Effects of Damming and Flow Stabilization on Riparian Processes and Black Cottonwoods along the Kootenay River

Mary Louise Polzin and Stewart B. Rood
Department of Biological Sciences
University of Lethbridge
Alberta, Canada T1K 3M4

ABSTRACT: The Kootenay (Kootenai) River of British Columbia and Montana was dammed in 1972 by the Libby Dam that is operated for hydroelectric power and flood control. Subsequently, downstream flows have been stabilized below the prior 1-in-2-year peak discharge. Historical changes in the river valley were assessed using air photos from 1930, 1962/1963 and 1992/1994. Prior to damming, the upstream and downstream reaches involved dynamic channels with changing positions and an abundance of barren sand bars. Following damming, the lower Kootenay channel has become fixed in position and barren bars are deficient. Field surveys in 1996 and 1997 involved three sites along each of the upstream and downstream reaches of the Kootenay and two sites along the free-flowing tributary, the Fisher River. Cross-sectional transects were established up the stream banks, and elevation, vegetation, and substrate were surveyed. These confirmed the abundance of barren sand bars along the upper Kootenay versus cobble substrate and a lack of barren bars along the downstream reach. The free-flowing upper Kootenay and Fisher reaches experienced extensive sediment deposition in the riparian zones after the 1996 and 1997 high water (mean changes of 26 and 52 cm for 1997) whereas the lower Kootenay experienced minimal change (<7 cm). Abundant black cottonwood (Populus trichocarpa) recruitment occurred in 1996 and 1997 along the upper Kootenay and Fisher rivers (1997 densities of 536 and 142 seedlings/m²) but no seedlings were successfully established along the lower Kootenay. Grasses have encroached to the river’s edge along the lower Kootenay, further preventing cottonwood recruitment. Flow stabilization has thus resulted in channel stabilization, minimal cottonwood recruitment, and diminished deciduous shrubs along the lower Kootenay. The conservation of the riparian woodlands along the lower Kootenay would benefit from the reestablishment of more naturally dynamic flow patterns that would include occasional high spring flows.

KEY WORDS: Cottonwood seedlings, floodplain ecology, fluvial geomorphology, instream flow needs.

INTRODUCTION

Riparian zones, or river valley floodplains, are adjacent to and shaped by streams. These provide interfaces between terrestrial and aquatic ecosystems and are often particularly rich in wildlife abundance and biodiversity (Finch and Ruggeriro 1993). Studies along a number of rivers in western North America have revealed recent declines of riparian woodlands. One major cause of the riparian decline involves impacts due to river damming and downstream flow regulation (Rood and Mahoney 1990).

Much of the research investigating the decline of riparian woodlands following
damming has focused on streams in semi-arid regions of western North America (Johnson et al. 1976; Bracley and Smith 1986; Rood and Heinze-Milne 1989; Rood and Mahoney 1990; Snyder and Miller 1991; Stromberg and Patten 1992; Johnson et al. 1995). Due to the hydrologic linkages in semi-arid regions, modifications to streamflow have relatively direct effects on water table levels of the riparian zone. Consequently, the vulnerability of riparian woodlands to flow regulation is expected. It might seem likely that riparian woodlands in forested regions would be less vulnerable to damming and flow regulation. These regions generally involve “gaining” or effluent systems in which the water table of the riparian zone is largely dependent on groundwater inflow from adjacent upland areas and is less dependent on streamflow (Gordon et al. 1992). However, the stream also has other hydrologic and geomorphic influences and thus, damming and flow regulation would still have some effects on riparian processes.

Cottonwoods (Populus species) are generally the dominant trees of the riparian woodlands in western North America. Declines in cottonwoods following damming can be caused through a number of alterations. One common effect involves the loss of seedling recruitment sites that are created by erosion and deposition during spring floods (Johnson et al. 1976; Crouch 1979; Bradley and Smith 1984; Rood and Mahoney 1990; Scott et al. 1996). Dams often attenuate flood events thus limiting the formation of new recruitment sites. Flood flow attenuation may also allow flood-intolerant upland vegetation to encroach to the river’s edge and this may further diminish opportunities for the recruitment of cottonwoods and willows (Debano and Schmid 1990; Rood and Mahoney 1995). Because cottonwoods are relatively short-lived, surviving for one or two centuries, there must be ongoing replenishment to maintain the population; a failure of recruitment may lead to progressive population decline.

To gain insight into the role of dynamic streamflows on riparian processes along a river in a mountainous, Ponderosa pine (Pinus ponderosa Laws)—dominated dry-forest region, we examined riparian processes along the Kootenay River upstream and downstream from the Kootenosa Reservoir. We investigated hydrologic, geomorphic, and ecological changes that occurred after damming and assessed the relations between instream flow patterns, channel processes, cottonwood recruitment and survival, and other riparian shrubs and trees.

**STUDY AREA**

The Kootenay River originates in Kootenay National Park, British Columbia, Canada, and flows southward through southeastern British Columbia where it is joined by various tributaries that drain a number of Rocky Mountain ranges (Figure 1). The river crosses the Canada/United States border and turns westward to pass from Montana to Idaho. The river then flows northward to return to Canada and into Kootenay Lake and, subsequently, the Columbia River. The study reach was dammed for hydroelectric power generation and flood control in 1972 by the 134-m high × 916-m wide concrete Libby Dam. The resultant Koocanusa Reservoir extends for 144 km and has sufficient capacity to fully attenuate flood flows. The study focused on the river reaches upstream and downstream from this reservoir that straddles the Canada/United States border.

![Figure 1. Map of the East Kootenay watershed showing the Kootenay, Fisher and nearby rivers. The study areas are indicated by asterisks.](image-url)
Data Collection

Mean daily, monthly, and annual discharge data from 1914 to 1972 at station #08NC005 (Kootenay River at Wardner) and from 1963 to 1997 at station #08NC065 (Kootenay River at Fort Steele) were obtained through Environment Canada’s “Hydat” data base. Hydrologic data from 1911 to 1991 at station #12303000 (Kootenay River at Libby), from 1968 to 1994 at station #12301933 (Kootenay River below Libby Dam), and from 1969 to 1994 at station #12302055 (Fisher River near Libby) were obtained from Earthinfo’s U.S. Geological Survey data base, and 1996 to 1997 discharge data were obtained from the U.S. Army Corps of Engineers internet site. Flood recurrences were analyzed using the log Pearson Type III distribution, a commonly used distribution that fit the Kootenay River data reasonably well.

Daily temperature and precipitation data for 1996 were obtained from Environment Canada for the Cranbrook Airport, British Columbia, and from the U.S. Forest Service, Libby Ranger Station for Libby, Montana.

Historical Channel Patterns

We used aerial photos of the upper and lower Kootenay River reaches to analyze changes in channel position and pattern. Corroborating evidence was obtained from other aerial photos, as reported in Polzin (1998). We assessed channel change by overlaying 1960s air photo tracings with 1990s tracings. The changes along the middle of the channel were measured at 1-cm intervals on the tracings. On 8 August 1996, in a low-elevation (180 m) flight over the upper Kootenay River reach, we took oblique aerial photographs for analyses of channel changes after 1994.

Field Studies—Riparian Transects

Field studies were conducted along the upper Kootenay River from about 12 km south of Fort Steele, British Columbia (49°31’N, 115°33’W), to the British Columbia Highway #3 Bridge near the upstream end of Koocanusa Reservoir (Figure 1). The downstream study reach extended from the outflow of Libby Dam to about 5 km upstream of Troy, Montana (48°26’N, 115°50’W). To provide another control comparison, we also established study sites along Montana’s free-flowing Fisher River that joins the Kootenay River between the Libby Dam and the town of Libby. Study sites along the Fisher River were situated about 5 km upstream from its confluence with the Kootenay (48°19’N, 115°18’W). Our field studies were primarily conducted from May to October 1996, and from April to October 1997; we also visited all sites in October 1998.

We began the field studies by conducting reconnaissance surveys by vehicle and raft to observe general features of the entire river reaches. Subsequently, we selected suitable study sites that were accessible, had minimal effects from livestock or human developments, and appeared to be typical of the reach. Three such study sites were established along the upper and lower Kootenay River reaches and included gradually sloping banks of point bars along meander lobes, which are prominent zones for cottonwood and willow recruitment (Braatne et al. 1996).

Three cross-sectional belt transects were established at each study site. One transect was positioned at the approximate apex of the meander lobe and the other lines were established on either side at typical distances of 50 to 100 m. For each transect, a mature black cottonwood (Populus trichocarpa Torr. and A. Gray) was selected to serve as the transect anchor and identified with a numbered metal tag. A tape measure was extended from the tree to the river’s edge and positioned perpendicular to the direction of dominant streamflow. One meter long iron rebar stakes were positioned near the river’s edge to enable repositioning of the transect lines. Some transects were established without rebar due to subsurface cobble and boulders on the lower Kootenay reach and several rebar stakes were toppled or buried after the spring peak flow in 1997 along the upper Kootenay River. All lines had sight points established across the river for transect realignment. Despite this, transect lines could not be precisely reestablished and repositioning of the quadrats and staff gauge varied by a few centimeters during the repetitive visits.

Two meander lobe study sites were similarly established along the Fisher River. Two transects were established at Fisher River, site 1, and three transects were established at site
2. All rebar along the Fisher River was buried or toppled in 1997 and both tagged trees at site 1 were uprooted by the 1997 peak flow.

A total of 22 transects (9 along the upper Kootenay, 8 along the lower Kootenay, and 5 along the Fisher) were established. These were surveyed for elevation using a transit and staff gauge in spring 1996 (May: upper Kootenay; June and July: lower Kootenay), and resurveyed in September and October 1997 and October 1998. Cottonwood densities and sizes were determined within 20-cm x 50-cm (0.1 m²) quadrats that were positioned at locations where seedling bands intersected transect lines. In total, 87 quadrats containing cottonwood seedlings (56 along the upper Kootenay and 31 along the Fisher) were established along 14 transects. These were revisited to assess seedling growth and survival. No surviving seedlings and, thus, no quadrats occurred along the 8 lower Kootenay transects. Along all transects, surface substrate texture and plant species and abundance (proportion cover) were assessed within 1-m wide belts with sequential 1-m long quadrats. Larger 4-m long x 10-m wide quadrats were superimposed for assessments of shrub and tree cover. Taxonomic treatment of trees follows that reported in Farrar (1995) and other plants are designated in accordance with Moss (1977). The positions of the stream edge along transects were recorded at each site visit to permit site-specific stage-discharge analyses.

Mature trees that occurred along transects were aged by ring counts from increment cores extracted 25 cm above the substrate surface. Densities of saplings (juveniles) were determined in 2 m² quadrats (1 m length x 2 m width) along and beside the transects with ten quadrat samples for each sapling patch. Saplings were aged by counting the number of annual growth scars along main stems and by counting rings from cross-sectional cuts.

Floodplain positions are expressed relative to a reference position corresponding to the estimated position of the river’s edge at base flow. Base flow was established as the typical flow for mid-October, the end of the cottonwood-growing season (81 m³/s, 0.505 m on gauge for the upper Kootenay; 170 m³/s, 5.6 m on gauge for the lower Kootenay). These base flows were then converted to base stages using discharge/stage ratings curves for the Fort Steele, British Columbia, and Libby, Montana, gauging stations combined with actual river positions during the study when stages were assessed relative to the current discharges. Base-stage elevations were set to ‘0’ and all surveyed transect elevations are expressed relative to these base stages.

RESULTS AND DISCUSSION

Hydrology

To assess hydrologic changes, we analyzed pre- and post-dam discharge patterns. These included comparing annual flow patterns along the upstream and downstream reaches prior to the dam, comparing the seasonal hydrographs and the timing of pre-dam peak flows with the post-dam peaks, and comparing upstream versus downstream flows during flood events that occurred after Libby Dam had been installed.

Predictably, discharges between 1914 and 1971 had greater peaks at Libby compared to Wardner, due to contributions from free-flowing tributaries, especially the Elk River (Figure 2). Prior to construction of Libby Dam, annual peaks along both upstream and downstream reaches occurred between late May and early June and occasional peaks occurred in early May or mid-June (Figure 2). In contrast, the post-damming downstream peaks typically occurred from late October to early January during periods of high electric power demands in the Pacific Northwest. The mean

![Figure 2. Mean monthly discharge of the reaches of the Kootenay River, upstream (Wardner, British Columbia gauging station 08NG005, 1914 to 1997) and downstream (Libby, Montana gauging station 12363000, pre-dam: 1914 to 1971; post-dam 1972 to 1997) of Libby Dam.](image-url)
post-dam spring peak was about 250 m³/s (Figure 2), approximately one-half of the post-dam winter peak. This reversal of peak seasonality coupled with the lower discharges during spring peak periods has resulted in an inverted hydrologic regime along the lower Kootenay River.

After completion of Libby Dam in 1972, no flooding has occurred downstream (Figure 3).

The 1974 upstream flood exceeded a 1-in-200-year event along the free-flowing upstream reach and would probably have been at least a 1-in-100-year event at Libby and possibly exceeded the 1916 flood without flow attenuation by the Koocanusa Reservoir. This demonstrated the capability of the Libby Dam and Koocanusa Reservoir to fully attenuate major flood events.

![Figure 3. Annual peak discharges for the Kootenay River at (top) Wardner, British Columbia, gauging station 08NG005 and (bottom) Libby, Montana, gauging station 12303000 (1914-1991) and 12301933 (1991-1997). The 1-in-2, 1-in-10, and 1-in-100-year flood recurrence values (1914-1971) are plotted, based on a log Pearson Type III distribution.](image)

**GEOMORPHOLOGICAL CHANGES**

**Historical Channel Patterns**

Studies of other river systems have shown that dams that attenuate spring peaks have affected downstream riparian processes (Bradley and Smith 1984; Williams and Wolman 1984; Debano and Schmidt 1990; Rood and Mahoney 1990; Rood and Mahoney 1995; Scott et al. 1996). The main changes with respect to fluvial geomorphology generally include (1) reduced channel meandering, (2) channel narrowing, and (3) sediment trapping by reservoirs that results in fine sediment removal to produce coarser substrate textures of the channel and stream bank.

One means of assessing changes in channel meandering is to examine sequential historical air photos. The 30-year (1962/1963 - 1992/1994) comparison revealed that the free-flowing upper Kootenay River showed progressive meandering with erosion of the concave banks accompanied by deposition on the inside meander lobe point bars. In contrast, the lower Kootenay River channel position was relatively static. Analysis also revealed that in-channel bars and islands became attached to stream banks producing some channel narrowing along the lower Kootenay River. The mean change in the apparent thalweg position over the 30-year period along the upper Kootenay was 18.2 m (SD= 1.2 m), five-fold greater than along the lower Kootenay (3.7 m (SD= 0.3); t-test: t=5.99, df=63, P<0.001)). Air photos from 1930 were also evaluated and a comparison of these with the 1963 photos revealed that the lower Kootenay River reach had been more dynamic prior to damming (Polzin 1998).

Cross-sectional elevations along transect lines were used to investigate the extent of annual deposition and erosion along the Kootenay River. Figure 4 (bottom) shows one of the eight transects along the lower Kootenay River;
the others showed similarly minor changes in surface elevation (all transects are presented in Polzin 1998). Some apparent minor changes were due to imprecise staff gauge repositioning and the largest apparent changes occurred along the three transect lines where rebar was not established due to coarse cobble. Mean elevation change for the lower Kootenay River sites was 6.7 cm (SD= 7.9, N=77). If the three transect lines with repositioning problems are excluded, the mean change was 4.7 cm, but even this value is probably an overestimate.

In contrast to the static surface elevations along the flow-attenuated lower Kootenay reach, the free-flowing upper Kootenay demonstrated substantial bank change due to scour and deposition (Figure 4, top). Some measuring points along the upper Kootenay transects had up to 1 m of elevation change, whereas the maximum along the lower Kootenay was 18 cm. The mean elevational change along the upper Kootenay transects was 26 cm (SD=22, N=121), significantly different (ANOVA: F=51.4, df=1, P<0.0001) and about four-fold greater than that along the lower Kootenay River.

The free-flowing Fisher River served as another control reach for the lower Kootenay, and the Fisher sites experienced substantial scour and deposition. The Fisher has coarser substrate than the upper or lower Kootenay and, unlike the low gradient study reaches of the Kootenay, the high gradient Fisher River reach had sufficient velocities during peak flows to transport this larger material. The Fisher River transects showed greater elevational change than the lower and even upper Kootenay reaches (mean change = 51 cm (SD=46, N=54); ANOVA comparison with lower Kootenay: F=70.8, df=1, P<0.0001).

Surface Substrate

The surface substrate along the lower Kootenay River was strikingly different from that along the free-flowing upper Kootenay (Figure 5). The upper Kootenay stream banks were covered with fine substrate of sand and silt with no exposed cobble or rock along the study reach meander lobes. The lower Kootenay had only coarse textured cobble-covered sites; no fine substrate covered bars were observed from the Libby Dam to Troy, Montana, except for a single sand bar right below the Fisher River confluence.

A century ago, surveyor Mumbrue (1893) reported extensive sandy beaches along with some areas of cobble and rocky beaches, along the lower Kootenay River. Similarly, longtime residents from the Libby area reported an abundance of sandy beaches along the lower Kootenay River prior to damming (Polzin 1998).

We attribute the loss of fine substrate along the lower Kootenay River to the Kooxcnusa Reservoir and Libby Dam. This large reservoir slows flows allowing suspended materials to settle out (Williams and Wolman 1984). Sediment-free water is released downstream and has a high capacity to scour and transport preexisting sediment. Consequently, small particles are progressively removed, leaving
the underlying gravel and cobble as the channel and stream-bank substrate. This phenomenon of the "silt-shadow" is well-documented and can extend for hundreds of kilometers before sediment loads recover (Williams and Wolman 1984).

Not only does the reservoir act as a sediment trap, it also traps woody debris flushed downstream from tributaries and the main river. A major source of woody debris for the lower Kootenay River is the Elk River. The steep gradient and narrowness of the Elk Valley results in many streamside trees being undercut and toppled into the river where they are tumbled, shearing branches (Polzin 1998). The Elk River enters the Koochane Reservoir that prevents further passage of this debris. Because black cottonwoods can reproduce asexually through branch fragments (Braatne et al. 1996), this trapping of woody debris reduces one form of propagation of cottonwoods and willows from the lower river (Figure 5).

Branches and tree trunks also act as sediment traps when they are deposited during receding flows. The tributaries of the lower Kootenay River, including the Fisher River, add relatively little debris to the lower Kootenay. Thus another consequence of river damming is the depletion of large and small woody debris that influence both geomorphic and ecological processes.

![Photographs at river level along the free-flowing upper Kootenay River (top, 19 Aug. 1997) and along the flow-stabilized lower Kootenay River (bottom, 24 Sept. 1997). Along the upper Kootenay (top), cottonwood samplings and willows dominate the zone of shorter vegetation closest to the meander lobe apex. A barren sand bar occurs at the water's edge with branch fragments including some that have produced adventitious roots. Along the lower Kootenay (bottom), coarse cobble substrate dominates, grasses have encroached to the typical stream edge and there is a lack of willow and cottonwood saplings in the riparian recruitment zone.](image)

**VEGETATION ECOLOGY**

**Cottonwood Seedling Recruitment**

The maintenance of cottonwood stands relies partly on seedling replenishment that is dependent on a dynamic hydrologic regime (Bradley and Smith 1984; Rood and Mahoney 1990; Stromberg and Patten 1991; Rood and Mahoney 1995; Braatne et al. 1996; Scott et al. 1997; Mahoney and Rood 1998). Dynamic flow patterns with periodic flood events provide the physical disturbances that produce barren, moist recruitment sites that are suitable for cottonwood seedlings.

The lower Kootenay River no longer supports naturally dynamic hydrologic and geomorphic processes. As a consequence, virtually no sediment deposition or scour occurred

![Vegetation cover (%) versus distance from the river on transects along the Kootenay River in 1996 on three meander lobs upstream and downstream from the Libby Dam. The 0 distance is the position of the river's edge at base flow.](image)
on the meander lobes and lateral bars during the two years of this study (Figure 4). The loss of disturbance and lack of periodic inundation has also led to the encroachment of flood-intolerant upland vegetation into the obligate riparian zone along the lower Kootenay River. This contrasts sharply with the extensive vegetation-free streamside zones along the upper Kootenay (Figures 5 and 6).

Cottonwood seedlings were abundant in 1996 and 1997 on the barren bars along the free-flowing upper Kootenay and Fisher rivers (Figure 7). This supports the conclusion that barren recruitment sites and appropriate hydrograph patterns are essential for cottonwood and willow seedlings (Mahoney and Rood 1998; Rood et al. 1998; Rood et al. 1999). Seedlings were established between 10 and 40 m from the position of the river’s edge at base flow in areas with 10% or less vegetation cover for the upper Kootenay. Seedlings were established between 1 and 3.8 m in elevation above the base stage along the upper Kootenay River (Figure 7), an elevational range consistent with the “Riparian Recruitment Box” model (Mahoney and Rood 1998). Vegetation-free zones from 5 to 27 m from the river’s base position along the Fisher River were suitable sites for cottonwood seedling establishment with seedling elevations ranging from 0.4 to 1.2 m (Figure 7). This lower elevational band along the Fisher versus the upper Kootenay River is consistent with the typically reduced stage change magnitude along smaller rivers and with the coarse Fisher substrate that provides less moisture retention and capillarity than the sand and silt of the bars along the upper Kootenay.

There was no seedling survival observed at the lower Kootenay sites and this provided a dramatic difference between the free-flowing and flow-regulated reaches (Figure 7). Upland vegetation, particularly dense grasses with 80 to 100% cover (Figure 6), had encroached along the lower Kootenay River. This eliminated the barren recruitment sites and would have contributed to the lack of cottonwood seedling survival along the lower Kootenay. The lack of a suitable stage pattern has also contributed to the deficiency of seedlings; appropriately timed peak flows followed by gradual drawdown are critical for cottonwood seedling survival (Mahoney and Rood 1998).

Juvenile and Mature Cottonwoods

Along the lower Kootenay River, mature cottonwoods were restricted to narrow bands (6.5 to 26 m wide) along the back of the meander lobes. Increment core age determinations revealed that these mature trees ranged from 30 to 100+ years old, indicating establishment prior to the Libby Dam. The lower Kootenay sites did not have a full range of age (size) classes of cottonwoods as few juveniles occurred at any of the sites.

The upper Kootenay reach also had mature trees, ranging in age from 40 to 100+ years for the trees sampled, but these were found in wide and extensive bands (Figure 8). Bands of juvenile cottonwood saplings mixed with willows (Salix sp.) also occurred along the streamside of the bands of mature trees at the upper Kootenay sites. This same banding pattern was also found along the Fisher River, with mature trees from 60 to 90+ years old, and bands of juveniles from 6 to 20+ years old closer to the stream. The extensive initial seedling recruitment that occurred in 1996 and 1997 along both the upper Kootenay and Fisher rivers will probably further contribute to the replenishment of these populations.
and most occurred in sparse bands within about 1 m from the "drip line" of mature cottonwoods, the area below the outermost branch tips. Dense grasses surrounded the clonal saplings.

The other sites along the lower Kootenay River had juvenile saplings that occurred in patches rather than in bands and on the lower elevation areas of the meander lobes. Twenty juveniles were excavated at each site and all were linked to lateral roots indicating root sucker origin. These clonal shoots ranged from 1 to 9 years of age with heights from 0.4 to 3.4 m. In these sapling patches, clonal densities averaged 5.7 stems/m².

The upper Kootenay River also had numerous juveniles of root sucker origin that were confirmed by excavation. Some were found along narrow bands about 1 m from the drip line of the mature trees, but the majority of the juveniles were mixed with willows forming dense arcuate bands along the outer areas of the meander lobes. Some of the juvenile saplings (from 3 to 8 years) near the open beaches were excavated and found to be mainly of seedling origin. There was one 4-year-old root sucker originating from a 6-year-old of seedling, indicating the capability of suckering early in the cottonwood life cycle. The excavated saplings typically had from 1 to 3 years of stem growth buried with deposition.

Other Riparian Vegetation

Historical survey notes by Mumbrue (1893) and Bickel (1898) reported that cottonwood trees on most of the meander lobes along the lower Kootenay River were mixed with mountain alder (Alnus incana ssp. Tenuifolia (Nutt.) Breit.), western red-cedar (Thuja plicata Donn ex D. Don) and a dense understory of shrubs. The surveyors consistently noted that closer to the stream there were dense bands of willow, cedar and cottonwood saplings. The historical vegetation association along the lower Kootenay apparently resembled that presently found along the upper Kootenay with the exception of the cedar.

In contrast, these species assemblages are now scarce along the lower Kootenay River (Figure 8). During our study, most of the meander lobes had very sparse shrub communities and lacked the mixed stands of willow, cedar, and cottonwood saplings (Table 1). The narrow bands of mature cottonwoods along
Vegetation cover (%) of trees and shrubs in riparian zones along the upper and lower reaches of the Kootenay River. Position 0 represents the transect anchor tree situated at the river side edge of the zone of mature cottonwoods and increasing values indicate progression toward the river. Each value is the mean from nine, 4-m long x 10-m wide quadrats (3 transects from each of 3 sites).

Trees and shrubs were black cottonwood (Populus trichocarpa), trembling aspen (Populus tremuloides), sandbar, Mackenzie's and Pacific willows (Salix exigua, S. prolixa, S. lucida), water and paper birch (Betula occidentalis, B. papyrifera), mountain alder (Alnus incana), red osier dogwood (Cornus stolonifera) and a mix of conifers, especially Engelmann spruce (Picea engelmannii) along the upper Kootenay and Ponderosa pine (Pinus ponderosa) along the lower Kootenay. An additional shrub, Columbia hawthorne (Crataegus columbiana T. J. Howell) was found in some upper Kootenay position 0 quadrats (4.7%). Total cover can exceed 100% due to the combination of understory (shrub) cover plus tree canopy cover.

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The lower Kootenay were associated with some of the same shrubs and small trees that historically occurred and still persist along the upper Kootenay, but densities were greatly reduced along the lower Kootenay. There were only a few alders, and water and white birch (Betula occidentalis Hook., and B. papyrifera Marsh.) occurrence was less than one- half of that along the upper Kootenay. Red-osier dogwood (Cornus stolonifera Michx.) generally consisted of single bushes rather than dense patches or bands as found along the upper Kootenay (Table 1). Douglas maple (Acer glabrum Torr. var. douglasii) and white Clematis (Clematis ligusticifolia Nutt.) occurred rarely and their densities were also lower along the lower Kootenay River.

Along the upper Kootenay, the abundant cottonwood saplings were mixed with deciduous shrubs including dogwood and various willows such as sandbar willow (Salix exigua Nutt.), Mackenzie's willow (S. prolixa Andersson), Pacific willow (S. lucida ssp. lasiandra (Benth.) E. Murra), and willow hybrids. In contrast, the small patches of cottonwood saplings along the lower Kootenay were generally mixed with conifer saplings including ponderosa pine, grand fir (Abies grandis (Dougl.) Lindl.), Douglas fir (Pseudotsuga menziesii (Mirb.) Franco var. glauca (Beissn.) Franco), western larch (Larix occidentalis Nutt.) and Rocky Mountain juniper (Juniperus scopulorum Sarg.).

It should be recognized that livestock grazing can dramatically alter shrub composition along streams. However, cattle were rarely observed in the study sites and fecal pads were scarce.
indicating minimal grazing pressure from livestock. Further, the consistent and widespread patterns along the downstream versus upstream reaches also supported impacts due to damming and flow regulation rather than grazing or other site-specific human impacts.

Another possible confounding factor was also considered—climatic differences across the study areas that were 200 km apart. However, temperatures were very similar near the upper and lower Kootenay sites during the study and precipitation was also generally similar, although the lower Kootenay receives slightly more winter precipitation (Polzin 1998). Thus, the patterns observed across the study sites were probably not caused by differences in weather and climate.

CONCLUSION

The operation of Libby Dam attenuates spring flood flows and releases maximal flows during the winter when power demands are greatest. These hydrologic changes combined with sediment trapping by the reservoir have resulted in geomorphological and ecological changes that include (1) reduced channel movement, (2) depletion of fine sediments, (3) scarcity of woody debris, and (4) the encroachment of upland vegetation into the recruitment band of the riparian zone. These hydrologic, geomorphic, and vegetation changes have combined to exclude seedling recruitment, which has contributed to dramatic decreases in young cottonwoods and willows.

Some limited clonal recruitment of cottonwoods has persisted downstream, producing patches of juveniles originating from root suckers. However, this recruitment model is sparse and spatially limited. Besides influencing the cottonwoods, the understory shrubs along the lower Kootenay River have also been reduced as a consequence of damming and flow regulation.

Although seedling recruitment has been deficient along the lower Kootenay River following the commissioning of Libby Dam, it has persisted along the free-flowing upper Kootenay River and the Fisher River. This indicates that the lack of cottonwood recruitment along the lower Kootenay is neither symptomatic of a general recruitment deficiency in the river basin nor reflective of regional conditions, such as climatic patterns. Instead, the lack of seedling recruitment and the subsequent population imbalance along the lower Kootenay River is probably due to the presence, and particularly the pattern of operation, of Libby Dam.

Further reductions in cottonwoods, willows, and deciduous shrubs will result in the progressive change in the riparian woodlands along the lower Kootenay River and will generally diminish wildlife habitat. The conservation of the riparian cottonwood forest ecosystems downstream from Libby Dam will probably rely on the recovery of more natural and dynamic instream flow patterns that include occasional high flows in late spring.

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M. L. Polzin and S. B. Rood


