increasing erosion. Grazing animals often trample streamside vegetation, destabilizing the banks and providing less shade for fish habitat. Reduced vegetation and increased flash flows contribute to down-cutting of streams. As riverbanks erode, sediment concentrations rise in river channels, leading to decreased water quality (Wohl, 2005).

Samuelson and Rood (2011) concluded that higher elevation mountain zones were sensitive to grazing presumably due to harsh environmental conditions. The GYE vegetation has adapted to a cool, short growing season and shallow, nutrient-poor soils. Combinations of physical challenges and grazing pressure can lead to degraded riparian areas (Samuelson & Rood, 2011). In the western U.S., livestock grazing is the highest threat to the integrity of trout stream habitat (Webb et al., 2007; Wohl, 2001).

In the northwestern section of the GYE, Gallatin Canyon road construction in 1898 allowed entrepreneurs to take advantage of grazing lands. From 1898 to 1923, Marshall Seymour Cunningham and Hans Behring ran the largest and longest operated cattle outfit in Gallatin Canyon headquartered along Taylor Fork. Their operations began before the creation of federal forest reserves and thus they were free to graze their initial 1,260 head of cattle without regulation. In 1900, their operation was enlarged to include nine other partners and they expanded beyond the Gallatin Canyon to the Madison and Ruby Valleys and land on the Crow Reservation around Hardin, MT. In the Gallatin Watershed they expanded downstream of Taylor Fork to include West Fork, and upstream to Teepee and Daly Creek drainages (Cronin & Vick, 1992).

Downstream of Taylor Fork and the Gallatin River confluence, Sam Wilson and his father combined their homesteads in 1900 to create the 320 Ranch. Wilson briefly attempted to raise horses and angora goats, but both herds died due to particularly harsh winters. In 1906, the 320 Ranch later converted to a dude ranch and still operates as one today (Cronin & Vick, 1992).

Further downstream, in 1902, the Crail family began ranching in West Fork basin and ranching continued until Big Sky Resort opened in 1970. The first Crails primarily grazed sheep until 1934 when they switched to cattle. In order to sustain the cattle over the long cold winters, they grew hay in surrounding, wide-open river basins. They fed cattle hay until the grass was tall enough to support herds and then they moved cattle to summer pastures leased from the Northern Pacific Railroad or U.S. Forest Service. The 320 Ranch also used the West Fork basin as a summer range for their cattle and Ken McBride ran sheep there until the creation of Big Sky Resort (Strickler et al., 2012). Ranching operations persisted until 1968 when Chet Huntley bought the property and developed the resort (Cronin & Vick, 1992).

In 1865, farming and ranching began along the Upper Yellowstone River (UYR), a year after the infamous Nelson Story drove a herd of cattle into the valley from Texas and established livestock production. Sheep production occurred in the 1890s and 1950s, but cattle operations were the most consistent commercial livestock along the UYR. Despite protection of land with the creation of Yellowstone National Park in 1872, the park encouraged development of natural resource use along the UYR. The first settlers established in the mid 1860s, including Strickland Ranch at the base of Trail Creek, Bottler Ranch near Emigrant Gulch, and the Henderson place at the mouth of Yankee Jim Canyon. Settlement initially clustered in well-watered low elevation settings around the UYR. Under the Homestead Act, ranches acquired deeded land originally in approximately 65 ha (160 ac), 130 ha (320 ac), and 260 ha (640 ac) parcels. Some of the first photos of this area occurred when Ferdinand Hayden led geological surveys in 1871, 1872, and 1878 (Haggerty, 2004).

After 1900, homesteaders began to settle along the Gros Ventre River, a tributary of the Snake River. In this region, willows dominated stream banks and wet soils of this semiarid drainage. In 1883, cattle numbers started at about 100 and increased over time until Teton National Forest restricted numbers to approximately 15,000 (Gruell, 1980a). Since then, cattle have grazed this area primarily during spring and fall. Additionally, southerly exposures and consequent reduced snow packs have made this area a suitable wintering habitat for elk. In 1929, the Wyoming Game and Fish Department provided supplemental feed in the drainages of the Gros Ventre in an effort to prevent large-scale mortalities of elk due to severe winters (Dean et al., 2004). As a result, both cattle and elk have impacted riverine habitat in the Gros Ventre River watershed.

Even though agriculture was also prolific in the Wind and Madison watersheds, agricultural histories for these rivers are not mentioned because this study does not include photos of this land use along these rivers in the GYE.

Mining

Mining operations dramatically altered riverine systems. Placer mining, the movement of channel bed sediment to filter out gold flakes, led to channel destabilization and extreme erosion (Wohl, 2001). Hydraulic mining, a technique used to remove river deposits, resulted in extreme riverine impacts. This technique used high-pressured water jets, scouring riverbanks to break apart alluvial deposits. Additionally, miners dredged channel sediments and processed them with mercury amalgamation on dredge boats. High mercury concentration "hot spots" can still be found in dredge tailings along many western rivers (Wohl, 2001). The net effect of the mining on river reduced diversity and stability (Wohl, 2006).

With the 1872 General Mining Act, the federal government created an informal system of acquiring and protecting mining claims on public land, allowing individuals to operate mined land without a patent. Thus individuals could mine land with low taxes and lack of regulations for the governmental purpose of settling the western U.S. As a result of this free-for-all mining strategy, Montana now has 20,000 to 26,000 abandoned sites, polluting 2,092 km (1,300 mi) of rivers, representing a third of the affected sites in the western U.S. and Alaska (Stiller, 2000).

There were many small-scale mines throughout the GYE, but large mining pursuits began in 1869 with placer gold operations in the Beartooth Mountains outside of Cooke City, MT. This mining region, known as the New World Mining District, produced approximately 1,800 kg (4,000 lbs) of gold, 14,000 kg (31,000 lbs) of silver and 3,700 metric T (4,100 US T) of copper, zinc and lead from 1900 and 1955. However, due to the high elevation and rugged landscape, mining companies had difficulty getting gold transported to Anaconda, MT for processing. Even though operations ceased around 1950, mining tailings continued to pollute surrounding streams (Montana Department of Environmental Quality, 2009). Erosion from this mine contaminated the floodplain of Soda Butte Creek in Yellowstone National Park (YNP) (Marcus, Stoughton, Ladd, & Richards, 1995). The federal government purchased the

New World mine in 1996 (final land purchase in 2010) to keep this mine closed (Montana Department of Environmental Quality, 2009).

Changes in rivers caused by mining can be difficult to assess using repeat photography, because rivers directly next to most large-scale mining operations, especially with extensive dredge deposits, have severely altered valley topography. Without photos of pre-mine conditions we cannot access change or recovery when the landscape no longer has any riverine structure nor function. Repeat photography may be able to determine changes in turbidity, but this tool is not useful for detecting changes in toxicity, which is why mining comparisons are not included in this study.

Other Anthropogenic Impacts

In addition to natural resource use, other human impacts including road building, recreation, and residential development have greatly influenced the GYE. As industry and tourism expanded, road building increased causing stream diversion and sedimentation, natural habitat reduction and fragmentation, weed invasion, and increased access to hunting and poaching. Tourism and recreation have been long-term uses of the GYE impacting vegetation and wildlife. Developed recreation (i.e., campgrounds and resorts) is concentrated and has a broad impact, often encroaching upon riverine habitat (e.g., golf courses) and modifying whole watersheds (e.g., Big Sky Resort). Exurban development, often associated with developed recreation, increases recreation's cumulative effects. Even though private land only comprises about 20 percent of the GYE, this land includes the majority of lower elevation riverine and wetland habitats.

Population expansion and development in these areas will continue to alter these habitats (Glick, Carr, & Harting, 1991).

METHODS

Photo Collection

Various universities, museum archives, and national datasets (USGS, Library of Congress, etc.) provided historical photos of rivers in the Greater Yellowstone Ecosystem (GYE). We selected photos predating 1950 (unless they were in a sequence or similar location to an earlier photo) that we deemed suitable for a repeat photography study of resource use. The classifications for suitable photographs were: 1) they had a photo date, date range, or something in the photo that could identify the time period (e.g., car, postcard attributes, or infrastructure), 2) photo summaries included location descriptions or photos displayed sufficient topographical features for relocation. This research is part of a larger project to produce two repeat photography books, one of the Gallatin River and one of the GYE. Of 626 photos found for the larger project, I selected 102 photos that displayed instances of historical land use (e.g., ranching, logging, damming, and mining). From this selection, I was able to retake and utilize 54 photos for this research within the practical constraints of as accessibility, funding, and time. The data represent a stratified sampling of historical oblique photos by date and region, displaying natural resource use in the GYE.

Site Selection and Retake

GYE history books and discussions with the local community provided more insight on photo locations and backgrounds. The use of regional maps and map exploration software (i.e., Google Earth, Google Inc., Mountain View, California, USA) helped to pinpoint the exact photo point locations. Once I established these locations, I proceeded with physical investigations to establish photo angles and feasibility of retaking each photo. Each retake took into consideration landscape features, camera angle, field of view (FOV), and time of day of historical photos. The majority of repeat photos were taken with a Nikon D40X camera and Nikon 18-55mm lens, with the exception of three photos, by Dr. Jeff Burrell of the Wildlife Conservation Society, with a Canon 5D Mark II and Canon 24-105 lens.

To the best of my ability, I tried to take repeat photos at a similar time of year as historical photos by identifying water flow as high or low and leaf cover as budding, full, or absent. Additionally, I classified each historical photo by the approximate time of day based on azimuth and shadows within photos. Classifying photos taken on cloudy days was difficult due to limited shadows.

At each photo point, I recorded the location measured with a global positioning system (GPS) device, the azimuth recorded with a hand-held compass, the time of day, the estimated cloud cover percentage, signs of disturbance (i.e., beaver dams, grazing, human modifications), channel type (i.e., entrenched, confined, frequently confined, occasionally confined, unconfined, and not applicable), and human structures associated with the river (i.e., riprap, levees, and point structures). Where appropriate, these signs are discussed with the comparisons. The estimated precision of each of the photo point locations was less than six meters and I took multiple photographs within a circa six-meter radius of the recorded GPS location to ensure that I achieved as accurate a repeat photo as possible.

Photo Analyses Approaches

In order to establish and evaluate consistency across repeat photo perspectives, each pair was imported into Adobe Photoshop CS6 Extended and adjusted to maximize the objectivity of comparisons. Some historical photos were cropped to remove borders. The repeat photo was then made transparent and laid over the corresponding historical photo, and the repeat photo was scaled and cropped to match the size and pixel resolution of the historical photo. On two occasions the historical photo was cropped to match the repeat photo. After the photos were in common form, I assessed the comparability of the images to determine the type of analysis that would be possible for each site.

I divided the 54 photos into three types of analytical classification: descriptions of change, rank order of change, and quantification of land cover. Each photo was scrutinized based on photo comparison accuracy, distinctiveness of vegetation patches, quality of view, and scale of change. All photos were described, focusing on changes in vegetation, river channels, and land uses. Of the 54 photos, 37 were ranked on a scale of one to five from relatively little change to substantial change (Table 2). Rank order photos did not include photos that revealed a comparison of no vegetation to visible vegetation or vice versa because change could not be accurately accessed when starting with nothing. Of these 37 ranked photos, only 15 were analyzed quantitatively, because the rest lacked completely accurate comparisons, due to obscured vegetation, inaccessible photo point locations, or change being too complex to rank or quantify.

Table 2. Rank order classification based on a scale of one to five.

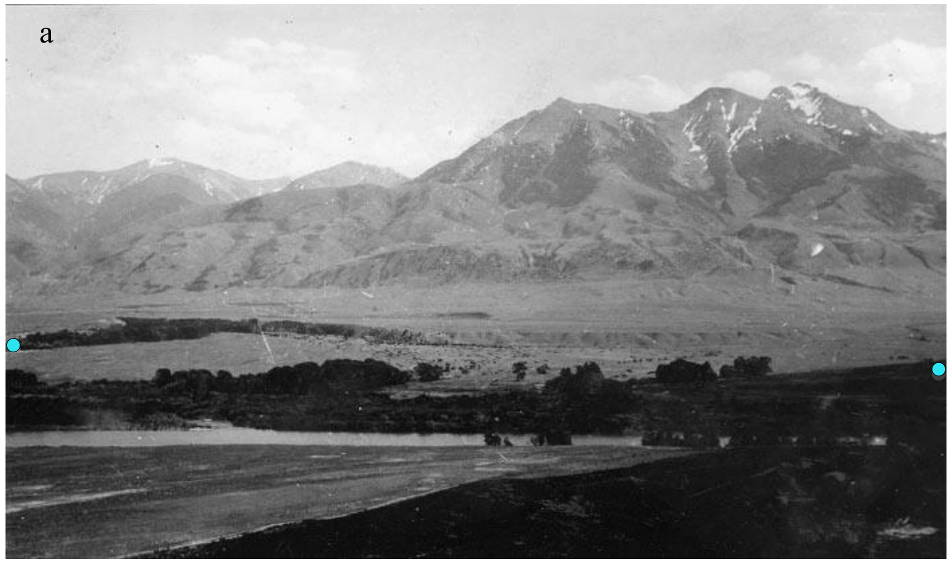
Rank	Type of Change	Description
1	Insignificant	Individual plants have grown, but the number of plants does not appear to have increased or decreased; no detectible change in sinuosity.
2	Minor	Vegetation patches have slightly increased or decreased; no visible sign of change in river geomorphology.
3	Moderate	Visible shift in channel morphology and reduced or increased riparian vegetation patches.
4	Major	Obvious vegetation and sinuosity change.
5	Substantial	Dramatic signs of vegetation and sinuosity change due to large impacts, such as infrequent events (i.e., flooding, tie driving, and damming).

Land cover quantification requirements included exact photo overlay, clearly defined vegetation patches, and unobstructed views of riparian habitat in both photos (i.e., historical and repeat). In order to quantify these 15 photos, I outlined vegetation polygons in Adobe Photoshop CS6 Extended. Photo comparisons were the same size and pixel resolution; therefore, I could measure the area of polygons in pixels and relate how a current vegetation polygon compared to a historical polygon. I repeated this method for visible river surface areas (i.e., channel, bankfull area, or floodplain). I also determined the sinuosity (i.e., thalweg length divided by Euclidean distance) of rivers by drawing a line along the thalweg. Due to the constraints of Photoshop, I had to create a polygon and subtract the non-thalweg sides to achieve a pixel length of the river channel.

The quantifications (i.e., vegetation polygon percent change and sinuosity difference) can only be compared between photos of the same site. These quantifications do not represent a general magnitude of change for comparison across all photos. The percent change in vegetation polygons indicates a change in pixel coverage (i.e., number of pixels within a polygon) of vegetation patches, not actual area of these patches.

Aerial Photo Analyses

Aerial interpretations of the Upper Yellowstone River (UYR) helped to supplement oblique analyses. I selected three oblique photos along the UYR near Emigrant, MT to use for aerial analysis. After uploading GPS photo point locations into ArcGIS 10.2 overlaid on 2011 orthorectified photos, azimuths (obtained from oblique photo data collection) were drawn from each photo point (Figure 2). These lines helped to determine the fields of view (FOVs) of oblique photos from an aerial perspective. FOVs were further identified using topographic markers. In order to verify FOVs, GPS photo points were uploaded into Google Earth to match the FOVs to oblique photos. In order to create the photo wedges, circles were drawn around photo points out to the furthest topographic markers (i.e., glacial river benches, tributaries etc.) just beyond the riparian land cover as identified by Merigliano and Polzin (2003). Topographic markers were determined in the oblique photos. Circles were cut according to topographic markers so that only about one fourth of the circle remained, creating a photo wedge (Figure 2).



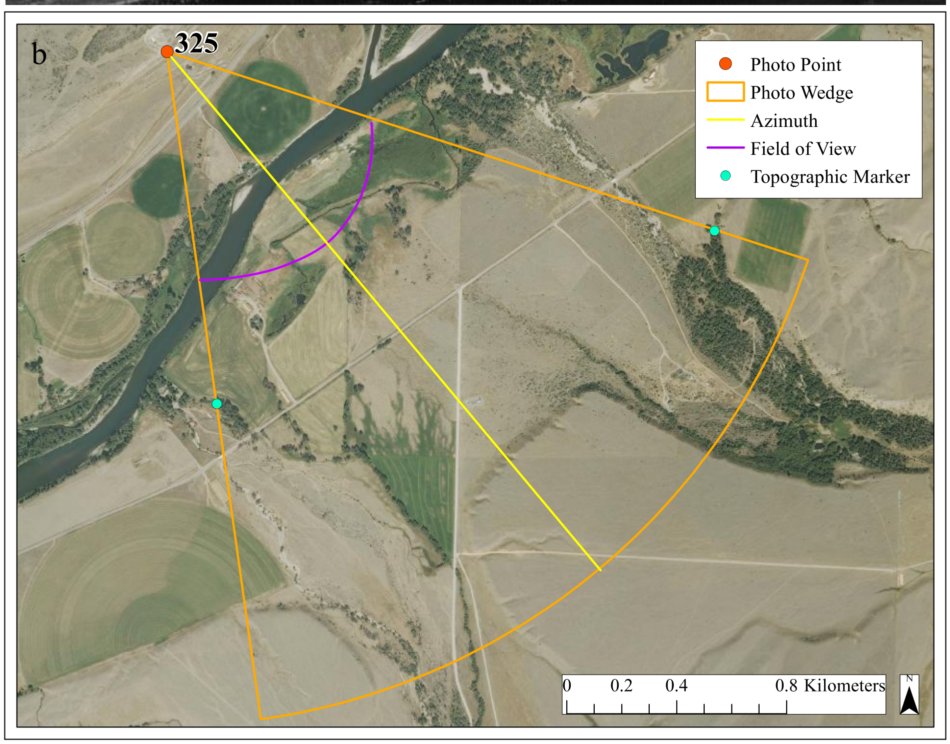


Figure 2. a. Topographic markers for aerial analysis of oblique photo near historical Bottler's Ranch, Yellowstone River, Emigrant, MT (photo point 325) Clark, H.M. 8/25/2013. b. Photo wedge with photo point, azimuth, field of view (FOV), and topographic markers of photo point near Emigrant (Figure 29).

From the 1948 and 1999 photo wedges for each of the three photo points, I was then able to quantify the land cover area by summarizing the total area in each cover class (Table 3). In order to get a percent change, I calculated percentage of land cover within each photo wedge. Sinuosity was determined within each wedge by dividing thalweg length by Euclidean distance.

Table 3. Land cover descriptions as classified by Merigliano and Polzin (2003)

Land Cover	Description
Surface Water	Water surface within the channel and in isolated bodies on the flood plain
Gravel bar	Bare gravel bar, typically flooded at normal high flows
Gravel bar vegetation	Gravel bar with sparse, young (<5 yrs.) vegetation
Shrub	All willow, and cottonwood 10-20 years old
Young Cottonwood	Pole-sized cottonwoods, 20 to 40 years old, all understory types
Mature cottonwood	Cottonwood 40-100 years old, all understory types
Old cottonwood	Cottonwood 100+ years old, all understory types
Meadow	Nonwoody vegetation patches, includes wet and dry herbaceous areas
Juniper	Rocky Mountain juniper dominates (tallest plant)

RESULTS AND INTERPRETATIONS

Photo comparisons are arranged into six geographic regions. Paired scenes are numbered consecutively with the historical, “a” on the right and the retake, “b” on the left. In sequences of three photos, “c” marks the most recent retake. The dates of historical photos are as precise as possible and estimated (est.) dates are considered accurate within approximately 15 years. Photos are addressed going downstream, with the exception of several tributaries. In figure captions, “Unknown” signifies undetermined photographers. Quantified polygons are outlined in white.

Gallatin River

Gallatin River comparisons cover three different regions in the Gallatin River watershed: Taylor Fork, near 320 Ranch, and West Fork (Figure 3). Photo comparisons from this geographic area reveal how tie driving and ranching have influenced the riverine landscape.

Taylor Fork

Cooper tie drive operations had three camps along Taylor Fork with additional camps owned by subcontractors up Wapiti Creek and several camps along Buck Creek (Cronin & Vick, 1992). Several surge dams along Taylor Fork held ties until spring. These dams significantly influenced the landscape by scouring banks, saturating vegetation, and accumulating sediment (Figure 4 and Figure 5). Even though the surge dam near the base of Koch Peak had not been in operation for four years at the time of the historical photo in 1911, the impacts are still apparent (Figure 4a). The surge dam caused riverbank scouring and converted the former river channel into a pond, saturating riparian vegetation. About a century later, the riverine landscape (i.e., within this FOV) appears to have recovered as seen by increased river meandering and riparian coverage—notably willow—with pixel coverage of bankfull area decreasing by 64% (Figure 4).

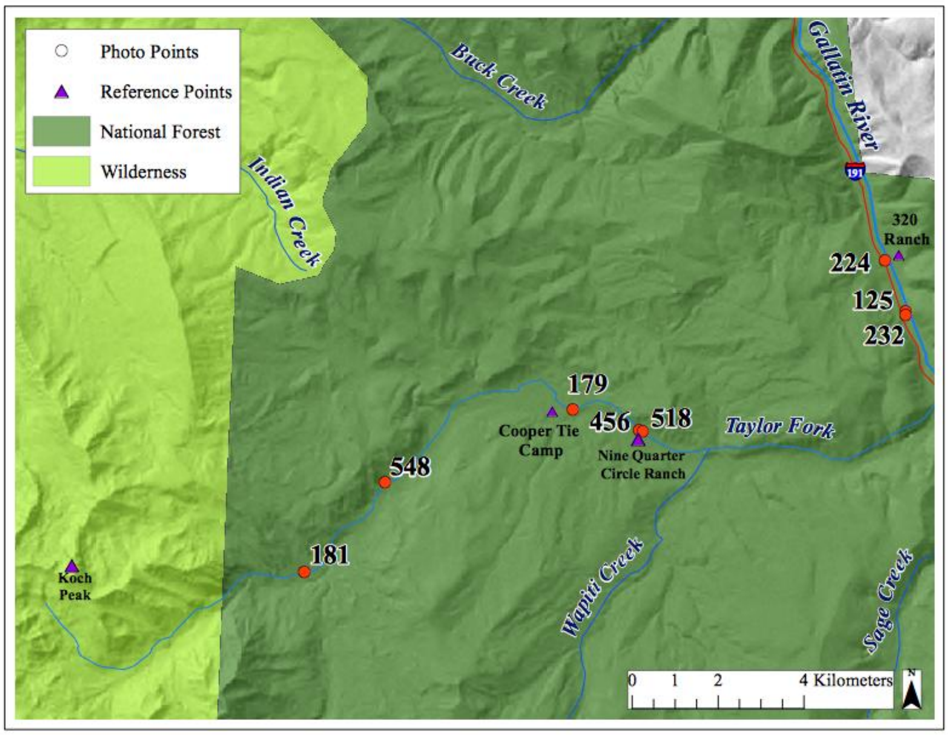


Figure 3. Taylor Fork of the Gallatin River photo points

Downstream, another historical photo near an old surge dam captures a view 40 years following tie drive operations (Figure 5a). Even after this extended time period, dam impacts are still apparent with scoured banks and little vegetation. About 60 years later, the stream channel migrated to the right and the formerly dammed area filled in with riparian vegetation, suggesting recovery (Figure 5b).

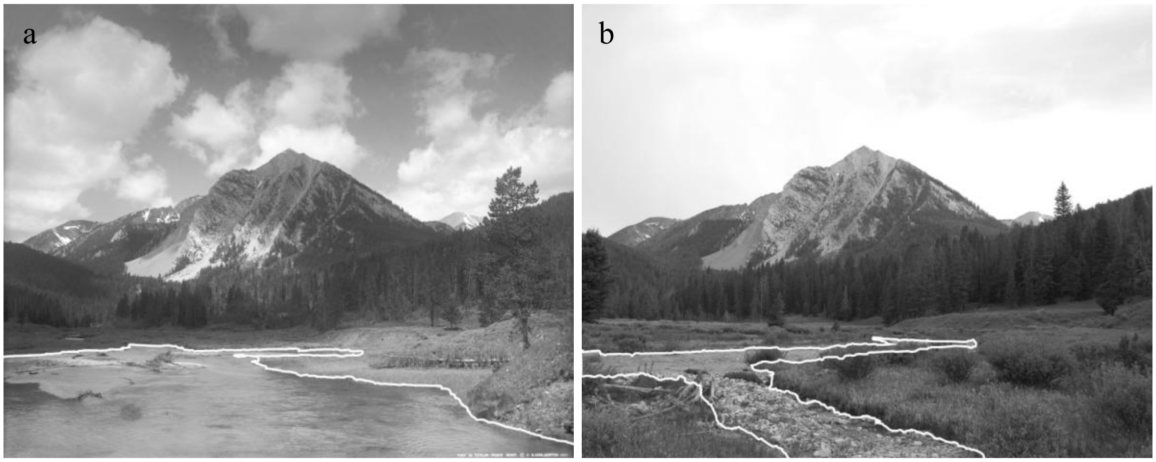


Figure 4. Behind a surge dam, near the base of Koch Peak, Taylor Fork, MT (photo point 181) a. Schlechten, Albert 1911, Courtesy of Museum of the Rockies. b. Clark, H.M 6/29/2013.

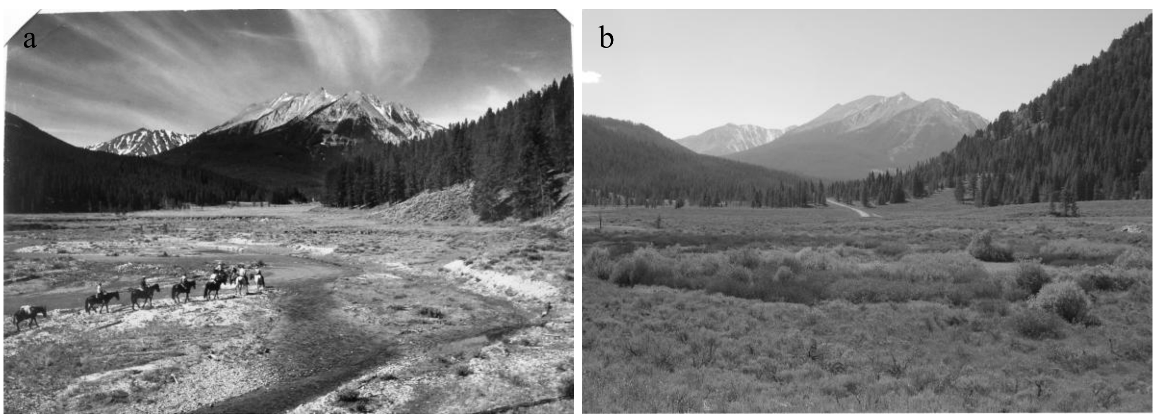


Figure 5. Behind a surge dam, Taylor Fork, MT (photo point 548) a. Unknown ca. 1930-1940s, Courtesy of Museum of the Rockies. b. Clark, H.M. 6/15/2013.

Farther downstream, below the Cooper Tie Company headquarters and above the Nine Quarter Circle Ranch, tie drives continued to impact Taylor Fork (Figure 6). Due to lack of large disturbances, conifers have started to establish in the middle ground and by 2013, they have become so dense that the hill in the background is no longer visible (Figure 6c). Pixel coverage of river bankfull has only slightly increased by 15%, reveling little change.

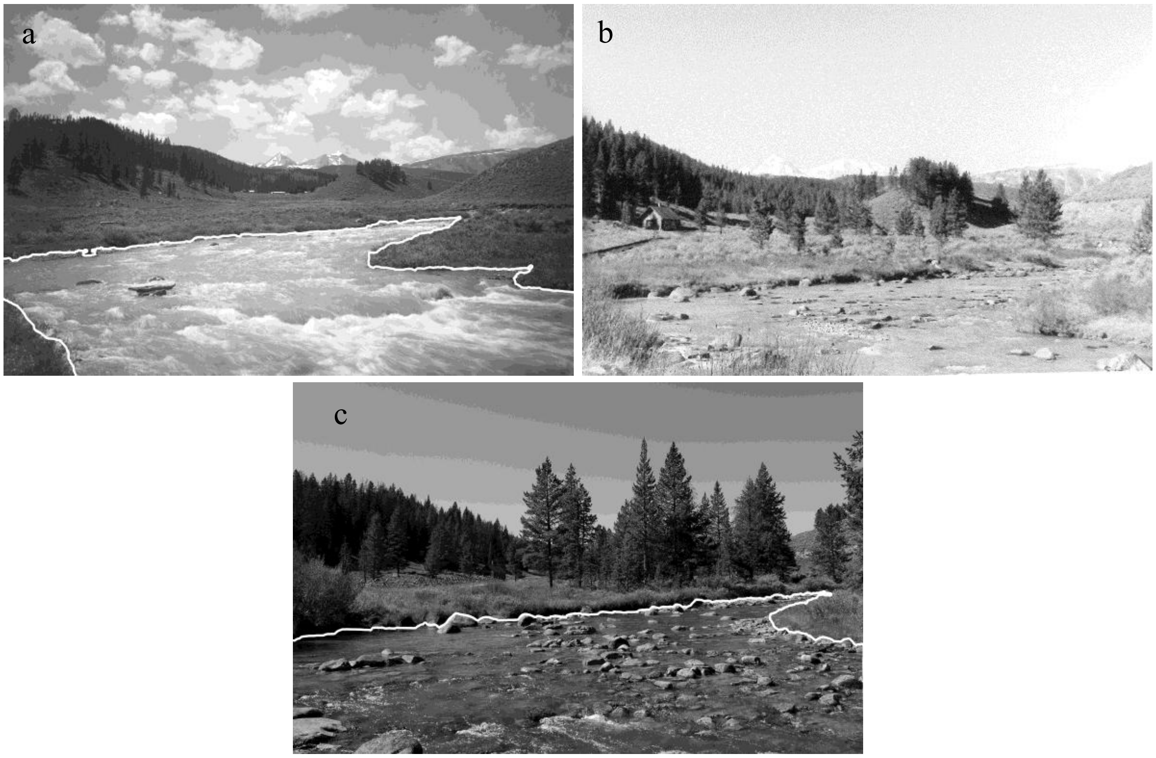


Figure 6. Downstream of former Cooper Tie Camp, Taylor Fork, MT (photo point 179) a. Schlechten, Albert. 1911, Courtesy of Museum of the Rockies. b. Patten, D.T. 1961 c. Clark, H.M. 9/21/2013. Quantified polygons are outlined in white (the repeat photo reflects the 1911 photo, because the 1961 photo is not an exact comparison; (photos were taken at different times of the year: spring and summer).

Downstream and across from the Nine Quarter Circle Ranch, riverbanks exhibit signs of scouring (Figure 7). Tie drives eroded channel banks, leaving only coarse soil suitable for conifer growth (Figure 7b). Riparian vegetation has increased and the riverbank has become more stabilized in the absence of tie driving (Figure 7 and Figure 8). Historical photos from ca. 1900 and ca. 1930 (Figure 7a and Figure 8a) show how tie driving prevented riverine vegetation establishment along the banks.

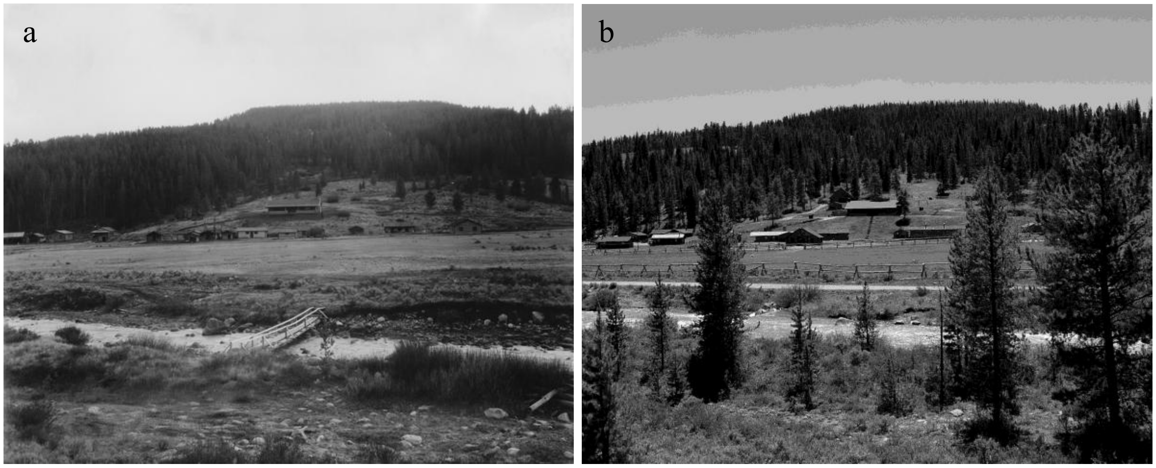


Figure 7. Nine Quarter Circle Ranch, Taylor Fork, MT (photo point 456) a. Unknown ca. 1900s, Courtesy of Museum of the Rockies. b. Clark, H.M. 6/15/2013.

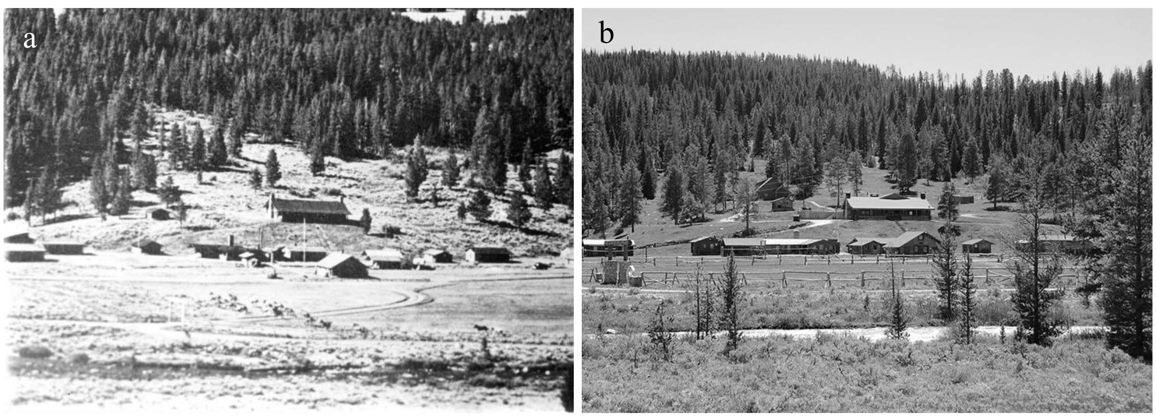


Figure 8. Nine Quarter Circle Ranch, Taylor Fork, MT (photo point 518) a. Unknown ca. 1930s, Courtesy of the Pioneer Museum. b. Clark, H.M. 6/15/2013.

<u>Near 320 Ranch</u>

Below Taylor Fork and the Gallatin confluence, tie hacks had to dislodge logjams with long steel hooks when ties became tangled up on logs or snags (Figure 9 and Figure 10) (Cronin & Vick, 1992). This area does not indicate much change other than increased conifer growth along riverbanks. After the cessation of tie driving, lack of disturbance most likely led to succession toward later seral stages.

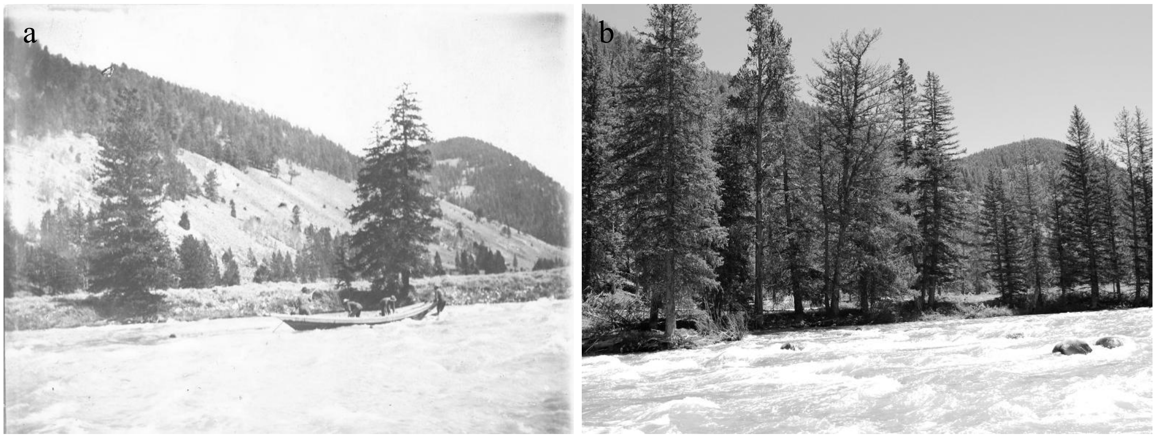


Figure 9. Upstream of 320 Ranch, Gallatin Canyon, MT (photo point 125) a. Unknown ca. 1907, Courtesy of the Museum of the Rockies. b. Clark, H.M. 6/15/2013.

Figure 10. Upstream of 320 Ranch, Gallatin Canyon, MT (photo point 232) a. Unknown ca. 1907, Courtesy of the Museum of the Rockies. b. Clark, H.M. 6/15/2013.

Downstream from 320 Ranch Bridge, photos indicate more noticeable changes (Figure 11). With the conclusion of tie driving, the right middle ground has been able to stabilize and fill in with vegetation (Figure 11). In this photo comparison, tie drive impact is hard to assess, because the trees could have regrown over the last century and there is no change in the pixel coverage of river surface area (i.e., 0%); however, there must have been extensive initial impacts from ties, especially because about 75% of ties floated down the right side of the river where there appears to have been a side channel

(Figure 11a). This side channel is now sufficiently elevated beyond reach of relatively high flows.

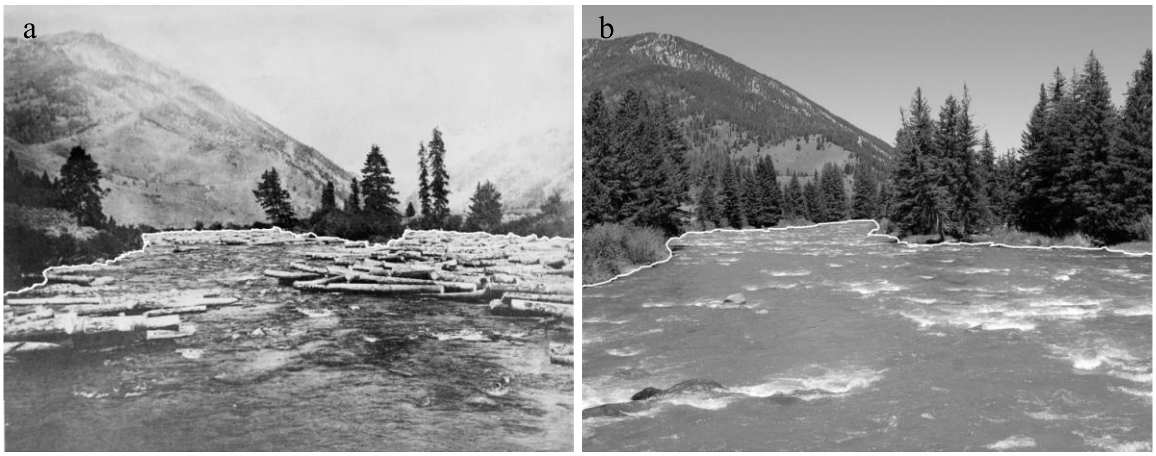


Figure 11. 320 Ranch, Gallatin Canyon, MT (photo point 224) a. Unknown 1906, Courtesy of Museum of the Rockies. b. Clark, H.M. 6/15/2013. Quantified polygons are outlined in white.

West Fork

The next series of photo comparisons are near Big Sky, MT where the Crail Ranch began cattle operations in the early 1900s (Figure 12). Expansion of Highway 191 and the bridge dramatically altered the willow community on the right side of the river as well as along the outlet of West Fork (Figure 13). However, vegetation along the left side of the river has remained mostly unperturbed by humans since tie driving, because this area is now protected as a Gallatin Valley Land Trust conservation easement. In this area, conifers have shaded former dense willow patches, decreasing their size.

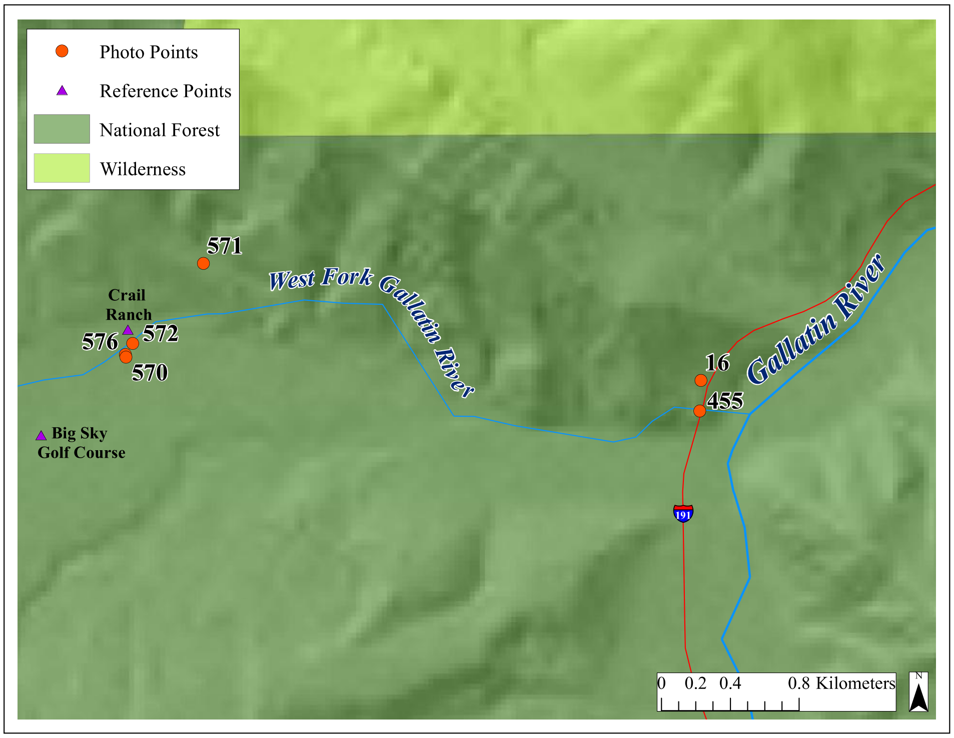


Figure 12. West Fork of the Gallatin River photo points

Figure 13. Big Sky intersection (HWY 191), Gallatin Canyon, MT (photo point 16) a. Unknown ca. 1930-1933, Courtesy of Montana State University. b. Clark, H.M. 8/24/2013.

Up West Fork from Highway 191, conifers have continued to mature; however, the riparian plant community−mostly willow−has encroached on the river channel (Figure 14). The cessation of disturbance—either from removal of grazing pressures in the early 1970s or reduced high flows resulting from development of housing and the Big Sky Golf Course upstream—could have contributed to this encroachment.

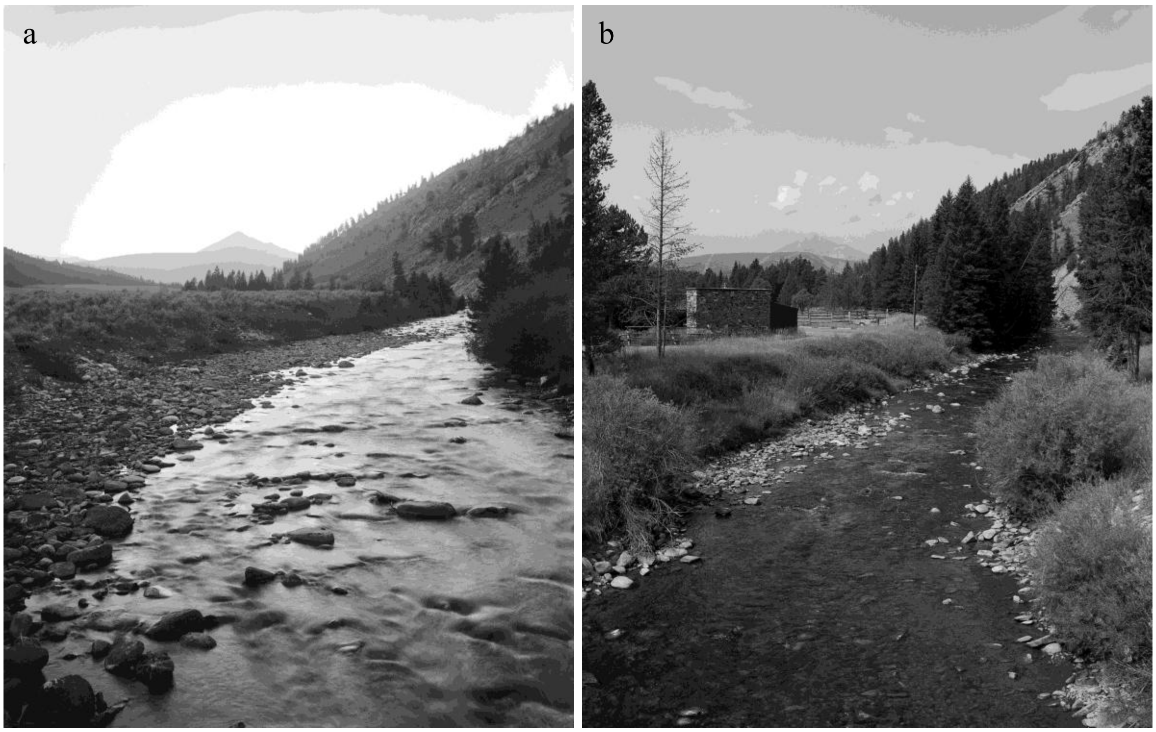


Figure 14. Outlet of West Fork, Big Sky, MT (photo point 455) a. Schlechten, Albert ca. 1910, Courtesy of Museum of the Rockies. b. Clark, H.M. 8/24/2013 (the repeat photo was taken from a higher perspective than the historical photo due to the 191 bridge and highway expansion).

Further upstream near Crail Ranch, cattle heavily grazed the valley; however, the riverine landscape does not appear to have fully recovered even after ranching ceased with development of Big Sky. Big Sky Golf Course, housing developments, and man-made ponds have altered the West Fork; nevertheless, protection from the golf course has also allowed willows to reestablish in certain areas, creating fragmented patches of riparian vegetation (Figure 15).

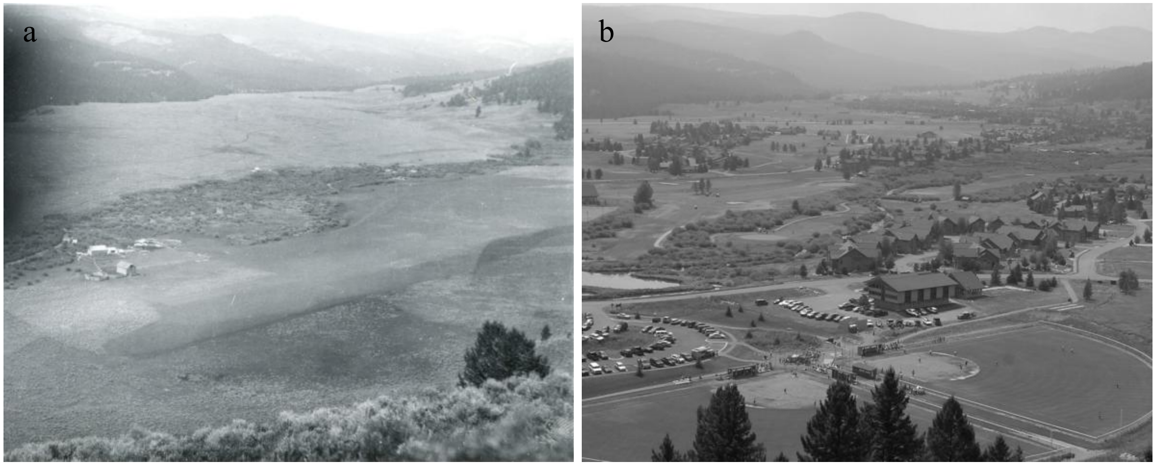


Figure 15. West Fork, Big Sky, MT (photo point 571) a. Unknown, ca. 1913-1924, Courtesy of Historic Crail Ranch Conservators. b. Clark, H.M. 6/24/2013.

Figure 16. West Fork, Big Sky, MT (photo point 576) a. Unknown, est. 1916-1920, Courtesy of Historic Crail Ranch Conservators. b. Clark, H.M. 6/24/2013.

In some areas, the Big Sky Golf Course has restricted willow growth, while elsewhere willows have been able to recover in the once heavily grazed, low floodplain (Figure 16 and Figure 18). One photo comparison of West Fork suggests a lack of willow regrowth, where the far bank has been cut back and some vegetation has encroached on newly exposed cobbles (Figure 17). However, in another comparison, since ca. 1920s, pixel coverage of willows increased by 32% on the right side of a reach, whereas on the left bank, Big Sky Golf Course has prevented most reestablishment of willow (Figure 18).

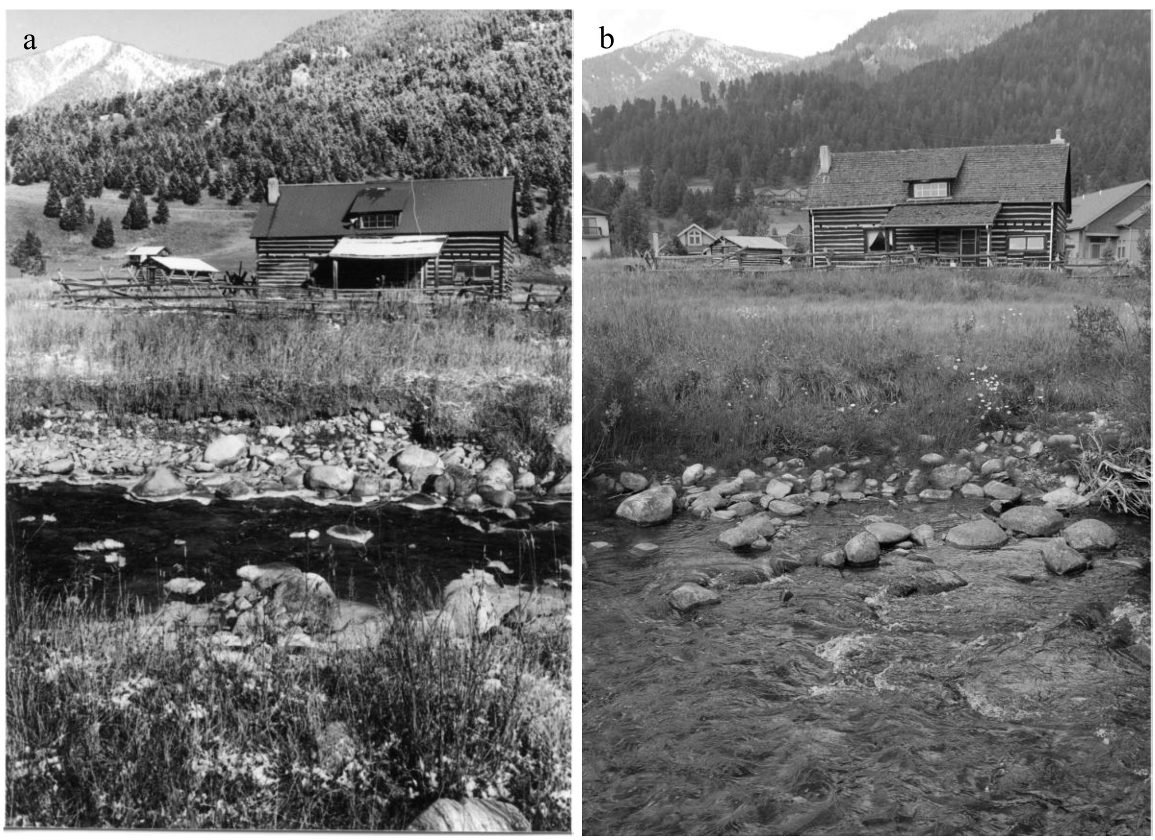


Figure 17. West Fork, Big Sky, MT (photo point 572) a. Unknown, est. 1960-1970, Courtesy of Historic Crail Ranch Conservators. b. Clark, H.M. 6/24/2013 (photos were taken in different seasons—spring vs. late summer—and from slightly different locations due to willow growth).

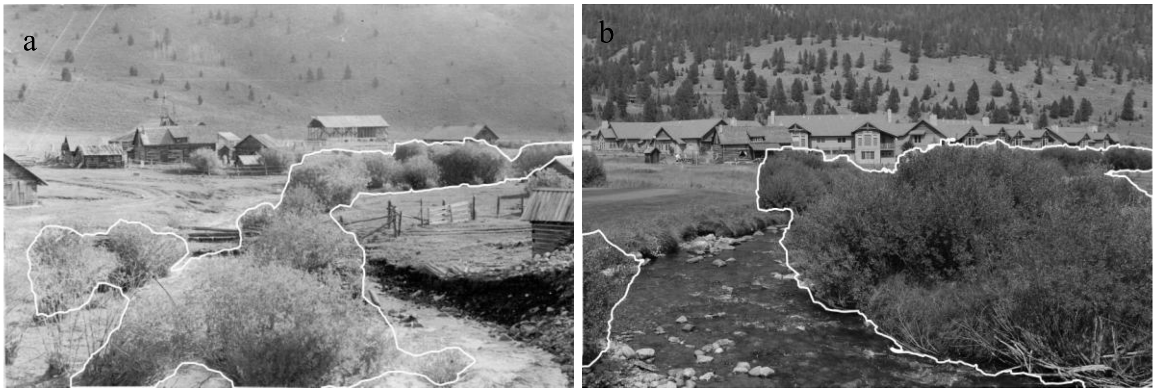


Figure 18. West Fork, Big Sky, MT (photo point 570) a. Unknown, ca. late 1920s to mid 1930s, Courtesy of Historic Crail Ranch Conservators. b. Clark, H.M. 6/24/2013. Quantified polygons are outlined in white.

Yellowstone River

This study includes few photo comparisons within Yellowstone National Park (YNP), because since formation of the park in 1872, there has not been intensive natural resource use (i.e., tie driving, agriculture, and damming) within in the park. However, there are many historical photos documenting past ecological and cultural scenes within YNP.

Yellowstone Lake

The outlet of Yellowstone Lake (Figure 19) acts as a control to compare to dammed lakes in the GYE. Sediment deposition in Yellowstone Lake has relocated and conifers lining the lake have become denser (Figure 20). Looking downstream from approximately the same photo point where Fishing Bridge crosses the Yellowstone River at the lake outlet, there has been little riverine change except for increased conifer growth on the near and far banks (Figure 21).

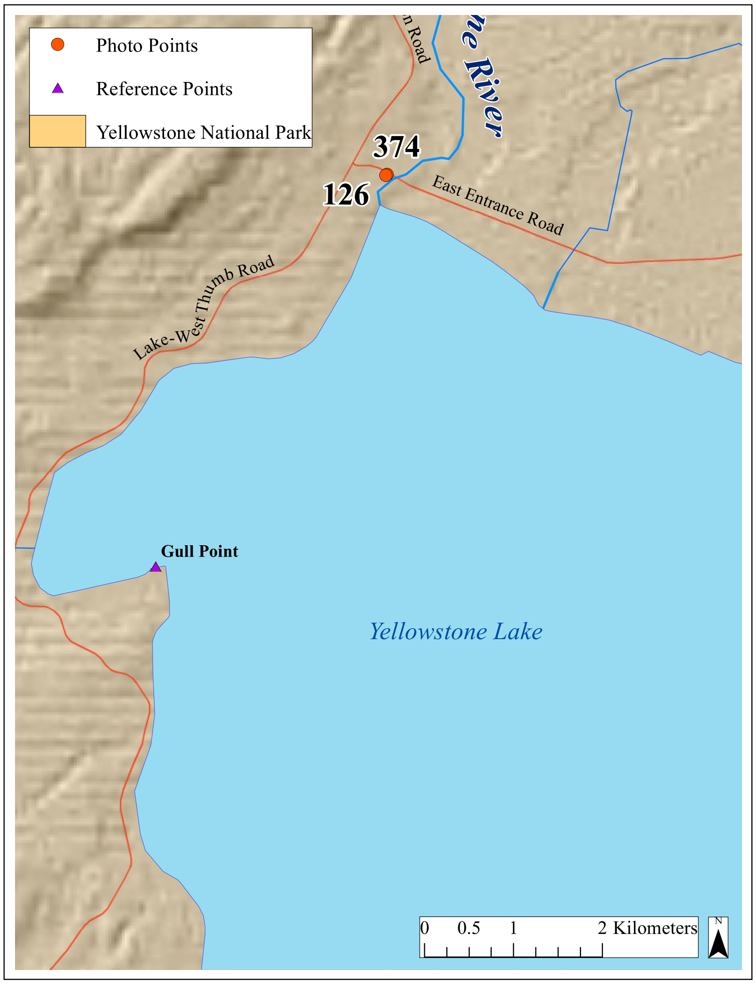


Figure 19. Yellowstone Lake photo points

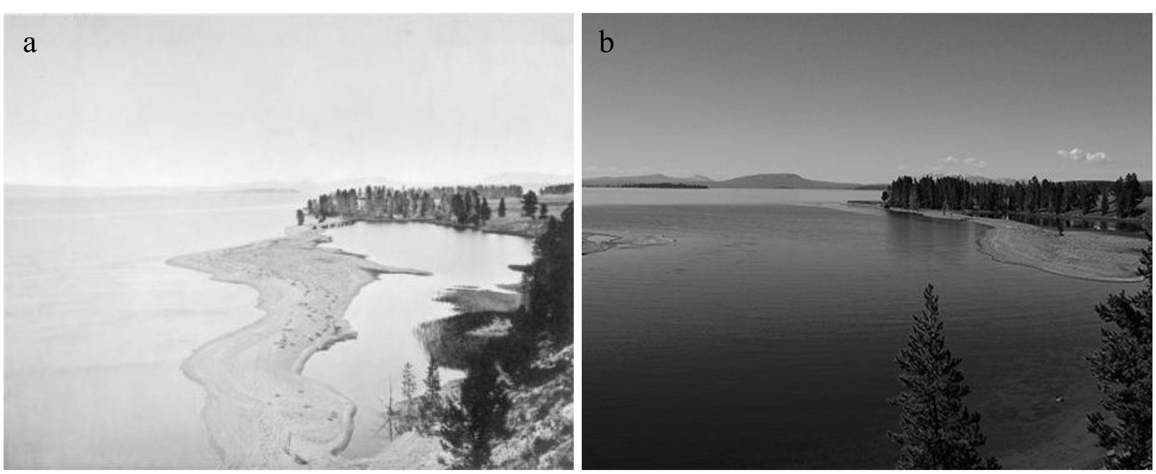


Figure 20. Looking toward Gull Point, Yellowstone Lake outlet, WY (photo point 374) a. Jackson, W.H. 1871-1879, Courtesy of Denver Library. b. Clark, H.M. 7/19/2012.

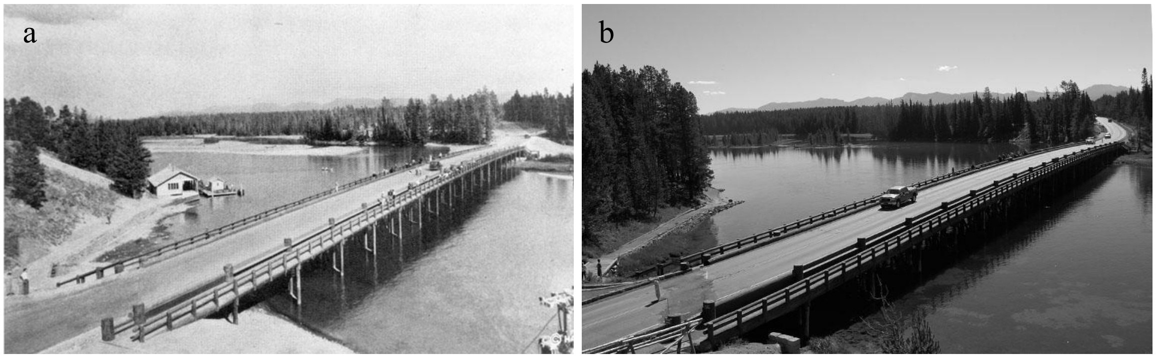


Figure 21. Downstream of Yellowstone Lake outlet, WY (photo point 126) a. Unknown, est. 1920-1950, Courtesy of Pioneer Museum. b. Clark, H.M. 7/19/2012.

Upstream of Yankee Jim Canyon

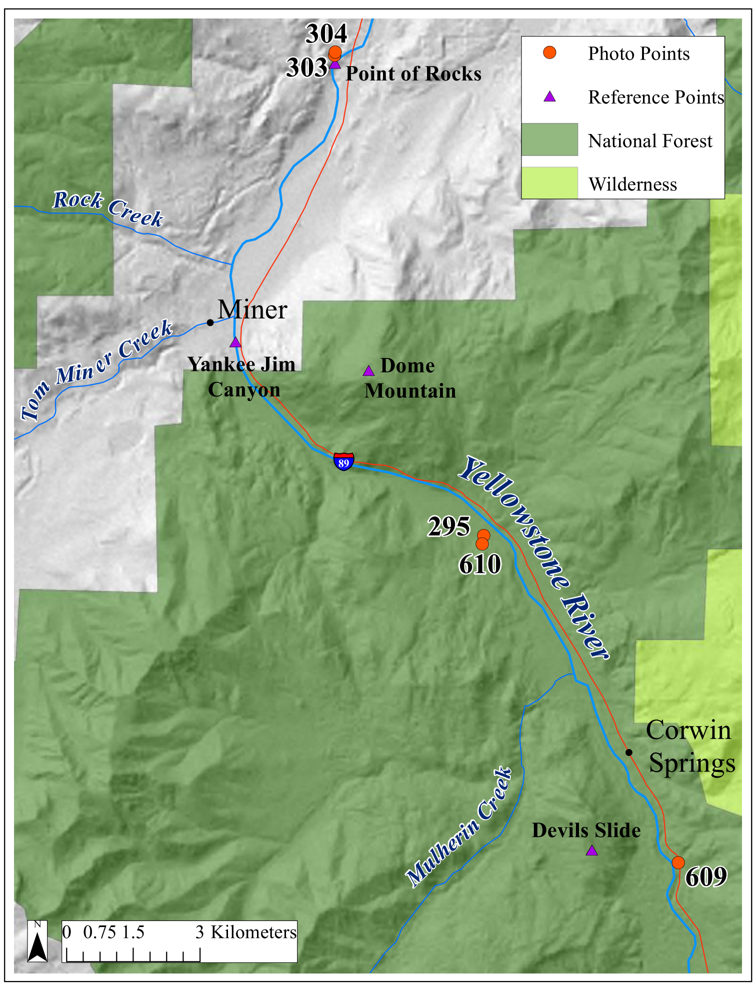


Figure 22. Yellowstone River photo points near Yankee Jim Canyon.

The Upper Yellowstone River (UYR) has played an integral role in ranching livelihoods due to rich floodplain soil and water for irrigation. Photo comparisons upstream of Yankee Jim Canyon (Figure 22) reveal little change in vegetation and bank stability other than the removal of railroad tracks (Figure 23, Figure 24, and Figure 25). Lack of change could be attributed to continued ranching use since the Hendersons homesteaded in the 1870s (Haggerty, 2004). In a July, 1871 journal entry by the Hayden Expedition's mineralogist, Albert Peale, he observed little vegetation along this part of the river, noting only sparse trees and sagebrush (Merrill, 2003).

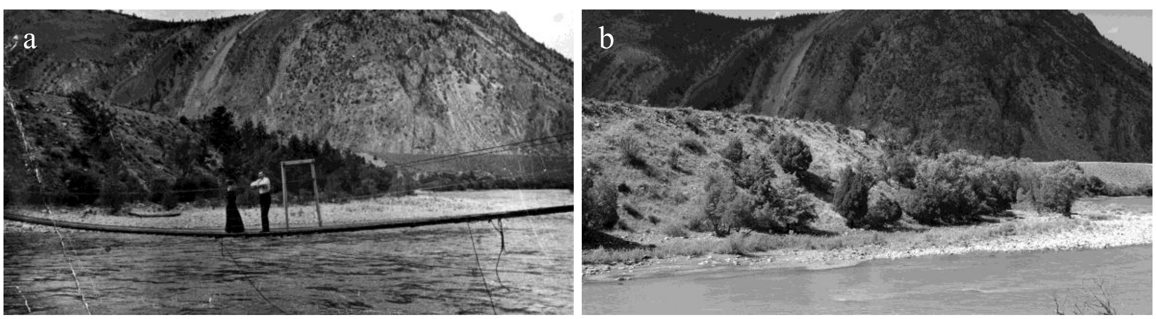


Figure 23. Devil's Slide, Yellowstone River, MT (photo point 609) a. Unknown, ca. 1902-1916, Courtesy of Yellowstone Gateway Museum. b. Clark, H.M. 8/25/2013.

Figure 24. Just upstream of Yankee Jim Canyon, Yellowstone River, MT (photo point 295) a. Jackson, W.H. 1871, Courtesy of USGS. b. Clark, H.M. 7/19/2012.

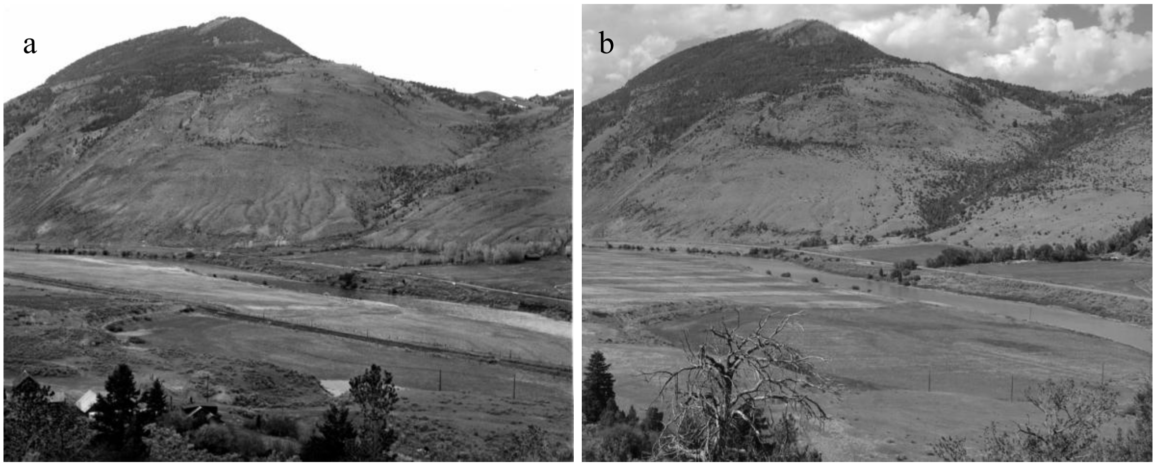


Figure 25. Just upstream of Yankee Jim Canyon, Yellowstone River, MT (photo point 610) a. Whithorn, Bill, ca. 1962, Courtesy of Yellowstone Gateway Museum b. Clark, H.M. 8/25/2013 (photos were taken at different times of the year: spring and summer).

Point of Rocks

Downstream of Yankee Jim Canyon, comparisons capture change near Point of Rocks (Figure 22). Just upstream from Point of Rocks, willow and cottonwood now occupy vacant sand bars, becoming a stable part of the floodplain (Figure 26). Woody vegetation along a former island in the left middle foreground has decreased as the river eroded the edge of the island, increasing pixel coverage of river surface area by 25% (Figure 26).

Looking downstream from Point of Rocks, pixel coverage of vegetation (predominantly cottonwoods) has increased by 65% since 1898 (Figure 27). By the time of the Hayden Surveys in 1871, 1872, and 1878, Paradise Valley had already been impacted by the arrival of 1,000 cattle in 1866 (Haggerty, 2004). Ranching must have impacted the vegetation along the Yellowstone River; however, a large flooding event in 1894 was most likely amplified the decline in woody vegetation (Figure 27a) (Merigliano & Polzin, 2003).

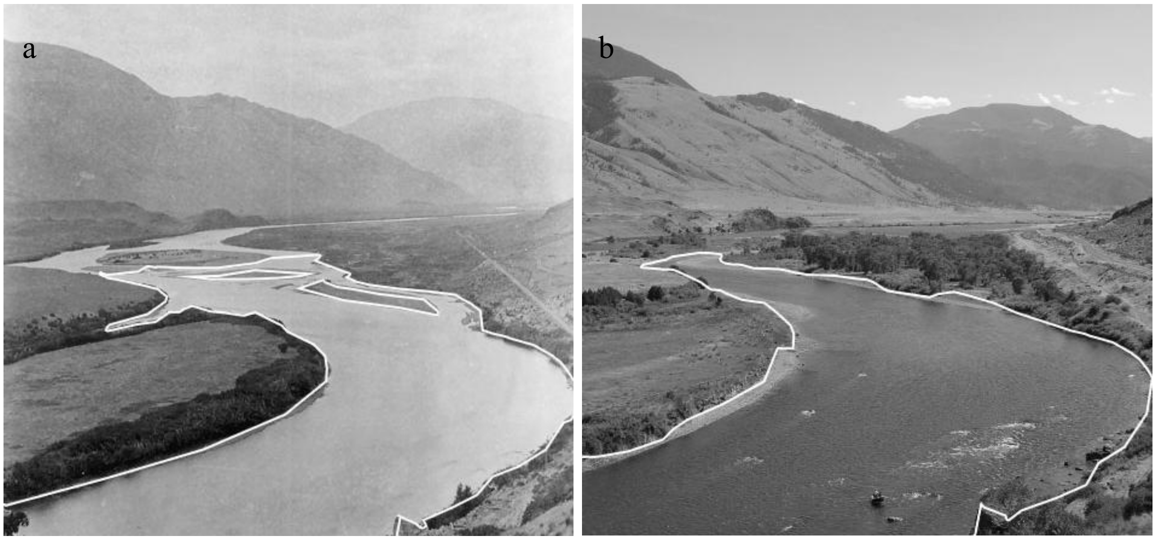


Figure 26. Upstream of Point of Rocks, Yellowstone River, MT (photo point 303) a. Walcott, C.D. 1898, Courtesy of USGS. b. Clark, H.M. 8/7/2013. Quantified polygons are outlined in white.

Figure 27. Downstream of Point of Rocks, Yellowstone River, MT (photo point 304) a. Walcott, C.D. 1898, Courtesy of USGS. b. Clark, H.M. 8/7/2013. Quantified polygons are outlined in white.

Emigrant

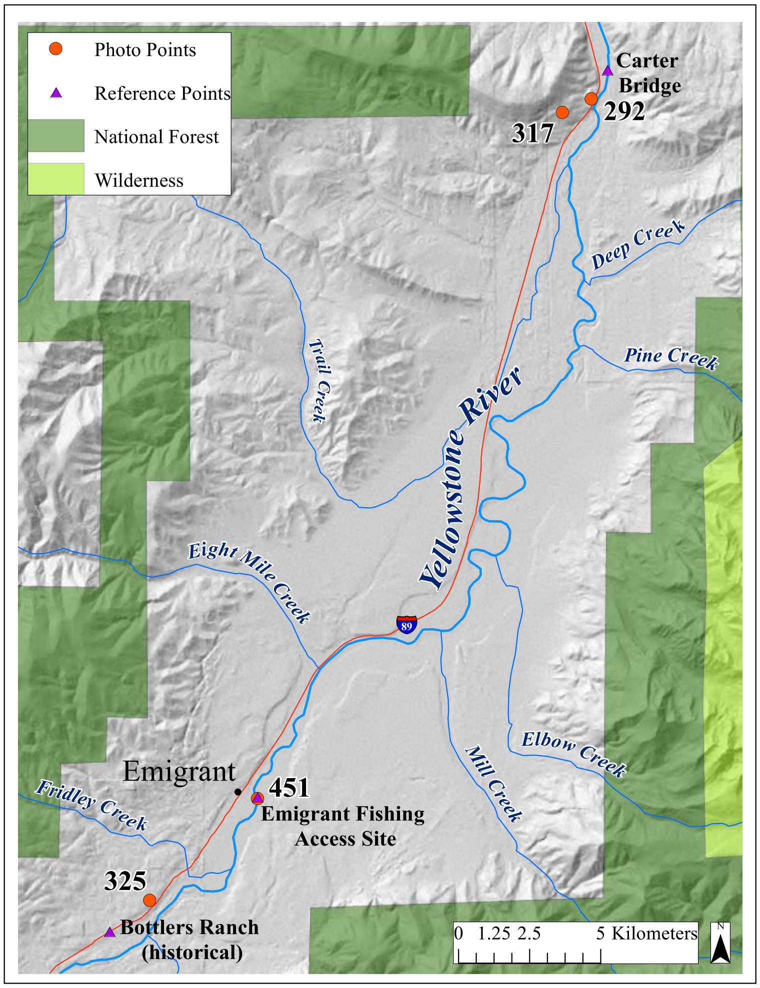


Figure 28. Yellowstone River photo points near Emigrant.

Farther downstream along the Yellowstone River near Emigrant, photo comparisons reveal changes due to continued agricultural practices (i.e., grazing and irrigation) (Figure 22). In a river reach near Emigrant, pixel coverage of woody vegetation patches decreased by 67% from 1922 to 2013. Agricultural practices from Emigrant Peak Ranch land use with 42 ha (105 ac) of irrigated land and 17 ha (43 ac) of grazed land could have accounted for this decrease (Figure 29) (Montana State Library, 2014). Downstream near Emigrant Fishing Access Site, photo comparisons reveal a naturally functioning riverine system with resistance to former grazing and current boat launch use (Figure 30). This riparian area borders the Yellowstone Ranch which has 33 ha (81 ac) of irrigated land and 76 ha (188 ac) of grazed land (Montana State Library, 2014).

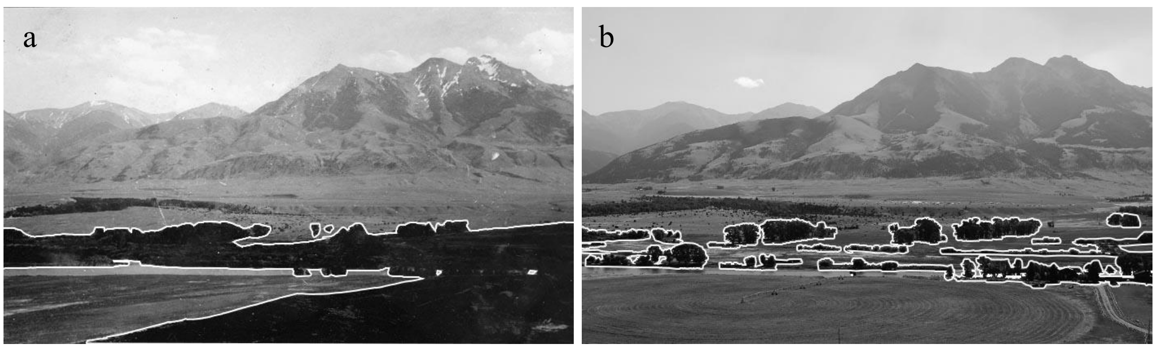


Figure 29. Near historical Bottler's Ranch, Yellowstone River, Emigrant, MT (photo point 325) a. Alden, W.C. 1922, Courtesy of USGS. b. Clark, H.M. 8/25/2013. Quantified polygons are outlined in white.

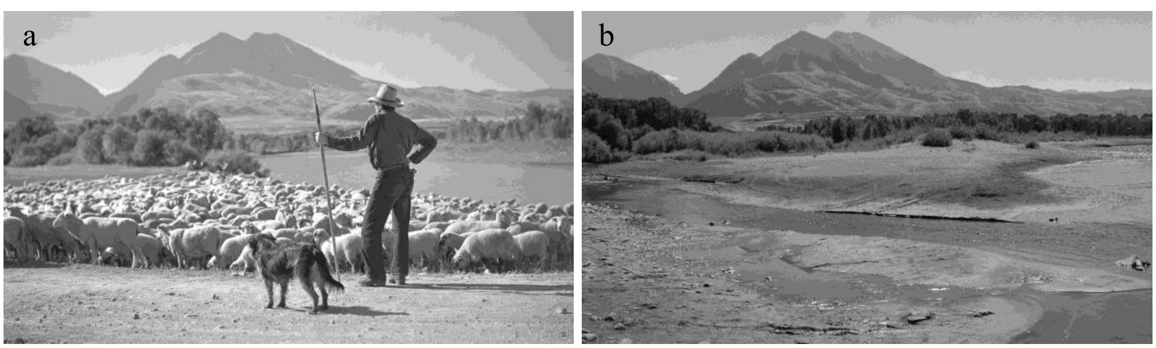


Figure 30. Emigrant Fishing Access, Yellowstone River, MT (photo point 451) a. Haberstroh, John C. 1939, Courtesy of Museum of the Rockies. b. Clark, H.M. 8/7/2013.

South of Carter Bridge, comparisons provide a larger depth-of-field of the Yellowstone River (Figure 22). The river channel appears to have migrated, permitting some riparian invasion of abandoned channels and bars (Figure 31). Based on their retake of the same historical photo, Merigliano and Polzin (2003) described an increase in mature cottonwood and scattering of old cottonwoods with prominent patches of willow and cattail from 1872 to 1999 (Figure 31). Just downstream, a large gravel bar formed in 1996 or 1997 following two 100-year floods (Merigliano & Polzin, 2003). The cottonwood community from 1871 is still present, even after channel braiding following the 100-year floods in the 1990s (Figure 23).

Figure 31. Upstream of Carter’s Bridge, Yellowstone River, MT (photo point 317) a. Jackson, W.H. 1872, Courtesy of USGS. b. Clark, H.M. 8/25/2013 (not an exact comparison, because trees blocked the historical photo point).

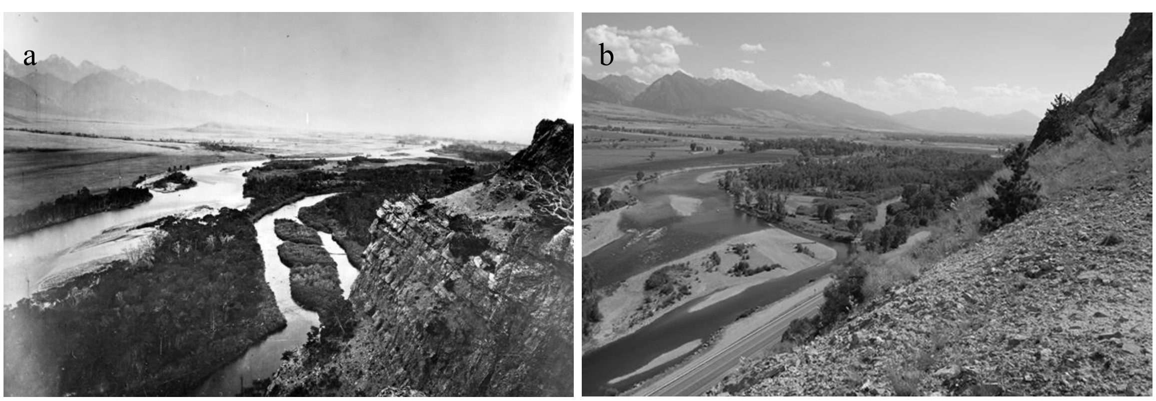


Figure 32. Upstream of Carter’s Bridge, Yellowstone River, MT (photo point 292) a. Jackson, W.H. 1871, Courtesy of the USGS. b. Clark, H.M. 8/14/2013 (not an exact comparison, because Jackson’s position was removed by highway construction).

Wind River

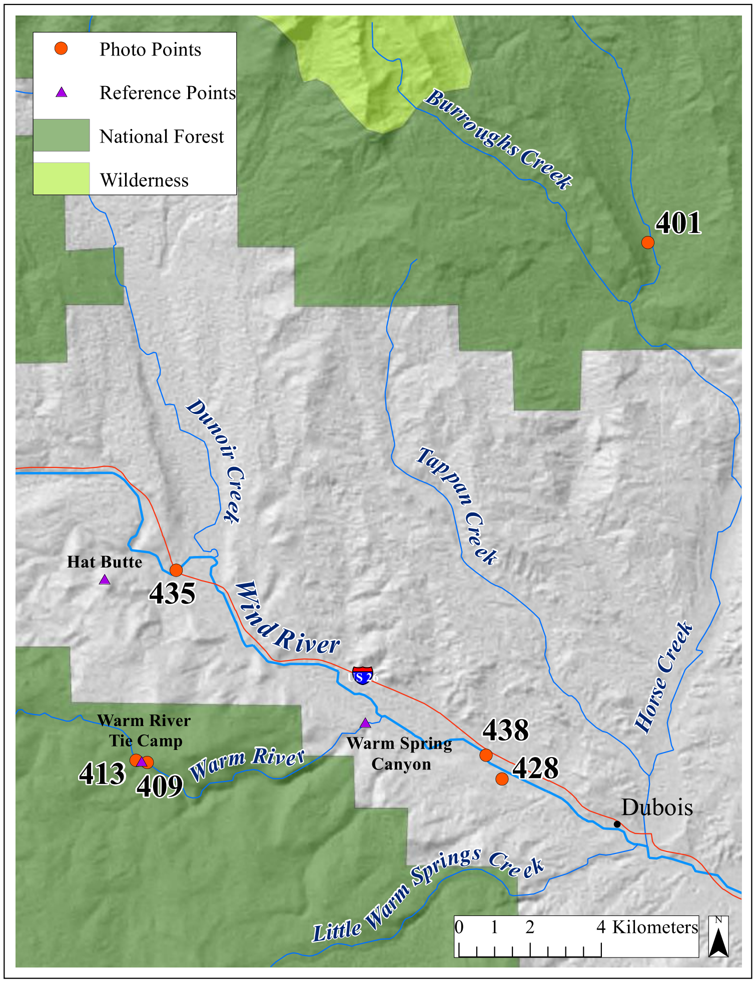


Figure 33. Wind River and tributary photo points.

Wind River comparisons include a group of photos along the Upper Wind River as well as some tributaries, Warm River and Horse Creek (Figure 33). Comparisons illustrate how ranching and tie driving have influenced the landscape, in addition to one example of damming.

Upper Wind River and Horse Creek

Figure 34. Upstream of Dunoir River, Wind River, WY (photo point 435) a. Unknown 8/1/1921, Courtesy of Dubois Museum. b. Clark, H.M. 6/9/2013 (actual view) c. Clark, H.M. 6/9/2013 (slightly to the left to include the river).

Livestock impacted and continue to affect riparian areas along the Wind River. Even though tie driving has ceased, signs of scouring and lack of vegetation suggest lingering impacts (Figure 34a). Currently, heavy livestock use extends into the river, increasing erosion and decreasing vegetation, leaving cottonwood roots exposed (Figure 34).

In other reaches, willow patches appear to have recovered since early ranching use (Figure 35). Along upper Horse Creek, ranching ceased after the first homesteader was unable to prove up ca. 1900 and about 20 years later, the property became a dude ranch and has remained one since 1919 (Wyoming State Historic Preservation Office, 2008). Without a photo from ca. 1900, one can only speculate that willows would have increased from that time until ca. 1930. From ca. 1930 to 2012, lack of change in woody vegetation pixel coverage (-3%) exemplifies how a riverine system with relatively little use, is able to remain dynamic as shown by the increase in pixel sinuosity (2.61).

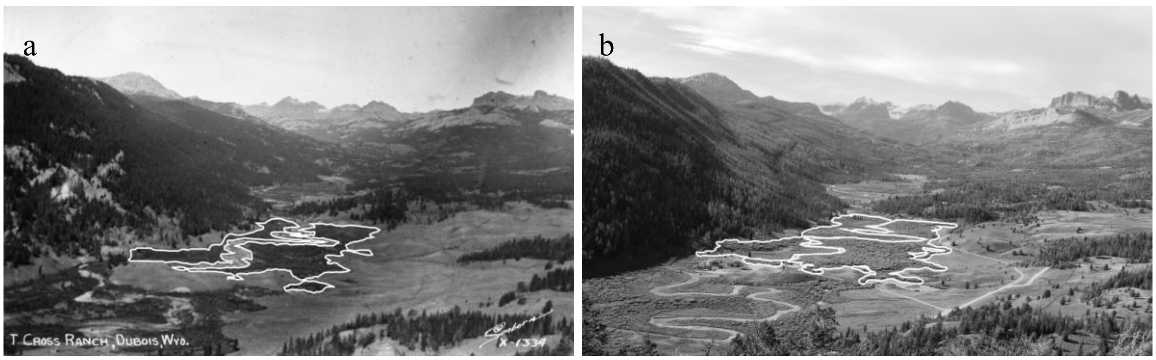


Figure 35. Horse Creek, tributary of the Wind River, WY (photo point 401) a. Unknown ca. 1930, Courtesy of Dubois Museum. b. Clark, H.M. 6/16/2012. Quantified polygons are outlined in white.

<u>Warm River</u>

Other ranches in the Wind River watershed exhibited more substantial changes over time. Ranching and tie driving both impacted the river reach near Warm River Ranch. Habitation along with ranching pressure influenced riparian vegetation around Warm River Ranch. Near ranch buildings, pixel coverage of willow vegetation decreased by 32% from ca. 1940 to 2013 (Figure 36). Human habitation—which is intrinsic to ranching—rather than direct livestock pressure, may have altered the vegetation. Cottonwoods do not appear to have increased in count, but in size, particularly planted trees near the ranch buildings (Figure 36 and Figure 37). Overall these comparisons indicate additional anthropogenic pressures of ranch life beyond livestock impacts.

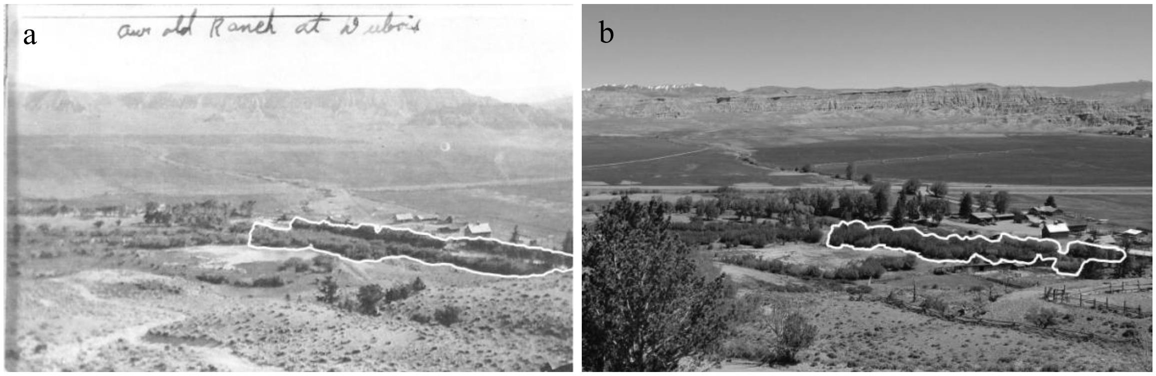


Figure 36. Warm River Ranch, Wind River, WY (photo point 398) a. Unknown ca. 1940, Courtesy of Dubois Museum. b. Clark, H.M. 6/9/2013. Quantified polygons are outlined in white.

Figure 37. Warm River Ranch, Wind River, WY (photo point 428) a. Unknown 8/4/1945, Courtesy of Shoshone National Forest. b. Clark, H.M. 6/9/2013.

In addition to ranching, tie driving was a major influence in the Wind River basin. Several surge dams were located along the Warm River above the Warm River Canyon. A surge dam, at the mouth of the canyon, created a large pond containing about 300,000 ties at a time (Figure 38). Tie hacks fed ties from this pond down a flume, transporting ties through the canyon and ultimately reaching the Wind River. When tie operations terminated, the dam was destroyed and the river resumed a natural flow, allowing vegetation to reestablish. Accumulation of sediment behind the dam provided a base for natural plant colonization. A variety of floodplain species, including willow, have grown in and along the channel and stabilized the riverbanks (Figure 39).

Figure 38. Warm River, tributary of the Wind River, WY (photo point 413) a. Unknown ca. 1940, Courtesy of Dubois Museum. Clark, H.M. 6/9/2013.

Figure 39. Warm River, tributary of the Wind River, WY (photo point 409) a. Trego, A.B. ca. 1940, Courtesy of Dubois Museum. b. Clark, H.M. 6/9/2013.

Ties flowed past Warm River Ranch from 1914 to 1946 (Pinkerton, 1981). When trucks replaced flume operations in 1943, tie hacks stored ties along the riverbank just upstream from Warm River (Figure 40). Ties remained along riverbanks until summer when bulldozers would push them into the Wind River (Rosenberg, 1999). This activity completely removed any riparian vegetation on the right bank. Presumably due to the conclusion of tie operations in 1946 (Pinkerton, 1981) and livestock exclosure fencing, willows were able to recover along this reach (Figure 40).

Figure 40. Upstream of Warm River Ranch, Wind River, WY (photo point 438) a. Unknown 8/4/1945, Courtesy of Dubois Museum. b. Clark, H.M. 6/9/2013.

<u>Diversion Dam</u>

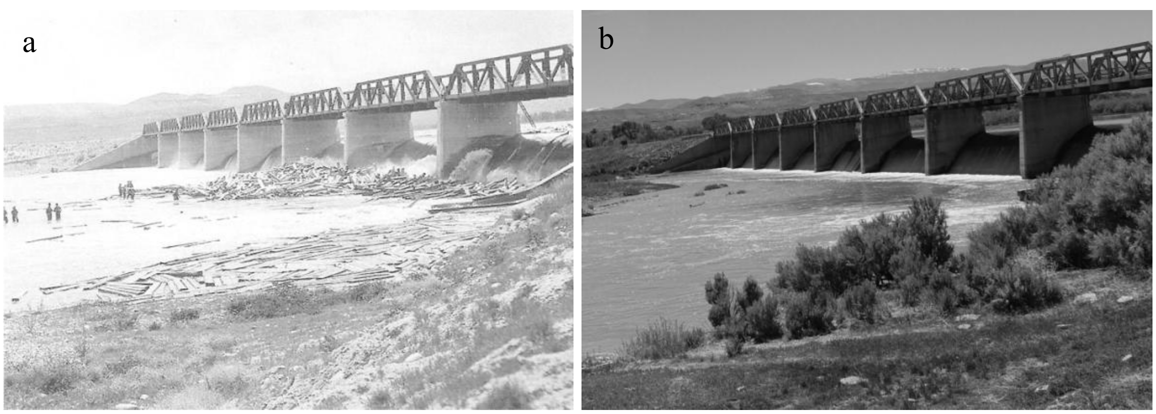


Figure 41. Diversion Dam, Wind River, WY (photo point 412) a. Unknown ca. 1930, Courtesy of Dubois Museum. b. Clark, H.M. 6/9/2013.

On the 100-mile drive to Riverton, WY, ties had to encounter a major obstacle towards the end of the drive, the Wind River Diversion Dam (Figure 42). Tie hacks had to direct ties over this spillway to avoid jams (Figure 41a) (Pinkerton, 1981). Near this diversion dam, the riverbank appears to have recovered with sagebrush establishment along the upper bank (Figure 41). However, the photo comparison does not suggest riparian species growing on the riverbank.

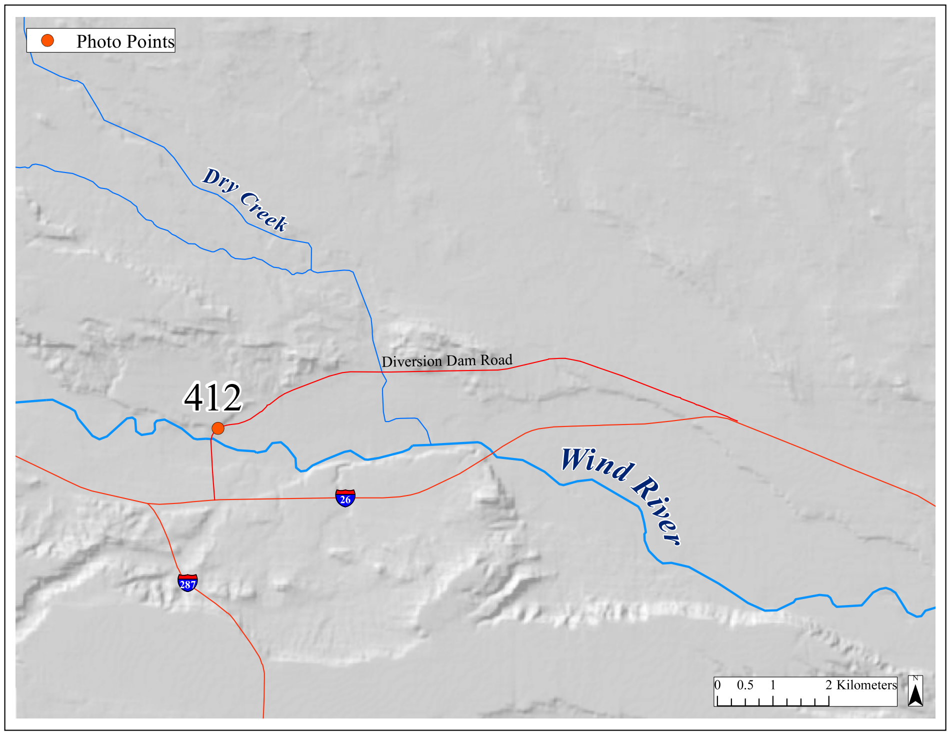


Figure 42. Wind River Diversion Dam photo point.

Gros Ventre River

The Gros Ventre River comparisons occur in the Upper Gros Ventre (Figure 43), indicate how grazing as well as elk browsing can affect riverine vegetation. In 1918, willows dominated stream meanders before the Wyoming Game and Fish Department began supplemental elk-feeding in 1929 in the Gros Ventre drainage (Figure 44a) (Dean et al., 2004). Elk influenced the landscape by eliminating sagebrush, allowing perennial grasses to grow (Figure 44b); elk have continued to heavily browse reducing willow patches (Figure 44c).

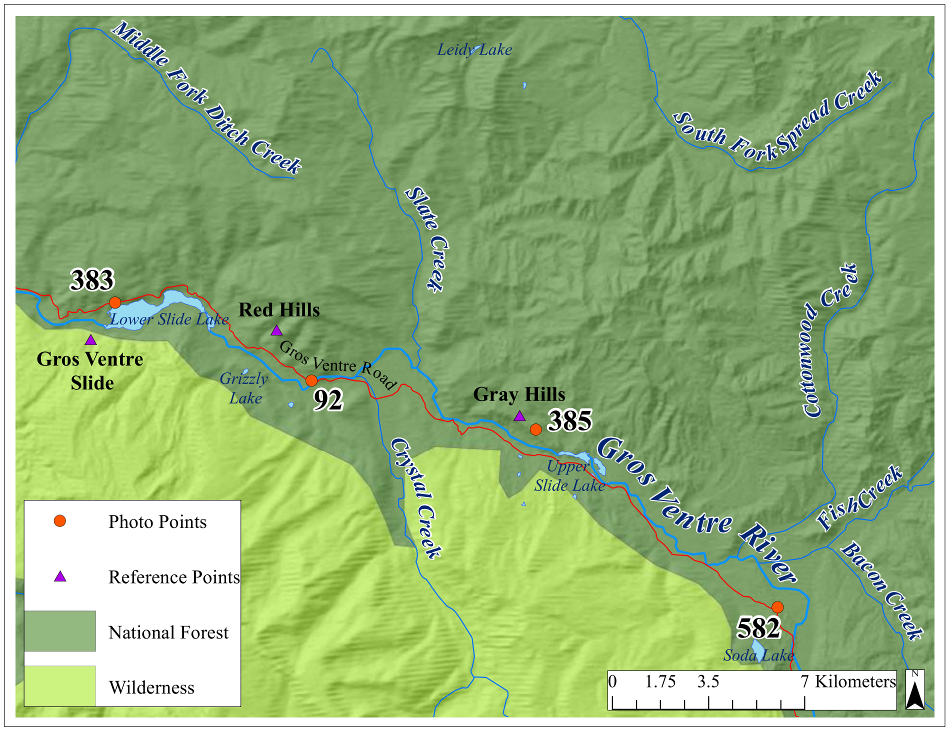


Figure 43. Gros Ventre River photo points.

Pixel river sinuosity has increased slightly from 1918 to 2013 (0.61), likely attributed to a decrease in bank stabilization due to reduced vegetation and consequent higher erosion potential causing meanders to be farther apart. As a result, the 1918 river bend became isolated from the main channel by 1970 (Figure 44a and Figure 44b) (Gruell, 1980a).

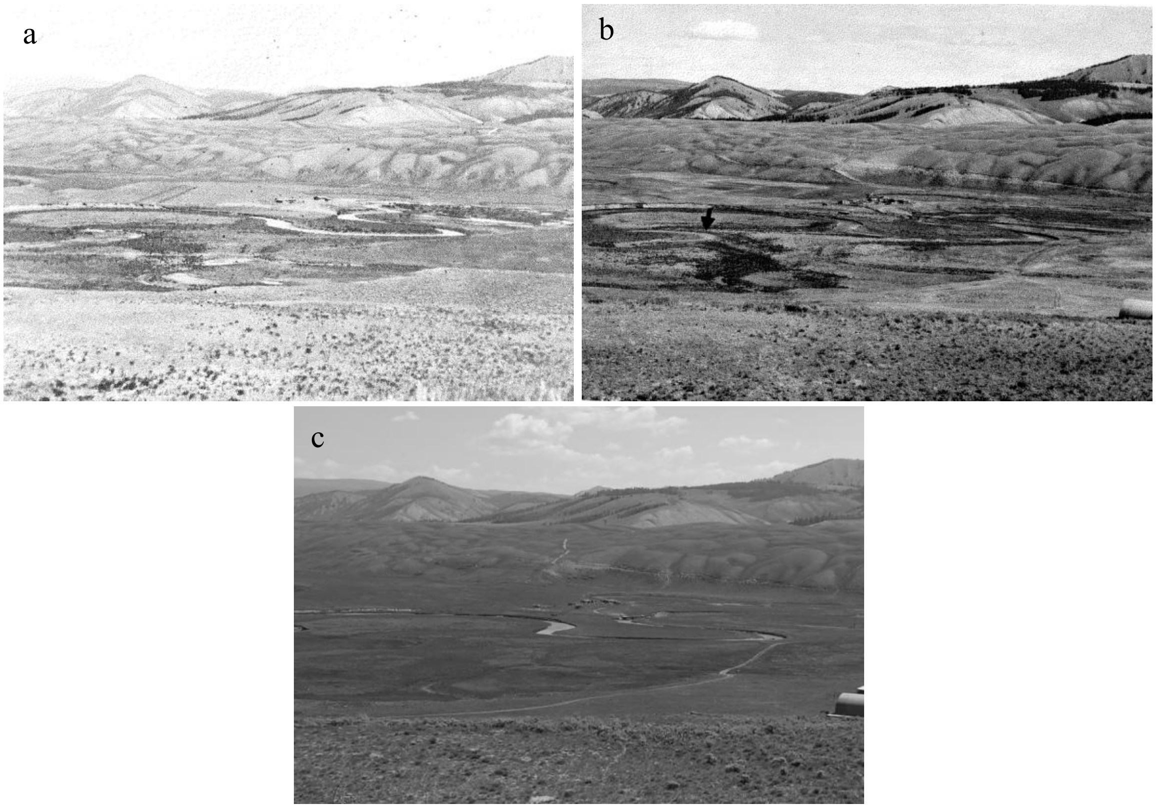


Figure 44. Upper Gros Ventre River above Fish Creek Confluence, WY (photo point 582) a. Anderson, M. 8/1918, Courtesy of USDA. b. Gruell, G.E. 9/23/1969. c. Clark, H.M. 8/12/2013.

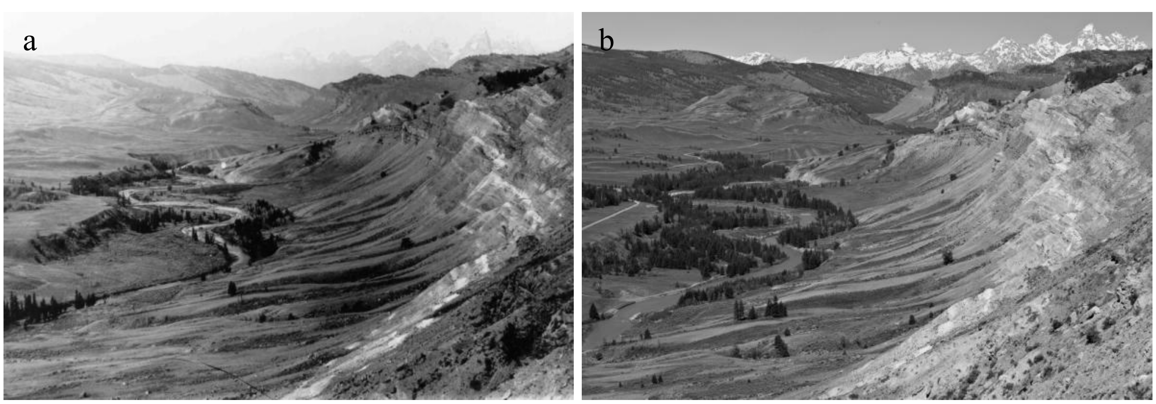


Figure 45. Grey Hills, Gros Ventre River, WY (photo point 385) a. Unknown, est. 1900s, Courtesy of the Jackson Hole Historical Society. b. Burrell, J. 6/7/2013 (not an exact comparison due to presumable erosion of the historical photo point).

Downstream, after the confluence of the North Fork of Fish Creek and the Gros Ventre River, spruce have matured in the riparian zone (Figure 45). In this reach, sinuosity appears to have slightly increased as well, suggesting a dynamic riverine system (Figure 45).

Figure 46. Below the outlet of Slate Creek, Gros Ventre River, WY (photo point 583). a. Unknown 1905, Courtesy of USDA. b. Gruell, G.E. 9/25/1970 c. Clark, H.M. 7/20/2013.

In 1927, the Steven N. Leek developed a hunting camp on Jackson Lake (Daugherty, 1999). A photo comparison from one of his early hunting trips up the Gros Ventre River shows how spruce have matured on the near bank (Figure 46). However, scouring on the opposite bank has prevented vegetation from growing along the river (Figure 46a). Scouring could be attributed to heightened flows following a wildfire in 1879. Signs of recovery as of 1970 include spruce regeneration and increased buffalo berry and willow on the far bank (Gruell, 1980a). About 40 years later, spruce have continued to mature on the near bank and vegetation has established along the opposite bank.

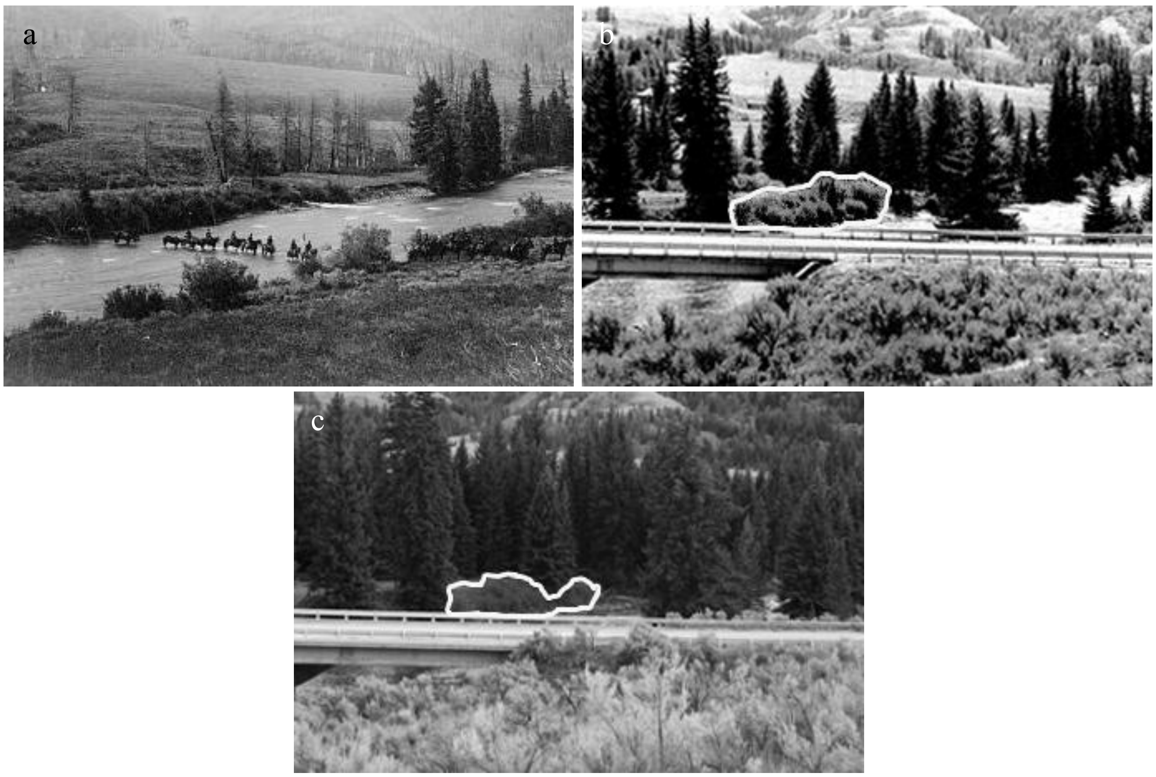


Figure 47. Near Miner Creek, Gros Ventre River, WY (photo point 92) a. Haynes, F.J. 8/1883 Courtesy of USDA. b. Gruell, GE 8/21/1970. c. Clark, H.M. 8/12/2013. Quantified polygons are outlined in white.

Farther downstream near Miner Creek, a photo comparison indicates riparian succession (Figure 47). Willows lined the riverbanks as shown in Haynes's historical photo as part of President Arthur's 1883 expedition (Figure 47a). Ring counts of fire-scarred trees suggest that a fire in 1879 killed spruce in the foreground, allowing aspen to advance in succession (Gruell, 1980a). Pixel coverage of a patch of willows on the far bank has decreased from 1970 to 2013 by 35% and spruce trees now dominate the riparian area. By 1970, sagebrush occupied the foreground, continuing to dominate in 2013. Determining the exact reasons for riverine change in this series is difficult, because a variety of human infiltration influenced this area, including bridge construction and the Gros Ventre cattle drive (Gruell, 1980a) (Figure 47b).

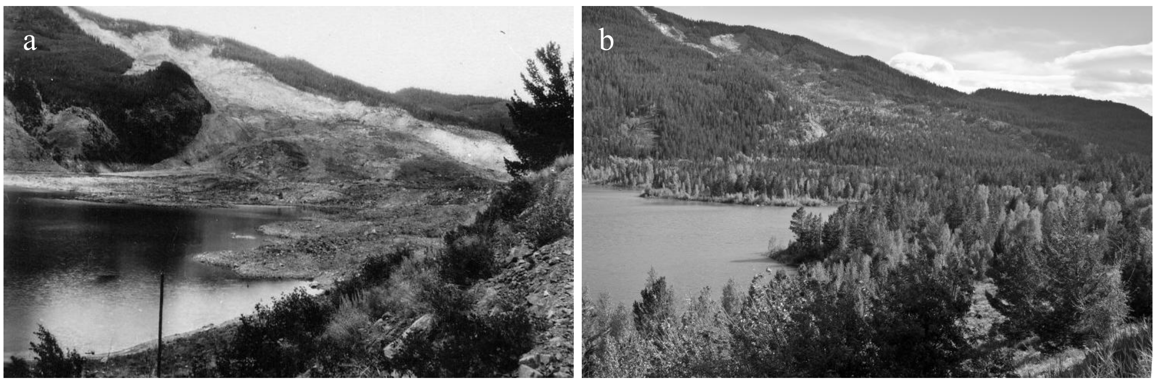


Figure 48. Gros Ventre Slide, Lower Slide Lake, WY (photo point 383) a. Unknown ca. 1925, Courtesy of the Jackson Hole Historical Society. b. Clark, H.M. 6/7/2013.

Succession is also evident in the Gros Ventre Slide area. In 1925, a slab of sedimentary rock sloughed off Sheep Mountain, damming the Gros Ventre River and creating Lower Slide Lake. However, two years later on May 18, 1927, Slide Lake breached the dam, flooding the town of Kelly and destroying downstream properties and ranches along the Gros Ventre and Snake Rivers (Daugherty, 1999). After 88 years, the once barren slope has filled in with vegetation and willows, aspens, and conifers now line the edge of the lake (Figure 48).

Snake River

Snake River comparisons illustrate how the Jackson Lake Dam (JLD) and levees have altered the Snake River. Repeat photos show changes around Jackson Lake (Figure 49) and near Wilson Bridge-Highway 22 (Figure 58).

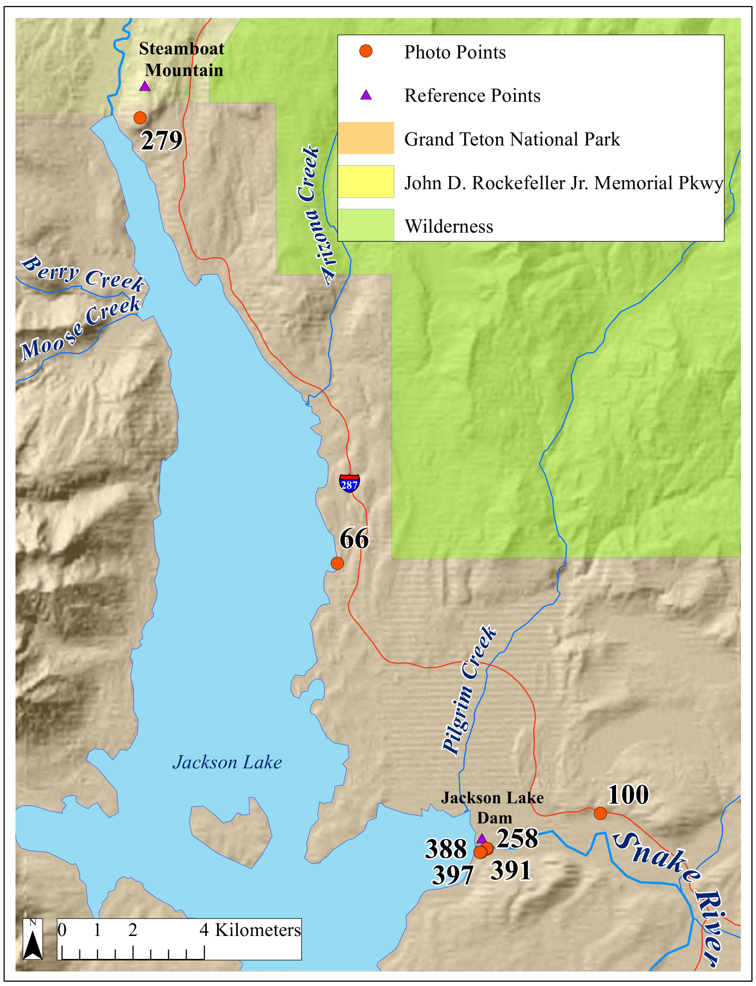


Figure 49. Jackson Lake and nearby Snake River photo points.

Jackson Lake Dam

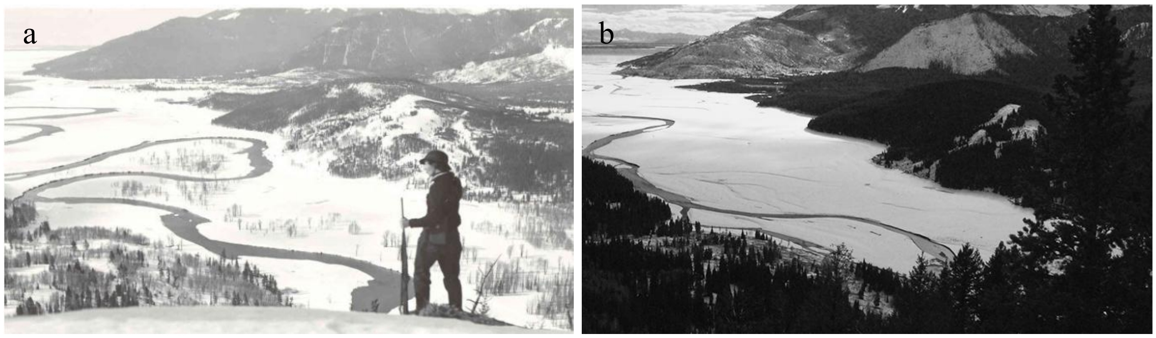


Figure 50. Just upstream of Jackson Lake, Snake River, WY (photo point 279) a. Unknown ca. 1930s, Courtesy of Museum of the Rockies. b. Clark, H.M. 11/9/2013.

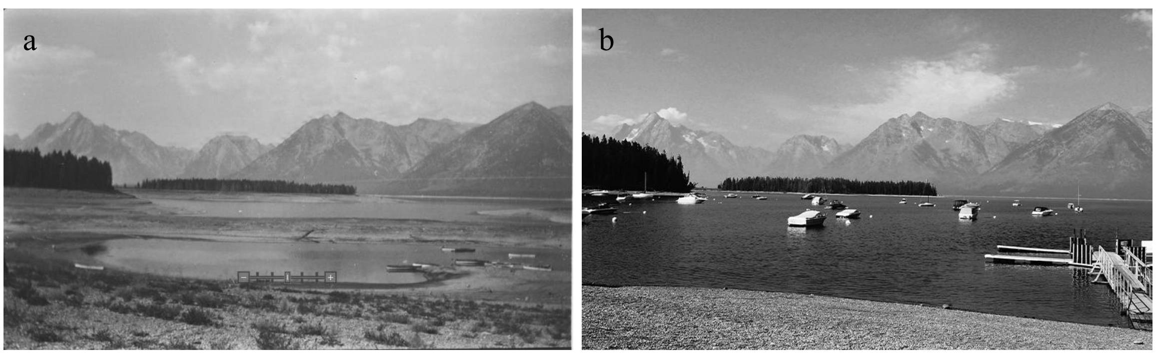


Figure 51. Leeks Marina, Jackson Lake, WY (photo point 66) a. Bernfield, Seymour 1934, Courtesy of Seymour Bernfield Collection, American Heritage Center, University of Wyoming. b. Clark, H.M. 8/26/2012.

Construction of Jackson Lake Dam (JLD) raised the lake by about 12 m (40 ft) and thus altered the lake basin and surrounding landscape (Marston et al., 2005). As Jackson Lake increased in height and width, heightened water levels saturated the inlet of the Snake River. Circa 1930, this area had numerous deciduous trees, most likely cottonwood (Figure 50). About 15 years after JLD construction, the cottonwoods have still persisted or existed as snags; however, by 2013 there do not appear to be any standing deciduous trees. As a result, the Snake River was able to meander, cutting off an oxbow and decreasing sinuosity (-1.50) (Figure 50). Despite this decrease, the river appears to be functioning naturally above the reservoir.

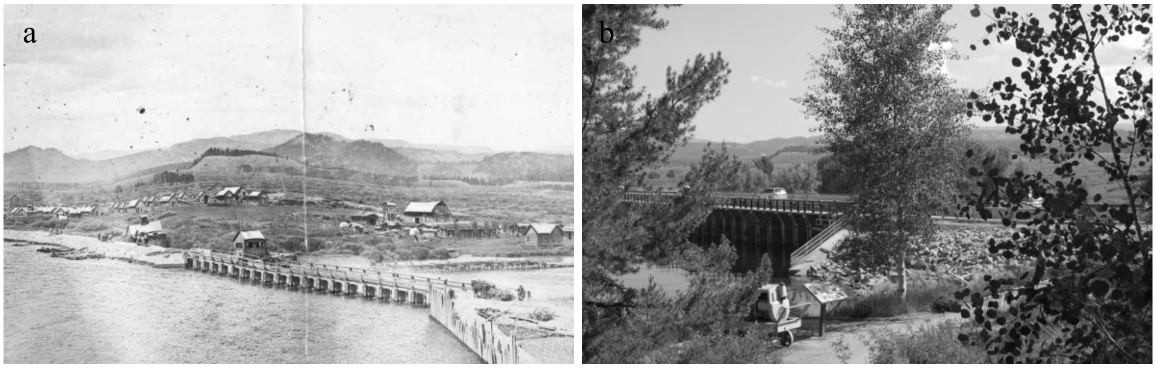


Figure 52. Jackson Lake Dam, WY (photo point 396) a. Unknown 1907, Courtesy of the Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Figure 53. Jackson Lake Dam, WY (photo point 397) a. Unknown 1910-11, Courtesy of the Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Dam operations dramatically lower reservoir water level depending on downstream need for water. A 1934 historical photo of Jackson Lake and retake (Figure 51) suggests how the 1930s Dust Bowl drought severely decreased stream flow further supported by dendrochronology data (Wise, 2010) and low record discharge of the Snake River near Shelley, ID gauge (SHYI1) during this time (National Weather Service, 2013; Wise, 2010).

Figure 54. Downstream of Jackson Lake Dam, WY (photo point 391) a. Unknown, est. 1900s, Courtesy of the Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Photo comparisons (Figure 52, Figure 53, Figure 54, Figure 55, and Figure 56) show how JLD affected the former town of Moran and surrounding riparian vegetation. In 1916, dam improvements and increased riprap, further influenced the downstream riverine area (Figure 52 and Figure 53).

As pictured in these comparisons, Moran no longer exists. Moran thrived as a tourist attraction in the 1920s; however a fire in 1935 destroyed the main lodge. In 1955, the National Park Service and Grand Teton Lodge Company decided to move many of the cabins to Colter Bay (Daugherty, 1999).

Since dam construction, directly downstream of JLD, the Snake River has widened and stabilized with riprap reinforcing the banks (Figure 54, Figure 55, and Figure 56). Cottonwoods downstream of JLD appear to have grown after dam construction and relocation of Moran. Prior to dam construction, the channel was dynamic with gravel bars providing areas for willow establishment (Figure 55a) and floods reduced mature vegetation when breaching the channel (Figure 56a). However, dam regulated flows produced high velocities directly below JLD, prompting installation of riprap along nearby riverbanks. Stabilized banks disconnected the river from the floodplain, preventing gravel bar establishment with low floodplain terraces available for cottonwood and willow colonization, and allowing cottonwood to mature on stable banks (Figure 54, Figure 55, and Figure 56).

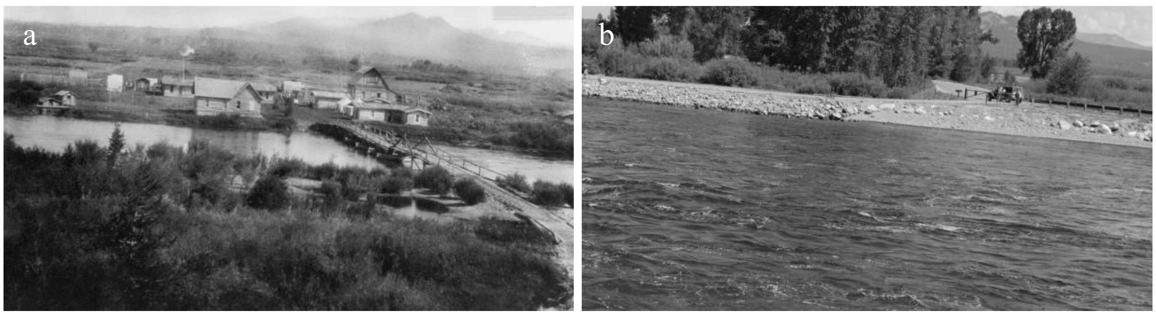


Figure 55. Downstream of Jackson Lake Dam, WY (photo point 388) a. Unknown est. 1900s, Courtesy of Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Figure 56. Downstream of Jackson Lake Dam, WY (photo point 258) a. Unknown est. 1900s, Courtesy of Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Downstream of JLD, an oxbow has experienced little change (Figure 57). Comparison between pixel coverage of river surface areas reveal no difference and riverbank vegetation does not appear to have changed other than matured conifers and willows (Figure 57).

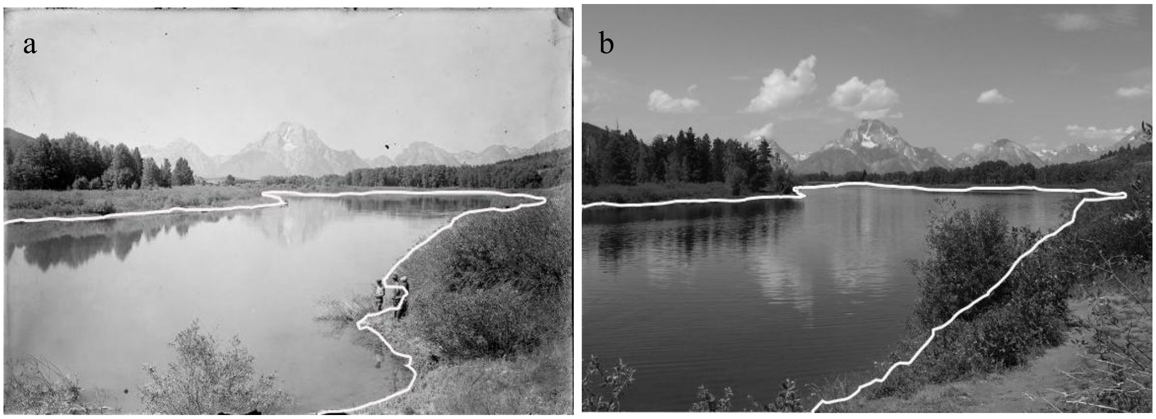


Figure 57. Oxbow Bend, Snake River, WY (photo point 100) a. Beard, George ca. 1910-1919, Courtesy of L. Tom Perry Special Collections, Harold B. Lee Library, Brigham Young University, Provo, UT. b. Clark, H.M. 7/4/2013. Quantified polygons are outlined in white.

Wilson Bridge

About 48 km (30 mi) downstream of JLD, construction of levees in 1964 resulted in further alterations (Figure 59, Figure 58, and Figure 60). Levees caused a dramatic decline in floodplain areas from approximately 10,000 ha (25,000 ac) to 1,000 ha (2,500 ac). Levees reduced natural channel width from historical ranges of about 300 to 1,200 m (1,000 to 4,000 ft) and extending to 2,400 m (8,000 ft) in some parts, to post-levee channel widths of 300 to 500 m (1,000 to 1,600 ft) (Anthony, 1998).

Levees resulted in dramatic changes in riparian vegetation, floodplain connectivity, and river sinuosity (Figure 59). JLD altered natural flow and levees reduced floodplain area, channelizing this reach of the Snake River. Even though this reach can no longer connect to its former floodplain, cottonwood-dominated vegetation has grown and sustained due to a maintained water table; Anthony (1998) noted that ground water levels ebbed and flowed similar to presumable natural conditions despite construction of levees. However, restricted floodplain area reduces gravel bars and bare soil for cottonwood and willow recruitment (Anthony, 1998).

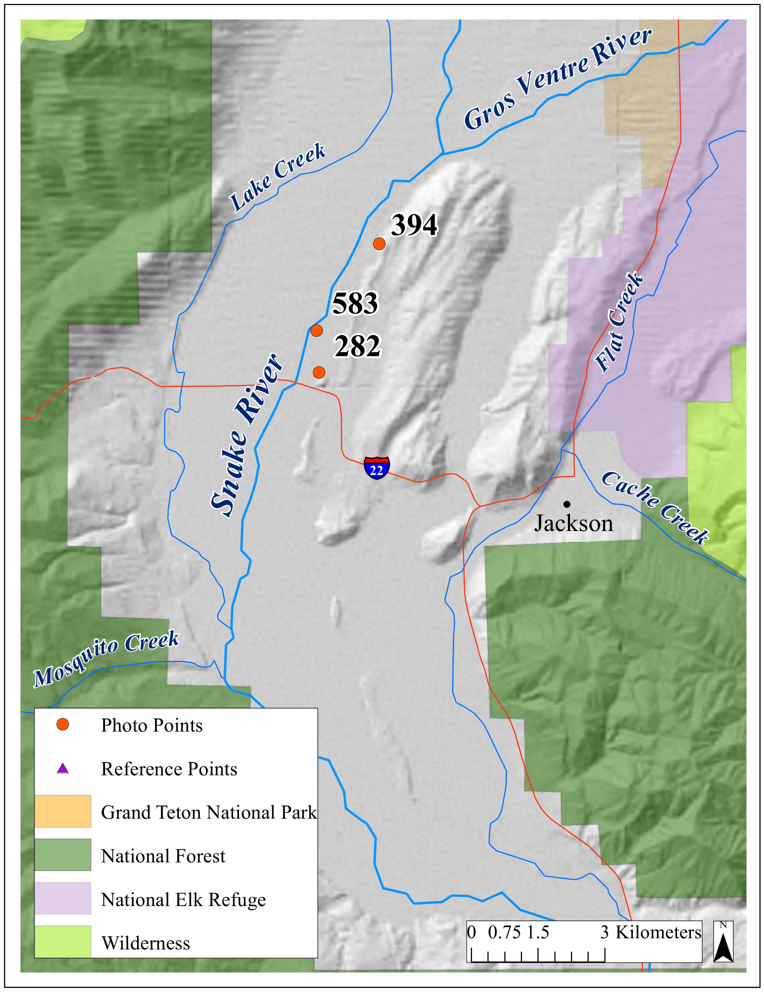


Figure 58. Snake River photos near Wilson Bridge - Highway 22.

Snake River floodplain reduction is evident by a 90% decrease in pixel coverage of visible channel area when comparing a post-flood unrestricted floodplain to current levee restriction (Figure 59). Two large flooding events occurred in the early 1900s that destroyed parts of Wilson Bridge. In 1917, high water washed away bridge approaches, which local residents attributed to the Reclamation Service for releasing too much water from Jackson Lake. In turn, the service blamed local officials for inadequate riprap. In 1922, construction of a new Wilson Bridge included reinforced levees and riprap. However, when Slide Lake breached 1927, the flood washed out the bridge again (Figure 60) (Daugherty, 1999).

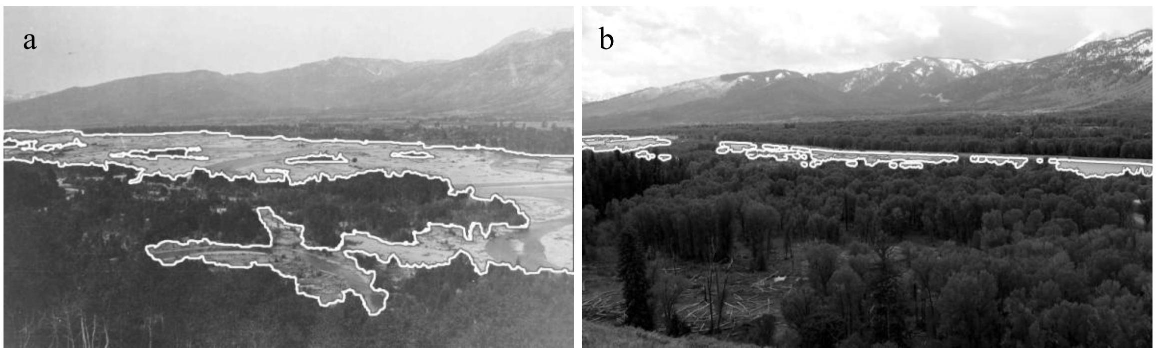


Figure 59. Upstream of Wilson Bridge (HWY 22), Snake River, WY (photo point 394) a. Unknown, est. 1920s, Courtesy of the Jackson Hole Historical Society. b. Clark, H.M. 5/29/2013. Quantified polygons are outlined in white.

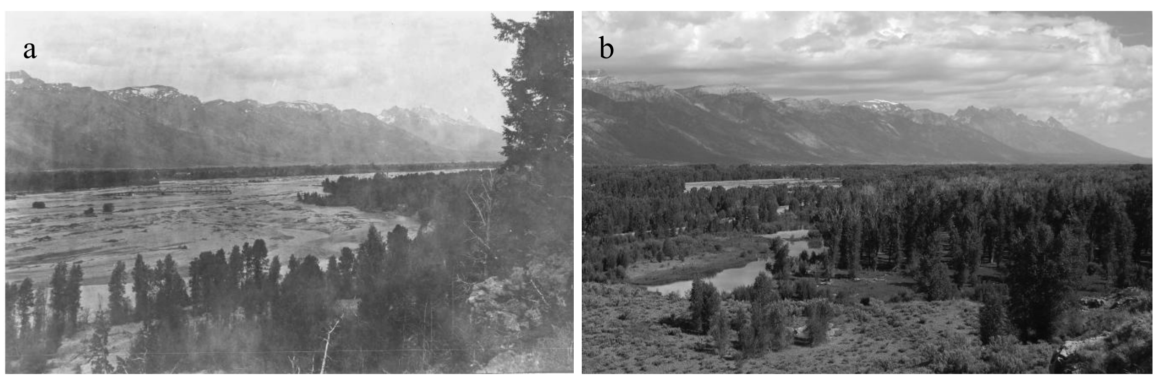


Figure 60. Upstream of Wilson Bridge (HWY 22), Snake River, WY (photo point 282) a. Unknown ca. 1923-1929, Courtesy of Jackson Hole Historical Society. b. Clark, H.M. 7/4/2013.

Green River

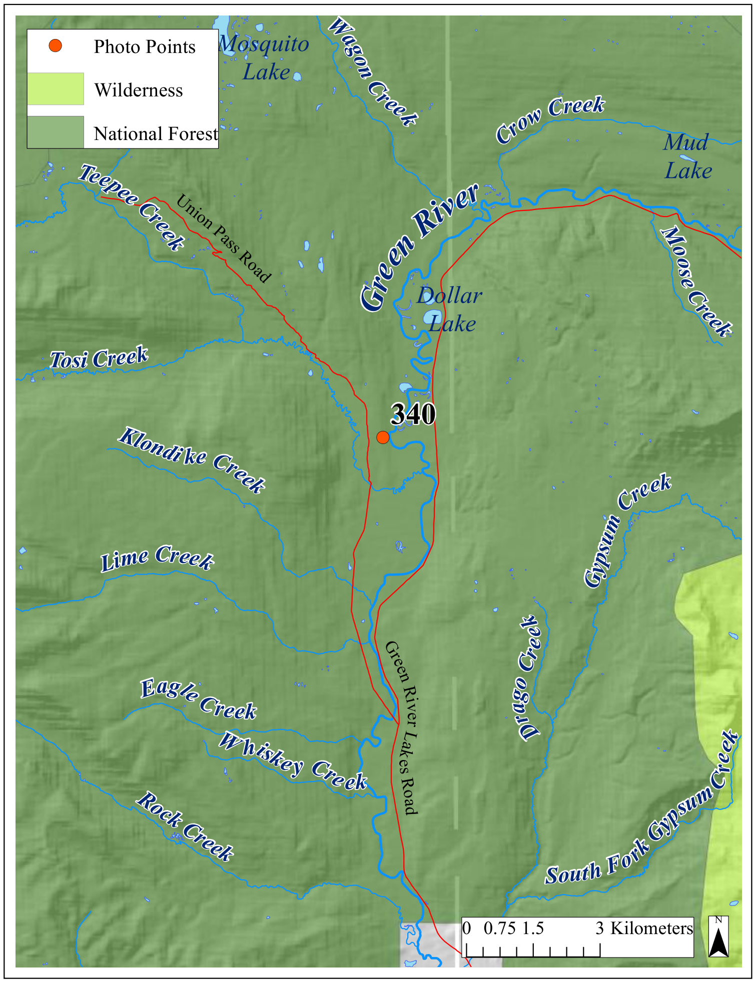


Figure 61. Green River photo point.

Despite several attempts to retake photos of the Green River tie drive historical photos, we were unsuccessful due to flood and wildfire road closures. However, one retake of the Green River depicts an area upstream of former tie driving operations and presumably unaffected by them (Figure 61 and Figure 62). This comparison reveals intact vegetation patches and a sinuous reach showing little change, indicating an intact reach of the Green River. However, Green River Lumber and Tie Company headquarters were located just downstream near Whiskey Creek with cutting areas along Klondike, Rock, Gypsum, and Pot Creeks (Rosenberg 1969). According to the Wyoming Game and Fish Department (2011), below former headquarters, there are long flat stretches of poor fish habitat—widened shallow channels with little bank cover—due to tie drives.

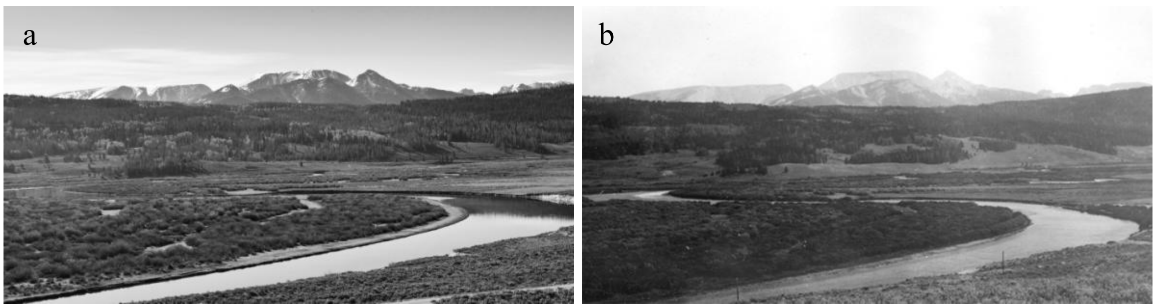


Figure 62. Tosi Creek Outlet, Green River, WY (photo point 340) a. Alden, W.C. est. 1920s, Courtesy of USGS. b. Burrell, J. 6/7/2013.

Madison River

This section includes photos along the Madison River from outside of Yellowstone National Park and addresses photos going downstream.

Earthquake Lake

A substantial earthquake in 1959 dammed the Madison River, forming Earthquake Lake (Figure 63). Prior to the earthquake, a reach of the Madison River was lined with spruce trees and other conifers (Figure 64). Earthquake Lake inundated these conifers, killing them. The snags still remain, which would otherwise be removed in the creation of a man-made lake.

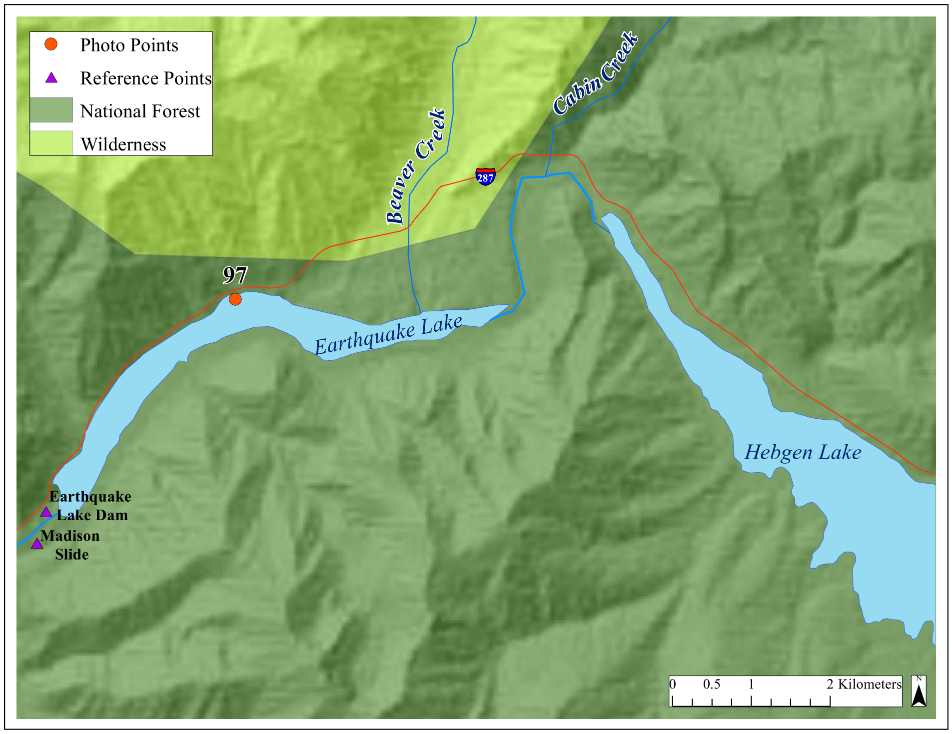


Figure 63. Earthquake Lake photo point.

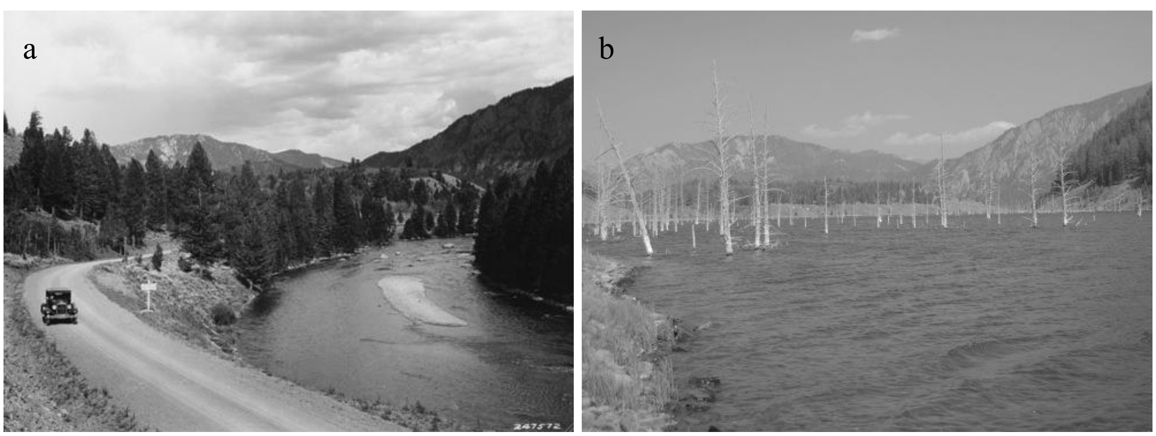


Figure 64. Earthquake Lake, MT (photo point 97) a. Swan, K.D. 8/13/1930, Courtesy of Forest History Society. b. Clark, H.M. 8/16/12 (photo comparison is not exact because the historical photo point is now underwater).

Bear Trap Canyon

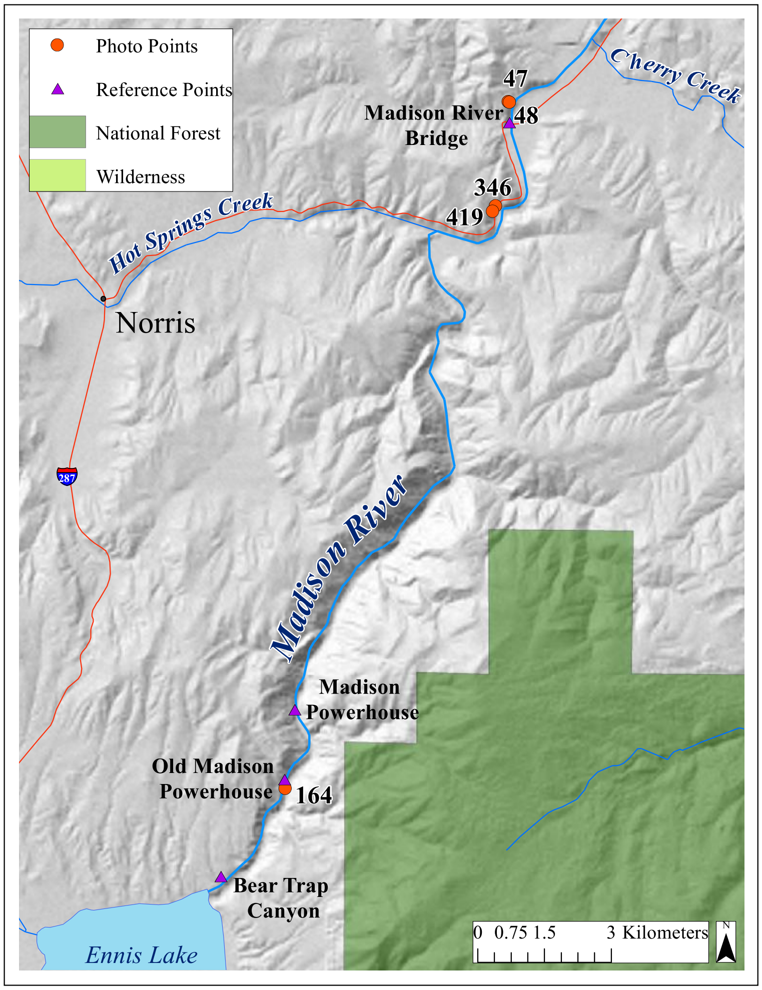


Figure 65. Madison River Bear Trap Canyon photo points.

The next dam along the Madison River, the Madison Dam, is a hydro- electric dam (Figure 65). The dam and area just below appears to have experienced little change since construction of the dam in 1901 (Figure 66).

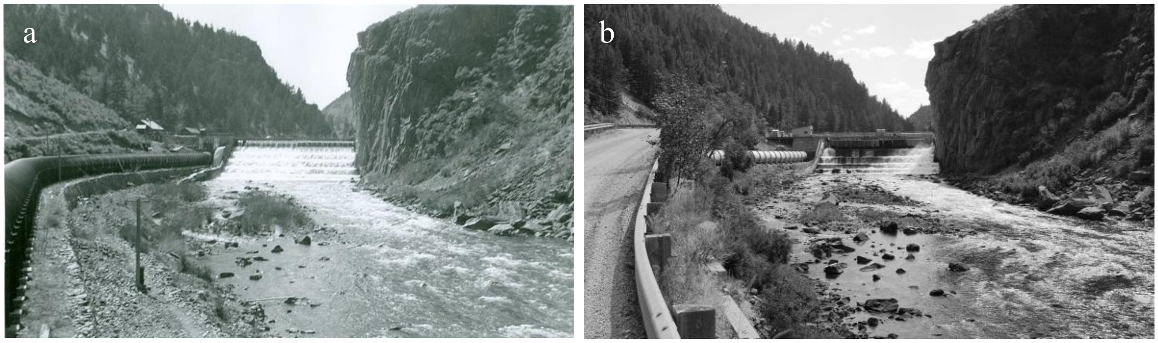


Figure 66. Madison River Dam, MT (photo point 164) a. Unknown 7/24/1941, Courtesy of Pioneer Museum. b. Clark, H.M. 8/7/2012.

Farther below the Madison Dam, just downstream of Bear Trap Canyon, photo comparisons suggest little change over time (Figure 67 and Figure 68). With the exception of juniper growth along the banks of the channel, there are few visual vegetative alterations due to controlled flows. Another downstream comparison (Figure 69) suggests minimal change as well with riparian vegetation in a similar state throughout the photo comparison series.

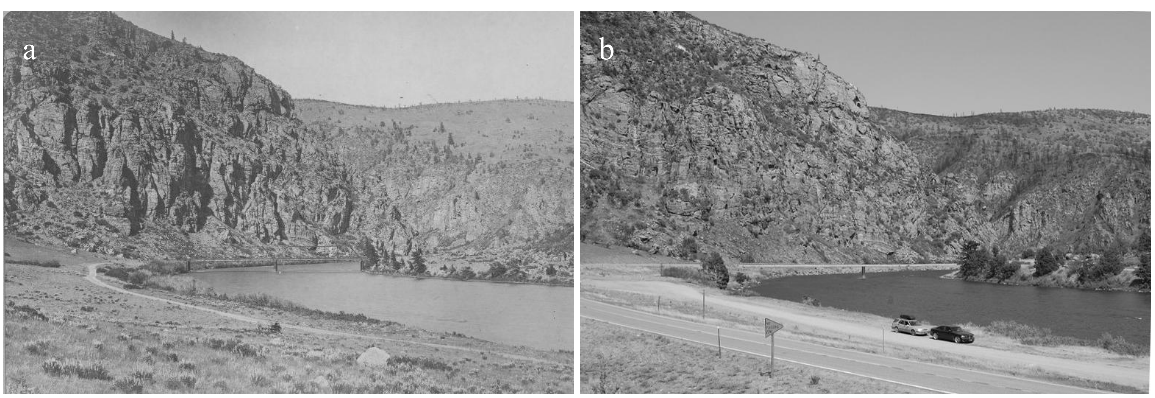


Figure 67. Downstream of Bear Trap Canyon, Madison River, MT (photo point 346) a. Unknown ca. 1890s, Courtesy of Pioneer Museum. b. Clark, H.M. 8/7/2012.

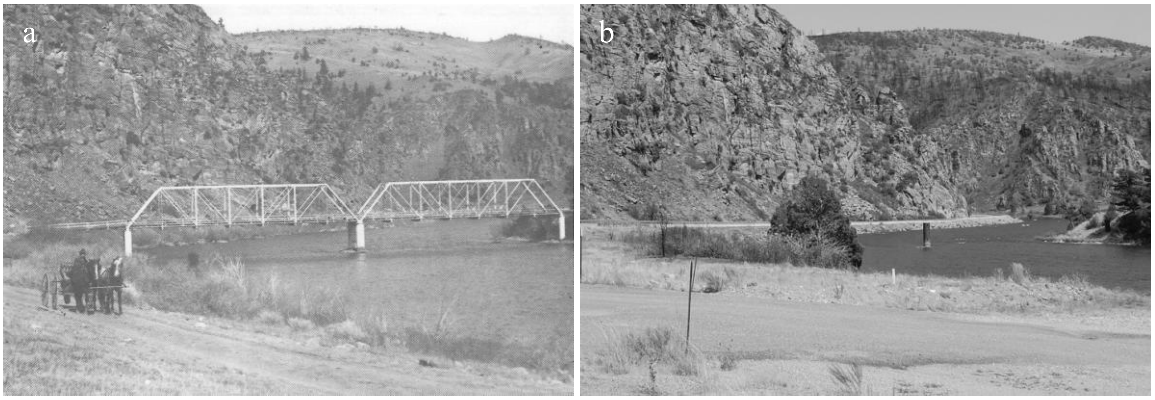


Figure 68. Downstream of Bear Trap Canyon, Madison River, MT (photo point 419) a. ca. 1890, Courtesy of Pioneer Museum. b. Clark, H.M. 8/7/2012.

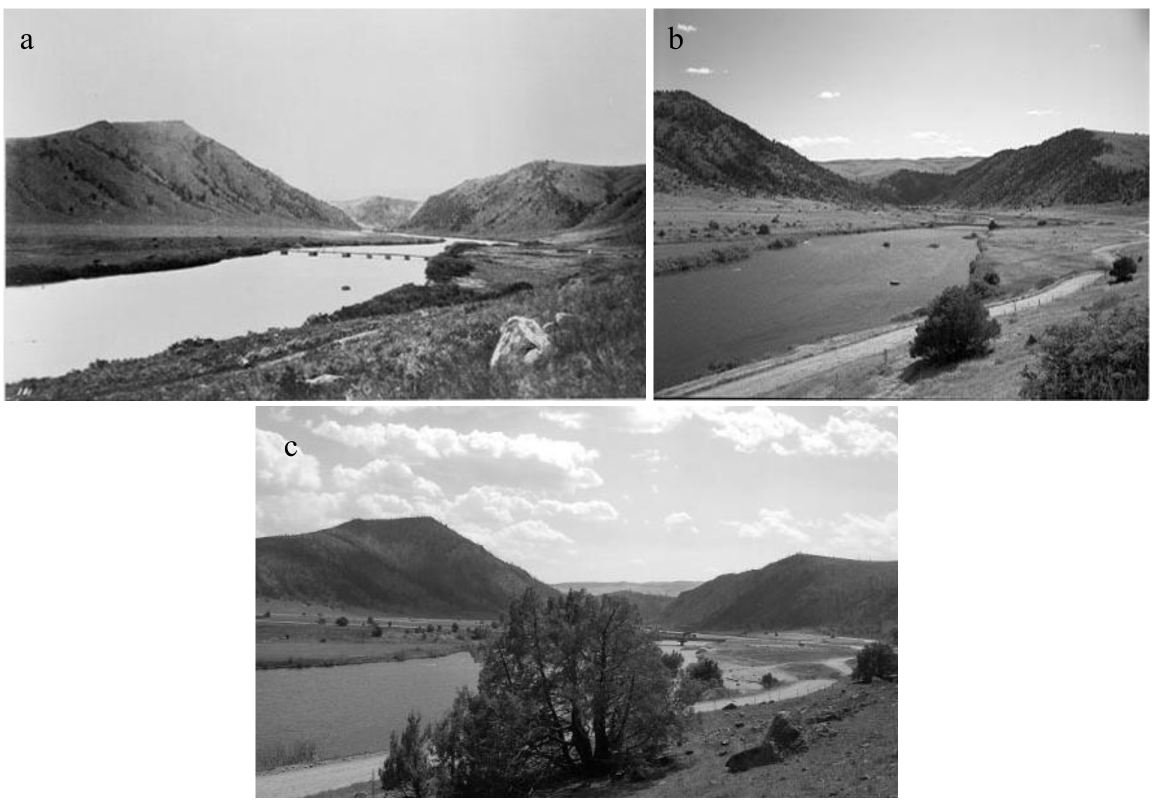


Figure 69. Norris Bridge, Madison River, MT (photo point 47) a. Jackson, W.H. 1871, Courtesy of University of Montana. b. Gruell, G.E. 8/31/1982, Courtesy of University of Montana. c. Clark, H.M. 8/7/2012.

Aerial Photo Analyses

Aerial comparisons of three reaches near Emigrant indicate a trend of decreased mature cottonwoods and increased old cottonwoods between 1948 and 1999. An aerial analysis of a section of the UYR (Upper Yellowstone River) (reflecting FOV of Figure 31) reveals a decrease in mature cottonwoods (-12%) (Figure 70). Slight changes in surface water, young cottonwood, shrub, old cottonwood, meadow, gravel bar, and gravel bar vegetation are not substantial (<5%) (Figure 70). An aerial comparison of vegetation (reflecting FOV of Figure 29) indicates an increase in old cottonwood (78%) and decrease in mature cottonwood (-10%), shrub (-46%), and meadow (-21%) (Figure 71). Slight changes of the other cover types are not substantial (< 5%) (Figure 71). Another aerial comparison (reflecting FOV of Figure 30) shows an increase in old cottonwood (11%) and meadow (28%), whereas shrub and mature cottonwood decline. The decrease in gravel bar (-15%) resulted in an increase in gravel bar vegetation (7%) (Figure 72).

Aerial comparisons, revealed little change in lateral channel movement between 1948 and 1999 (Table 4) with the exception of one reach (Figure 70), which changed from sinuous (1.16) to braided (1.34) as classified by Morisawa and Clayton (1985). Photo wedge area could attribute to these differences; FOVs of the all of the reaches were dissimilar and thus photo wedges were different sizes (Table 4).

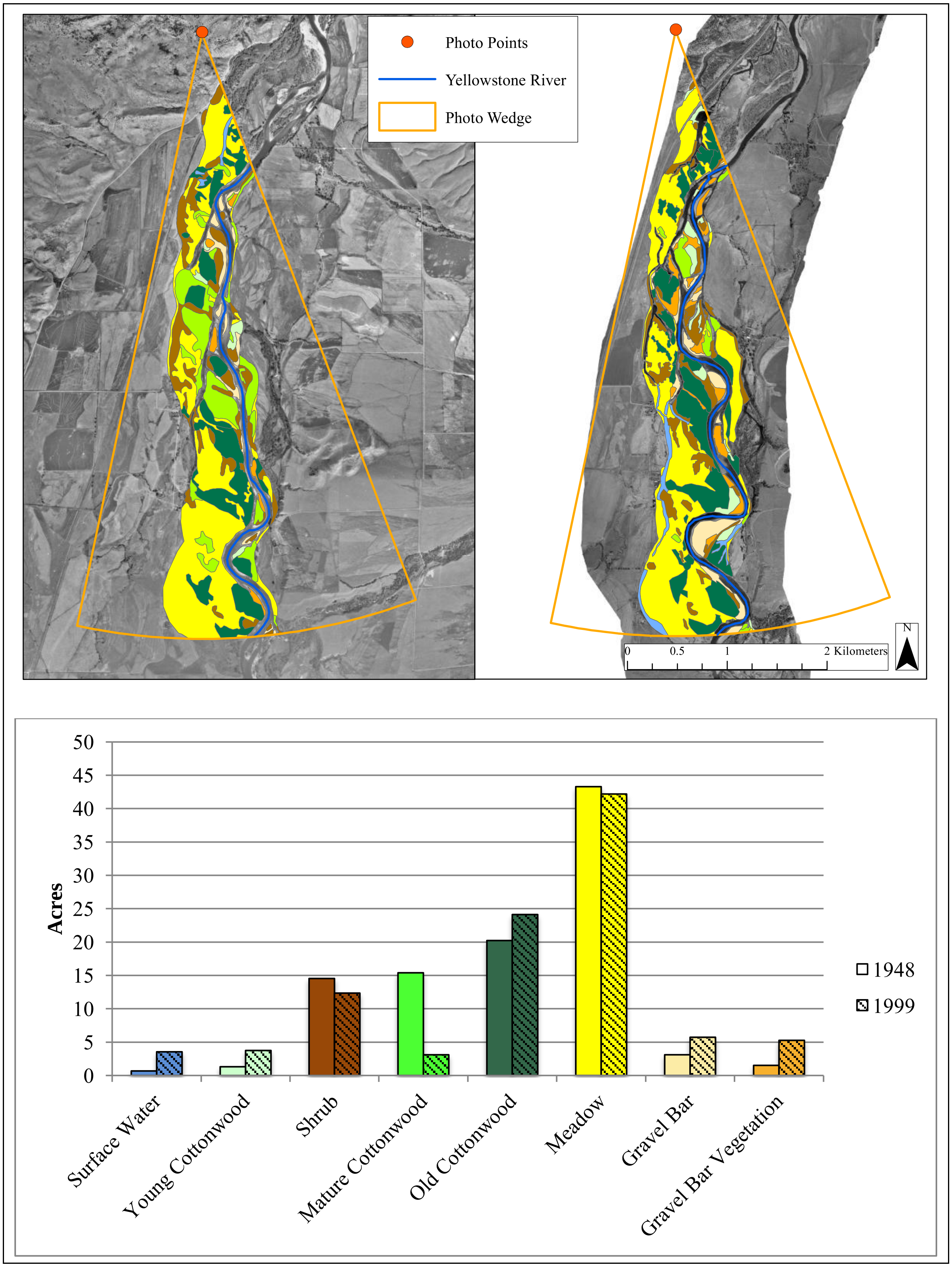


Figure 70. Percentage of riparian vegetation in photo wedges between 1948 and 1999 (photo point 317).

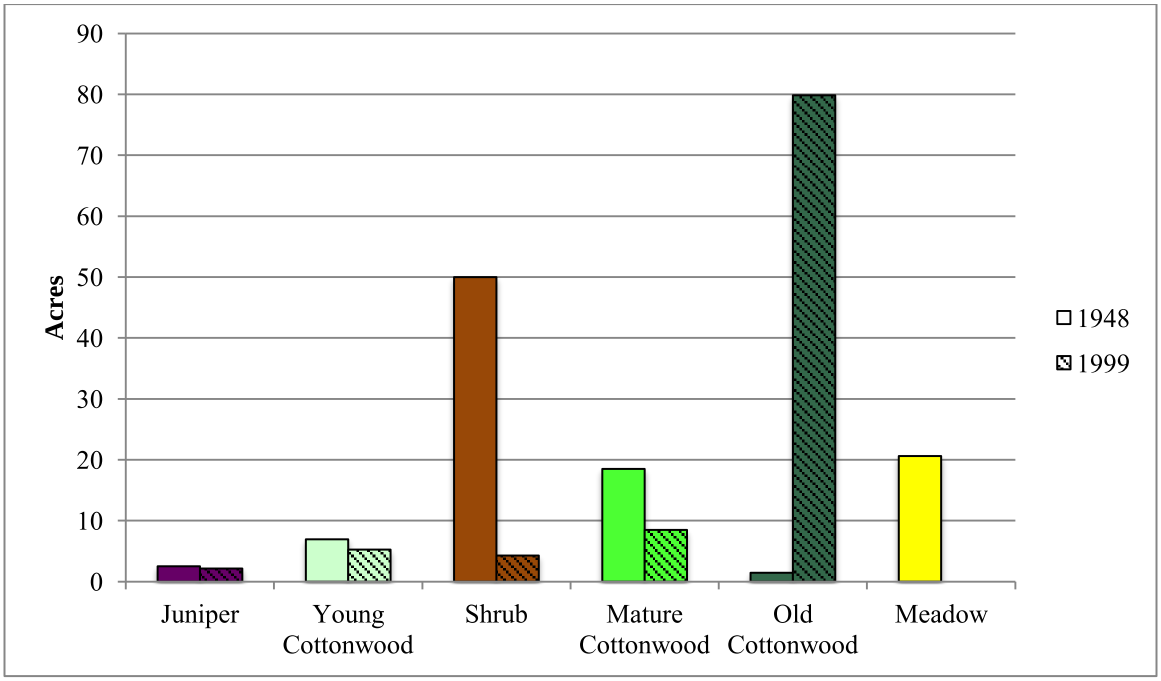


Figure 71. Percentage of riparian vegetation in photo wedges between 1948 and 1999 (photo point 325).

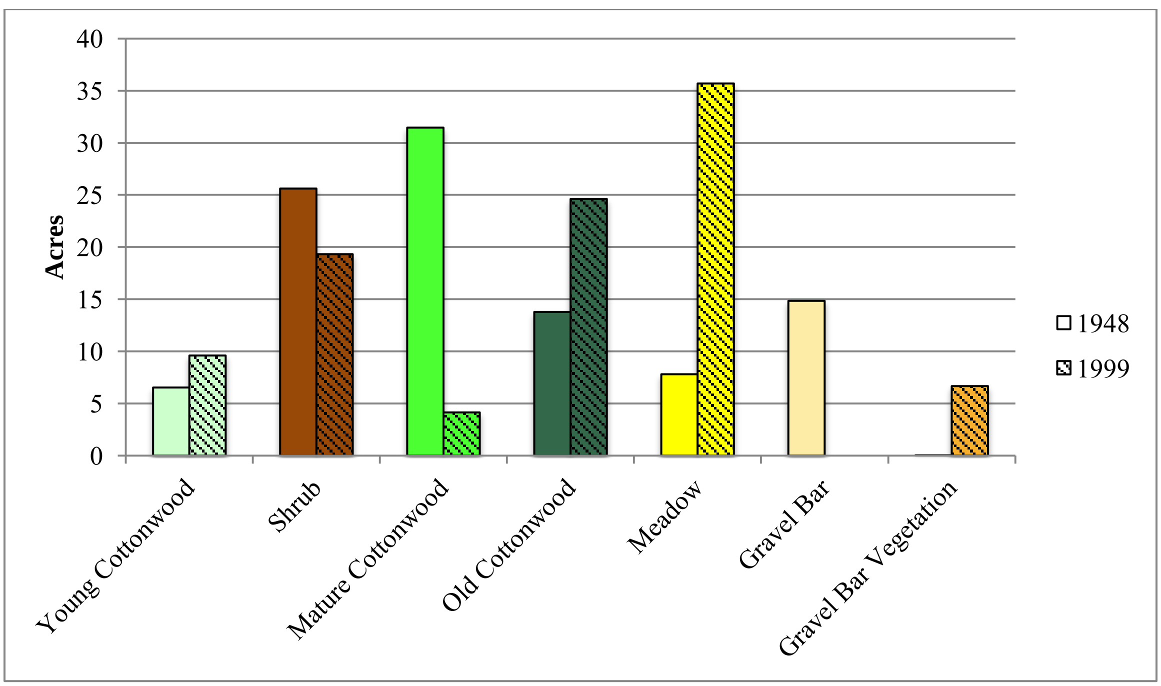


Figure 72. Percentage of riparian vegetation in photo wedges between 1948 and 1999 (photo point 451).

Table 4. A comparison of sinuosity among three photo points between 1948 and 1999 within photo wedges. Photo wedge areas in hectares. Photo point (PP) numbers included.

Figure	PP	Year	Wedge Area (ha.)	Sinuosity	Type
29	325	1948	336	1.02	Straight
29	325	1999	336	1.02	Straight
30	451	1948	26	1.18	Sinuous
30	451	1999	26	1.02	Straight
31	317	1948	1,045	1.16	Sinuous
31	317	1999	1,045	1.34	Braided

DISCUSSION

Table 5. Quantitative comparison results for increased (↑), decreased (↓), and relatively unchanged (→) pixel coverage of vegetation and river dynamics (i.e., floodplain, bankfull, river width) of reaches impacted by damming (D), agriculture (A), and tie driving (TD) over time, where NA indicates where there was not enough information to assess the change. Asterisks (*) indicate where the predictions matched photo comparison results. Photo point (PP) numbers included.

Figure	PP	Use	Vegetation	% Change	River	% Change
4	181	TD	NA	NA	↓*	-64
6	179	TD	NA	NA	↑	15
11	224	TD	NA	NA	→	0
18	570	A	↑	32	NA	NA
26	303	A	↓	-44	↑	25
27	304	A	↑	65	NA	NA
29	325	A	↓*	-67	NA	NA
35	401	A	→*	-3	NA	NA
36	398	A/TD	↓	-32	NA	NA
47	92	A	↓	-35	NA	NA
57	100	D	NA	NA	→*	0
59	394	D	↑	34	↓*	-90

Historical timber harvest, agriculture, and domestic grazing influenced most mountain rivers (Wohl, 2006). Understanding historical implications of riverine change is crucial, because ecological impacts often continue for over a century after active alterations cease, as evident by historical tie driving (Wohl, 2006; Young et al., 1994). Simultaneous occurrence of land use activities (e.g., dams, tie driving, and agriculture) produce cumulative effects. For instance, in the Colorado Front Range, lode mining promoted timber harvest, which necessitated transportation corridors, leading to urbanization (Wohl, 2006). Photo comparison results (i.e., descriptions, rank orders, and quantifications) are mostly consistent with predictions, with the exception of certain instances of increased older cottonwood growth in dammed and agricultural areas.

Table 6. Pixel sinuosity (Sin.) of three reaches affected by agriculture (A) and damming (D) over time. Photo point (PP) numbers included.

Figure	PP	Use	Year	Sin.	Sin. Change
35	401	A	ca. 1930	3.23	2.61
35	401	A	2012	5.84	
44	582	A	1918	2.13	-0.61
44	582	A	1976	1.51	
44	582	A	2013	1.62	
50	279	D	ca. 1930	2.56	-1.50
50	279	D	2013	1.06	

Tie Drive Impacts

Tie drive comparisons revealed recovery, yet still showed signs of former impacts. River reaches directly upstream of surge dams exhibited the most change (Figure 4 and Figure 5). Increased vegetation and river meandering suggests that riparian areas directly above surge dams have recovered from tie impacts. Sediment trapped by former surge dams, most likely enhanced riparian recovery. When tie driving concluded, vegetation was able to colonize and establish on open gravel bars without being destroyed the following year by the annual drive.

Despite recovery of tie-effected systems, there are still discernible signs of tie driving indicated by scoured banks, widened channels, and young vegetation (Figure 8 and Figure 7). Evidence of tie impacts, exists on the Green River where widened, shallow channels provide poor fish habitat (Wyoming Game and Fish Department, 2011). Research in the Front Range of Colorado, comparing tie driven rivers to reference rivers, indicates that effects of tie drives were still apparent 100 years later. Tie driven rivers had wider, shallower channels with less heterogeneity and woody debris. Vegetation along the banks decreased in diversity and less mature when compared to reference reaches (Wohl, 2005). Young et al. (1994) indicated that tie drives altered channel morphology and removed coarse woody debris (CWD), thereby reducing complexity of stream channels. They found increased plunge and dammed pools associated with CWD in study reaches where tie driving had not occurred. Tie drives widened and straightened channels, reducing heterogeneity leading to increased riffle abundance (Young et al., 1994).

Table 7. Tie driving (TD) rank orders of photo comparisons affected by historical tie driving (Y) and a control without impacts (N) where rank is based on a scale of one to five from minor to major changes as outlined in
Table 2. Photo point (PP) numbers included.

Figure	PP	TD	River	Location	Rank	1	2	3	4	5
4	181	Y	Gallatin	Taylor Fork	5					X
5	548	Y	Gallatin	Taylor Fork	5					X
6	179	Y	Gallatin	Taylor Fork	4				X	
7	456	Y	Gallatin	Taylor Fork	4				X	
11	224	Y	Gallatin	Taylor Fork	3			X		
36	398	Y	Wind	Wind River	2		X			
37	428	Y	Wind	Wind River	1	X				
39	409	Y	Wind	Warm River	5					X
62	340	N	Green	Tosi Creek	1	X				

Even though photo comparisons along with previous research indicate impacts of tie driving, all of the tie drive photo comparisons reveal recovery, including: increased vegetation along riverbanks (Figure 6 and Figure 40), decreased scouring (Figure 7, Figure 8, and Figure 11) and increased instream heterogeneity, especially in former dammed locations (Figure 5, Figure 38, and Figure 39).

Dam Impacts

Table 8. Dam rank orders of reservoirs with constructed dams (Built), natural dams (Nat.) and natural lakes without dams (None) where rank is based on a scale of one to five from minor to major changes outlined in
Table 2. Photo point (PP) numbers included.

Figure	PP	Dam	River	Location	Rank	1	2	3	4	5
20	374	None	Yellowstone	Yellowstone Lake	2	X				
21	126	None	Yellowstone	Yellowstone Lake	2		X			
48	383	Nat.	Gros Ventre	Slide Lake	5					X
50	279	Built	Snake	Jackson Lake	4				X	
55	388	Built	Snake	Jackson Lake	5					X
56	258	Built	Snake	Jackson Lake	5					X
57	100	Built	Snake	Jackson Lake	2		X			
59	394	Built	Snake	Wilson	5					X
60	282	Built	Snake	Wilson	5					X
64	97	Nat.	Madison	Earthquake Lake	5					X
67	346	Built	Madison	Beartrap Canyon	1	X				
68	419	Built	Madison	Beartrap Canyon	1	X				
69	48	Built	Madison	Norris Bridge	2		X			

Comparisons of dam photos indicate how dams have dramatically influenced upstream and downstream riverine regions. Overall, dam operations restrict natural flow dynamics and flood frequency, influencing vegetation patterns far downstream of the dam (Marston et al., 2005). Vegetation may be changed along both downstream and upstream channels. These changes may include reproduction by on-site regeneration, colonization of other parts of the floodplain, loss of riparian vegetation, or replacement of existing riparian vegetation by a new type of plant or community. These processes all influence riverine aquatic and terrestrial biota (Naiman & Decamps, 1997).

Photo comparisons upstream of Jackson Lake revealed loss of riparian vegetation, reduced bank stabilization, and decreased sinuosity due to Jackson Lake Dam (JLD). Dam operations raise and lower lake levels depending on need for water. For instance, since the Reclamation Act, Idaho agriculture dictates the release of water from JLD (Daugherty, 1999). Both manmade and natural dams trap sediment and impede water flow, creating or expanding an existing reservoir (Figure 48 and Figure 64). As a result, terrestrial and riparian vegetation becomes inundated and dies; occasional inundation upstream of reservoirs often wipes out entire populations of valley bottom species (Nilsson & Berggren, 2000), evident by remaining snags (Figure 50). Prior to damming, some inundated areas are cleared of woody vegetation, but in many cases, especially naturally formed dams, vegetation remains (Nilsson & Berggren, 2000).

Drought in the 1930s considerably lowered summer flows as evident in a photo comparison (Figure 51) and in discharge analyses of the Snake River from 1903 to 1989 (Marston et al., 2005). Man-made reservoirs usually experience larger water level fluctuations than natural lakes, creating a zone of disturbance along the shoreline. This littoral region includes the geophysical environment and its biota in the shallow belt of water (about 1-5m) around the shoreline of a lake (Zohary & Ostrovsky, 2011). During episodes of drought, reservoir levels can drop drastically exposing barren land—vulnerable to erosion and likewise unsuitable for long term vegetation establishment—and decreasing littoral habitat (Zohary & Ostrovsky, 2011).

Like reservoirs, natural lakes can also fluctuate and accumulate sediment often forming bars near outlets (Figure 20); however, dammed reservoirs create a new sediment trap and sediment that would normally flow downstream forms large deltas entering the reservoir (Nilsson & Berggren, 2000). Ecological consequences of sediment depletion by dams are generally most severe immediately downstream (Rood et al., 2005). Lack of sediment and regulated flows lead to widened channels. To prevent further erosion and channel widening, banks are often reinforced with riprap (Figure 53, Figure 54, Figure 56).

Vegetation changes related to dams were not consistent with predictions, because increase in vegetation was attributed to aging of cottonwoods, not new establishment (Figure 59). Regulation of flows and riprap reduces flooding impacts near dam outlets, establishing stability, allowing existing cottonwoods to grow and mature but offering little substrate for new cottonwood recruitment (Shafroth, Stromberg, & Patten, 2002).

Relatively little change in the Snake River oxbow (Table 8) is consistent with the findings of Nelson et al. (2013) who indicated a lack of channel changes attributed to insufficient sediment availability directly below JLD and upstream of Pacific Creek. Deficiency of sediment supply below dams and above tributary confluences can reduce channel change and consequent vegetation colonization (Nelson, Erwin, & Schmidt, 2013). Whereas downstream sediment supply from downstream tributaries (e.g., Buffalo Fork) led to multithread reaches allowing the Snake River to dynamically meander (Nelson et al., 2013).

Large flood events can inundate the floodplain, destroying vegetation, but leaving sediment deposits available for vegetation reestablishment as evident by the Snake River flood events in 1917 and 1927 (Figure 60a and Figure 59a). Intensive flooding creates smaller, fewer, and more open stands of floodplain vegetation. Dams regulate river flow, creating a new equilibrium with more stable flows and associated fluvial groundwater levels, reducing pioneer species' reproduction and leading to older seral, less productive stages of riparian vegetation (Hansen et al., 2003; Marston et al., 2005; Nilsson & Berggren, 2000; Shafroth et al., 2002). For example, completion of the Garrison Dam in 1953 on the Missouri River brought about a decline in pioneer stages and increase in older stages of poplar-cottonwood communities (Naiman & Decamps, 1997). However, JLD regulated hydrologic changes are relatively modest compared to other dam-operated rivers (Nelson et al., 2013).

Levees promote channelization and increase river velocity, eliminating islands and reducing potential for cottonwood recruitment within the floodplain (Figure 59 and Figure 60) (Anthony, 1998). Along the levee section of the Snake River, cottonwoods have become mature and able to sustain growth behind the levees. This occurrence is likely a result of sustained flows, providing a suitable water table level outside of the levees for cottonwood growth. Old cottonwood forests tend to dominate these areas, where potential for new cottonwood establishment via new gravel bar habitat has declined. Additionally, levee channelization and consequent higher velocities have led to extensive bank erosion downstream of levees, altering bedload movement and diminishing fish habitat (Anthony, 1998).

The Madison River Dam appears to have little impact on downstream riparian vegetation and channel (Table 8). All dams affect the same riparian processes; however, individual responses may dramatically differ between regions and/or channel morphology (Nilsson & Berggren, 2000). Depending on dam flow releases and geomorphology of channels, dams can have little impact on the river channel and riparian vegetation (Nelson et al., 2013). Terrain features, like Bear Trap Canyon on the Madison River, contain flows, limiting appreciable channel changes. In canyons like Bear Trap, streambeds have usually reached bedrock and flows are contained (Gruell, 1980b).

Overall historical photo comparisons of dams indicate that dam construction leads to channelization, cottonwood forest maturation along the rivers, reduced sediment aggradation, and decreased cottonwood and willow recruitment and establishment on sediment bars within channels. For JLD, flow regulation by dam operations, installation of downstream riprap, and lack of downstream sediment accumulation have prevented channel and vegetation changes directly downstream of the dam, decreasing resilience.

Agricultural Impacts

Photo comparisons of agriculture suggested three trends: 1) increase in vegetation, 2) decrease in vegetation, and 4) relatively little change in vegetation. Pre-existing conditions of agricultural areas in mountainous regions are difficult to determine with repeat photography, because many agricultural practices began before photography was readily available; however, archaeological and sedimentological records indicate that early agriculture in mountainous regions caused changes in water and sediment yield (Wohl, 2006). Belsky et al. (1999) reported that domestic grazing has damaged approximately 80% of streams and riparian ecosystems in the western U.S.

Increased Vegetation

Photo comparisons from the Gros Ventre and Yellowstone Rivers exhibit areas currently or historically grazed; however natural disturbances appear to have caused these changes (Table 9). Presence or absence of later seral species can provide clues about the history of natural disturbances.

Table 9. Agricultural rank orders with relatively little change (→Ag.) and change largely attributed to the transition of agriculture to development (Ag. → Dev.), natural disturbances (Nat. Dist.), increased agriculture (↑ Ag.), and decreased agriculture (↓ Ag.) where rank is based on a scale of one to five from minor to major changes as outlined in Table 2. Photo point (PP) numbers included.

Figure	PP	Trend	River	Location	Rank	1	2	3	4	5
13	16	Ag. → Dev.	Gallatin	West Fork	3			X		
14	455	Ag. → Dev.	Gallatin	West Fork	3			X		
15	571	Ag. → Dev.	Gallatin	West Fork	4				X	
16	576	Ag. → Dev.	Gallatin	West Fork	3			X		
17	572	Ag. → Dev.	Gallatin	West Fork	3			X		
18	570	Ag. → Dev.	Gallatin	West Fork	4				X	
23	609	↑ Ag.	Yellowstone	Yankee Jim	2		X			
24	295	↑ Ag.	Yellowstone	Yankee Jim	1	X				
26	303	Nat. Dist.	Yellowstone	Point of Rocks	4				X	
27	304	Nat. Dist.	Yellowstone	Point of Rocks	4				X	
29	325	↑ Ag.	Yellowstone	Emigrant	3			X		
32	317	↑ Ag.	Yellowstone	Near Carter's Bridge	4				X	
35	401	↓ Ag.	Wind	Horse Creek	3			X		
36	398	→Ag.	Wind	Warm River Ranch	2		X			
37	428	→Ag.	Wind	Warm River Ranch	1	X				
44	582	Nat. Dist.	Gros Ventre	Upper Gros Ventre	4				X	
45	385	Nat. Dist.	Gros Ventre	Upper Gros Ventre	3			X		
47	92	Nat. Dist.	Gros Ventre	Upper Gros Ventre	3			X		
48	583	Nat. Dist.	Gros Ventre	Upper Gros Ventre	2		X			

In the valleys and low elevation canyon bottoms of the Gros Ventre River, fire was most likely responsible for historical decreases in conifers—notably, Engelmann and blue spruce trees—at the time historical photos were taken (i.e., late 1800s and early 1900s) (Table 9). These areas appeared to have been burned more frequently due to drier conditions and fuel accumulation (Gruell, 1980b). As of 1976, willows were less plentiful than they had been in the late 1800s and early 1900s as conifer stands began to grow and mature, revealing succession toward later seral stages (Gruell, 1980b).

Increased spruce also provides evidence of a lack of destructive floods for once spruce establishes in a floodplain, they will dominate at the expense of other communities (i.e., willow) (Wohl, 2006).

Repeat photographic evidence of the Gros Ventre River from Gruell (1980a) along with charcoal and more recent burns indicate that fire plays a prominent role in willow revegetation (Gruell, 1980a). Late summer and early fall wildfires stimulate sprouting—temporarily eliminating competition—and provide new habitat for seed colonization. A fire in 1879 promoted willow colonization along riverbanks (Gruell, 1980a), but spruce establishment created competition for willows, reducing their patch sizes (Figure 47). Additionally, elk and moose browsing most likely reduced willows patches (Gruell, 1980b).

In the upper Gros Ventre region, proximity to agricultural lands (e.g., Red Rock Ranch) reduces flows as well as transpiration to a lesser extent. Plant succession reduces river flow as mature and over mature forests draw heavily on the groundwater (Figure 45, Figure 46, and Figure 47). This occurrence has the most extreme effect in summer when transpiration is highest (Gruell, 1980b).

Fire could have contributed to historical riverbank scouring in the Gros Ventre River (Figure 46). Forest fires exacerbate flooding impacts by removing vegetation and organic matter making soil highly vulnerable to erosion and also increasing overland flow, which cause flash flows that scour riverbanks (Wohl, 2006).

Flooding can have a similar impact as fires, removing vegetation and creating open habitat for primary succession. Early grazing impacts in Paradise Valley in the

1860s, most likely contributed to decreased vegetation exhibited in historical photos (Figure 26 and Figure 27). Cattle consume and trample highly palatable young vegetation, preventing establishment of seedlings and clonal ramets, which results in a sparse over-mature tree population (Samuelson & Rood, 2011). However, natural disturbances probably impacted the area as well, leading to a lack of mature woody vegetation (Figure 26 and Figure 27). Flood time series data near Livingston, MT indicate a large flood event in 1894 (Merigliano & Polzin, 2003), which could explain the lack of cottonwood trees in the 1898 historical photos (Figure 26a and Figure 27a). Even though cottonwood communities have increased in both photo comparisons, they are currently restricted by agricultural use.

Even after grazing removal, exurban development can still impede recovery of riparian vegetation. For instance, development of Big Sky, MT replaced the ranching community along the West Fork of the Gallatin River. With a lack of photo documentation predating agriculture in the region and without complete removal of anthropogenic influence (i.e., the shift from ranching to development) resilience is difficult to determine.

Photo pairs displaying riverine change of West Fork of the Gallatin River suggests that removal of grazing led to increased willow in certain areas, but development restricted willow growth in other areas (Figure 15, Figure 18, Figure 16, and Figure 17). Overall changes along West Fork have been meager due to the shift from agriculture (i.e., ranching) to development (Table 9). However, occurrence of increased bank stabilization and willow growth suggests signs of resilience.

A tributary of the Wind River, Horse Creek, also shows signs of resilience. Thirty years after alleged ranching impacts ceased, increases in sinuosity (Table 6) and sustained willow patches are indicative of a dynamic resilient system (Figure 35).

Additionally, near the Emigrant fishing access area along the Yellowstone River shows signs of riverine recovery after removal of sheep grazing in the 1950s, where sheep had historically completely grazed and trampled the riparian area (Figure 30). Despite apparent decreases of vegetation due to gravel bar migration, river meandering suggests a recovered functional riverine system at this site. Aerial comparisons between 1945 and 1999 revealed an increase in old cottonwood and meadow with a decrease in shrub and mature cottonwood. Decrease in gravel bar area resulted in an increase in gravel bar vegetation (Table 5). Even though Hansen et al. (2003) concluded that the braided reach types overall had become less dynamic from 1948 to 1999, results from oblique photos of this site suggest levels of recovery since 1939 (Figure 30).

Decrease in Vegetation

In historical photos, larger crop fields, center pivot irrigation, cattle fences, and local histories provide evidence for increase in intensity of agricultural use. Cattle enclosures directly overlying the Wind River near DuNoir River have allowed cattle to completely graze and trample within a fenced-in area, most likely leading to soil erosion and manure contamination (Figure 34) (Belsky, Matzke, & Uselman, 1999). Excessive livestock use can degrade riparian habitats by reducing vegetation, increasing bare ground, diminishing rare species, and allowing invasive weed infiltration; in particular, high elevation zones are especially sensitive to grazing pressures (Samuelson & Rood, 2011).

Along a reach of the Yellowstone River (Figure 29) agriculture has directly influenced the riverine system by reducing riparian vegetation (Table 5) and indirectly by extracting groundwater for pivot irrigation. Aerial analyses from 1948 to 1999, revealed an increase in old cottonwood and decrease in mature cottonwood, shrub, and meadow, indicating a less dynamic river system with cottonwood stands succeeding to later seral stages without subsequent regeneration (Figure 71) (Hansen et al., 2003).

Aerial results near Carter's Bridge (Figure 70) are consistent with findings of Hansen et al. (2003), who indicated that the 2001 UYR cottonwood communities were less dynamic than communities 100 to 150 years ago, before the onset of white settlement and stabilization efforts. Anthropogenic impacts decreased channel migration and cottonwood recruitment, degrading riparian systems (Hansen et al. 2003). However, cottonwood growth has increased since 1872, when settlement impacts substantially reduced vegetation (Figure 30 and Figure 31).

Photo comparisons indicate that willows have declined along a reach of the upper Gros Ventre River (Figure 44). Gruell (1980b) attributed reduced willow to heavy browsing, moisture deficiencies from competition, soil moisture changes due to stream channel dynamics, pathogen attacks, lack of seed establishment, and fire. Prior to the 1930s, willows were sizeable because large wintering elk populations did not devastate their growth. During some severe winters, elk would heavily browse; however, moderate winters would allow willow to reestablish. By the late 1930s, willow appeared to decline attributed to elk browsing near elk feeding grounds (Gruell, 1980b). Gruell (1980b) speculated that during this period, moose were the main drivers of willow decrease on floodplains with help of cattle and elk.

Photo comparisons indicated that a reach of the Gros Ventre River decreased in sinuosity from 1918, 1976, and 2013 as a result of bank destabilization due to reduced vegetation (Table 6). Decrease in sinuosity is also influenced by reach geomorphology; this section of the upper Gros Ventre flows through a broad floodplain of soft sedimentary rock, where deposition and erosion create a highly changeable system (Gruell, 1980a). River dynamics combined with reduced vegetation from elk browsing created a degraded riverine habitat.

Little Change in Vegetation

Relatively little change in riparian vegetation results from continued use at a relatively constant intensity. Warm River Ranch photo comparisons indicate slight change, exemplifying how cattle grazing and human habitation continue to influence willow and cottonwood communities along the Wind River (Table 9). Additionally, continued agricultural use at the mouth of Yankee Jim Canyon, has revealed minor changes in vegetation and channel movement over time (Table 9).

Resilience and Restoration

Repeat photography provides a broader ecological timeline and therefore is a valuable tool to understand current impacts and predict future outcomes. This technique can help to examine riparian processes before anthropogenic perturbations (i.e., dams), to investigate sites where historical human perturbations have ceased (i.e., tie driving), and to understand how continued use has impacted habitats (i.e., ranching). Repeat photography can also aid in understanding natural changes in rivers over time. Nilsson and Berggren (2000) described three effects of large-scale hydrogeomorphic alterations on riparian system as 1) effects within watershed areas, 2) differences between watersheds, and 3) change over time. This study covers all three effects and thus the photo comparison results are valuable for describing hydrologic alterations of riparian systems within the GYE.

Repeat photography is a valuable tool to better understand riverine resilience. Resilience is the ability to recover following disturbances and differs from resistance in that resistance is the capacity of an ecosystem to maintain ecological structure and function during natural and anthropogenic disturbances. Species extinction, introduction of invasive species, excessive soil erosion, pollution, and dramatic change in geomorphology or hydrology can diminish recovery, reducing resilience (Kauffman et al., 1997). Repeat photos help to detect changes in vegetation, bank stability, and landscape alterations, indicating signs of recovery.

In riverine systems, physical and biological parameters influence resilience, particularly reach-scale gradient, habitat diversity, (Wohl, 2006) and flood intensity and frequency (Helfield et al., 2007). For example, higher gradient stream segments are more resilient to increased sediment deposition than lower gradient pool-riffle channels (Wohl, 2006). Additionally, increased riparian vegetation can lead to channel heterogeneity and heightened resilience. In the western U.S., riparian vegetation—in particular, willows, cottonwoods, and alders—provides wildlife habitat, maintains the dynamic nature of stream channel morphology, and promotes aquatic habitat (Kauffman et al., 1997). Repeat photography can reveal recovery of woody vegetation following disturbance and highlight signs of resilience. Intensity and frequency of floods can also influence riverine resilience. Riparian areas with intermediate flood frequencies maintain high levels of spatial heterogeneity providing species-rich communities. With higher species diversity, communities have the ability to recover from large disturbances, because likelihood of survivorship will be higher among a variety a species than within a homogeneous community (Helfield et al., 2007).

Repeat photograph evidence of Wind River tributaries indicates signs of resilience (Figure 35, Figure 38, and Figure 39). The Front Range of Colorado provides examples where stream physical processes and aquatic biota have been resilient to former impacts of natural resource use, mainly mining and deforestation. Recovery of these streams following natural resource use is evident by improved channel stability and habitat diversity, which supports a variety of aquatic and riparian species. This recovery is apparent where anthropogenic perturbations have ceased; however, continued contamination and regulated flows still affect riverine systems in this area, reducing resilience (Wohl, 2006).

Cessation of an anthropogenic perturbation in order to allow a natural system to recover is a form of passive restoration and is one of the most effective and sustainable ways to restore habitats (Kauffman et al., 1997). A goal of riverine restoration is to utilize natural resilience by facilitating self-sustaining natural processes and interfaces between terrestrial, riparian, and aquatic populations. However, this goal can often require active restoration, which involves human intervention (i.e. reinforcing banks, planting seedlings, and adding boulders and woody debris), which can be more costly and less successful than passive restoration.

Repeat photographs can provide valuable information when restoring riverine systems. Before implementing active restoration, managers must evaluate the ecological status of both riparian and aquatic components. Prioritization of efforts should focus on riparian zones capable of recovery, or resilient habitats, because these areas have a high potential for success with lower costs and risks (Kauffman et al., 1997). A thorough evaluation must include an understanding of historical land use patterns and their associated impacts on rivers (Wohl, 2005; Young et al., 1994). Knowledge of hydrological and geomorphic alterations is valuable for river restoration and is needed to evaluate changes attributed to current impacts and to predict outcomes of planned projects (Kauffman et al., 1997; Nilsson & Berggren, 2000). Therefore, repeat photography is a useful tool in active and passive restoration to speculate resilience of a system in order to proceed with a restoration plan.

Of the many forms of anthropogenic riverine perturbations in the GYE, ranching continues to occur. Recognizing the importance of "healthy" riverine systems, many ranchers are implementing active restoration techniques and reducing stressors to enhance resilience of rivers. For example, grazing strategies for riparian protection include installing alternative water systems away from riparian areas, implementing rotational grazing, providing controlled stream crossings (e.g., bridges, ramps or designated fords), and fencing livestock out of heavily damaged areas. Alternative water sources and controlled stream crossings minimize stream bank degradation. Additionally, grazing management, such as rotational grazing, allows plants to reestablish and reproduce, providing key components of resilience. Further considerations, such as, not grazing when plants are reproducing (i.e., spreading or setting seed, or in sapling stage) can promote riparian recovery. Ranchers also work to minimize livestock dependency on riparian vegetation by reducing grazing in riparian communities when foliage has developed and installing exclosures around riparian vegetation. Placing brush or boulders along river banks also deters livestock from utilizing riparian areas (Bellows, 2003). Agriculture, especially ranching, represents a livelihood and a rich, profound culture in the western U.S., so full removal is not an option; however, active restoration techniques help to prevent riparian degradation.

Regulating flows from dams can also promote riverine improvement by maintaining peak flows. Dam operations may control floods that reduce damage to human infrastructure in flood-prone zones. As part of environmental flows, floods are now recognized as essential natural disturbances that drive geomorphic change and promote riparian vegetation recruitment. Restoring flow dynamics addresses the whole riverine ecosystem, not just specific sites. Appropriate flow regulations should be based on natural hydrographs because aquatic and riparian biota have adapted to annual hydrological patterns. Gradual flow decline after flood peak, or “down ramping,” provides hydrological requirements that promote riparian seedling establishment, particularly among cottonwood and willow (Rood et al., 2005). Appropriate down ramping rates also enable roots of newly established seedlings to elongate and remain in contact with the receding moisture zone. Restoration of flows can promote riparian vegetation recovery, but river channels often take a long time to recover from anthropogenic perturbations and reconnect to the floodplain becoming sinuous again. Thus, along with recreating appropriate ramping rates, restoration of natural flows to reconstruct river channels can create sinuous meanders to enhance further cottonwood and willow recruitment (Rood et al., 2005).

CONCLUSION

Critical Assessment of Repeat Photography

Repeat photography is an effective way to understand historical impacts and, in some situations, this tool can be useful for restoration activities by helping to understand riverine recovery processes. However, repeat photography requires copious amounts of time and precision. Modern technology (i.e., Google Earth, digital cameras, and GPS devices) has helped to make the process less intensive, but there are many necessary steps to make repeat photography a useful and viable research tool.

The first hurdle is obtaining photos, which often requires permission and associated costs. Additionally, acquiring many photos of a specific site or topic may require multiple sources and in-person meetings with archivists. Once a large collection of photos is obtained, managing them effectively in a database to keep track of different sources, dates, descriptions, and photo identification numbers becomes vital.

After obtaining and organizing the photos, one can begin investigating photo point locations. This step can be challenging because many historical photos lack complete descriptions. History books, archivists, and local knowledge are useful sources in determining locations. Even after determining approximate locations, geographical navigation tools (i.e., Google Earth) help to search for exact sites, saving time when navigating in the field. Additionally, exact replication requires estimating approximate time of year and day of the photo. Furthermore, requesting permission from property owners is necessary when photo point locations are not on public lands.

Even after gaining permission and finding historical locations at the estimated times of day and year, there are other complications. Tangible obstacles (i.e., trees, roads, or buildings) that have developed since the historical photo may block the current view. Additionally, the historical photo point location may no longer exist due to erosion, construction, or removal (such as a bridge). Viewing the retakes on a computer screen rather than a digital camera can reveal subtle differences, warranting a return to retake the photo. Other variables, such as weather, inaccessible roads (due to construction, flooding or fire), and inability to initially contact the landowner may necessitate several visits.

After the photo investigation and retake process, photo analysis is a complex procedure. Identifying exact matches and outlining polygons of parameters that changed (i.e., riparian cover) is a very detailed technique. Even with extensive riverine knowledge and attention to detail, the process of quantifying changes over time is still largely subjective and subject to error. One must also recognize that historical photographs only provide a snapshot of an area and interpretation of past conditions based on the present is highly speculative. When analyzing changes over time, one should consider length of time between photographs, how long perturbations lasted and the time they ceased or if impacts are still occurring. Lack of research or documentation of the histories of photo locations can lead to inaccurate interpretations.

Overall, advantages of repeat photography far outweigh disadvantages. Challenges include large amounts of time per photo, repeated visits, and error in obtaining an exact retake and in precisely quantifying and interpreting photo comparisons. However, during each of the retake steps, one gathers supplemental information to further explain changes over time. For instance, one learns about a particular site by digging through archives and describing the current natural site and observed disturbances. This background information may provide the researcher with more information than obtained from photo comparisons. As stated in the introduction, repeat photography provides a unique perspective on a moment in time that may not be obtained through other research means.

Recommendations

This study identified stream reaches exhibiting apparent recovery; however, comparisons between vegetative and aquatic data from formerly affected reaches and relatively unperturbed would be valuable. Such comparisons could help to further determine the level of resilience of streams in relation to historical information gained from repeat photography.

Restoration research in Sweden provides an example of comparing unaffected versus impacted stream reaches. Tie driving degraded many of the streams creating channelized homogeneous reaches with little riparian and aquatic diversity. Swedish restoration efforts included replacing instream boulders and removing floatway structures, or levees lining the channels. These restoration methods resulted in increased channel width, sinuosity, and bed roughness (Helfield et al., 2007). All of which help to retain water, sediment, organic matter, and nutrients and improve conditions for aquatic and riparian biota (Wohl, 2006). Plant species richness and evenness were also significantly higher at restored sites when compared to channelized sites (Helfield et al., 2007).

Another consideration for further research is implementing ways to utilize repeat photography to help with interpretation of ecosystem responses to climate change. As climate changes in the western U.S., reduced water supply and changing hydrological patterns become an imminent threat (Stromberg, Lite, & Dixon, 2010). Specific risks of changing climate to riverine systems include: low base flows, late summer high water temperatures, larger and more recurrent flood events, and frequent wildfires. Identifying available and useful management responses is important when combating anticipated climate changes scenarios (Rood et al., 2008). The implementation of beaver dam structures or beaver mimic dams may serve as a way to increase summer flows by promoting natural high elevation water storage, which increases groundwater flow beyond the near-pond area to downstream of dams (Miller, Cross, & Schrag, 2008; Westbrook, Cooper, & Baker, 2006). Repeat photography would be useful to investigate where to implement beaver dam structures to promote riverine resilience.

Of the many forms of historical data, repeat photography provides a unique and valuable way to analyze change over time. Photographs capture glimpses of ecosystems and thus can convey information on many different variables (e.g., vegetation, geology, and geomorphology). Historical oblique photos offer a wider span of time than historical aerial photos; however, when coupled these two sources provide a more detailed understanding of a site. Additionally, the visual aspect of repeat photography allows this tool to serve as a vector between the scientific community and general public because photographs portray change in a more apparent and understandable than scientific graphs and descriptions. With a better understanding of habitat resilience and riverine processes people can restore degraded rivers, provide guidelines for sustainable resource industries, and supplement conservation studies.

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APPENDICES

APPENDIX A

PHOTO SOURCES AND LOCATIONS

Photo information includes historical photo sources, identification numbers, original photographers, land use categorization (i.e. tie driving (TD), ranching (R), and damming (D)) repeat photo photographers (i.e., Heidi Clark (HC) and Jeff Burrell (JB)), GPS coordinates (UTM), and azimuths

Photo ID		Historical Photo				Repeat Photo							
Figure	**PP**	**Source**	**Source ID**	**Photographer**	**Title**	**Use**	**Date**	**Photographer**	**River**	**Time**	**UTM E**	**UTM N**	**Azimuth**
4	181	Museum of the Rockies	x80.06715 #36	Schlechten, Albert	View in Taylor Peaks, Mont.	TD	6/29/13	HC	Gallatin	1:13 PM	0469242	4987014	260
5	548	Museum of the Rockies	97.19.90	Unknown	Madison Range Taylor Fork	R/TD	6/15/13	HC	Gallatin	2:41 PM	0471131	4989104	200
6	179	Museum of the Rockies	x80.06.713 #35	Schlechten, Albert	Taylors Fork, Mont.	R/TD	6/15/13	HC	Gallatin	2:41 PM	0476488	4990770	265
7	456	Museum of the Rockies	x84.4.547	Unknown	9 Quarter Circle Dude Ranch, Gallatin Canyon, Montana	R/TD	6/15/13	HC	Gallatin	1:57 PM	0477050	4990323	172
8	518	Pioneer Museum	4714-1	Unknown	Nine Quarter Circle Ranch, ca. 1930s	R/TD	6/15/13	HC	Gallatin	2:14 PM	0477135	4990297	200
9	125	Pioneer Museum	P839N-2	Unknown	Log Drive Down the Gallatin	TD	6/15/13	HC	Gallatin	1:16 PM	0483262	4993097	120
10	232	Museum of the Rockies	x83.13.812	Unknown	Cooper Tie Company Boat	TD	6/15/13	HC	Gallatin	1:25 PM	0483261	4999023	150
11	224	Museum of the Rockies	x80.06.1440	Unknown	Last run on the Gallatin River Cooper Tie Camp Taken from bridge at 320 Ranch	TD	6/15/13	HC	Gallatin	12:10 PM	0596440	4823001	320
13	16	MSU	778	Unknown	Gallatin River with Road Across Bridge and Valley with Scattered Buildings	R	8/24/13	HC	Gallatin	12:34 PM	480132	5012652	163
14	455	Museum of the Rockies	x80.6.918	Schlechten, Albert	West Fork of the West Gallatin River, Gallatin Canyon, MT	R/D	8/24/13	HC	Gallatin	12:02 PM	0480125	5012473	260
15	571	Historic Crail Ranch Conservators	2004.1.00295	Unknown	Shows view of Crail Ranch from a distance	R	8/24/13	HC	Gallatin	1:30 PM	0477238	5013333	210
16	576	Historic Crail Ranch Conservators	2004.1.00413	Unknown	Lilian Crail standing on bridge above creek with two horses grazing in background	R	8/24/13	HC	Gallatin	2:28 PM	0476788	5012787	310
17	572	Historic Crail Ranch Conservators	2004.1.00297	Unknown	Shows Crail cabin with modern roof with West Fork of Gallatin River in foreground	R	8/24/13	HC	Gallatin	2:34 PM	0476826	5012866	312
18	570	Historic Crail Ranch Conservators	2004.1.00288	Unknown	View of Crail Ranch with 11(possibly 12) buildings	R	8/24/13	HC	Gallatin	2:23 PM	0476784	5012803	35
20	374	Denver Library	WHJ-10284	Jackson, W.H.	Yellowstone Lake, where the river leaves it	C	7/19/12	HC	Yellowstone	11:11 AM	0548947	4935021	190
21	126	Pioneer Museum	P8011N-2	Unknown	Fishing Bridge	C	7/19/2012	HC	Yellowstone	11:11 AM	0548961	4935032	95
23	609	Yellowstone Gateway Museum	2006.044.2271	Unknown	The Cutler home and ranch buildings Alex Hill had previously owned	R	8/25/2013	HC	Yellowstone	1:55 PM	0517705	4992928	278
24	295	USGS	Jackson, W.H. 69	Jackson, W.H.	The second canyon of the Yellowstone River above Minor	R	8/25/13	HC	Yellowstone	3:38 PM	0513296	5000096	310
25	610	Yellowstone Gateway Museum	2006.044.2971	Whithorn, Bill	Yellowstone River in Paradise Valley showing both the west side and east roads	R	8/25/13	HC	Yellowstone	3:22 PM	0513334	5000281	317

Photo ID		Historical Photo				Repeat Photo							
Figure	PP	Source	Source ID	Photographer	Title	Use	Date	Photographer	River	Time	UTM E	UTM N	Azimuth
26	303	USGS	Walcott, C.D. 539	Walcott, C.D.	Looking north down Yankee Jim Canyon	R	8/7/13	HC	Yellowstone	3:59 PM	0509976	5011079	162
27	304	USGS	Walcott, C.D. 539a	Walcott, C.D.	Looking north down Yankee Jim Canyon	R	8/7/13	HC	Yellowstone	4:14 PM	0509991	5011155	47
29	325	USGS	Alden, W.C. 1227	Alden, W.C.	View southeast across Yellowstone Valley to Emigrant Peak	R	8/25/13	HC	Yellowstone	1:11 PM	0517872	5020168	123
30	451	Museum of the Rockies	87.92.694	Haberstroh, John C.	Norris Spangler and Herd, Emigrant Bridge, Paradise Valley, Montana	R	8/7/13	HC	Yellowstone	1:49 PM	0521465	5023739	153
31	317	USGS	Jackson, W.H. 213	Jackson, W.H.	Valley of the Yellowstone	R	8/25/13	HC	Yellowstone	11:04 AM	0532171	5047863	145
32	292	USGS	ID. Jackson, W.H. 68	Jackson, W.H.	Valley of the Yellowstone River above Livingston	R	8/14/13	HC	Yellowstone	3:54 PM	0533183	5048330	147
34	435	Shoshone National Forest	df2238, ref #159203	Cook, A.M.	Ranger Station, Sheridan Creek	R/TD	6/9/13	HC	Wind	12:00 PM	0597266	4828402	230
35	401	Dubois Museum	2013.017.056	Unknown	T-Cross Ranch, Dubois, Wyo.	R	6/16/12	HC	Wind	5:45 AM	0610512	4837614	350
36	398	Dubois Museum	2002.009.282	Unknown	Our old Ranch at Dubois	R/TD	6/9/13	HC	Wind	11:05 AM	0606461	4822434	10
37	428	Shoshone National Forest	DF 4749	Higgins, Jay	Heritage, a view of one of the better ranches on Wind River	R/TD	6/9/13	HC	Wind	10:55 AM	0606418	4822530	40
38	413	Dubois Museum	2002.011.035	Unknown	Over 300,000 ties clog Warm Springs Creek	TD	6/9/13	HC	Wind	4:17 PM	0596141	4823058	85
39	409	Dubois Museum	2002.009.044	Unknown	Looking west toward Warm Springs dam after drive is completed	TD	6/9/13	HC	Wind	4:38 PM	0596452	4822995	300
40	438	Shoshone National Forest	DF 4630	Higgins, Jay	Starting the ties on their downstream journey	TD	6/9/13	HC	Wind	11:30 AM	0605968	4823196	100
41	412	Dubois Museum	2002.009.076	Unknown	Diversion Dam	TD	6/9/13	HC	Wind	1:42 PM	0666173	4787889	230
44	582	Forest Service	49913A	Anderson, M.	Gros Ventre River below the outlet of Slate Creek	R	7/20/13	HC	Gros Ventre	11:57 AM	0561300	4820520	42
45	385	JH Historical Society	2005.0052.049	Unknown	Scenic Gros Ventre River	R	6/7/13	JB	Gros Ventre	10:45 AM	0552500	4826984	282
46	583	courtesy of Mr. and Mrs. Claude Crisp	NA	Unknown	The S.N. Leek hunting party crossing the Gros Ventre River below the outlet of Slate Creek	R	7/20/13	HC	Gros Ventre	10:37 AM	0513408	4817386	315
47	92	Library of Congress	LC-USZ62-137260	Haynes, F. Jay	Presidential escort crossing Gros Ventre River	R	8/12/13	HC	Gros Ventre	5:54 PM	0544345	4828759	163
48	383	JH Historical Society	1958.0376.001P	Unknown	Scenic Slide Lake on Grovont River: Gros Ventre Slide	D	6/7/13	JB	Gros Ventre	5:40 PM	0537194	4831596	210
50	279	JH Historical Society	2007.0009.003	Unknown	Verba Lawrence, Steamboat Mt.	D	11/9/13	HC	Snake	2:18 PM	0523336	4876643	200

Photo ID		Historical Photo				Repeat Photo							
Figure	**PP**	**Source**	**Source ID**	**Photographer**	**Title**	**Use**	**Date**	**Photographer**	**River**	**Time**	**UTM E**	**UTM N**	**Azimuth**
51	66	UWY: American Heritage Center	21623	Bernfield, Seymour	Water, trees, and mountains, Grand Teton National Park	D	8/26/12	HC	Snake	10:19 AM	0474566	4885014	270
52	396	JH Historical Society	1958.0762.001P	Unknown	Jackson Lake Dam Distortion	D	7/4/13	HC	Snake	10:30 AM	0532926	4856003	350
53	397	JH Historical Society	1958.2769.001	Unknown	Jackson Lake Dam with Moran at bas	D	7/4/13	HC	Snake	10:38 AM	0532895	4856005	2
54	391	JH Historical Society	2004.0109.224	Unknown	Moran and first bridge/dam.	D	7/4/13	HC	Snake	10:58 AM	0533079	4856116	18
55	388	JH Historical Society	1958.0995.001P	Unknown	Early Moran town site and toll bridge	D	7/4/13	HC	Snake	11:09 AM	0533096	4856107	355
56	258	JH Historical Society	1958.0994.001P	Unknown	No title	D	7/4/13	HC	Snake	11:17 AM	0533075	4856110	15
57	100	JH Historical Society	MSS P-3 # 247	Beard, George	Arthur, Edgar, Paul and Mother - Snake River just below Moran City Government Dam. Mount Moran in Center	D	7/4/13	HC	Snake	11:40 AM	0536286	4857103	220
59	394	JH Historical Society	2005.0024.056	Unknown	Snake River Bridge.	D	5/29/2012	HC	Snake	3:10 PM	0514817	4819332	250
60	282	JH Historical Society	2005.0024.055	Unknown	Snake River Bridge	D	7/5/13	HC	Snake	10:17 AM	0513460	4816443	343
62	340	USGS	Alden, W.C. 1426	Alden, W.C.	Wind River Mountains, looking southeast across Green River from Teepee Creek	TD	6/7/13	JB	Green	8:40 AM	0579477	4796619	120
64	97	Forest History Society	MAC32	Swan, K.D.	Road	D	8/16/12	HC	Madison	4:15 PM	0458408	4966598	190
66	164	Pioneer Museum	P10868-1	Unknown	Spillway at Madison River Dam		8/7/12	HC	Madison	3:41 PM	0450190	5035559	30
67	346	Pioneer Museum	13428-46	Unknown	The Red Bridge	D	8/7/12	HC	Madison	3:20 PM	0454851	5048535	50
68	419	Pioneer Museum	90.2760	Unknown	The Red Bridge on the Madison River in Bear Trap Canyon	D	8/7/12	HC	Madison	2:40 PM	0454916	5048658	60
69a	47	University of Montana	85.0147	Jackson, W.H.	Madison River below Highway 84 bridge	R/D	8/7/12	HC	Madison	1:47 PM	0455225	5050989	160
69b	48	University of Montana	85.0148	Gruell, G.E.	Madison River below Highway 84 bridge	R/D	8/7/12	HC	Madison	1:43 PM	04055200	5051001	160

APPENDIX B

DATA DICTIONARY

Reference Maps

Federal Lands and Boundaries

Dataset; **GYE_Noss_Boundary**
Source; Andra Bontrager, Wildlife Conservation Society
Description; Vector polygon data set of GYE boundary, scale unknown, date unknown
State Plane, Transverse Mercator projection
Used in study site maps

Dataset; **fedland020**
Source; National Atlas
Description; Vector polygon data of federally owned or administered lands of the U.S., 1:2,000,000, published in 2005
State Plane, Lambert Conformal Conic projection
Used in study site maps

Hillshade

Dataset; **hillshade**
Source; Montana State University Geography 504 course data
Description; Raster data set of hill shade, 1 meter squared cell size, date unknown
NAD 1983 UTM Zone 12N, Transverse Mercator projection
Used in study site maps

Dataset; **DEM**
Source; Andra Bontrager, Wildlife Conservation Society
Description; Raster data set of hill shade, 31 meter squared cell size
State Plane, Transverse Mercator projection
Used in study site maps

Photo Points

Dataset; **GYE Photo points and Historical Reference Points**
Source; Garmin handheld GPS receiver (etrex vista HCx)
Description; Vector point data set of gps waypoints transferred from Garmin device to a shape file using GPSDNR (accurate within 6 m), scale unknown, published in 2013
State Plane, Transverse Mercator projection
Used in riverine change analysis

Reference Points

Dataset; **Montana Names from Geographic Names Information System (GNIS)**

Source; USGS (accessed from NRIS)
Description; Vector point data of Montana physical and cultural geographic features, 1:24,000, published in 2012
Montana State Plane, Lambert Conformal Conic projection
Used in study site maps

Dataset; **Wyoming Land Features from the USGS Names Database**
Source; USGS
Description; Vector point data of Wyoming physical and cultural geographic features, 1:24,000, published in 1981
GCS_NAD 1983, Lambert Conformal Conic projection
Used in study site maps

Dataset; **Cities**
Source; Montana State University Geography 504 course data
Description; Vector point data of cities, scale unknown, date unknown
State Plane, Lambert Conformal Conic projection
Used in study site maps

Roads

Dataset; **Road Names**
Source; National Atlas
Description; Vector line data of roads in Wyoming, 1:24,000, published in 1981
State Plane, Lambert Conformal Conic projection
Used in study site maps

Dataset; **YNP Road Names**
Source; Montana State University Geography 504 course data
Description; Vector line data of roads in Yellowstone National Park, scale unknown, date unknown
State Plane, Lambert Conformal Conic projection
Used in study site maps

Dataset; **GYA Road Names**
Source; Montana State University Geography 504 course data
Description; Vector line data road in the Greater Yellowstone Area, scale unknown, date unknown
State Plane, Lambert Conformal Conic projection
Used in study site maps

Waterways

Dataset; **Streams_7_17_12**

Source; National Atlas
Description; Vector line data of streams, 1:10,000, published in 2012, GCS_NAD 1983 State Plane, Lambert Conformal Conic projection
Used in study site maps

Dataset; **Waterbodies_7_18_2012**
Source; National Atlas
Description; Vector polygon data of water bodies, 1:10,000, published in 2012 State Plane, Lambert Conformal Conic projection
Used in study site maps

Dataset; **National Hydrography Datatset Waterbody Reach Features (Lakes)**
Source; USGS in cooperation with U.S. Environmental Protection Agency
Description; Vector polygon data of water bodies, 1:100,000, published in 2000 Montana State Plane, Lambert Conformal Conic projection
Used in study site maps

Aerial Analysis

Aerial Photos

Dataset; **Upper Yellowstone River: pm009_1948_TF2002_mosaics**
Source; Chuck Dalby, DNRC Water Resources Division
Description; Raster data set of aerial photographs, 2.2999999 ft squared cell size, published in 2002, Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Photo type: black and white, digital mosaics of the 1948/49 channel corridor were prepared for use in mapping historic changes in planimetric channel features, riparian vegetation and land use of the Upper Yellowstone River corridor
Accuracy: the RMS errors for tiles 1 and 6 compared to the base imagery (USFS 1:24000 scale orthphotos, horizontal RMSE=30 ft) and 2,3,4, and 5 controlled using a more accurate base, the American Society of Photogrammetry and Remote Sensing (ASPRS Accuracy Standards for Large-Scale Maps, 1990) are as follows:

1 - pm009_1948_Springdale-DryCreek: 16.9 ft
2 - pm009_1948_DryCreek-PineCreek: 21.9 ft
3 - pm009_1948_PineCreek-MillCreek: 14.3 ft
4 - pm009_1948_MillCreek-BigCreek: 18.1 ft
5 - pm009_1948_BigCreek-Corwin: 14.4 ft
6 - pm009_1948_Corwin-Gardiner: 15.1 ft

Dataset;	**1954-1955 Aerial Photos, Yellowstone River in Park County, Montana**
Source;	Montana State Library Natural Resource Information System
Description;	Raster data set of aerial photographs, 2.5000001 ft squared cell size, published in 2010, Montana State Plane, Lambert Conformal Conic projection Used in riverine change analysis Photo type: partially rectified, black and white digital mosaics of historic aerial photos of the Yellowstone River corridor from Gardiner to Springdale, Montana Accuracy: the RMS errors for each tile, compared to the 1999 orthophotos are as follows: 1 - Joe Brown to Point of Rocks: 22.1 ft 2 - Point of Rocks to Meditation Point: 24.7 ft 3 - Meditation Point to Grey Owl: 12.9 ft 4 - Grey Owl to Mallards Rest: 19.6 ft 5 - Mallards Rest to Dry Creek: 28.0 ft 6 - Dry Creek to Greeley Creek: 20.2 ft 7 - Greeley Creek to Springdale: 22.6 ft
Dataset;	**1999 Park County, Montana 6-inch Resolution Aerial Photos**
Source;	Montana State Library Natural Resource Information System
Description;	Raster data set of aerial photographs, 0.1524 m squared cell size, published in 2010, Montana State Plane, Lambert Conformal Conic projection Used in riverine change analysis Photo type: monochrome black and white visible-band orthophotos along part of the Yellowstone River in Park County Accuracy: the data set meets the National Map Accuracy Standards for 100 ft per inch horizontal mapping
Dataset;	**1999 Park County, Montana 2-foot Resolution Aerial Photos**
Source;	Montana State Library Natural Resource Information System
Description;	Raster data set of aerial photographs, 0.60961732 m squared cell size, published in 2010, Montana State Plane, Lambert Conformal Conic projection Used in riverine change analysis Photo type: monochrome black and white visible-band orthophotos along part of the Yellowstone River in Park County Accuracy: Nineteen of twenty orthophotos have 100 percent coverage while orthophoto 6A has approximately 98 percent coverage. The sliver of

missing coverage falls over one mile from the Yellowstone River along the eastern edge of the ortho, but does not affect the intended study area.

Dataset; **Yellowstone River Corridor Orthophotos, 2011**
Source; Montana State Library Natural Resource Information System
Description; Raster data set of aerial photographs, 1 meter squared cell size, published in 2013
Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Photo type: monochrome black and white visible-band orthophotos along part of the Yellowstone River in Park County
Accuracy: Color, stereo, vertical aerial photography acquired at twelve-inch (12") pixel resolution with a 1"= 200' accuracy (4.39 ft RMSE) and which meet or exceed American Society of Photogrammetry and Remote Sensing (ASPRS) Class I Standards for well-defined points.

Land Cover

Dataset; **riptrend 1948**
Source; Mike Merigliano, University of Montana
Description; Vector polygon data of the 1948 riparian vegetation of the upper Yellowstone River based on the 1948 aerial photo mosaics, 1:10,000, published in 2001
Not projected but overlaid on Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Attribute definition: Feature Type

Code	**Name**	**Description**
5000	Surface Water	Water surface within the channel and in isolated bodies on the flood plain
6170	Gravel bar	Bare gravel bar, typically flooded at normal high flows
6175	Gravel bar vegetation	Gravel bar with sparse, young (<5 yrs.) vegetation
6130	Shrub	All willow, and cottonwood 10-20 years old
6110	Young Cottonwood	Pole-sized cottonwoods, 20 to 40 years old, all understory types
	6115 = 0-40% cover	
	6116 = 40-60% cover	
	6117 = 60-80% cover	
	6118 = 80-100% cover	
6140	Mature cottonwood	Cottonwood 40-100 years old, all understory types
	6145 = 0-40% cover	
	6146 = 40-60% cover	
	6147 = 60-80% cover	
	6148 = 80-100% cover	
6150	Old cottonwood	Cottonwood 100+ years old, all understory types

	6155 = 0-40% cover	
	6156 = 40-60% cover	
	6157 = 60-80% cover	
	6158 = 80-100% cover	
6180	Aspen	Mature aspen, all understory types
6120	Tree willow	Mature, planted non-native, tree-sized willows
6160	Meadow	Nonwoody vegetation patches, includes wet and dry herbaceous areas
3200	Upland shrub	Sagebrush, snowberry, silver buffaloberry, or chokecherry
3400	Juniper	Rocky Mountain juniper dominates (tallest plant)
4000	Limber	Limber pine and Douglas-fir
2000	Agriculture	Row crops and hayed lands
7510	Levee or small dam	Prominent levees and small dams
1100	Urban	Dense housing and prominent roads
7300	Talus	Boulder-sized colluvium

Dataset; **riptrend 1999**
Source; Mike Merigliano, University of Montana
Description; Vector polygon data of the 1999 riparian vegetation of the upper Yellowstone River based on the 1999 aerial photo mosaics, 1:10,000, published in 2001
Not projected but overlaid on Montana State Plane, Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Attribute definition: Feature Type
Same as riptrend 1948

Photo Wedges

Dataset; **Veg_CL**
Source; Heidi Clark, Montana State University
Description; Vector line data of the photo angles origating from the GPS GYE photo points, 1:8,000, published in 2013
Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Dataset; **Veg_poly**
Source; Heidi Clark, Montana State University
Description; Vector polygon data of the photo wedges for which angles were compiled based on repeat photographs of the Upper Yellowstone River origating from the GPS GYE photo points based on the 2011 orthophotos, 1:8,000, published in 2013
Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

River Channels

Dataset; **1948mchannelbrd**
Source; Chuck Dalby, DNRC Water Resources Division
Description; Vector line data of digitized centerline trace for the 1948-49 channel of the Yellowstone River based on the 1948 aerial photo mosaics, 1:8,000, published in 2001
Not projected but overlaid in Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Dataset; **1999mchannelbrd2**
Source; Chuck Dalby, DNRC Water Resources Division
Description; Vector line data of digitized centerline trace for the 1948-49 channel of the Yellowstone River based on the 1999 orthophotos, 1:8,000, published in 2001
Not projected but overlaid in Montana State Plane, Lambert Conformal Conic projection
Used in riverine change analysis

Field	**Type**	**Description**
Segment	text	Original segment ID's. Sequential with duplicate numbers for USFS and USACE ortho base.
NEWsegID	text	New segment ID's with a unique number for each channel segment; start at upstream end move sequentially downstream. NOTE: 1999 length comparison begins at NEWsegID=7
Elevation	integer	From either the USACE orthos or from a dtm supporting file for the USFS orthos-- NOTE: since some polylines have been modified these elevations may not precisely coincide with the contour intersections.
Tributary	text	Notation of locations near where a tributary enters the channel network
rivmile	integer	1976 DNRC river mi; digitized coverage as provided by USACE
ID	text	Identifies the source ortho imagery from which the CL trace was digitized

ctype	text	M for main channel
Chanchg	text	Comments on the nature of 1948-99 to 1999 channel changes for a particular segment.

APPENDIX C

MAP DATA SOURCES

Data originating from Heidi Clark (HC), Department of Natural Resource Conservation (DNRC), Montana Natural Resource Information System (MT NRIS), Montana State University Geography 504 (MSU GPHY504), National Atlas, University of Montana (UMT), U.S. Geological Survey (USGS), and Wildlife Conservation Society (WCS).

Study Site
Figure 1: WCS, National Atlas, MT NRIS, and HC
Methods
Figure 2: MT NRIS and HC
Gallatin River
Figure 3: National Atlas, MSU, MT GNIS, and HC
Figure 12: National Atlas, MSU, MT GNIS, and HC
Yellowstone River
Figure 19: National Atlas, MSU, MT GNIS, and HC
Figure 22: National Atlas, MSU, MT GNIS, and HC
Figure 24: National Atlas, MSU, MT GNIS, and HC
Wind River
Figure 33: National Atlas, MSU, USGS, and HC
Figure 42: National Atlas, MSU, USGS, and HC
Gros Ventre River
Figure 43: National Atlas, MSU, USGS, NHD, and HC
Snake River
Figure 49: National Atlas, MSU, USGS, and HC
Figure 58: National Atlas, MSU, USGS, and HC
Green River
Figure 61: National Atlas, MSU, NHD, and HC
Madison River
Figure 63: National Atlas, MSU, MT GNIS, and HC
Figure 65: National Atlas, MSU, MT GNIS, and HC
Aerial Analyses
Figure 70: MT NRIS, UMT, MT DNRC, and HC