Temporal patterns of channel migration, fluvial events, and associated vegetation along the upper Yellowstone River, Montana

Michael F. Merigliano and Mary Louise Polzin

College of Forestry and Conservation
The University of Montana
Missoula, Montana 59812

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Contents

Illustrations

Tables

Appendices

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Abstract: Flood plain dynamics and vegetation along the upper Yellowstone River flood plain varied by geomorphic setting, which varied from broad, un-confined braided channel systems to single-thread channels with narrow flood plains confined by glacial terraces and bedrock. Although the general appearance of the vegetation and river system is similar to that of 100 years ago, retrospective age distributions and real-time trend analysis reveal a reduction in fluvial activity, cottonwood recruitment on an areal basis, and cottonwood forest area. The flood plain turnover period for the braided reaches is between 550 and 1700 years. Dated flood plain area was positively correlated with flood size, and cottonwood area decay curves indicate that most flood plain erosion and deposition occurs during large floods. Agriculture has caused a net reduction in forest area in the last 50 years, but loss to natural succession was about twice the loss due to agricultural conversion. Diversity of vegetation types was higher in naturally-unconfined, braided channel reaches compared to naturally-confined, single-thread channel reaches. Patch sizes were larger, and hydric and mesic plants were more common in the un-confined reaches.

Introduction

As part of the Governor's Upper Yellowstone River Task Force and the U.S. Army Corps of Engineers (COE) Cumulative Effects study along the upper Yellowstone River, we examined the vegetation along the river from Gardiner to Springdale, Montana. The main intent of the study was to gain an understanding of fluvial geomorphic processes and its relation to flood plain vegetation. There were two primary tasks: mapping and quantification of existing vegetation on the flood plain and or streamside areas, and estimating the inherent – or natural – flood plain dynamics via the spatial pattern of cottonwood tree ages. Flood plain dynamics is the change in location and thickness of the flood-prone land due to erosion and deposition of sediment carried by the river channel. Cottonwood trees were a dominant feature along the river and likewise dominated our efforts. Due to their life history, cottonwoods served as a clock for flood plain age and time since stand development. The study was retrospective, in that flood plain dynamics was inferred from historic evidence. The study period was from October 1999 to September 2002. A primary concept and metric for flood plain dynamics is the turnover period, which is the time needed for the channel to completely erode and re-deposit its flood plain.

Recent, substantial bank protection structures motivated the study. Previous studies indicate that cottonwood forest regeneration depends on a dynamic flood plain system (Everitt, 1968; Bradley and Smith, 1986; Akashi, 1988; Merigliano, 1996; Scott et al., 1997), and bank protection could reduce flood plain dynamics and in turn diminish cottonwood regeneration. Because many of the structures are recent (NRCS 1998) and response time of vegetation to these structures was assumed to exceed the study period, the observed, general, flood plain dynamics were assumed to be natural and our findings would serve as a baseline or pre-disturbance condition in terms of bank stabilization. There are some older bank protection features that may have influenced flood plain dynamics long enough to effect vegetation locally, but most of these features are too limited in extent compared to the scale of the channel and flood plain system.

The primary study objectives were to determine flood-plain turnover rate and classify and characterize streamside vegetation structure. Other objectives that follow from the primary ones were to relate the magnitude and frequency of flow events to flood plain turnover, characterize the age distribution of the cottonwood forest in general and patches that comprise the forest, incorporate the influence of ice drives, and assess cottonwood longevity and limitations on it.

Methods

Stratification

Stratification was based on anticipated, inherent, channel migration rates. The three basic channel patterns: braided, meandering and straight (Leopold and Wolman, 1957), were subdivided into six different channel classes to better represent the variation within each basic pattern. Classes and their sources are listed below.

1) Wandering gravel-bed (Nanson and Croke, 1992)
2) Confined coarse textured (Nanson and Croke, 1992)
3) Entrenched (Rosgen, 1994)
4) Confined wandering gravel-bed (adapted from Nanson and Croke, 1992)
5) Urbanized (not based on channel morphology: it is the Livingston area)
6) Canyon

There is a wide range of channel forms classified as braided. Nanson and Croke (1992) divided braided river flood plains into different levels: Wandering gravel-bed river flood plains exhibit irregularly sinuous channels with stable, well-vegetated and sometimes naturally-leveed islands, anastomosing channels, braid bars, and one dominant channel. The classic braided rivers have more channels and braid bars than wandering gravel-bed rivers, and do not have a dominant channel (Nanson and Croke, 1992). Desloges and Church (1987, 1989) describe the wandering gravel-bed river more fully. Because channel migration rate was an important aspect of the study that would likely vary by geomorphic setting, we used our own sub-class of the wandering gravel-bed river, called the confined wandering gravel-bed river. The latter class was similar to the former except its braid-belt width was constrained by resistant alluvial terraces or bedrock.

For the wandering gravel bed (WGB) and confined wandering gravel bed (CWGB) strata, the inclusion criterion was alluvium inundated by recent large floods or if not flooded, having naturally occurring riparian vegetation. The stratum boundary, which includes the wetted channel, was delineated using 1:24,000 color IR aerial photography taken August 8, 1999. The toe of terraces visible in stereo on photos often formed the boundary. Where there was no visible terrace edge and the woody vegetation had been cleared, the extent of the 1997 flood water visible on aerial photos helped establish these boundaries. Areas that were difficult to delineate using photo interpretation were visited in the field to look for indicators not visible on aerial photos.

Land fitting the above criteria but separated from the channel's influence by roads were included. Essentially, the criteria for the WGB and CWGB strata was alluvium that was likely to be flooded in the present climate if not blocked by human influences.

For the entrenched (E) and confined coarse-textured (CCT) strata, the included areas were the channel and areas fitting the above criteria and extending up steep banks to the streamward edge of a valley flat such as a terrace tread. Typically, there was a sharp break, parallel to the channel, in woody vegetation dominance, and woody vegetation often lost dominance at the topographic break.

In contrast to the WGB and CWGB strata, the E and CCT strata include land that was well-above the flood zone of the known flow record, but often very close (about 33 m, ~ 110 ft,) to the channel and apt to include streamflow influences such as mass wasting as well as erosion and deposition within the active channel.

The urban reach, which would naturally fall into both wandering gravel-bed classes, was not sampled because of its relative lack of natural vegetation and difficult logistics in land access. The canyon reach, entirely within Yankee Jim canyon, was not sampled in detail, but its vegetation is well documented in repeat photography dating from 1871.

Sampling Design

The total area within each stratum was split into several equal-sized polygons to serve as listing units, called 'sections'. Section sizes for the WGB, CWGB, E, and CCT strata were respectively 73.1, 44.5, 5.4, and 5.4 ha (181, 110, 13.3 and 13.4 acres). For each stratum, sections were randomly selected for the first stage of sampling; respective sample sizes were 9, 8, 15, and 15 chosen from respective totals of 33, 17, 49, and 67. Variances were adjusted with the finite population correction factor. Figure 1 shows how the study area was split up for sampling.

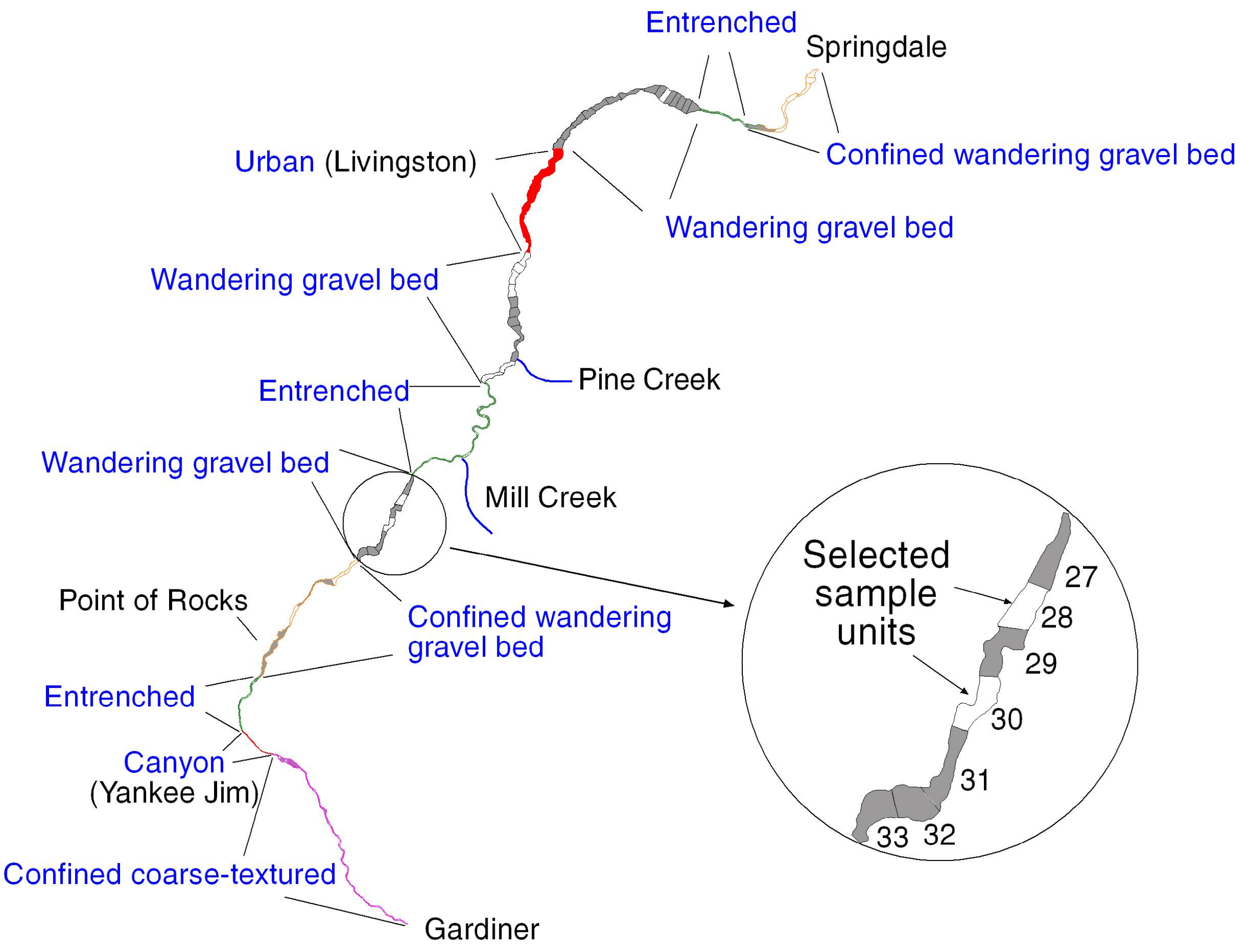


Figure 1. Schematic of sampling design. Primary strata (blue type) and landmarks labeled along entire study area. Example of random selection of sample units, or sections, is shown in circle.

Criteria for section size within the WGB and CWGB strata was to minimize the standard error of the age distribution on an area-basis, be large enough to include spatial variability in stand sizes, and provide spatial context. The standard error is a function of the observed standard deviation and sample size (n), and this was optimized to agree with the anticipated total sampling effort, which is n*(plot size). Merigliano (1996) used a 104 ha plot on a similar river system and found that it provided an acceptable standard error with n = 10. Access was limited in some areas because of landowner preference, so our sample is random in respect to willing landowners.

The criterion for section size within the E and CCT strata was to minimize the standard error in abundance of distinct vegetation types. Historic aerial photography and field observations revealed that channel migration was negligible in these two strata, so quantifying flood plain ages was not important. There were no access restrictions on selected sections for the E and CCT strata.

Tree and Flood Plain Aging

Cottonwood forest age structure and flood plain aging were derived from cottonwood tree ages; the oldest tree within a patch defines the minimum age of the establishment surface within the flood plain it occupies. Typically, the flood plain is made up of sediment layers, and at a given locale, the older layers are deeper than the younger ones. The establishment surface is what colonizing plants (e.g., cottonwood) first germinate and survive on. It is this surface that is being dated via cottonwood ages. Age distributions on an area basis are observed within a section. The flood plain aging effort was restricted to the WGB and CWGB strata, where cottonwood patches are more extensive and extensive channel migration was obvious on aerial photography.

Selected plots on 1:24000 aerial photography were enlarged about 400% to allow large, detailed delineations of putative cottonwood cohorts. Within such cohorts, trees were selected with the number of trees per area dependent on the cohort's patch size. Selected trees were approximately evenly spaced. Because cohorts were putative before coring was completed, patch size of a cohort influenced how many trees were selected because larger patches, even if they appeared to be one cohort, were more likely to include more than one cohort. The minimum number of trees per cohort was 2 and the maximum was 45. Distance between trees was dependent on patch size and number of sample trees. The maximum distance between trees was about 33 m (100 ft); the minimum was about 8 m.

Multiple-stem trees were avoided when single stems were in the same area, and obvious root sucker trees were not sampled. Sample trees were marked on the enlarged air photos, which were in turn used to find the trees on the ground. Land formations such as old channels were marked on the air photos as well. The marked trees were then cored with a 0.2-m (18-in) long, 12-mm (1/2-in) diameter increment corer. Tree conditions, such as bark texture and branch architecture, were used as visual age indicators for identifying putative cohorts. Trees were cored at ground level unless core rot or other circumstances prevented it. The cores were mounted on boards and sanded with at least 400-grit paper to facilitate ring counting. Ages from ring counts were then assigned to the marked trees on the aerial photos. The pre-aged patch boundaries were re-mapped using the spatial pattern of tree ages, patch characteristics on historic aerial photography, and pre-determined age classes. The pre-determined age classes were 10-years wide for tree ages between 1 and 100, 25-years wide for tree ages between 101 and 200, and 50-years wide for ages between 201 and 400. The range of tree ages, increment-core quality, and practical convenience influenced the widths of the pre-determined age classes. Maximum tree age within a patch defined the age class of that patch.

For a true, total tree age, the increment core should include all of the rings at the root collar level. Not all increment cores included the pith due to rot, old beaver scars, or excessive diameter. Most trees were cored near ground level, which is typically above the original root collar due to sedimentation after seedling establishment. Corrections were made to ring counts to obtain a truer total age by estimating the amount of missing rings and adding this amount to the ring count, and using a correction factor for coring height above ground level. The missing rings adjustment was the difference between stem radius and core length multiplied by the number of rings in that distance back from the pith end of the core. The correction factors for core height above the root collar are in Table 1. These corrections factors are approximate and are based on field observations of young trees along the Yellowstone River, Snake River in Idaho, and the Elk River in British Columbia, Canada.

Table 1. Increment core correction factors

Height above ground, cm	Correction Factor, years
0 to 19	+ 1
20 to 40	+ 2
41 to 70	+ 3
71 to 100	+ 4
101 to 130	+ 5

Reconnaissance revealed that some cottonwood patches have a spatial distribution of tree ages that indicates multiple establishment times on what appears to be a distinct, uniform geomorphic surface. A system of randomly placed quadrats was used to assess fine-scale age structure and the frequency of un-even aged patches on the landscape in the CCT, E, CWGB, and WGB strata. Three sections from each stratum were randomly selected and within each section, one patch of each distinctive age-class was randomly selected. Within each patch, a 100-m2 quadrat was randomly placed. Quadrats were 10 by 10 m in the CWGB and WGB stratum, and 5 by 20 m in the E and CCT stratum, where patches were typically less than 10 m wide. Patches in the CWGB and WGB strata were cored and aged before sampling with fixed plots. Patch age classes (see Table 2) in the E and CCT strata were ocularly estimated during vegetation mapping; many of these patches appeared to be multi- aged, and the estimated age class of the most dominant trees served as a patch age. Only trees within quadrats were cored and aged. Seedling (< 1 m tall or < 10 years) patches were excluded from the age-structure sampling in all strata, but seedlings were included in quadrats having some trees larger than seedlings. Narrowleaf cottonwood (*Populus angustifolia* James) is the predominant cottonwood species, and it can sprout from roots and stumps (Schier and Campbell, 1976; Ernst and Fechner, 1981; Gom and Rood, 1999).

Total number of trees cored were as follows: patch ages for flood plain aging: 1074, within-patch stand age structure (fixed plots): 925. Sample sizes for statistical analysis was based on the number of plots, not trees, however, due to sample design and non-independence of trees.

Vegetation Classification and Mapping

Vegetation types were delineated with a landbird habitat purpose in mind. The vegetation type sampling uses the flood plain sample units as a basis. Within the WGB, CWGB, E, and CCT strata, each polygon was visited in the field, delineated, and classified using the criteria in Table 2. The vegetation types in Table 2 were defined after field reconnaissance. The minimum mapping unit was about 0.01 ha. Riparian vegetation is minimal in the canyon stratum (Yankee Jim), and the vegetation within this rugged reach was viewed from convenient vantage points. We did not characterize vegetation within the urbanized reach. Type descriptions are in Appendix A.

Most types are hierarchical within the National Wetlands Inventory Classification system. The synonymy between the vegetation types for wildlife and the NWI mapping is in Table 2. The NWI mapping is more detailed in the uplands and within herbaceous wetlands. The wildlife habitat mapping emphasizes vegetation canopy structure and age classes of cottonwood, willow, and aspen. The Agriculture type includes pasture and cropland; such areas would likely be disturbed too much or have limited cover for ground nesting birds.

Abundance of a species or structural layer within a type was based on ocularly estimated canopy cover. Spaces between individual leaves were included in total cover of individual woody plants, large herbs, and grass swards (Daubenmire, 1959). Rocky Mountain juniper was considered a shrub.

Six age classes (CW1 to CW6) were ocularly estimated for each cottonwood polygon (Table 2). These estimated ages are meant to reflect tree conditions important to land birds such as size, bark texture, branch architecture, decay, foliage density, and stem density. Although these age classes are best viewed as condition classes, age is still important from a dynamics perspective. Ocular estimates were calibrated with aged trees during reconnaissance and previous studies. One person (Merigliano) did all estimations to allow better consistency.

The synonymy between the habitat types and the NWI system is somewhat complicated by the two systems within NWI, which are Cowardin et al. (1979) wetland types and the newer US Fish and Wildlife Services riparian area mapping system (USFWS, 1997). The latter includes sites that are drier than the Cowardin system. For example, a cottonwood forest polygon may be in the Palustrine system if it appears wet enough, or in the Riparian system if its signature or location indicates that it is drier and seldom flooded. Under NWI, the younger (1 to 3 years old) CW1 types will likely be classed as R3USA (gravel bars) rather than PSS1A (Scrub-shrub), as these areas look bare on 1999 photography.

Some of the CW3S*m* will likely be classified as Palustrine Forest (PFOA) rather than under the Riparian system if they are wet enough. The CW4S*m* and CW5S*m* with shrub subclasses (*m*) of 2 and 3 would likely be classified as PFOA too. This is based on conversations with US Fish and Wildlife Service personnel (Chuck Elliot and Kevin Bon) and the NWI map. Upland classes under USGS Code (Table 2) are based on Anderson et al., (1976).

Some types were combined to simplify results. All cottonwood age classes were combined to form the "Cottonwood" type, while the Sandbar willow+, Bebb willow, yellow willow, and Pacific willow types were combined to form the "Mixed Riparian Shrub" type.

Vegetation Analysis

For diversity and ordination analyses, vegetation types were treated as "species," and abundance was based on a type's areal extent within a sample unit. Fidelity of natural vegetation types to geomorphic setting was determined using Indicator Species Analysis, or ISA (Dufrêne and Legendre, 1997), and this was calculated using PC-Ord 3.20 (McCune and Medford, 1997). Natural vegetation excludes agricultural fields and planted willow trees. Diversity metrics (Richness, Evenness, and Shannon's H') were also done with PC-Ord. SYSTAT version 8.01 (SPSS, 1998) was used for univariate and bivariate statistical tests.

Gradient analysis of vegetation types was conducted to test how such types were related to the environment. The composition of natural vegetation types was converted into a gradient via the multi-dimensional scaling algorithm Detrended Correspondence Analysis, or DCA (Hill and Gauch, 1980). Site scores from the first DCA axis (ter Braak, 1995) served as the gradient in vegetation types, excluding non-native species and agriculture patches. The environmental variables were confinement ratio and channel slope. The confinement ratio is the active channel area divided by area of all vegetated area. Slopes for the channel from Gardiner to Mission Creek were provided by the geomorphology study. Channel slopes downstream of Mission Creek were extracted from the US Geological Survey 1:24,000 digital elevation model (decimal elevations) for this area using ArcGIS version 8 (ESRI 2001) Surfer version 7 (Golden Software, 1999), and ArcView GIS version 3.2a (ESRI, 2000). The Spearman rank correlation coefficient was used to test whether the gradient in vegetation type composition was independent of either channel confinement or channel slope.

To assess field estimates of cottonwood ages, estimated ages of cottonwood patches were compared to more precise, patch ages based on increment cores. Using ArcView GIS, polygons from the vegetation mapping, which followed patch boundaries, were overlaid on the typically larger flood-plain aging polygons. This assigned the precise ages to the cottonwood polygons. The error between them was logically calculated for a given cottonwood polygon as follows: If the age class of the estimated polygon included the patch age based on cored trees, the error was 0. If not, the core-based patch age was either subtracted from the low-end of the estimated age class to give an error for over-estimated ages, or the high-end of the estimated age class width was subtracted from the core-based patch age for under-estimated ages. Sliver polygons less than 20 m^2 were not included.

Table 2. Upper Yellowstone River Vegetation types, age classes, and codes

Type	Age Class, years	Code	NWI or USGS	SCode
Tree dominated:				
Young cottonwood	1 to 10	CW1	PSS1A	6175
Sapling cottonwood	11 to 20	CW2	PSS1A	6130
Pole cottonwood/Herb	21 to 30	CW3H	RP1FO6CW	6110
Pole cottonwood/Shrub	21 to 30	CW3Sm	RP1FO6CW	6110
Mature cottonwood/Herb	31 to 70	CW4H	RP1FO6CW	6110, 6140
Mature cottonwood/Shrub	31 to 70	CW4Sm	RP1FO6CW	6110, 6140
Old cottonwood/Herb	71 to 125	CW5H	RP1FO6CW	6140, 6150
Old cottonwood/Shrub	71 to 125	CW5Sm	RP1FO6CW	6140, 6150
Very old cottonwood/Herb	125 +	CW6H	RP1FO6CW	6150
Very old cottonwood/Shrub	125 +	CW6Sm	RP1FO6CW	6150
Aspen/herb		ASH	RP1FO6AS	6180
Aspen/shrub		ASSm	RP1FO6WI	6180
Tree willow (introduced)		ST	RP1FO6WI	6120
Limber pine		LP	42	4000
Douglas-fir		DF	42	4000
Shrub dominated:				
Chokecherry		CC	32	3200
Young sandbar willow	1 to 5	SB1	PSS1A	6175
Mature sandbar willow	5 +	SB2	PSS1A,	6130
Mature sandbar willow and other tall shrubs	5 +	SB2+	PSS1A,	6130
Bebb willow		BW	PSS1A,	6130
Pacific willow		PW	RP1SS6WI	6130
Silver buffaloberry		S	RP1SS6?	3200
Rocky Mountain Juniper		J	RP1FO7JU	3400
Upland shrub		US	32	3200
Non-woody dominated:				
Wet (seasonally or permanently) herbaceous		E	RP1EM, PEM1	6160
Agriculture (pasture and tilled)		A	21	2000
Upland grasses and herbs		U	31	6160
Non-vegetative:				
Active channel, off channel water		AC, OCW	R3SB, R3RS,	5000
Talus		T	74	7300
Urban		UB	16	1100
Road		Road	14	1100
Levee, other flow control structure		LEVEE	No code	7510

Note:
Integer type codes correspond to USGS classifcation (Anderson et al., 1976)
The ” /” separates overstory and understory dominant*s*
H denotes an herbaceous understory
m is a shrub cover modifier, where 1 = 10 to 25%, 2 = 26 to 50%, 3 = >50%
Age classes of sandbar willow (*Salix exigua*) based on height. Young < 1 m, Mature > 1 m. Other tall shrubs in SB2+ are: Bebb willow *(Salix bebbiana),* Pacific willow *(S. lasiandra)*, Yellow willow *(S. lutea)*, River birch *(Betula occidentalis*)

Decay Curves and Turnover Period

To define decay curves for each geomorphic strata, we closely followed the method in Everitt, (1968). For cottonwood forest decay, we fit curves using the area of cottonwood patches defined during vegetation mapping. For flood plain decay, we fit curves using as much of the flood plain as possible. The latter effort required ages to be extrapolated from aged cottonwood stands to non-cottonwood areas that could not be independently aged. The extrapolation required subjective judgment that relied on the juxtaposition of adjacent aged patches, reconstruction using historic aerial photography, and likely channel migration patterns. Some of the flood plain was too old to realistically extrapolate an age to, and these areas were left out of decay curve calculations. Flood plain decay curves were only done for the WGB and CWGB strata, as there was negligible channel migration in the E and CCT strata and extrapolating ages into non-cottonwood areas would be nebulous.

The decay curve (Equation 1) was fit using non-linear regression in SYSTAT version 8.01 (SPSS, 1998); curves were fit with the Robust procedure with weighting by absolute values of the residuals. This procedure diminishes the effect of outliers. Turnover period is the time it takes for the flood plain to be completely recycled by channel erosion and deposition, and this time is found where the curve intercepts the x-axis, or abscissa. Actually, the decay function is asymptotic towards the x-axis (time), so cottonwood or flood plain area never – theoretically – decays to zero. Two points along the curve were calculated: an area of 1 m^2 per ha (0.01 percent), is used to estimate "full" turnover, and half-turnover, where 50% has eroded and re-deposited.

$$\alpha = a\left[e^{(t(-b))}\right] \tag{1}$$

where:

α = CWA/SUA/ACW or FPA/SUA/ACW

e = the base of the natural (Naparian) logarithm, approximately 2.71828

a = the ordinate or y-axis intercept

b = the slope of the line.

t = mid-point of an age class in years

and
CWA = cottonwood patch area in an age class (for cottonwood decay)
FPA = flood plain patch area in an age class (for flood plain decay)
SUA = area of the sampling unit
ACW = age class width in years

The general equation for the time required (*T*) to reach a proportion of turnover (e.g., half-turnover = 0.5) is:

$$T = \log_e \sqrt[b]{1/P} \tag{2}$$

where:
P = 1- proportion of turnover, and all other symbols as in (1).
Note: Computer or calculator constraints limit the calculation of *T* using *P* values greater than 0.98 and slope (*b*) values we observed.

The equation for expanding present day-flood plain area of a given age (α_p) back to its original size (α_o) is:

$$\alpha_o = \alpha_p\left[e^{((Age(b))}\right] \tag{3}$$

Mid-points of classes were used for patch ages. All other symbols as in (1).

The curves, or fitted lines, are based on a model with the following assumptions: 1) The probability of erosion for a given time period is equal across the entire flood plain, 2) the erosion rate is constant over time, and 3) the cumulative probability of erosion for a particular parcel of the flood plain increases with parcel age.

Theoretically, Equation 1 is based on a continuous function of age rather than classes. When classes are used, most of the decay occurs in the early part of the class period, so using class mid-point time overestimates the area. However, the error is negligible for our class widths and observed decay-curve slopes.

For comparison to other river systems, some of which had flow regulation (see Discussion section), curve fitting was only through age classes of cottonwood areas that originated before regulation. Seedling classes are episodic, and can be absent by chance during a study, so curve fitting did not include the seedling class in these comparisons.

Hydrology

Annual peak discharges were obtained from US Geological Survey gage records for the Livingston (06192500 and Corwin Springs (06191500) stations. The Corwin Springs record years were 1890-1893, 1911 to present, while the Livingston record years were 1897 to 1905, 1929 to 1932, 1938 to present. Years missing from both records were 1894 to 1896 and 1906 to 1910. These records were combined to yield a more complete flood record for Livingston. Annual peaks for missing years at Livingston yet measured at Corwin Springs were predicted using a regression of observed flows common to both gages. Details of this analysis are in Appendix B. Historic large floods were documented in the Flood Insurance Study for Livingston (FEMA 1987). All but one of the documented historic floods was captured in the gage records. The flood of 1894 was missing from the record, and we estimated its discharge using the stage:discharge relation based on observed floods and gage heights at the Livingston gage, and observed flooding depths on islands near Livingston for the historic floods (FEMA 1987).

Trend Analysis

Comparing vegetation over as long a period as possible was done at two scales and perspectives: land-based photography of scenes and aerial photography. The former begins in 1871 and various prints of scenes from the Yellowstone Valley from Gardiner to Livingston were obtained from the US Geological Survey Photo Library in Denver. Most of these scenes were re-photographed during 2000 to 2002. The day and time of the original photography was available for some photos, while others were derived from visits to re-photograph them. Twenty-six of the thirty scenes were re-photographed; a selection is included in this report. This selection focuses on the river environment and does not duplicate information. Details on repeat photography are in Appendix C. We incorporate narratives from early explorations of William Clark in 1806 (Moulton, 2002) and the Hayden Surveys of 1871 and 1872 (Hayden, 1872; 1873).

Detailed mapping used aerial photography from 1948 and 1949 (herein 1948) 1976, and 1999. We adapted the methods from the wildlife habitat study conducted along the upper Yellowstone River (Hansen et al., 2003, personal communication, 2002). Their sample areas were larger and fewer in number than ours, and included the 1948 and 1999 periods. We transferred their mapping results to our sample areas and then used their photo interpretation protocol to extend the mapping to our sample areas that they did not cover. We simplified their system by ignoring cottonwood canopy cover classes within each age class. Changes in vegetation type area as measured on geo-rectified aerial photography of the above periods formed the basis of our analysis. Cover types are shown in Table 2, under “SCode”.

The respective discharges for the August 26, 1948, August 16, 1949, September 26, 1976, and April 11, 1999 geo-rectified photography were: 88, 93, 81, and 40 m^3s^{-1} (3100, 3290, 2860, and 1420 ft^{3s-1}). The August 25, 1999 color infrared photography was used to distinguish and delineate the unvegetated and vegetated gravel bars, because the flow (97 cms) and season associated with this flight were more consistent with the earlier flights, and the vegetated gravel bar patches were more obvious. We changed some of Hansen et al. (unpublished data, 2002) gravel bar classifications and patch boundaries for our work. We also edited their boundaries and attributes if tree aging or ground-truthing information differed from their photo interpretation.

For 1999, the trend map was adapted from the more detailed riparian mapping. Shrub and cottonwood cover types were collapsed into the simpler ones used in trend mapping. But patch ages were corrected, and the active channel in the riparian vegetation mapping included bare gravel bars, while in the trend mapping, the active channel was split into surface water and bare gravel bars.

Cottonwood forest loss was determined by calculating the area of all cottonwood ages, including Riparian shrub which in turn includes young cottonwoods, that was lost due to channel erosion, conversion to cropped lands (agriculture), or meadow.

Flood Plain Topography and Vegetation

The surface of flood plain and cobble layer were surveyed and the present vegetation noted to relate species composition and site age to flood plain elevation and the thickness of overbank deposits. In essence, how do the common species array themselves across the flood plain, and how fast does the flood plain raise in elevation via sedimentation during floods. One long transect, two short transects, and 68 plots were surveyed with a Topcon GTS 211D total station. Precision was about 2 cm (0.75 in). The long transect was subjectively placed across a flood plain area that accreted in one direction over the past 100 years. The plots were chosen via a three-stage cluster design as described in the tree aging section. The short transects augmented the data set for young stands.

Results

Vegetation Characterization

Existing vegetation varied by geomorphic setting. In general, the more confined reaches (Entrenched and Confined coarse-textured) had less cottonwood and willow area, and more juniper and limber pine woodlands. The braided reaches had more area in cottonwood and willow. Juniper was common on the flood plain, but in the understory of older cottonwood stands. Figure 2 shows how common types occurred in the study area.

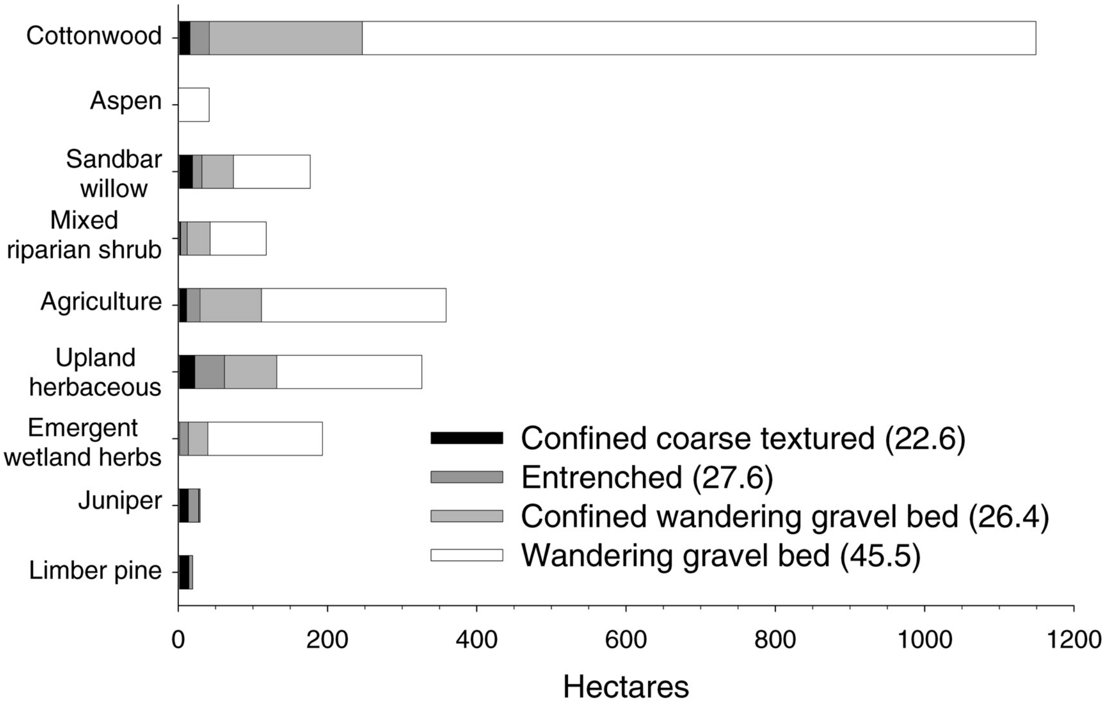


Figure 2. Total area of common vegetation types by geomorphic setting. Total main channel lengths (km) for each stratum are shown in the legend.

Although the amount of cottonwood forest area varied with geomorphology, the distribution of cottonwood ages, estimated via tree characteristics, was similar in shape across geomorphic settings (Figure 3). The braided reaches harbored larger patches (Figure 4), but the relative amounts of the age classes are roughly similar. Only estimated ages are available for the confined reaches.

There was more area in the two oldest age classes, but this was partly an artifact of the wider class widths used for the older age classes. That is, if consistent-width age classes were used (say 10 years) for the entire range of ages encountered, the respective areas within the 31 to 70, 71 to 125, and 125 + classes would be divided and spread out, and the resulting narrower classes would each have much less area. The decay curve approach presented later incorporates this idea. The undivided (raw) age classes are used as a starting point.

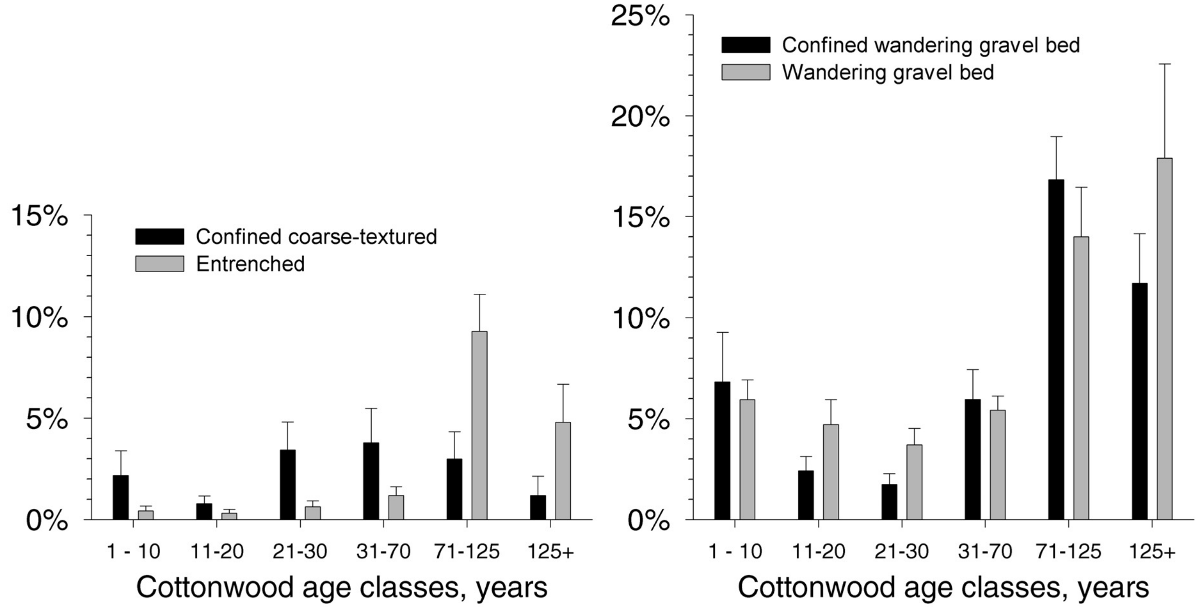


Figure 3. Estimated cottonwood age classes by geomorphic setting, with braided (left) and single-thread on the right. The filled bars indicate sample means and error bars are for 1 standard error of the mean. The percentage within a given age class is patch area relative to the entire flood plain area, including the channel.

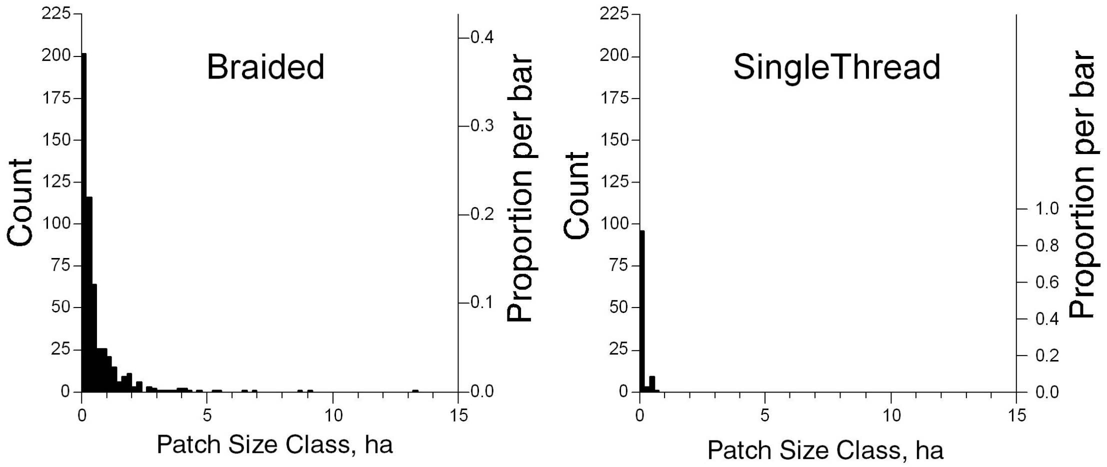


Figure 4. Size distribution of cottonwood patches by geomorphic setting. The CWGB and WGB strata are braided, while the CCT and E strata are single thread. Patch size class widths are 0.2 ha, or about 0.5 acres.

Some vegetation types had high fidelity to geomorphology (Table 3). That is, some types were largely restricted to a given geomorphic setting. The following is based on sampling, so even if mean area is zero, the type may still occur but it would be very scarce. Only the types that had statistically significant ($p < .06$) importance values are included. The types are sorted by how important they were in the two most different geomorphic settings; types more common in the Wandering gravel bed reaches are listed before those more common in the Confined coarse-textured reaches. Plants that typically grow on uplands were more common along the confined reaches (E and CCT), while plants typical of riparian flood plains were more common along the braided reaches (WGB & CWGB).

Table 3. Vegetation types with high fidelity to flood plain geomorphology.

	Geomorphic Strata												
	Confined coarse-textured			Entrenched			Confined wandering gravel-bed			Wandering gravel-bed			
Vegetation Type	Mean[1]	Freq.[2]	IV[3]	Mean	Freq.	IV	Mean	Freq.	IV	Mean	Freq.	IV	p*
Pacific Willow	0.000	7	0	0.001	7	0	0.002	38	7	0.007	78	56	0.002
Aspen	0.000	0	0	0.000	0	0	0.000	13	0	0.017	56	55	0.001
Old Cottonwood/Herb	0.000	7	0	0.022	40	4	0.090	100	40	0.110	100	49	0.005
Silver buffaloberry	0.000	0	0	0.000	0	0	0.001	13	3	0.004	56	40	0.004
Bebb Willow	0.000	0	0	0.000	0	0	0.001	13	2	0.003	44	36	0.007
Emergent wetland herbs	0.006	20	1	0.033	67	16	0.035	88	22	0.063	89	41	0.050
Young Cottonwood	0.012	40	3	0.004	33	1	0.047	88	29	0.073	100	55	0.001
Old Cottonwood/Shrubs	0.021	33	3	0.039	67	10	0.087	100	33	0.120	100	45	0.009
Mature	0.010	33	4	0.002	20	0	0.039	88	37	0.043	100	46	0.008
Mature	0.017	60	19	0.005	33	3	0.009	50	8	0.023	100	44	0.022
Upland shrubs	0.017	27	26	0.000	0	0	0.001	13	0	0.000	0	0	0.055
Rocky Mountain juniper	0.050	73	41	0.039	73	32	0.001	13	0	0.000	22	0	0.058
Limber pine	0.054	60	47	0.014	13	3	0.000	0	0	0.000	0	0	0.002

1. Mean unit area across all sites for a type, by stratum
2. Proportion of sites occurrence for a species
3. Importance value = (Relative Abundance X Relative Frequency)100%

* proportion of randomized trials with indicator value (IV) equal to or exceeding the observed maximum IV.

Diversity, on a vegetation-type basis, differed significantly between braided and single-thread channel strata (Table 4). The Shannon diversity index, H', combines the number of types and how evenly abundant the types are across the sites. Richness was more than double on braided reaches compared to unbraided reaches, while evenness was similar for both reach types.

Table 4. Diversity of vegetation types by geomorphic strata.

Diversity metric	Strata	Mean	Standard deviation	Student's t	p*
Richness	Single-thread (CCT, E)	7.100	2.820	10.33	<.0001
	Braided (CWGB, WGB)	18.294	3.933		
Evenness	Single-thread (CCT, E)	0.720	0.184	1.26	0.2134
	Braided (CWGB, WGB)	0.768	0.072		
H'	Single-thread (CCT, E)	1.334	0.439	8.31	<0.001
	Braided (CWGB, WGB)	2.218	0.288		

* p is the probability of obtaining a difference as large or larger than observed when the true difference is zero.

Gradient analysis shows a similar pattern as Table 3, where the vegetation type composition was related to the confinement ratio (Figure 5). The gradient is a representation of the shift in the composition vegetation types across sample sites. Sites with lower values have more riparian types, such as willow and cottonwood, while sites with higher numbers have more upland types, such as limber pine. The gradient is based on relative amounts of the types, so patch size effects are eliminated. The gradient was poorly related to channel slope ($r_s = 0.003$, $p = 0.99$). The low correlation between channel slope and vegetation gradient may be due to low precision of slope measurements for sample unit reaches. This is especially so for the CCT and E strata, where sample units had reach lengths between 170 and 754 m, and the elevation error from the digital terrain model is magnified compared to the longer reaches in WGB and CWGB, which were between 522 and 2200 m. The slope and confinement ratio values for strata are in Table 5. The relative range in difference is higher (2.2) in the confinement ratio compared to that of slope (1.4). Thus, geomorphic factors that lead to confinement may control vegetation type composition more than channel slope alone.

Table 5. Channel slopes and confinement for geomorphic strata

Stratum	Slope, m/m	Confinement Ratio[1]
CCT	0.00246	0.574
E	0.00210	0.623
CWGB	0.00174	0.400
WGB	0.00291	0.280

1. Based on sample estimates

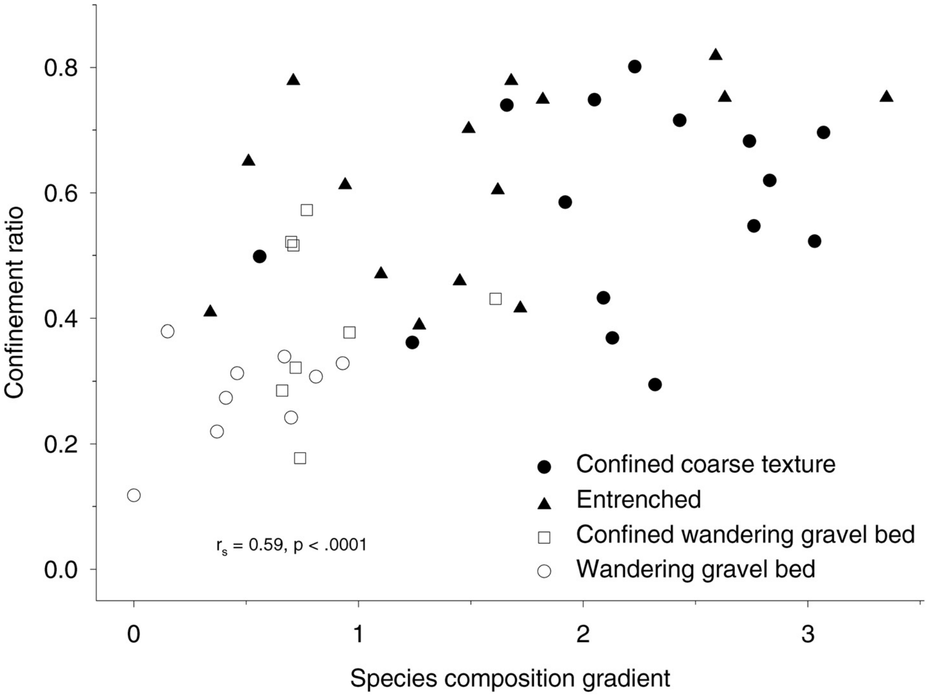


Figure 5. Vegetation type composition, expressed as gradient, as related to confinement ratio. Lower gradient values reflect a higher proportion of flood plain dependent species, while higher values reflect more upland species.

Cottonwood patch condition and ages were ocularly estimated during mapping. These same patches were aged by ring counts and historic aerial photography. Although vegetation structure was the overriding criteria for patch classification, the estimated ages were compared to the more precise ages obtained via coring. Figure 6 shows the distribution of error among sampled patches.

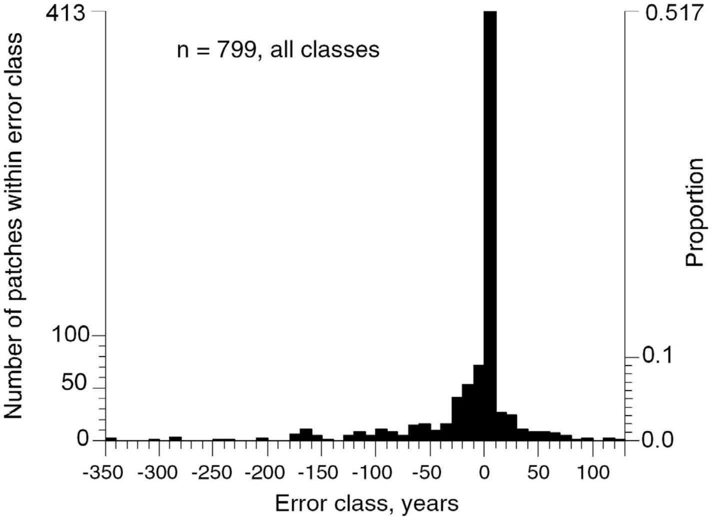


Figure 6. Error rate on a patch-basis for ocularly-estimated versus ring-count ages. Class width is 10 years. Most of the error was due to underestimates of the sapling, pole, and the very oldest stands.

Canopy cover in the understory of cottonwood stands tended to increase. Rocky Mountain juniper (*Juniperus scopulorum*) was the most common understory species in cottonwood stands. Figure 7 shows the trend in shrub canopy cover, often dominated by juniper, as cottonwood patches increase in age. The practical difference between the two geomorphic settings was not important, and the differences were not statistically significant; the smallest p-value was 0.98. Not all stands in the E and CCT strata were precisely aged, so detailed trend data for understory species are not available for these strata. Moreover, the mix of vegetation types and small patch sizes in the E and CCT strata makes a practical comparison to the CWGB and WGB strata difficult.

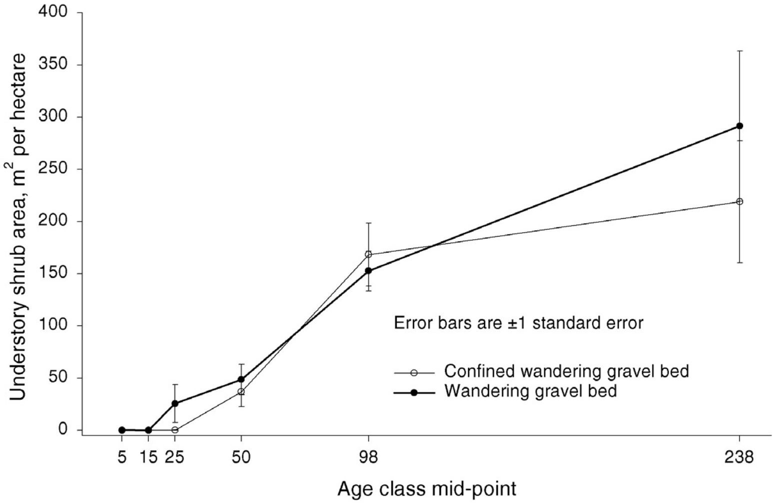


Figure 7. Understory shrub area in aged cottonwood patches. Patch ages are based on ring counts. The 95% confidence interval for the mean is approximated by twice the length of an error bar.

Cottonwood Age Distribution and Flood plain Dynamics

A tree-ring-based age distribution was obtained for the braided reaches (i.e., the WGB and CWGB strata). As with the distribution obtained via ocular estimates, the age distribution of cottonwood patches for the braided reaches shows an increase in area as age increases. Figure 8 shows the age distribution, on an area basis, for cottonwood patches. The values are expanded from a sample to an entire geomorphic setting (i.e., CWB, WGB). As in Figure 3, there is more area in the two oldest age classes because of their wider class widths. Subsequent figures will account for age-class width and use ring-count ages.

Another way to express an age distribution is with a decay function, or curve. Flood plain decay and turnover rates were estimated using cottonwood ages. Figure 9 shows the decay curves by geomorphic setting for the Yellowstone River, using cottonwood patch area only, while Figure 10 incorporates non-cottonwood parts of the flood plain. These two figures represent a compromise between aging precision and area precision. The curves based on cottonwood patches only is more precise in terms of age, but can underestimate flood plain area because trees are not ubiquitous. Flood plain areas devoid of cottonwood comprise 50% of the alluvium outside the active channel, and historical photos indicate that the age distribution of these areas is not simply proportional to that of the cottonwood patches. Extrapolation is prone to error in age, but it accounts for a significant proportion of the un-aged area of the flood plain and gives a fuller capture of flood plain dynamics than cottonwood patches alone.

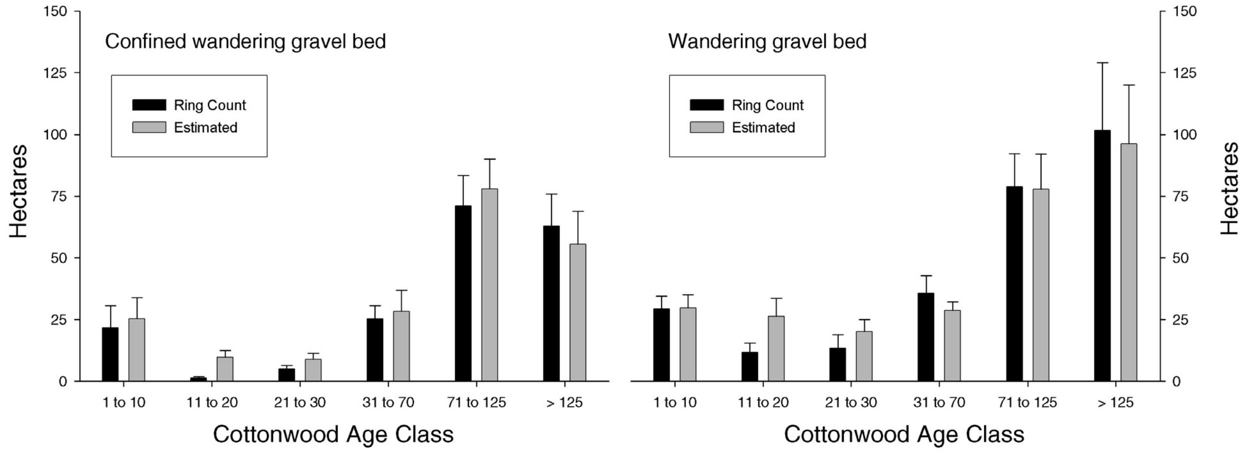


Figure 8. Age distributions of cottonwood forest patches on an area basis for the braided reaches. Ocularly-estimated and ring-count ages of cottonwood patches are comparable. Some young ring-count ages were obtained using historic aerial photography. Five percent of the patches could not be aged via aerial photography or tree rings.

Patch ages based on ring counts allow a more detailed distribution than above, especially for patches older than 70 years. Such patches make up 70 percent of the area of the cottonwood forest, and they are split into finer classes in the decay curves (Figures 9 and 10).

The fit lines in Figures 9 and 10 are based on an assumed exponential decay function. α is the area of cottonwood (or flood plain) per ha of sample area present in the year 2000 for a given age class, adjusted for age class-width. The higher-up the curve is on the graph, the more extensive (wider) the flood plain. The steeper the slope, the faster the flood plain is eroded and deposited, that is, recycled or “turned over.” The time required for the stream channel to completely erode and re-deposit its flood plain is the turnover rate, and this rate is estimated by the intercept of the fit line and the time axis. Table 6 summarizes the parameters associated with the curves in Figures 9 and 10.

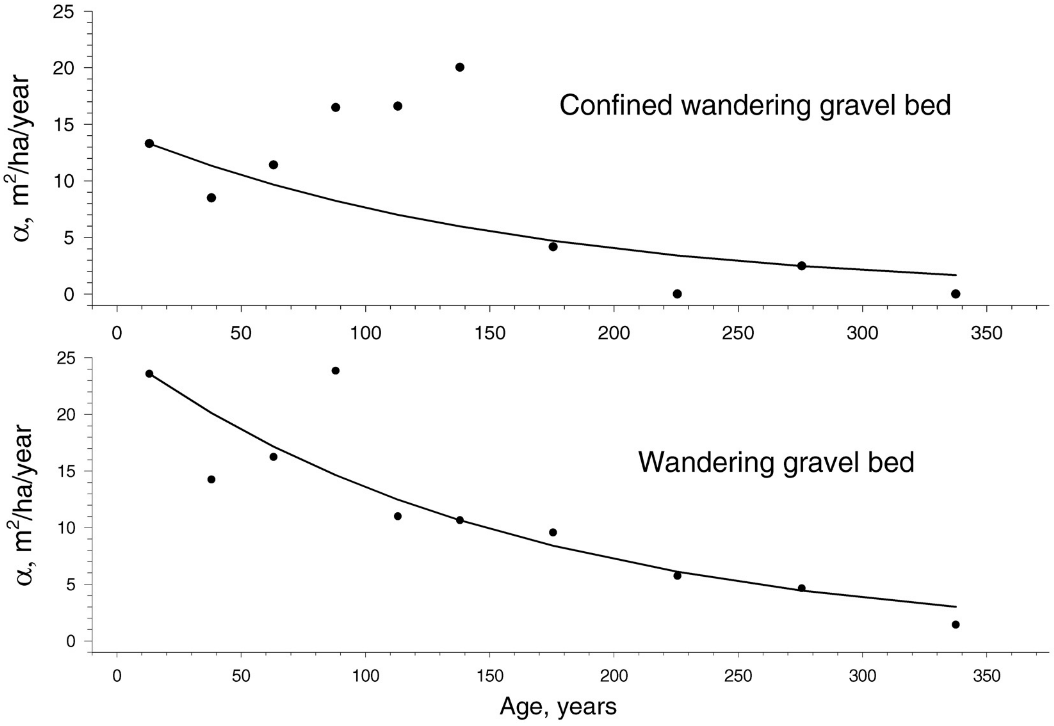


Figure 9. Cottonwood patch decay curves by geomorphic setting. Points are at age-class mid-points.

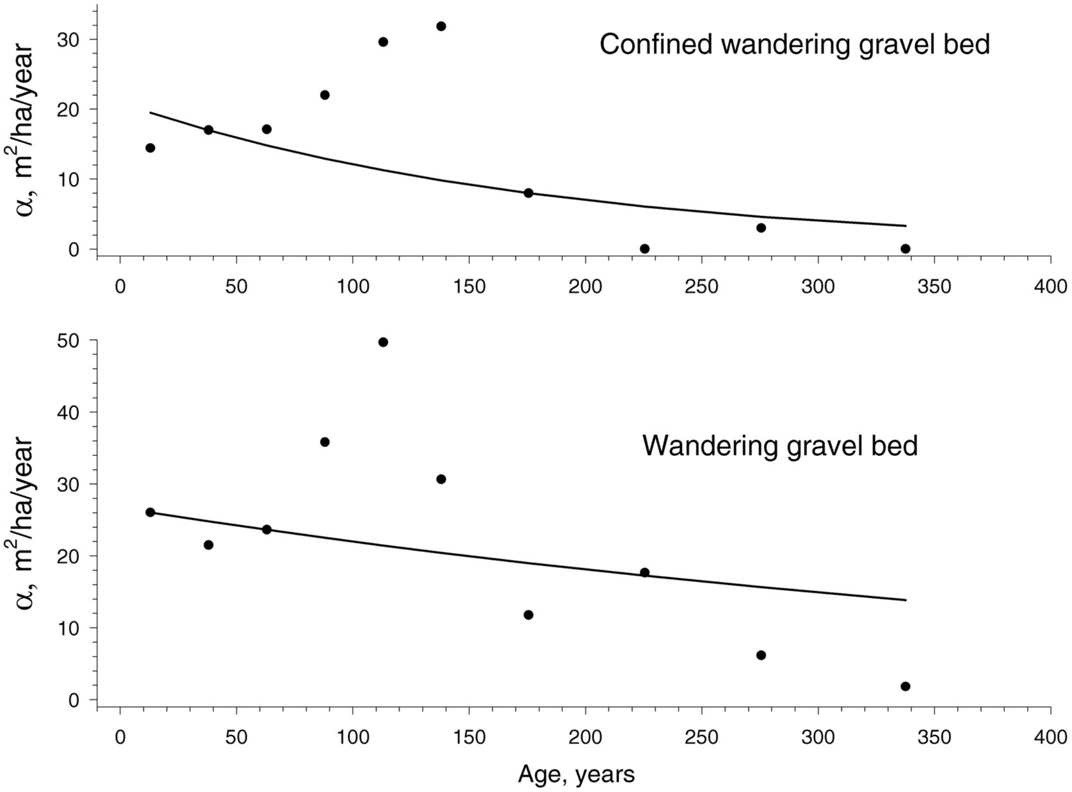


Figure 10. Flood plain decay curves by geomorphic setting. Points are at age-class mid-points.

Table 6. Decay curve summary statistics.

α (m^2ha^{-1}class width yr^{-1})	*a*	*b*	Turnover at α =1, years	Half-turnover, years	R^2
CWGB Cottonwood Patch	14.45	0.006392	418	108	0.66
WGB Cottonwood Patch	25.63	0.006351	511	109	0.92
CWGB Flood plain	20.92	0.005485	554	126	0.63
WGB Flood plain	26.72	0.001942	1692	357	0.76

Note: *a* is Y intercept (m^2ha^{-1}class width yr^{-1}), *b* is slope (m^2ha^{-1}class width $yr^{-1}yr^{-1}$), R^2 is based on model sum of squares/total sum of squares

As expected, the *a* parameter indicates a more extensive cottonwood forest and flood plain for the less-confined WGB geomorphic setting than the CWGB setting. The slope parameter, *b*, is similar for all except the WGB setting, where flood plain older than 200 years is more common, thus flattening the curve.

The decay curves serve as a reference, and the reference condition is: constant erosion and deposition rates through time, the cumulative erosion probability of a locale increases with its age, and channel width is constant through time. Deviations from the curves indicate non-reference conditions. The most striking deviation is the high amount of cottonwood or flood plain dating from the middle to late 1800's (Figure 9 and 10); this is especially so for the CWGB geomorphic setting.

Cottonwood seedlings were common on islands and other stream deposits created by the 1996 or 1997 floods, but rare to absent on older deposits as observed during our study. Cottonwood ages on older deposits would likely be associated with past flow events. Figures 11 shows the time series of annual floods passing the US Geological Survey gage at Livingston.

Flood magnitudes were compared with the cottonwood age distribution that coincides with the gaging record. Figure 12 shows how flood plain area created during 10-year time intervals from 1890 to 2000 are related to the maximum flood size during that period. The expectation is for an increase in flood plain area created as flood magnitude increases. That is, more deposition is likely during large floods. However, simultaneous erosion complicates this analysis, because the original sizes of flood plain locales of a given age are unknown for the older age classes. Older patches tend to become smaller with time due to erosion, and in the Yellowstone River case, two old 10-year-class areas (1890 to 1899, 1910 to 1919) were associated with unusually large floods (Figure 11) and the flood plain formed during these floods was likely much larger when first deposited compared to today. Subsequent floods would tend to reduce the total area of these older patches. The observed patch areas were adjusted with Equation 3 to estimate the original patch sizes sans erosion. The expected trend in observed flood plain size and associated flood magnitudes is evident in Figure 12, but the trend is only statistically significant for the CWGB reaches. For the CWGB reach, the correlation improves somewhat for the reconstructed patch areas, while the opposite is so for the WGB reaches. The slope parameter is relatively low for the WGB reaches, so older patches, some of which were associated with very large floods, were not expanded as much as with the CWGB reaches.

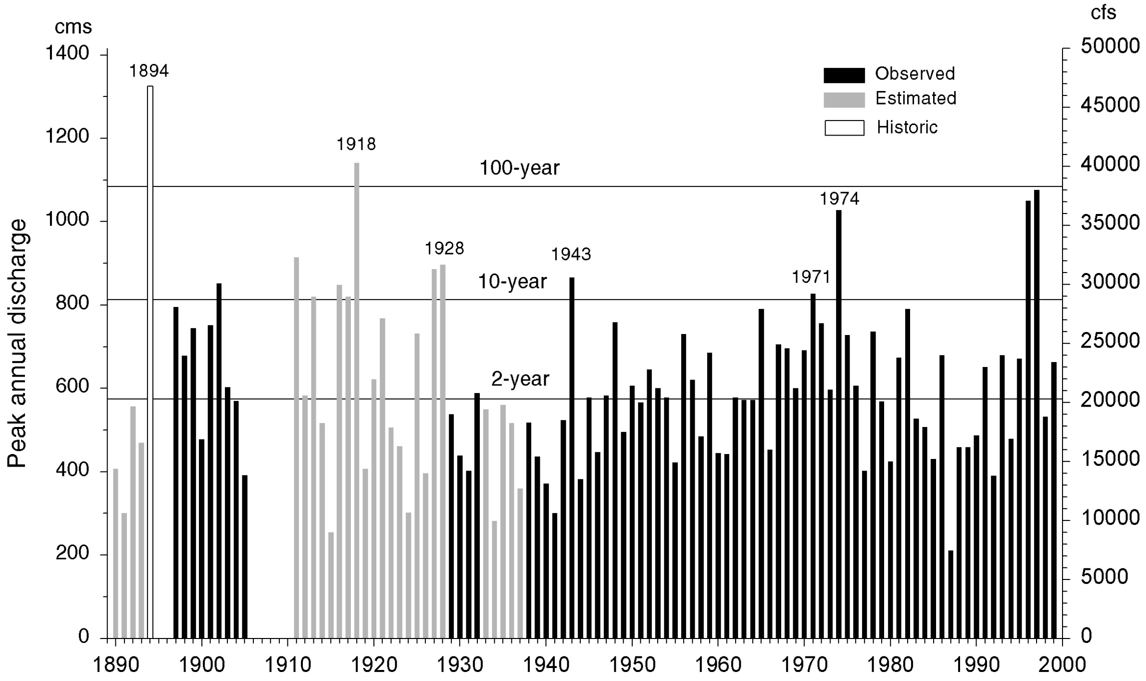


Figure 11. Time series of floods near Livingston, Montana. Darker bars indicate higher precision. Observed (black) floods were obtained directly from the Livingston gage record, Estimated (gray) floods were predicted from peak flows at Corwin Springs. The historic flood is estimated via flood stages at Livingston for 1894 and stages for floods with known discharge. The flood recurrence intervals are based on recent US Geological Survey flood frequency analysis that used observed peaks at Livingston only. Year-labeled floods are described in the Flood Insurance report for Livingston (FEMA 1987).

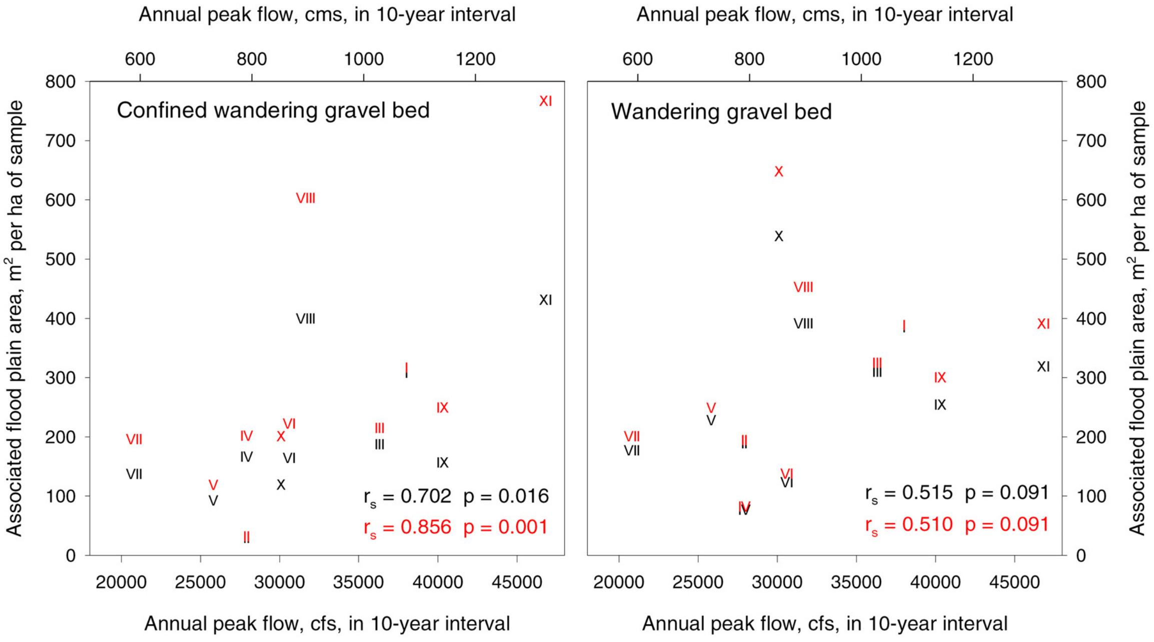


Figure 12. Trend in flood plain area by age class and maximum flood discharge during the period of that class. Symbols indicate 10-year classes from 2000 back to 1890, with I being the youngest (1990 to 1999) and XI being the oldest (1890 to 1899). Black symbols and statistics represent observed areas, red symbols and statistics represent reconstructed areas.

Within-Patch Age Structure of Cottonwood Trees

So far, cottonwood and flood plain dynamics have been based on flood plain establishment times derived from maximum tree age within patches. An even-aged patch model simplifies the flood plain dynamics task, but from the onset of the study, within-patch ages were thought to be un-even aged – at least in some places. Uneven-aged patches became apparent during reconnaissance, and a more rigorous sample quantified their prevalence. Figure 13 shows how the age range of cottonwood trees occurring on a limited (100 m^2) flood plain area increases with maximum tree age within that area. Most (58%) plots had an age range less than 20 years (Figure 14), but 6% of the plots had an age range of 100 years or more.

The simple correlation coefficient (r) between maximum tree age and age range was 0.731, while r between density and age spread was only 0.01. Partial correlations between density, maximum age, and age range point to a stronger relation between the latter two variables. The range within a plot was not strongly correlated (r = 0.377) to stem density while holding maximum age constant. Age range and maximum tree age remains strongly correlated (r = 0.775) when stem density is held constant. Thus, the observed range in ages is more likely related to parent tree age, external events that occur rarely, or a combination of these two factors rather than the amount of trees available for sampling on a plot.

The largest range was found on a plot in the Entrenched (E) stratum. This same stratum had the widest spread of age ranges in general. Although median values for age range differed noticeably between geomorphic strata (Figure 15), these differences were not statistically significant (Kruskal-Wallis statistic = 4.2, p = 0.24). Sample sizes (n) for the E and Confined coarse-textured (CCT) strata were small because of the limited amount of extent cottonwood patches.

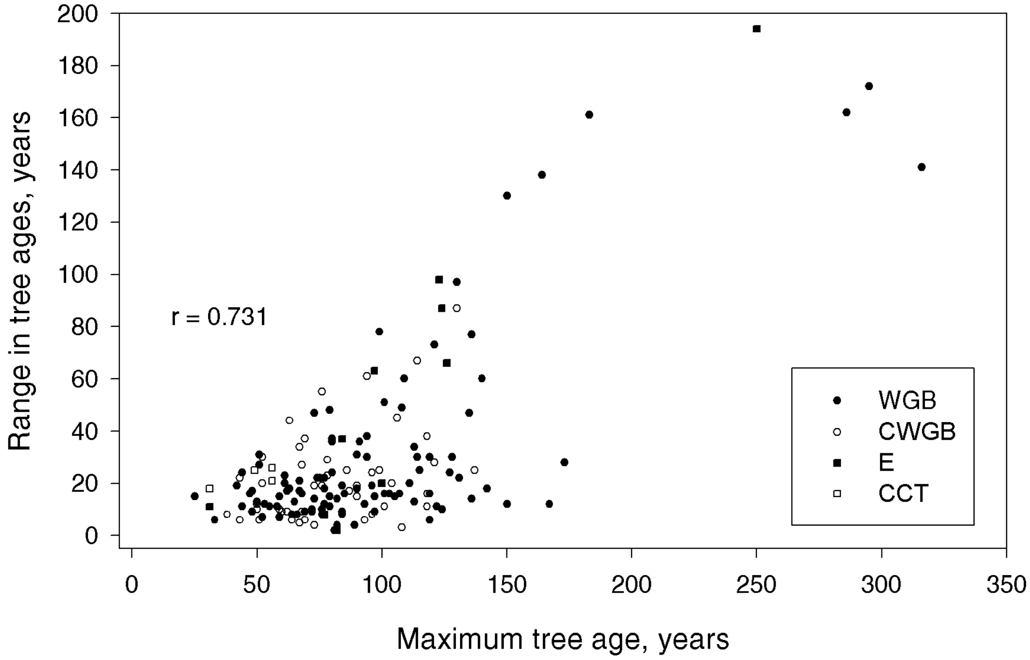


Figure 13. Trend in age range for cottonwood trees occurring on 100 m^2 sample plots. Four plots with only one tree were excluded. Apparent patch boundaries were avoided.

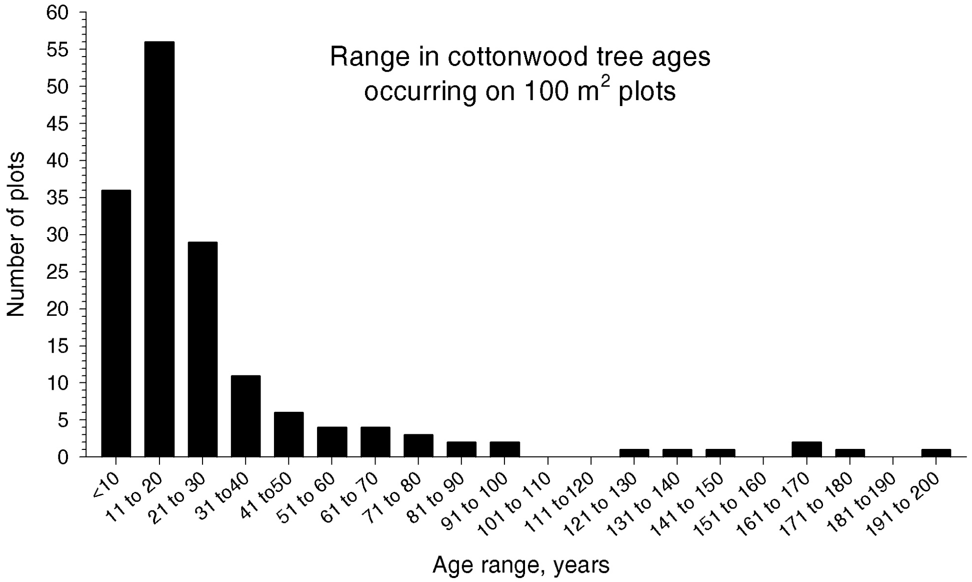


Figure 14. Frequency distribution of plots with age ranges that fall into 10-year range classes. Plots with one tree were excluded.

Figure 15. Quartiles of tree age ranges found on fixed plots in different geomorphic settings. Boxes indicate 25th, and 75th percentiles (ends) with 50th (median) line inside box. Whisker ends show 10th and 90th percentiles; points are outliers. The number (n) of fixed 100-m^2 plots with > 1 tree sampled within each stratum is shown on the left.

Trend Analysis

Early exploration notes and photographs from the late 18th Century depict vegetation that is similar to today's in a broad sense, but there are also important differences. William Clark's party traveled along the upper Yellowstone River July 15 and 16, 1806 from the present sites of Livingston to Springdale. He noted plentiful cottonwood and willow. Although he mentioned tall cottonwoods, they were too small to make a canoe that could carry more than three men. Rose bushes, rushes, and honeysuckle (snowberry, *Symphoricarpos occidentalis* per Moulton, 2002) were apparently common on the flood plain. Short grasses, a large bunch grass (Great basin wild rye, *Elymus cinereus* per Moulton, 2002) silkgrass (hemp dogbane, *Apocynum cannabinum* per, Moulton 2002) and sunflower were common on the upland terraces.

Clark encountered numerous elk, buffalo, and pronghorns along the upper Yellowstone River. For example, he saw "several gangs of Elk from 100 to 200 in a gangue on the river, great numbers of Antelopes." near his camp 3 miles below the Shields River, and "200 elk near and a gang of antelopes" near present-day Springdale. Beaver were in "Great numbers" along the Yellowstone River and tributaries.

During field work, we noticed high numbers of white-tail deer, but never saw the amounts of elk, buffalo, and Pronghorn that Clark mentions. Livestock use during summer was mostly on terraces, and few areas had noticeable livestock use on the flood plain. One very large black bear was encountered above Emigrant, and signs of beaver activity were common throughout the study area.

Ferdinand Hayden led two expeditions along the upper Yellowstone River in 1871 and 1872 (Hayden, 1872; 1873). Both trips staged out of Fort Ellis, near Bozeman (population about 500 in 1871). They traveled over Trail Creek into the Paradise Valley, and then up the Yellowstone and Gardner Rivers. Hayden devotes one sentence to Yellowstone valley vegetation, where he mentions the lower slopes and foothills were covered in grass. During Hayden's trips, the Yellowstone valley was sparsely settled by white people, and the Crow Indians were still in the valley. One ranch, Bottlers, across the valley from Emigrant Peak served as a stopping point for early travelers. Hayden stayed at Bottler's, and encountered invalids in the hot spring near Mammoth. The Emigrant Gulch mine, discovered in 1864, attracted about 300 people, but the town site (Yellowstone City) was abandoned by Hayden's arrival. Although there was some presence of new settlers, the valley vegetation probably reflected pre-European settlement conditions. One exception is beaver trapping, which is discussed later.

Photography by William H. Jackson during the two Hayden expeditions provides a record of the general environment along the Yellowstone River Valley. Jackson's early photographs, as well as from other early photographers, are shown along with recent versions of the same scenes. Jackson's captions are used when available, and are in italics. The scenes are ordered in the up-valley direction. US Geological Survey photo numbers are shown at lower right of image.

USGS W.H. Jackson 68

Plate 1. Paradise Valley from Allen's Spur. 1871. *Valley of the Yellowstone River above Livingston, looking south from first canyon. On the left the Yellowstone or Snowy Range stands out in bold relief, the eye following it to Emigrant Peak, 30 miles away. The river winds among groves of cottonwood through a broad lake-like valley, of from 3 to 5 miles in width, until it fades away in the distance, forming one of the most attractive views in the catalog. Park County, Montana. 1871.* Expedition itinerary indicates a photo date of July 15, 1871. (Hayden, 1872).

M. Merigliano University of Montana

Plate 2. Paradise Valley from Allen's Spur. July 1, 2002. Jackson's position was removed by highway construction; this scene is from a position slightly east and higher. Gravel bar at left was formed in 1996 or 1997. DePuy Spring Creek is prominent near center view. Most of the cottonwoods in center view were present during 1871. Prominent riparian shrubs are sandbar willow (*Salix exigua*).

USGS W. H. Jackson 1212

Plate 3. Paradise Valley from Wineglass Mountain, 1872. The arcuate boundary across the grasslands in center view is apparently an image defect. Prominent bottomland at near left-center appears to be dominated by shrubs and cattails. Expedition itinerary indicates a photo date of July 20, 1872. The winter of 1871-1872 was particularly severe and high streamflow from melting snow made travel difficult well into July (Hayden, 1873).

M. Merigliano University of Montana

Plate 4. Paradise Valley from Wineglass Mountain. July 9, 2002. The Douglas fir in Jackson's foreground was still alive in 2002, but limber pine and juniper blocked the historic viewpoint and this scene is from a lower and more southerly position. There is a general increase in mature cottonwood including the Nelson Spring Creek at far left-center. The prominent bottomland as in above is dominated by willow and cattail, with scattered old cottonwoods.

USGS W. C. Alden 2238

Plate 5. Lower Paradise Valley from Pine Creek moraine. 1936. The moraine has been deeply dissected by Pine Creek, and the resulting ravine is in the foreground. Wineglass Mountain is at left in the background. The prominent stringer of trees in the middle view are along Deep Creek.

M. Merigliano University of Montana

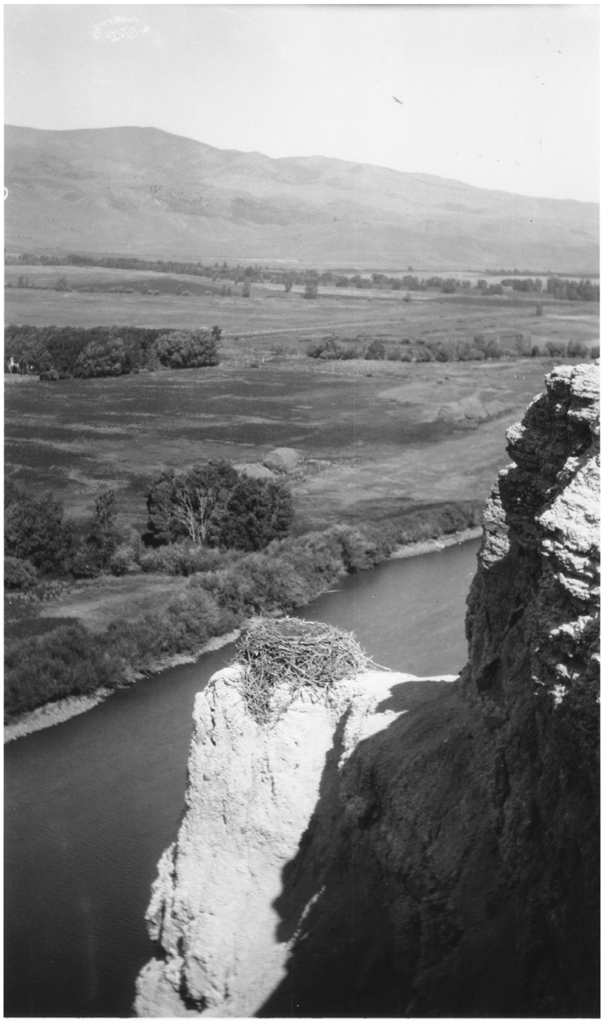
Plate 6. Lower Paradise Valley from Pine Creek moraine. July 2, 2002. Conifers have increased on the hill slopes in the background as well as the moraine; this is a general pattern for the lower mountain slopes. Alden's position had eroded away and this scene was taken from slightly east. Some signs of erosion since 1936 are visible in the steep slope of the moraine, especially to the right (east).

USGS W. C. Alden 1279

Plate 7. Upper Paradise Valley and Emigrant Peak. June 25, 1923. Cottonwoods line Big Creek at far right. The white cliffs are ancient (Miocene) lake deposits. The Yellowstone River flows in front of the cliffs and is visible left of center. A basalt flow caps the lake deposits and is known as Hepburn Mesa.

M. Merigliano University of Montana

Plate 8. Upper Paradise Valley and Emigrant Peak. July 1, 2002. The pastoral character of 1923 remains. Cottonwoods along a ditch in the close foreground are prominent, while less so below a lower diversion of Big Creek that crosses the lower right half of the scene. The extreme right edge of the original scene is missing here.



USGS J. T. Pardee 929

Plate 9. Yellowstone River at Hepburn Mesa. August 1924. The white cliffs of Plates 7 and 8 are in the foreground here. Cottonwoods line Dry Creek in the middle distance. Pacific willow *(Salix lasiandra)* borders the channel. The trees at left center surround a ranch house, and the trees to its right are along a ditch diverted from Big Creek. The mouth of Big Creek is a short distance upstream (left). The nest is probably a bald eagle's or osprey's.

M. Merigliano University of Montana

Plate 10. Yellowstone River at Hepburn Mesa. August 14, 2002. The Pacific willow are gone, but a cottonwood clump that may have been amongst them in 1924 remains along the channel. Several dead trees line the ditch diverted from Big Creek. Part of the white cliffs may have collapsed since 1924, as features of the 1924 scene could not be aligned using existing terrain. Part of the Fridley Fire of 2001 shows at upper left.

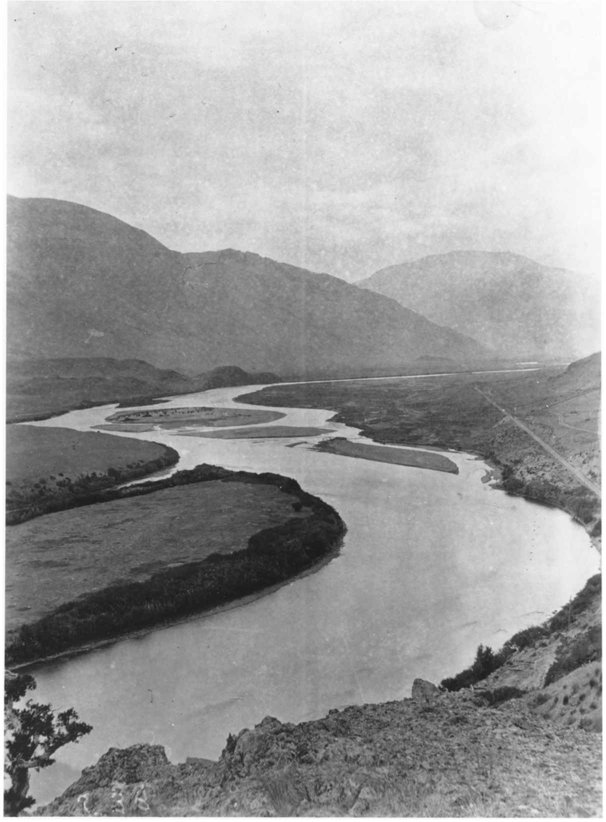
Today's natural vegetation differs from that of the late-18th century in two main ways: conifers have increased on the upland slopes, and cottonwood forests are generally more extensive with larger trees. The conifer increase is more visually dramatic than for cottonwood. Much of the grassland on the flood plain is now in agricultural production. The structure is probably similar to the native grasses, but species and disturbance regimes differ from the past. Domestic livestock share or have replaced the native ungulates, and some areas are hayed. Species composition of grasses on the drier parts of the flood plain is unknown. Today, smooth brome *(Bromus inermis)*, quackgrass (*Agropyron repens*), and western wheatgrass (*Agropyron smithii*) dominate. Only the latter is native. Wet meadows typically had native herbaceous species.

USGS W. H. Jackson 919

Plate 11. Yellowstone River downstream of Point of Rocks. 1871. Willows line the small side channel at center view. Cottonwoods dominate along the river downstream of the side channel. The forground vegetation is probably dominated by western needlegrass *(Stipa occidentalis)* and the scattered dark low shrubs look like green rabbit brush *(Chysothamnus viscidiflorus)*. There are two cairns (rock piles) near center view. Approximate photo date is July 16.

M. Merigliano University of Montana

Plate 12. Yellowstone River downstream of Point of Rocks. July 2, 2002. The cottonwoods at the extreme left (below the black defect in Plate 11) are at extreme left here. Rocky mountain junipers are now prominent in the forground. Emigrant Peak is in the background.



USGS C. D. Walcott 539

Plate 13. Yellowstone River upstream of Point of Rocks. 1898. Dome Mountain dominates the background. The terrace at left is probably rimmed with sandbar willow and chokecherry *(Prunus virginiana)*. A railroad and wagon trail show at right. The tree at lower left looks like a very old cottonwood.

M. Merigliano University of Montana

Plate 14. Yellowstone River upstream of Point of Rocks. July 7, 2001. Cottonwood and sandbar willow dominate the flood plain right-center view. Walcott's photo position (and perhaps the near hill slope) was removed by the road, and this scene is taken from slightly north and higher. Douglas fir has increased on Dome Mountain and the hill behind it.

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Nearly all of the woody species were native. However, there were several Russian olive trees *(Elaeagnus angustifolia)* along the reach within Livingston, and very few above and below this reach except for a large stand near Mission Creek. There were several non-native plantings of other species around homes, but we saw none of these invading undeveloped areas. Several weedy exotic species are extent, especially on new gravel bars and other disturbed areas.

Detailed mapping using aerial photography dating from 1948 to present reveals few statistically significant differences in cover types (Figure 16). The Riparian shrub type, which includes all willow and cottonwood saplings (10 to 20 years old) had the most consistent decrease in all geomorphic settings and across the three observed years (1948, 1976, 1999), but not all differences were statistically significant (Figure 16). Total area for all age classes of cottonwood combined had a consistent decline in all years and all strata except Entrenched, but none of the differences were statistically significant (Figure 16).

The broad age classes of cottonwood (Young, 20 to 40, Mature, 40 to 100, and Old, > 100 years) showed strong, statistically significant trends for all classes and for 1948, 1976, and 1999 in the CWGB stratum, while only the Young class had strong differences for the WGB stratum (Figure 17). The overall trend is a decline in young and mature cottonwood from 1948 to 1999, and an increase in Old cottonwoods for the same time interval (Figure 17). Recall that the total amount of cottonwood decreased over the last 50 years (Figure 16), so the cottonwood forest is shrinking and getting older.

USGS W. H. Jackson 920

Plate 15. Yankee Jim Canyon. 1871. View is upstream, with the foot of Dome Mountain on the left. Streamside vegetation is dominated by limber pine and Douglas-fir. Cottonwood is a minor component, and a mature cottonwood is at lower left.

M. Merigliano University of Montana

Plate 16. Yankee Jim Canyon. July 7, 2001. Streamside vegetation is similar to 1871, except for the removal from highway construction. Conifers increased on the hillside at right, as well as the bench the photo was taken from.

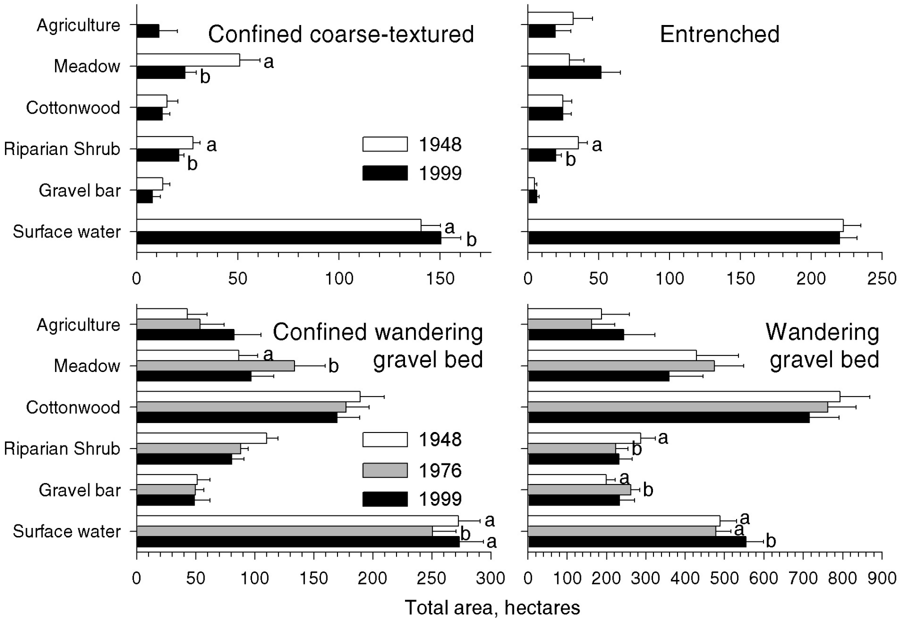

Figure 16. Total area of simplified cover types by geomorphic stratum. Different lower case letters indicate statistically-significant differences (paired t-test, $p = 0.05$); bars with no letter are not significantly different than other bars in the set. Error bars are +1 standard error of the mean. Riparian shrub includes young cottonwood 10 to 20 years old.

USGS W. H. Jackson 69

Plate 17. Yellowstone River Valley above Yankee Jim Canyon. 1871. *The second canyon of the Yellowstone River above Miner, from its upper end, looking down. Park County, Montana, 1971.* Approximate photo date is July 16.

M. Merigliano University of Montana

Plate 18. Yellowstone River Valley above Yankee Jim Canyon. July 7, 2001. Dome Mountain is at right. Scattered cottonwood trees and more continuous juniper and sandbar willow line the Yellowstone River. The foreground trees are limber pine. Conifers have increased on Dome Mountain and the ridge across the valley. This photo pre-dates the Dome Mountain fire, which started on August 1, 2001.

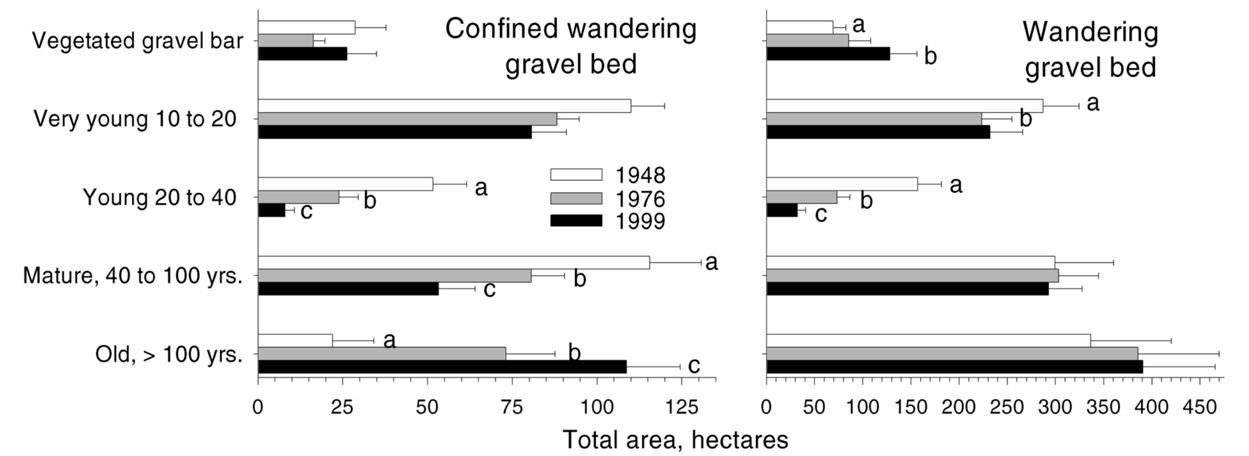

Figure 17. Trends in area of cottonwood age classes for the braided reaches. Different lower case letters indicate statistically-significant differences (paired t-test, p = 0.05). Error bars are +1 standard error of the mean. The Vegetated gravel bar class typically had cottonwood seedlings, and the Very young class includes willow.

Increases in Vegetated gravel bar (Figure 17) Agriculture, Meadow, and Channel (Figure 16) may have replaced areas formerly occupied by cottonwoods. However, a patch-by-patch analysis is needed to verify this, and only type means by sample plots were used. The patterns in the trend analysis for cottonwood age classes agree with the decay curves based on tree ages, where the shape of the curve indicates a period of high amounts of young cottonwood about 100 years ago, and then a slower rate of channel movement and cottonwood regeneration afterwards.

Cottonwood Mortality

Cottonwood forest area was lost over time due to channel erosion, conversion to agriculture, or natural succession to meadow. Figure 18 shows the relative losses of cottonwood area to these three factors for two periods for the braided reaches. For the three factors combined, the percentage of cottonwood area lost to the total land area in the study area is shown in Table 7.

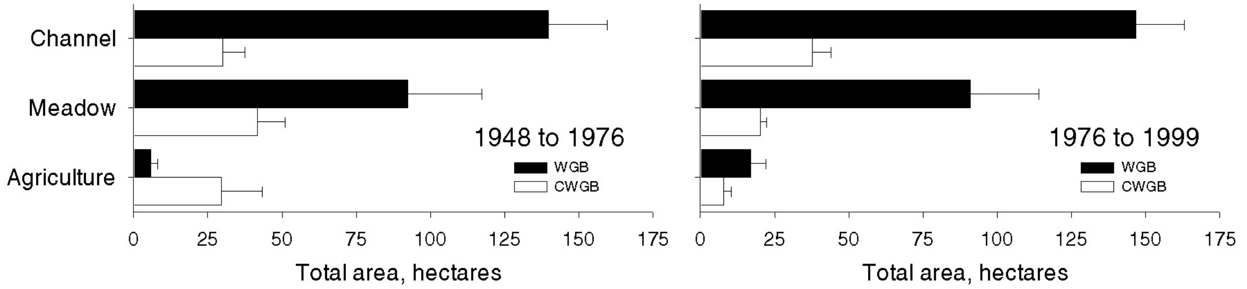

Figure 18. Cottonwood area loss due to channel erosion, cropland conversion, or natural succession to meadow. The error bars are 1 standard error of the mean.

Table 7. Percent loss of cottonwood area by stratum and period.

	CWGB	WGB
1948 to 1976	21	14
1976 to 1999	14	14

The meadow area includes wet herbaceous as well as uplands as they are difficult to always distinguish on aerial photography. Thus, some cottonwood area became new wet meadow via channel erosion and deposition, while for the upland meadow, the cottonwood died naturally or was cleared.

Flood Plain Topography and Vegetation Relations

The relation between dominant vegetation, age, and flood plain elevation is shown in Figure 19. Overbank deposits, which is sediment that settles on existing stable surfaces, consisted largely of medium to coarse sands. Overbank deposits smooth the original gravel bar surface by filling in the hollows. The elevation variance for the original gravel bar surface (assumed to be the cobble surface) was double that of the overbank deposit surface (0.223 versus 0.098). Sandbar willow dominated in old channels, while cottonwood was typically more common on bar crests. The dominant understory shrub on the long transect was silver buffalo berry *(Sheperdia argentea)*. The total amount of overbank deposits for a 1-m wide strip along the transect was estimated to be 660 metric tons (727 tons), and the average annual sedimentation rate per m^2 was 11.5 kg (25.4 lbs) over the last 120 years.

A flood plain sedimentation curve was constructed using elevations at the randomly-selected plots and the transects. The curve ascends steeply in about 20 years to the maximum elevations that are found across a broad range of site ages (Figure 20). The oldest sites have lower elevations than expected. Sediment tends to settle on existing flood plain surfaces during floods, and the general elevation of the flood plain surface tends to rise over time until it becomes too high to be flooded again, thus stabilizing at a maximum elevation that corresponds to the stage of the larger, most recent flood experienced.

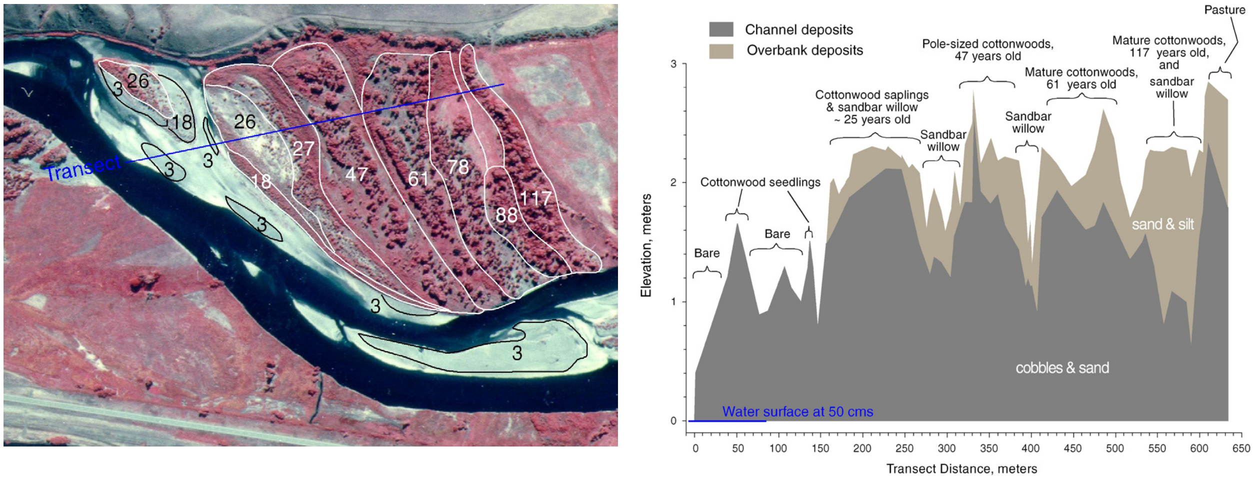

Figure 19. Flood plain transect location and profile near Emigrant. Numbers in polygons on the aerial photo are cottonwood ages in 2000. Channel deposits are laterally-accreted sediments and are comprised of cobbles, pebbles and sand. Overbank deposits settle vertically and they are dominated by coarse to fine sands.

Overbank deposit thickness on the sample plots followed the same pattern as on the long transect. It was thinner where the cobble surface was higher (crests) than at low spots in the cobble surface (Figure 21).

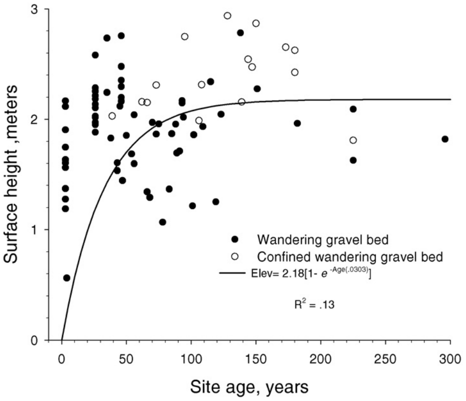

Figure 20. Flood plain sedimentation curve for braided reaches.

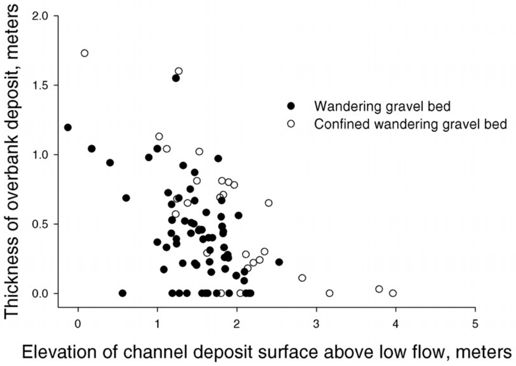

Figure 21. Overbank deposit thickness as related to elevation of channel deposit. The overbank deposit is the cap of fine soil over the original gravel bar.

Ice Effects

Field observations revealed that ice effects were limited to occasional scarring of trees on sharp bends. Thus, we did no detailed analysis of the effect of ice drives on channel dimensions and vegetation.

Discussion

Flood plain settings are inherently dynamic and the upper Yellowstone River's is no exception. Much of what we see today is a legacy of changes in the past, and in order for the flood plain vegetation to remain the same, changes must continue. There are two types of changes to consider: cyclic and directional. This study addressed both types of changes. Before discussing them in detail, the existing vegetation along the upper Yellowstone River (herein, UYR) is summarized for context.

The character of vegetation reflects its local geomorphic setting. The Wandering Gravel Bed (WGB) setting with the least confinement had the most cottonwood and willow area, even when adjusting for channel length (Figure 2). The Confined Wandering Gravel Bed (CWGB) setting still had more than double the amount of cottonwood and willow per channel length than the Entrenched (E) and Confined Coarse-textured (CCT) settings (Figure 2). This is not surprising, because the latter two reaches have essentially non-migrating channels, and cottonwood and willow depend on sites provided by a dynamic channel and flood plain system. All settings were naturally confined by terrace scarps, colluvium, or bedrock, but these barriers were further apart in the less-confined, braided reaches. Confinement varied more across the geomorphic settings than did slope (Table 5).

Other vegetation types had fidelity to geomorphic setting, and the general pattern was that plants typical of uplands were more common on the confined reaches (E and CCT) while plants typical of mesic and hydric sites were more common in the less-confined reaches (CWGB and WGB) (Table 3). There was not only a shift in the mix of vegetation types across the geomorphic settings (Table 3 and Figure 5), diversity was higher in the less-confined reaches (Table 4). Patch sizes differences of the various vegetation types followed the expected pattern: the least confined settings (WGB and CWGB) had more large patches than the confined settings (E and CCT) (Figure 4). Simply put, the confined reaches had smaller patches of mostly upland plants such as conifers and sagebrush, while the unconfined reaches had large patches of mesic and hydric plants such as cottonwood, willow, and sedges.

Several species are dependent on periodic disturbance from flooding, and along the Yellowstone River, these include cottonwood, willows, and herbaceous plants such as rush, spikesedge, sedge, cattail, and bulrush. The most important cyclic disturbances include bank cutting and sediment deposition; the latter is the key to rejuvenating many of the dominant flood plain species because they require bare, moist soil in full sunlight to regenerate (Noble, 1979; Fenner et al., 1984; Friedman et al., 1995; Scott et al., 1997; Auble and Scott, 1998; Cooper et al., 1999). Along the Yellowstone River, cottonwood and willow seedlings were common on new gravel bars that formed during the 1996 or 1997 floods, and historical photography revealed that most mature stands of these species began on gravel bars that were new long ago. Because erosion and deposition tends to be such a regular occurrence on the Yellowstone River, its absence or elimination could be considered a disturbance rather than its presence. Of course, locales of existing vegetation can experience the ultimate disturbance via erosion – they are washed away – but the system as a whole depends on disturbance to maintain its general character. Sediment deposition, or alluviation, not only provides sites for seedlings, it also influences the inundation frequency, water availability, and nutrient status of flood plain sites where there is existing vegetation (Wolman and Leopold, 1957; Boggs and Weaver, 1994). Site changes due to alluviation can be considered directional within the life span of a site. For example, Rocky Mountain juniper increases on flood plains as they become older, higher, and drier (Figure 7). But here we define a directional change as a general shift in the environment due to a wide-spread change in a driver such as flood frequency or sediment supply.

To measure cyclic and directional changes, we used the areal age distribution of cottonwood patches. How much area is distributed among cottonwood or flood plain age classes indicates how fast the channel erodes and re-deposits its flood plain. We measured the age distribution several ways, and they all point to a system that has slowed down in the last several decades.

Ocular estimates of tree ages for most settings yield age distributions that are dominated by older trees. The one exception is in the Confined Coarse-textured (CCT) reach (Figure 3). The Entrenched reach (E) has a fairly-even age distribution, while the braided reaches are the most heavily dominated by older cottonwood (Figure 3).

For the braided reaches (WGB and CWGB), the more reliable age distribution based on tree rings reveals that 70% of the cottonwood forest area has trees older than 70 years. We did not do a thorough aging sample within the confined reaches (E and CCT), but the ocular method probably provides a reasonable estimate, and in the confined reaches, 66% of the forest area was greater than 70 years. Error assessment within the braided reaches, where ocular and tree-ring dating was done on the same patches, shows that most patches were put in the zero error class (Figure 6), and the age distributions based on ocular and tree-ring methods were similar (Figure 8).

The six age classes for the ocular estimates were relatively crude compared to the 10 classes used in tree-ring aging, and we present them without adjusting for un-even class widths. Also, trees greater than 150 years old were common, and the oldest trees were about 375 years old. The decay curves based on ten age classes and tree-ring aging gives a more precise picture of forest age structure because un-even age class widths are accounted for, and finer classes were used for older trees. Recall that the assumptions for the decay curve are

1) The probability of erosion for a given time period is equal across the entire flood plain, 2) the erosion rate is constant over time, and 3) the cumulative probability of erosion for a particular parcel of the flood plain increases with parcel age. Thus, the fitted line serves as a reference for these theoretical, reasonable conditions. None of the observed data for the UYR cottonwoods fit these assumptions (Figure 9), although the observed WGB decay curve comes close. The amount of cottonwood area that's about 100 years old is greater than expected, (a "hump" shape in the points) especially in the CWGB reaches (Figure 9).

We put the UYR cottonwood decay curves together with other studied rivers for comparison. Figure 22 below shows how the Yellowstone River reaches compare on a valley-length basis, which allows a more consistent comparison

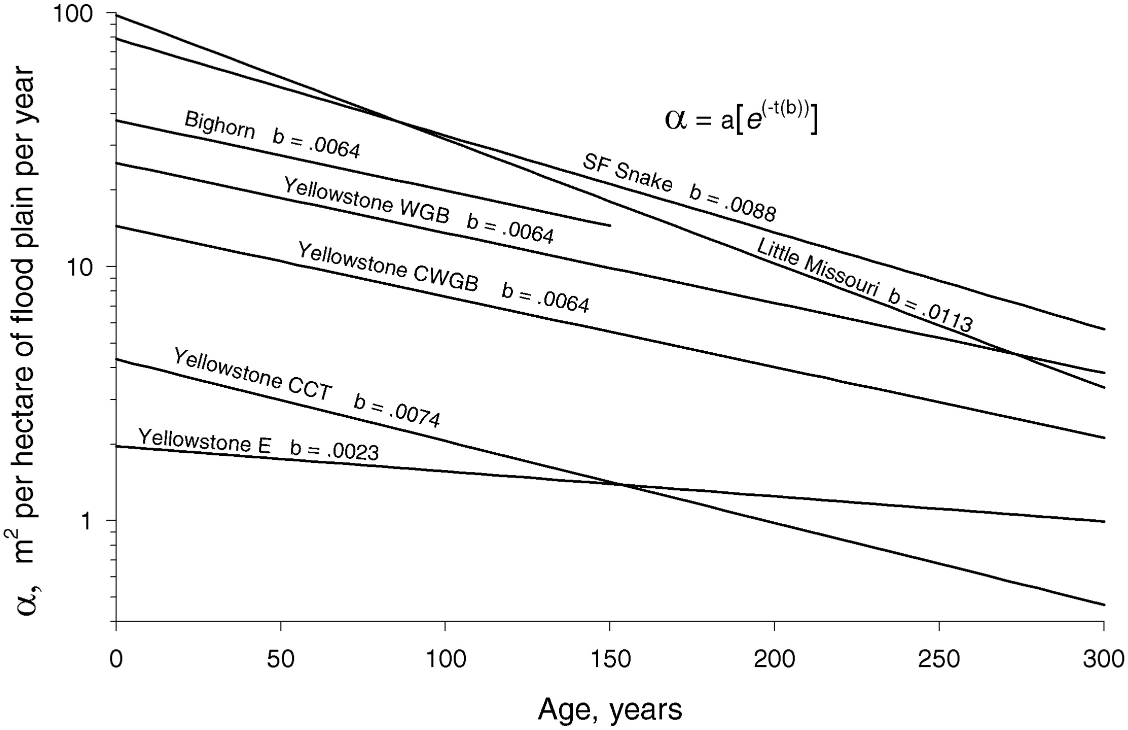

Figure 22. Cottonwood forest decay curves for four rivers. The **b** parameter indicates how fast the forest declines with time, while the **a** parameter, which can be read off the ordinate, indicates how much forest is eroded per year on average. Note: The Little Missouri curve is based on flood plain area, but much of the flood plain is forested with cottonwood.

The curves in Figure 22 assume exponential decay. Although this assumption is not completely met for some of the rivers, the relative positions are where expected if one is familiar with these river systems. For example, the confined reaches for the UYR (CCT and E) have limited cottonwood forest area (Figure 2), and their curves are the lowest on Figure 22. The WGB reach of the UYR looks very similar to the South Fork Snake River in Idaho (Merigliano 1996), and the their respective curves are near each other. The maximum age plotted is an estimate of tree life span, so any curve that extends beyond it without crossing the abscissa means the forest could out-live channel erosion on average, given the channel erosion rates experienced. All of the curves meet this criterion, which means non-cottonwood areas would exist due to mortality. Such areas exist on all of the rivers in Figure 22, although they were not quantified for the Little Missouri River but aerial photos help verify this. Much non-cottonwood area exists on the UYR (Figure 2).

Using cottonwood patch area alone does not fully capture the idea of flood plain decay, or turnover, because some trees die before the flood plain is eroded, and cottonwoods do not establish on all surfaces. The flood plain decay, using extrapolation of aged cottonwood patches, also has a dramatic hump for flood plain area between 100 and 150 years old (Figure 10). This hump indicates a substantial amount of flood plain construction during these years compared to today. If the channel migration rate was constant, the flood plain created during the last event (for UYR 1996 and 1997) would have the most area, but for the UYR, the flood plain created during the 1996 and 1997 floods is relatively modest. About 15% of the flood plain could not be aged with extrapolation. These areas were treeless on the 1948 aerial photographs, and treeless areas show on the historic photos (Plates 3, 9, 11, 13).

Our decay curve approach was retrospective: it looked at areas of all existing ages from the most recent time, but features that were extent long ago but now missing could not be measured. The real-time approach used in trend mapping, which incorporates extinct features, also shows a system that is becoming less dynamic. The forest had a higher proportion of younger trees in 1948, but this proportion declined in 1976 and 1999 (Figure 17). Upland herbaceous areas were likely cottonwood forest in the past, and trend analysis shows that some cottonwood patches changed to meadow, while some was lost to agriculture, especially in the CWGB reaches (Figure 18).

So, in essence, the UYR cottonwood system appears to have been more dynamic in the past, say 100 to 150 years ago. One could argue that the decline coincides with white settlement, and efforts to stabilize the channel have limited channel migration and cottonwood recruitment. This may be true, but is probably not the entire story. The shift in age distribution was consistent for all sampled reaches since 1948 (see Appendix D). Reaches with higher amounts of bank stabilization did not have the expected pattern; that is, larger proportions of older trees compared to more-natural reaches. Higher amounts of young patches were prevalent across the study area in 1948, while the opposite was true for 1999.

Of course, effective bank stabilization *will* limit channel migration – that is its purpose – and the most recent spate of projects may add to the underlying cause of the directional shift in fluvial activity and resulting age distribution. The effects of bank stabilization on extensive channel migration, flood plain turnover, and riparian vegetation are difficult to gauge for the upper Yellowstone River because extensive, robust stabilization features are too recent to manifest their effects. However, there are two notable exceptions: the Livingston area (our Urban reach), which we did not study, and the area west of Highway 89 just upstream from the first canyon above Livingston which was included in our sample. This area has been separated from the main river since railroad construction in the late 1800's, but the railroad was breached during the 1918 flood. The highway has effectively cut-off channel migration since it's re-construction in the mid-1960's. The area west of the highway harbors small, scattered patches of very old cottonwoods, extensive stands of sandbar willow, and aspen. Juniper is present on the higher, drier sites. Some surface water reaches this area via culverts, and this flow may by augmented by groundwater (Clark, 1991, personal observation), but flood waters are essentially blocked by the highway. Not all reaches have a positive groundwater influence (Clark, 1991) like the above area, so sites may become drier if separated from the main channel system.

For the upper Yellowstone River, a reasonable estimate of future flood plain dynamics given extensive, robust bank stabilization can be gained from experience along the Snake River in the Jackson Hole Basin in Teton County, Wyoming. This reach of the Snake is similar in morphology and hydrology to the braided reaches of the UYR, except peak flows are partially controlled by the Jackson Lake Dam. The dam did not trap sediment, because it raised an existing, natural lake. An extensive flood-control levee system was completed in 1964 (USACE, 1999), and from 1956 to 1986, riparian habitat area within the levees decreased by 57%. There was a 149% increase in cottonwood-spruce habitat outside of the levees; this type is analogous to the UYR's old cottonwood types with a juniper understory. Before levee construction, the Snake River channel would shift via bank erosion and accretion as well as extensive avulsions, where dominant flow within a braid-belt would shift back into old braid belts or make substantial new flow paths through existing flood plain. The levees now confine flow and channel migration, and a dynamic corridor of gravel harboring young cottonwoods and willow is surrounded by an aging, stable cottonwood forest outside of the levees. For much of the Snake River below Grand Teton National Park, flood plain turnover is limited to the area between the levees, which is about 20% of the historic riparian area. There is a considerable amount of cottonwood regeneration between the levees, but the patches are short lived due to rapid erosion rates within the levees.

Changes in riparian habitat due to channel stabilization are simpler to see when the features are extensive, and the effects of bank stabilization may not be a linear function of feature length. In non-continuous levee systems, the location of features relative to the channel system is often more important than length. For example, a short feature that blocks a potential avulsion into an old channel system may affect flood plain dynamics more then a long feature that fronts a stable terrace. The channel can also avulse or otherwise erode a flow path around a short feature. The latter was probably the main motivation for constructing the extensive, nearly continuous levee system along the Snake River in Jackson Hole, and the present situation along the UYR is similar to the Snake River's in the mid-1950's.

The above considers the effects of channel confinement, but inundation and sedimentation during flooding is also impacted by features that prevent over-bank flooding. Short-term, intermittent flooding may have little impact on average site moisture on old, higher flood plain surfaces, but may limit plant species that are intolerant of the short-term flooding that occurs there. Features that prevent overbank flooding would keep site elevations constant because of the lack of sedimentation. If water chemistry is different during floods than during low flow, nutrients within the flood plain would reflect groundwater supply as nutrients supplied by flood water is lost from the site via leaching.

Besides bank stabilization, climate change may be an underlying cause of the directional shift in channel and flood plain dynamics, and two lines of evidence support this. Stream flow and sediment supply are driven by climate, and the relation between climate, stream dynamics, and dependent vegetation such as cottonwood is easier to see on ephemeral channels. Such channels tend to have a wide range in flow through time. In other words, they are "boom & bust systems," and a cycle may be observed within human documentation. Friedman and Lee (2002) show how fluvial activity and cottonwood regeneration are not steady along ephemeral streams in the Colorado Piedmont section Great Plains. After infrequent, very large floods, extensive stands of cottonwood established on the flood plain and old channel bed during subsequent decades of small floods. The huge rainfall events that drove the big floods are limited in area, thus the infrequency for a stream with a small drainage area. These hit-and-miss storms could be thought of as large shifts in climate for a particular stream. In contrast, the UYR has a very large drainage area with spatially and temporally consistent snowfall, so climate changes would have to be more extensive for an effect to show up along the river. The large pro-glacial terraces along the UYR give a dramatic example of past climate. Sediment loads were much higher during the Pleistocene than today, and there were periodic deluges from ice dam failures (Church and Ryder, 1972; Embleton and King, 1975; Pierce, 1979). The high sediment loads moved by the ancestral Yellowstone River built a broad, high flood plain that has since been eroded by the modern river, leaving the large terraces. Church and Ryder (1972) estimated that sediment loads during de-glaciation along British Columbia rivers were 10 to 100 times greater than of today. One can imagine such a difference over centuries creating the broad, deep deposits that show so well in Paradise Valley, (e.g., the Weeping Wall), especially if streamflow was not accordingly as high to move all the sediment out of the valley.

Much of the cottonwood we see today along the UYR could be a legacy of higher sediment loads or streamflow in the recent past. Unlike many rivers in the Northern Rockies that we have visited or studied, or that documented by others (Leopold and Miller, 1954; Gottesfeld, 1990) we noted few modern-origin terraces along the UYR. The most noticeable ones were near Mallard's Rest, which is a transition zone between an Entrenched reach and a Wandering gravel bed (braided) reach. The transect near Emigrant (Figure 19) shows what may be a small terrace at the pasture, but this is probably a natural levee, and terraces on other rivers as large as the Yellowstone are about 1 m above the flood plain (Merigliano, personal observations). Terraces are easiest to see where young cottonwoods are adjacent to very old ones, and although not surveyed, the lack of a low terrace seemed conspicuously absent during field work.

The lack of a low, modern terrace on the UYR indicates a stable sediment regime, thus leaving a change in streamflow regime as a possible factor behind the directional shift in flood-plain and cottonwood dynamics. The end of the Little Ice Age coincides with the shift in dynamics on the UYR. The Little Ice Age in Europe and North America occurred from about 1400 to the mid-to late 1800's (Naftz et al., 1996; Rumsby and Macklin, 1996; Luckman, 2000). During the Little Ice Age, sedimentation rates were higher, large floods were more common, and in turn, fluvial activity was higher (Grove, 1972; Rûžičková et al., 1993; Rumsby and Macklin, 1996; Luckman, 2000; McCarroll et al., 2001). There was typically two pronounced peaks of glaciation, and they occurred in the late 1700's, and mid-1800's. Merigliano (1996) dated the low terrace on the Snake River and it was formed in the 1850's. Perhaps higher sediment loads and streamflow operated there, while enhanced fluvial activity on the UYR was due mainly to higher streamflow — especially larger floods.

Increased sediment loads from fire are a likely source for increased fluvial activity, and a recent study partially supports this (Ewing, 1996). The Yellowstone Plateau had historically large fires (Loope and Gruell, 1973; Romme and Despain, 1989), and the 1988 fires were comparable in size to pre-suppression era fires. Post-1988 fire measurements of suspended sediment loads for the UYR below Yellowstone Lake were higher than pre-1988 levels (Ewing, 1996). Spring flows had between 42 and 156 percent increases in sediment per unit discharge at Corwin Springs. A more detailed method better isolated the effects of erosional conditions, and the increase in load was about 60%. The few years following the 1988 fires had modest flows, and streamflow was not much higher despite 5 to 16 percent higher precipitation in source areas. Farnes analyzed the effects of reduced forest cover on the 1997 flood discharge and found minimal increases in flow due to the fire after controlling for snowpack, precipitation, and soil water (unpublished report on file at Governor's UYR Task Force Office, Livingston, MT). Ewing did not measure bed load, which would be an important part of sediment load and flood plain construction (Leopold, 1992).

We related streamflow events to cottonwood establishment years and found a trend (Figure 12). Flood magnitude was positively correlated with flood plain area dating to a given flood, although the coefficient was not statistically significant for the WGB reaches. Such a relation is inherently difficult to measure because deposits from old events tend to become smaller over time (the decay concept), and precisely dating cottonwood trees becomes more difficult with tree age (and human age). Moreover, not all trees colonize a new stream deposit at once (Merigliano, 1998; Auble and Scott, 1998; Friedman and Lee, 2002), so even exactly-aged trees may not all date to a flood year. From a logical standpoint, large floods are very likely responsible for most of the channel migration because if small, frequent floods eroded significant amounts of flood plain, there would be much less old cottonwood and flood plain along the UYR than there is. Estimates of flood plain turnover for the braided reaches are between 550 and 1700 years (Table 6). We did not calculate a decay curve for the non-braided reaches, because their scale of channel migration was negligible.

If cottonwood is so dependent on migrating channels and flood plain construction, their presence along the confined reaches is interesting. Along these reaches, three processes appear to be maintaining cottonwoods. One is the usual way, where a few small islands and attachment bars come and go with erosion and deposition. The second is scour and fill of small sheets of bank comprised of cobbles. We noted widely scattered, small patches of cottonwood regeneration along the banks of the confined reaches. These patches were far enough away from mature trees to preclude vegetative sprouting as a likely regeneration strategy. A third way may be vegetative reproduction via root and stump sprouts. Many stands had a mixed age appearance, and sampled stands had a range in ages that was beyond aging error (Figures 13 and 15). It is possible that sprouting is maintaining cottonwood stands on old, stable banks. Sandbar willow is very common along the banks, and it relies heavily on vegetative reproduction (Ottenbriet and Staniforth, 1992). The impact of beavers may be more concentrated along the confined reaches, as they are central-point foragers, and stem size and distance from water are important factors in stem preference (McGinley and Witham, 1985). Large trees far away from water are preferred less than young trees nearby.

Establishment of essentially even-aged stands on gravel bars was visible on sequential aerial photography, and this process was prevalent along the braided reaches. However, tree age ranges within small (100 m^2) plots indicate sprout origin in some areas (Figure 15). Further work is needed to verify whether these are clones or stems of seed origin. A few cottonwood patches expanded in size with no apparent deposition. Probably the most striking example of large, mixed-age stands is across from Mallard Rest on a point-bar like feature. A few very large, very old trees (say 200 + years) are scattered among an extensive stand of trees that are about 80 years old. The point bar is apparently very stable and has changed little in size during the last 50 years. At its core is one of the few low terraces, and although a large feature with vestigial braided channels, it seems to behave more like the small attachment bars along the Entrenched reach immediately above. Fire scars were rare along the study areas, but were locally common within extensive, mixed-aged stands.

Future Research

The mixed-age nature of the cottonwood patches are not unique to the Yellowstone River but their occurrence in different geomorphic settings and patch ages provides for an interesting study that could give insight into whether forests can be sustained in the absence of significant channel migration. While conducting the original study, DNA primers for cottonwood were developed to allow a genetic-based method to identify ramets (sprouts, asexual reproduction) and genets (seed origin stems, sexual reproduction). About 500 samples were collected from a subset of the fixed plots, and DNA extraction from young sprouted leaves is ongoing at the University of Montana. Test samples of extracted DNA have been sent to Oak Ridge National Laboratory, and DNA levels are within acceptable limits for microsatellite DNA analysis, which is the best method for identifying clones (Gerber et al., 2000; Schoot et al., 2000). The analysis at Oak Ridge will provide parentage and clone identification. This will enable correlation of clonal recruitment to river stage, elevation, substrate type, precipitation levels, and river scour. This in turn will help narrow down some of the factors influencing clonal recruitment along the Yellowstone River in narrowleaf cottonwood, but also the amount of clonal recruitment will be known. In essence, the study will address how common clonal recruitment is, ramet life span, and what are some important environmental factors. Many cottonwood systems have stabilized channels or flows due to damming, diversions, and bank revetments, and sexual reproduction is limited (Rood and Mahoney, 1990). Perhaps vegetative reproduction can mitigate these impacts.

Vegetation structure is an important avian habitat component, and this study provided data for the wildlife component. The natural potential for understory, late-successional shrubs along the UYR flood plain is unknown. Much of the cottonwood forest had an understory dominated by grasses or grasses and xeric shrubs including Rocky Mountain juniper, silver buffaloberry, snowberry, and skunkbush (*Rhus trilobata*). Hansen et al. (1995) suggest that such types would be dominated by red-osier dogwood (*Cornus stolonifera*) with less grazing pressure. Red-osier dogwood is palatable to wild ungulates and cattle and is sensitive to grazing. It was rare in the study area, and only a few stands larger than 0.25 ha (0.5 acres) were found. Cattle grazing levels observed during our study were low in most places, and one area that had not been grazed since the 1930's did not have significant amounts of dogwood. Another study (Merigliano, in review) found a strong correlation between dogwood and water availability, which was in turn related to soil texture. The UYR soils are typically medium to coarse sands and may be too dry in late summer to support dogwood. A study relating water availability and understory species composition on sites of known, low grazing use could determine the natural potential of sites.

Our cottonwood aging sample was limited to land we had owner permission to access. The reach from the Highway 89 bridge to near Mission Creek was under-sampled. This area has a broader flood plain than much of the other sampled areas, and our decay curve estimates may not represent this very well. One way to assess this is to use the size distribution and total area of new gravel bars created during large floods as an index of channel migration rates and flood plain turnover. This index may be an efficient and effective way to obtain flood plain turnover. The geomorphology study (Dalby and Robinson, 2003) may have the island measurements, and our study has them for our sampled reaches only.

The impact of beaver on cottonwood stand structure is not understood for the UYR, or for large braided, northern Rocky Mountain Rivers in general. A study that relates beaver densities, forage preference, and resulting stand structure would lend insight to their present impact, as well as allowing prediction of the effects of beaver trapping.

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Appendix A. Mapping unit codes, names, and descriptions

Scheme for field-checked riparian vegetation mapping done in 2000 to 2002

Code	Name	Description
A	Agriculture	Land supporting pasture grasses or row crops. Irrigated or non-irrigated. Soil is tilled, plants are cut or intensely grazed by livestock
AC	Active channel	Wetted surface plus are with little or no perennial plants
ASH	Aspen/Herb	Quaking aspen *(Populus tremuloides)* dominates an understory of grasses, forbs, and shrub cover less than 10 percent.
ASS1	Aspen/Shrub1	Same as ASH above plus a shrub cover between 10 and 25 percent. Shrubs include aspen seedlings and saplings.
ASS2	Aspen/Shrub2	Same as ASS1 above plus a shrub cover between 26 and 50 percent. Shrubs include aspen seedlings and saplings.
ASS3	Aspen/Shrub3	Same as ASS2 above plus a shrub cover exceeding 50 percent. Shrubs include aspen seedlings and saplings.
BW	Bebb willow	Bebb willow *(Salix bebbiana)* dominates the overstory. Hawthorn *(Crataegus* sp.), Yellow willow (*S. lutea*), and Pacific willow (*S. lasiandra*) sometimes co-dominate. Mesic and hydric grasses and forbs comprise the understory.
CC	Chokecherry	Common chokecherry (*Prunus virgniniana*) dominates the overstory, and Woods rose (*Rosa woodsii*) is a common associate. mesic and xeric grasses and forbs typically form the understory.
CW1	Cottonwood I	Seedlings of narrowleaf cottonwood (*Populus angustifolia*) dominate recent (post-1995) stream deposits. Bare ground (cobbles, pebbles, and sand) dominate the understory. Sandbar willow (*Salix exigua*) can co-dominate. Estimated age is from 1 to 10 years.
CW2	Cottonwood II	Saplings of narrowleaf cottonwood dominate and sandbar willow is a common co-dominant. A high cover of grass typically dominates the understory. Estimated age is from 11 to 20 years.
CW3H	Cottonwood III/Herb	Pole-sized narrowleaf cottonwood dominate a herbaceous understory comprised of mostly grass (usually *Bromus inermis* and *Agropyron repens*) and a sparse cover of mesic forbs. Estimated age is from 21 to 30 years.
CW3S1	Cottonwood III/Shrub1	Same as CW3H above plus a shrub cover in the understory between 10 and 25 percent. Shrubs are typically remnant sandbar willow.
CW3S2	Cottonwood/III/Shrub2	Same as CW3S1 but with a shrub cover in the understory between 26 and 50 percent.
CW3S3	Cottonwood III/Shrub3	Same as CW3S2 above, but with a shrub cover in the understory greater than 50 percent.

CW4H	Cottonwood IV/Herb	Mature narrowleaf cottonwood dominate a herbaceous understory comprised of mostly grass (usually *Bromus inermis* and *Agropyron repens*) and a sparse cover of mesic forbs. Estimated age is from 31 to 70 years.
CW4S1	Cottonwood IV/Shrub1	Same as CW4H above with a sparse shrub cover up to 10 percent. Rocky Mountain juniper (*Juniperus scopulorum*) and silver buffalo-berry (*Sheperdia argentea*) are common shrubs.
CW4S2	Cottonwood IV/Shrub2	Same as CW4S1 above but with a moderate shrub cover between 25 percent and 50 percent.
CW4S3	Cottonwood_IV/Shrub3	Same as CW4S2 above but with a high shrub cover exceeding 50 percent.
CW5H	Cottonwood V/Herb	Mature narrowleaf cottonwood dominate a herbaceous understory comprised of smooth brome (*Bromus inermis*) and quack grass (*Agropyron repens*), plus a sparse cover of mesic forbs. Estimated age is from 71 to 125 years.
CW5S1	Cottonwood V/Shrub1	Same as CW5H above, plus a sparse cover of shrubs between 10 and 25 percent. Rocky Mountain juniper is the most common understory shrub, with silver buffalo-berry a scattered co-dominant. Skunkbush (*Rhus aromatica*) is locally common on some sites.
CW5S2	Cottonwood V/Shrub2	Same as CW5S1 above, but with a moderate cover of shrubs between 26 and 50 percent. Rocky Mountain juniper is the most common understory shrub, with silver buffalo-berry a scattered co-dominant. Skunkbush (*Rhus aromatica*) is locally common on some sites.
CW5S3	Cottonwood_V_Shrub3	Same as CW5S2 above but with a high cover of shrubs exceeding 50 percent.
CW6H	Cottonwood VI/Herb	Mature narrowleaf cottonwood dominate a herbaceous understory comprised of mostly grass (usually *Bromus inermis* and *Agropyron repens*) and a sparse cover of mesic forbs. Estimated age is exceeds 125 years. Tree crowns are typically flattened in profile, and have sparse foliage. Rotten and broken limbs are common.
CW6S1	Cottonwood VI/Shrub1	Same as CW6H above, plus a sparse cover of shrubs between 10 and 25 percent. Rocky Mountain juniper is the most common understory shrub, with silver buffalo-berry a scattered co-dominant.
CW6S2	Cottonwood_VI_Shrub2	Same as CW6S1 above, but with a moderate cover of shrubs between 26 and 50 percent. Rocky Mountain juniper is the most common understory shrub, with silver buffalo-berry a scattered co-dominant.
CW6S3	Cottonwood VI/Shrub3	Same as CW6S2 above but with a high cover of shrubs exceeding 50 percent.
DF	Douglas fir	The overstory is dominated by Douglas fir *(Pseudotsuga menziesii)*, mixed with limber pine (*Pinus flexilis*). The understory is dominate by xeric and mesic grasses and forbs. Only one stand was encountered, and this type is atypical for the upper Yellowstone River riparian area.
E	Emergent wetland herbs	Herbaceous vegetation that includes a broad range of community types. Common species, which typically form small almost monotypic stands are spike sedge (*Eleocharis* sp.), bulrush (*Scirpus* sp.), cattail (*Typha latifolia*), beaked sedge (*Carex rostrata*) (Stokes), horsetail (*Equisetum* sp.), tufted

		hairgrass (*Deschampsia cespitosa*), and unusually robust stands of mesic grasses such as smooth brome mixed with with scattered species from the above list.
J	Rocky Mt Juniper	Rocky Mountain juniper (*Juniperus scopulorum*) forms a scattered overstory over xeric grasses. Woods rose is occurs occasionally. Juniper is common in older cottonwood stands on the flood plain, but this type is commonly found on steep banks along old terraces.
LEVEE	Levee or dam	Levees or other control structures. The mapped levees were prominent but do not include all levees along the river. The dams are small flow control structures along spring creeks and other off-channel water (see below).
LP	Limber pine	Limber pine (*Pinus flexilis*) forma a scattered overstory and often occurs with Rocky Mountain juniper and scattered Douglas fir. The understory can include chokecherry, Woods rose, silver buffalo-berry, and Pacific willow. Xeric grasses and forbs typify the groundcover.
OCW	Off channel water	Surface water that is not directly to the main channel system of the Yellowstone River at its upstream end. Includes spring creeks, oxbow ponds, and artificially-blocked side channels. Many channels and ponds would likely connect with the main flow during floods.
PW	Pacific willow	Pacific willow (*Salix lasiandra*) is a common but scattered co-dominant in mixed willow stands and some cottonwood stands. It sometimes dominates in stringers along side channels or as remnant patches in a matrix of hydic herbs to form this named type.
Road	Road	Prominent roads, including the traveled surface and associated fill. Paved and unpaved.
S	Silver buffalo-berry	Silver buffalo-berry (*Sheperdia argentea*) , which is typically an understory species, sometimes dominates in stringers or clumps in non-forested areas.

Scheme for trend mapping for the years 1948, 1976, and 1999.

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
6140	Mature cottonwood	Cottonwood 40-100 years old, all understory types
6150	Old cottonwood	Cottonwood 100+ years old, all understory types
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

Appendix B. Reconstruction of missing floods in the Livingston flow record.

Regression results from fitting relations between:

1) Mean maximum mean daily discharge at Livingston given maximum mean daily discharge at Corwin Springs
2) Instantaneous maximum discharge at Livingston given maximum mean daily discharge at Livingston predicted from (1).

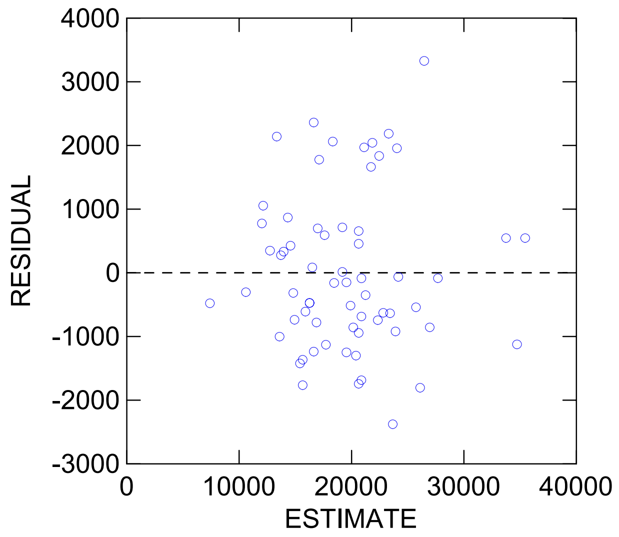
Variable names and definitions used in analysis:
INSTQLIV is maximum instantaneous discharge for a given year in cfs at the Livingston gaging station
INSTQCORW is maximum instantaneous discharge for a given year in cfs at the Corwin Springs gaging station
MAXMDFLIV is maximum mean daily discharge for a given year in cfs at the Livingston gaging station
MAXMDFCORW is maximum mean daily flow in cfs for a given year at the Corwin Springs gaging station

From SYSTAT 8.03, Comments inserted into `original output.`

```
>USE "E:\Mike\Hydrology\Missouri River Basin\Yellowstone\LivCorw.SYD"
SYSTAT        Rectangular        file        E:\Mike\Hydrology\Missouri        River
Basin\Yellowstone\LivCorw.SYD,
created Mon Dec 25, 2000 at 11:16:42, contains variables:
 YEAR         INSTQLIV     GHLIV        MAXMDFLIV    YEAR2        INSTQCORW
 GHCORW       MAXMDFCORW

>REGRESS
>MODEL MAXMDFLIV = CONSTANT+MAXMDFCORW
>ESTIMATE
44 case(s) deleted due to missing data.

Dep Var: MAXMDFLIV   N: 64   Multiple R: 0.975232320   Squared multiple R: 0.951078079

Adjusted squared multiple R: 0.950289016   Standard error of estimate: 1.24004E+03

Effect         Coefficient    Std Error     Std Coef Tolerance     t   P(2 Tail)

CONSTANT      -8.42013E+02  6.08135E+02  0.000000000  .        -1.38458  0.17114
MAXMDFCORW     1.213959430  0.034966486  0.975232320  1.00E+00 34.71780  0.00000

                             Analysis of Variance

Source             Sum-of-Squares   df  Mean-Square     F-ratio       P

Regression           1.85342E+09     1  1.85342E+09 1.20533E+03 0.000000000
Residual             9.53370E+07    62  1.53769E+06
-------------------------------------------------------------------------------

*** WARNING ***
Case          29 has large leverage   (Leverage =  0.198907405)

Durbin-Watson D Statistic     1.517
First Order Autocorrelation   0.211
```

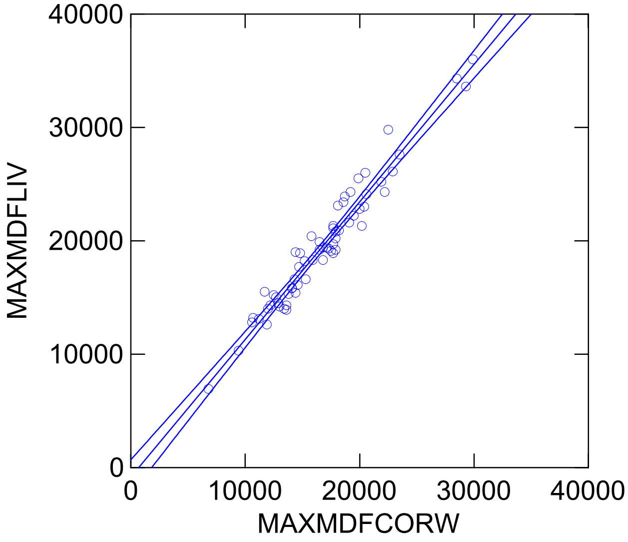
Comment: Case 29 is the 1918 flood and is not part of this regression data set, so it has no influence on this regression's calculations.

Plot of Residuals against Predicted Values



```
>PLOT MAXMDFLIV*MAXMDFCORW / SMOOTH=LINEAR  CONFI=0.950
```

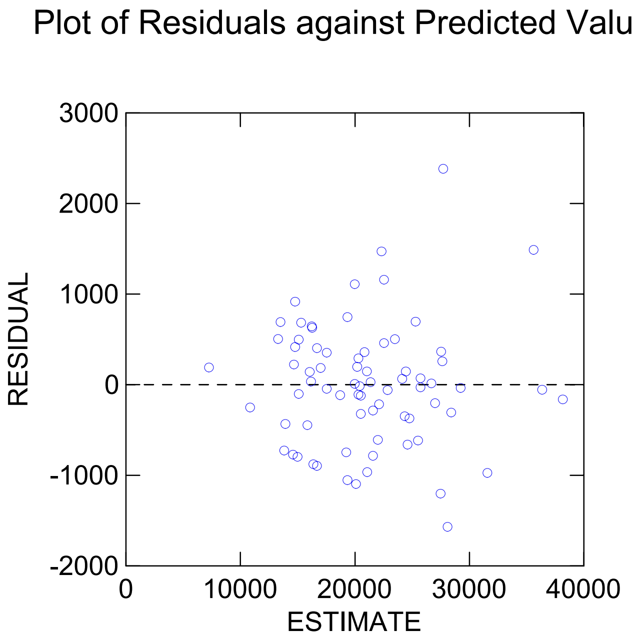
Comment: The graph below shows 95% confidence intervals for the regression line



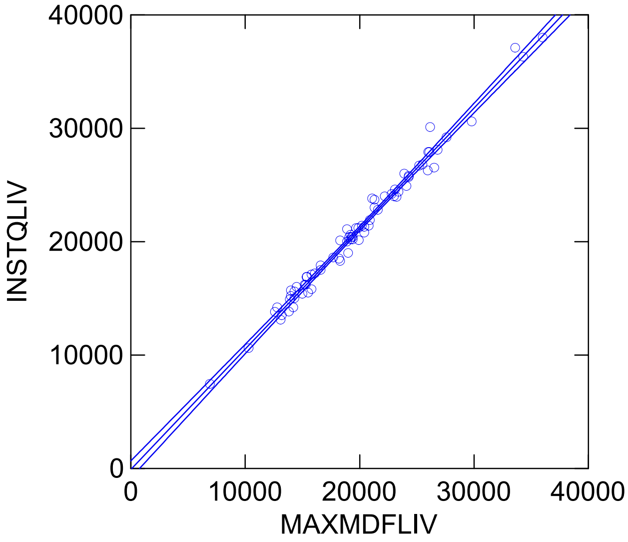
```
>MODEL INSTQLIV = CONSTANT+MAXMDFLIV
```

```
ESTIMATE
35 case(s) deleted due to missing data.

Dep Var: INSTQLIV   N: 73   Multiple R: 0.993340166   Squared multiple R: 0.986724685

Adjusted squared multiple R: 0.986537709   Standard error of estimate: 6.84918E+02

Effect          Coefficient    Std Error     Std Coef Tolerance     t   P(2 Tail)

CONSTANT      -9.28788E+01  3.01603E+02  0.000000000  .         -0.30795  0.75902
MAXMDFLIV      1.062686534  0.014628521  0.993340166  1.00E+00 72.64484  0.00000

                             Analysis of Variance

Source              Sum-of-Squares   df  Mean-Square     F-ratio       P

Regression            2.47563E+09     1  2.47563E+09 5.27727E+03 0.000000000
Residual              3.33070E+07    71  4.69113E+05
-------------------------------------------------------------------------------

*** WARNING ***
Case           13 is an outlier        (Studentized Residual =  3.866672385)

Durbin-Watson D Statistic     1.620
First Order Autocorrelation   0.188
```

Comment: Case 13 is the 1902 flood. Cook's distance (.2050) indicates slight influence.



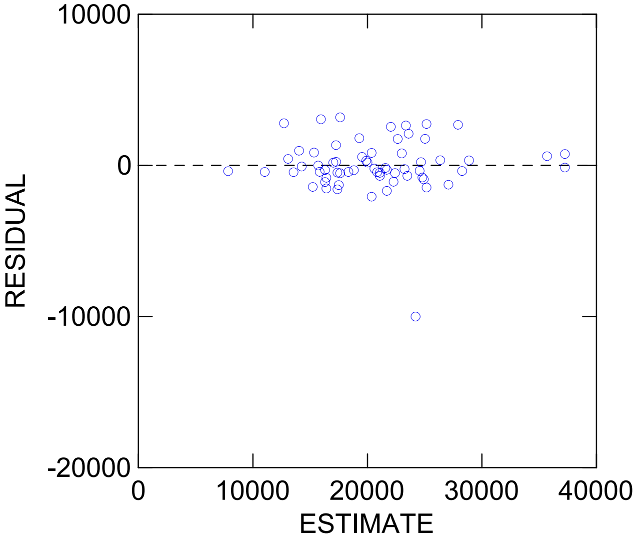
```
>PLOT INSTQLIV*MAXMDFLIV / SMOOTH=LINEAR  CONFI=0.950
```



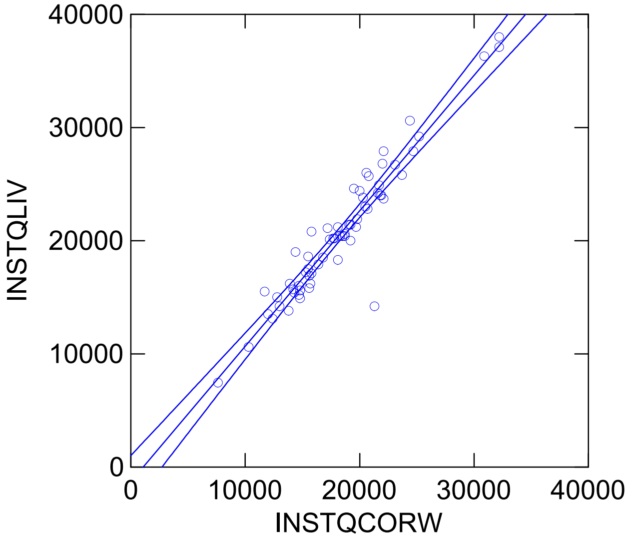
```
>MODEL INSTQLIV = CONSTANT+INSTQCORW


>ESTIMATE
44 case(s) deleted due to missing data.

Dep Var: INSTQLIV   N: 64   Multiple R: 0.953333892   Squared multiple R: 0.908845509

Adjusted squared multiple R: 0.907375276   Standard error of estimate: 1.81286E+03

Effect          Coefficient    Std Error     Std Coef Tolerance     t   P(2 Tail)

CONSTANT      -1.28071E+03  9.14635E+02  0.000000000  .        -1.40024  0.16643
INSTQCORW      1.196733674  0.048133303  0.953333892  1.00E+00 24.86290  0.00000

                             Analysis of Variance

Source              Sum-of-Squares   df  Mean-Square     F-ratio       P

Regression            2.03157E+09     1  2.03157E+09 6.18164E+02 0.000000000
Residual              2.03760E+08    62  3.28645E+06
-------------------------------------------------------------------------------

*** WARNING ***
Case           88 is an outlier        (Studentized Residual = -7.850010122)

Durbin-Watson D Statistic     1.965
First Order Autocorrelation  -0.007
```

Comment: Case 88 is the 1977 flood. Cook’s Distance (.3425) indicates that it is moderately influential.

Plot of Residuals against Predicted Values



```
>PLOT INSTQLIV*INSTQCORW / SMOOTH=LINEAR  CONFI=0.950
```



Appendix C. Repeat photography details.

Photographer	Photo #	Date	Photo point location	Photo Point Legal Description	Subject	Re-taken 2002	Re-taken 2001	Re-taken 2000
Barnett, V.H.	141	circa 1908	west of Livingston	?	plains, cottonwoods, Livingston Pk			
Barnett, V.H.	143	circa 1908	near Billman Creek	NE1/4 S27 T2S R9E	across plains towards mouth of 1st canyon	7/1/ 10:30		
Barnett, V.H.	142	circa 1908	mouth of first canyon	?	flood plain vegetation and channel			
Jackson, W. H.	68	1871	Allens Spur, east edge of 1st bench cliff	SE 1/4 S11 T3S R9E	Y River south of Allenspur Ridge, looking south	7/1/ 12:05		9/21, 9/29
Jackson, W. H.	1213	1872	Wineglass Mt., 2nd bench	SE 1/4 S11 T3S R9E	mouth of Suce Creek and ridges above	7/9 18:00		
Jackson, W. H.	1597	1872	Wineglass Mtn. 2nd bench	SE 1/4 S11 T3S R9E	Valley of Yellowstone	7/9/ 17:30		
Jackson, W. H.	213	1872	Allenspur Ridge, 2nd bench	SE 1/4 S11 T3S R9E	Yellowstone River (Y River) south of Allenspur Ridge	7/9/ 17:30		9/29
Jackson, W. H.	214	1872	Wineglass Mt., 2nd bench	SE 1/4 S11 T3S R9E	Y River south of Allenspur Ridge	7/9/ 17:30		
Jackson, W. H.	1212	1872	Wineglass Mt., 2nd bench	SE 1/4 S11 T3S R9E	Y River south of Allenspur Ridge	7/9/ 17:30		
Alden, W. C.	2239	1936	Pine Creek moraine	SE 1/4 S12 T4S R9E	Livingston Peak, moraine bench	7/24 14:30	8/2 18:14	
Alden, W. C.	2238	1936	Pine Creek moraine	SE 1/4 S12 T4S R9E	Y River and 1st canyon	7/2 18:20		9/29
Alden, W. C.	1150	1921	Along Old Yellowstone Trail, Eightmile Ck fan	SE1/4 NW 1/4 S2 T5S R8E	moraine/terrace along Trail Creek Road		7/1 18:30	
Alden, W. C.	1279	8575	west of Emigrant peak, between Big and Dry Crks.	NW1/4 SE1/4 S14 T6S R7E	Emigrant Peak and Yellowstone Valley	7/1/ 14:15		
Lee, W. T.	2388	1923	west of river opposite Emigrant Pk.	NW 1/4 SE 1/4 S8 T6S R8E	terrace, cottonwoods, Emigrant Pk		7/1 19:30	
Pardee, J. T.	928	August 1924	west of river opposite Emigrant Pk.	?	terrace, cottonwoods, Emigrant Pk			
Jackson, W. H.	961	1872	Bottler's Ranch	?	Emigrant Peak			
Pardee, J. T.	929	August 1924	East of mouth of Big Ck	S24 T6S R7E	eagle nest, pastures along Y River.	8/14 11:55		
Jackson, W. H.	919	1871	near Point of Rocks	S4 T 7S R7E	Y River near Donahue Crk. same as Walcott 539a	7/1 15:00		
Walcott, C. D.	539a	1898	near Point of Rocks	S4 T 7S R7E	Y River near Donahue Crk. same as Jackson 919	7/2 15:10	7/7 12:30	
Walcott, C. D.	539	1898	near Point of Rocks	S4 T 7S R7E	Y River south of Point of Rocks		7/7 12:00	
Alden, W. C.	1283	8578	Ridge above Tom Minor Creek	S1/2 NW 1/4/ S25 T7S R6E	Yankee Jim Canyon, Dome Mtn. on left		8/1 13:00	
Jackson, W. H.	920	1871	Yankee Jim Canyon near narrows, left bank	S4 T8S R7E	Yankee Jim Canyon		8/1 13:15 7/7 16:15	
Walcott, C. D.	539c	1898	Yankee Jim Canyon near narrows, left bank	S4 T8S R7E	Yankee Jim Canyon		8/1/1:30 7/7 15:30	
Lee, W. T.	2052	1921	Yankee Jim Canyon near narrows, left bank	S4 T8S R7E	Yankee Jim Canyon		8/1/13:40 7/7 15:30	
Jackson, W. H.	69	1871	south of Yankee Jim Canyon, near Corwin Springs	NW1/4 S11 T8S R7E	Y River south of Yankee Jim Canyon, looking northwest		7/7 17:00	
Jackson, W. H.	70	1871	same as W. H. Jackson 69	NW1/4 S11 T8S R7E	Approach to Cinnibar Mtn.		7/7 17:30	
Jackson, W. H.	71	1871	North East of Devils Slide	NE 1/4 S 31 T 8S R8E	Devil's Slide	8/1/11:15, 8/5 :10:30		
Jackson, W. H.	72	1871	North East of Devils Slide	NE 1/4 S 31 T 8S R8E	Devil's Slide	8/1/11:15, 8/5 :10:30		
Lee, W. T	2054	1921	North East of Devils Slide	NE 1/4S 31 T 8S R8E	Devil's Slide	7/2 14:00 7/1 16:30		
Alden, W. C.	1284	8578	North of Gardner, MT	N1/2 S 24 T9S R8E	Yellowstone valley near Gardiner, MT		7/7 18:00	

Note: bold dates denote scanned versions of color slides. Times for 8/1/02 are approximate

Appendix D. Cottonwood age distributions in 1948, 1976, and 1999.

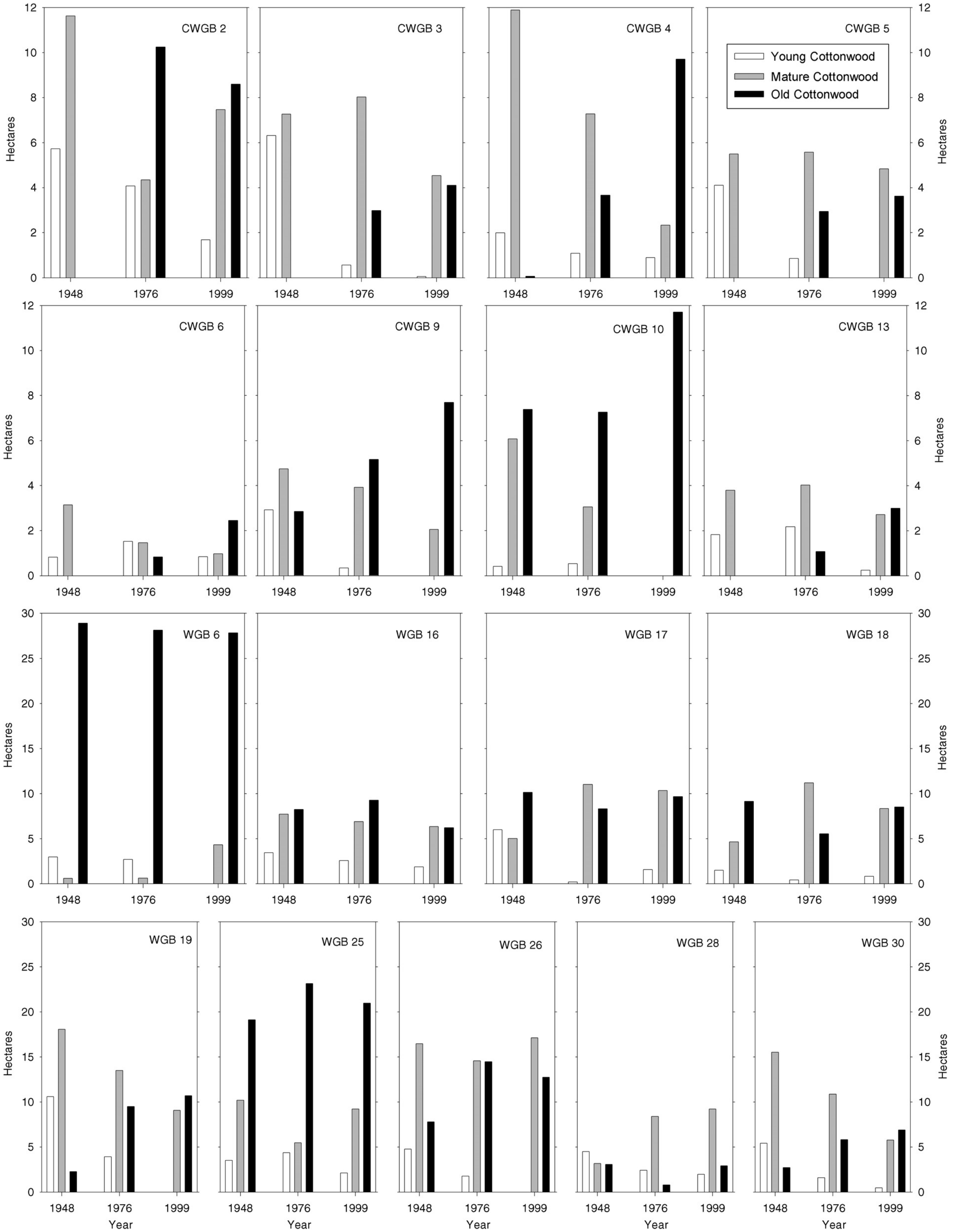


Figure D-1. Trend in cottonwood ages classes by sample plot. Common legend is at upper right, and age classes are: Young Cottonwood (20 to 40 yrs), Mature Cottonwood (41 to 100 yrs.), and Old Cottonwood, (>100 yrs.).