RIVER AND RIPARIAN DYNAMICS AND BLACK COTTONWOODS IN THE KOOTENAY RIVER BASIN, BRITISH COLUMBIA AND MONTANA

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Abstract

The black cottonwood, *Populus trichocarpa*, provides the foundation for the riparian woodlands throughout southern British Columbia (B.C.) and western Montana (MT). To study the interaction of riparian dynamics and cottonwood ecology, the present study investigated the influence of the extreme 1995 Elk River flood on the riparian zone and cottonwood ecology, and the effects of flood flow attenuation by the Libby Dam on riparian processes and cottonwoodland ecology of the Kootenai(y) River. Four river reaches were studied: the free-flowing Elk River near Fernie, B.C., the free-flowing Upper Kootenay River, B.C., upstream from the Koocanusa Reservoir, the free-flowing Fisher River, MT, near the Kootenai junction, and the flow-attenuated Lower Kootenai River near Libby, MT.

Air photos from 1930, 1962, 1992 and/or 1994 revealed substantial channel change and the development of barren point bars that served as recruitment sites for willows and cottonwoods along the free-flowing reaches. Conversely, the Lower Kootenai had a relatively static channel after damming. In total, thirty-five transects were studied in 1996 and 1997 at 3 sites along each river reach to assess elevation profiles, substrate composition, scour and deposition, vegetation patterns, and aspects of cottonwood reproduction. Abundant cottonwood recruitment occurred in 1996 and even more so in 1997, producing mean densities of 153, 536, and 142 seedlings/m^2 along the Elk, Upper Kootenay, and Fisher river transects, respectively. In marked contrast, no seedlings were successful along the Lower Kootenai River, downstream from the Libby Dam. The free-flowing river reaches experienced extensive sediment deposition in the riparian zone after the 1997 high water, whereas the Lower Kootenai experienced little change in stream bank configuration. The Elk River study revealed that the 1995 flood caused considerable geomorphic change and

the resultant unconsolidated deposits were easily scoured and transported during the subsequent two years providing abundant sites for new cottonwoods. The Kootenay River study revealed limited meandering and deposition along the flow-attenuated Lower Kootenai River compared to the hydrologically, geomorphologically, and ecologically dynamic, free-flowing upstream reach.

Along the Lower Kootenai River, there was a deficiency in black cottonwood population age structure due to limited recruitment. Flood-intolerant, upland plants have encroached to the river's edge, further eliminating cottonwood recruitment opportunities along the Lower Kootenai River. The vegetation encroachment, the static channel configuration, the minimal scour and sediment deposition and the lack of the essential stream stage pattern, combine to underlie the lack of seedling recruitment and the consequent deficiency in cottonwood population structure along the Lower Kootenai River.

The studies demonstrate that black cottonwoods require a dynamic hydrologic and geomorphic system with periodic flood events for continued replenishment. The observed loss of cottonwood recruitment along the Lower Kootenai River is thus the consequence of the flood flow attenuation due to the operation of the Libby Dam. The restoration of the Lower Kootenai cottonwoods will probably rely on a partial recovery of more natural and more dynamic instream flow patterns that include occasional high flows in late spring followed by gradual stage recession. Such flows would exclude upland vegetation, recover more dynamic geomorphic processes and provide the stream stage patterns that are directly essential for cottonwood seedling recruitment.

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Table of Contents

List of Tables

List of Figures

Chapter 1 Fluvial Geomorphology of Mountain Streams and Black Cottonwood Reproduction.

Introduction

British Columbia is dominated by coniferous forests with deciduous forests occurring mainly in the riparian zones, river valley floodplains. Riparian ecosystems are adapted to and dependent upon fluvial processes including periodic flooding. Riparian vegetation generally includes woody plant species, particularly willows (*Salix* species) and cottonwoods (*Populus* species). In western North America, cottonwoods are usually the dominant plant in riparian zones and provide the foundation for cottonwood forests or woodlands.

Assets of Riparian Woodlands

Riparian zones are adjacent to, and shaped by, streams; providing an interface between terrestrial and aquatic ecosystems. Riparian woodlands typically support the highest densities and diversities of wildlife including abundant bird populations (Finch and Ruggeiro 1993). The cottonwood trees provide nesting sites and food, especially insects, for birds. The deciduous plants of the riparian woodlands provide leafy foliage for herbivores as well as twigs and buds that offer important winter forage (Gregory et al. 1991). Beavers utilize the riparian zones as they prefer eating the inner bark of willows and for dam construction. Riparian zones also provide corridors for animal movement as well as for the dispersal of plants (Stanley et al. 1991).

Riparian zones modify the amount, form, and timing of nutrients exported from watersheds. These zones are uniquely situated to intercept surface and soil solutions as they pass through riparian zones before entering the stream channel. For example, riparian forests consisting mainly of cottonwood trees, are responsible for the removal of more than three-quarters of the dissolved nitrate transported from adjacent croplands (Gregory et al. 1991). This is especially important in a mountainous setting where many of the flood terraces along rivers have been cleared for cattle grazing and croplands. The riparian zone also delivers seasonal pulses of dissolved leachates derived from terrestrial litter into streams and rivers. It provides repositories for sediment, serving as a nutrient sink for the surrounding watersheds and as a key recharge point for renewing ground water supplies (Brinson 1990, Debano and Schmidt 1990, Stanley et al. 1991).

Cottonwoods, the foundation of riparian woodlands, stabilize riverbanks and islands (Debano and Schmidt 1990). The woodlands enhance fish habitat by providing a rich source of nutrients for caddis flies, mayflies and other insects that provide food for trout. The trout and other fish provide valued recreational resources and additionally, much of the world's freshwater fish production occurs in large floodplain rivers (Stanley et al. 1991). Cottonwoodlands modify solar inputs by shading which reduces stream temperatures, thus allowing cooler water temperatures during hot summers, which is beneficial to the fish populations (Debano and Schmidt 1990).

Fluvial Geomorphology

Fluvial geomorphology is the study of land forms produced by stream action. This study deals with alluvial streams. Alluvium is clay, silt, sand, gravel or similar detritus material deposited by running water. Rivers with alluvial bed channels are self-formed, resulting from the erosion (entrainment), transportation and deposition of the unconsolidated sedimentary materials of the valley, and floodplain deposits across which they flow (Richards 1982). Alluvial channels experience the majority of channel morphological changes during high water and flood events. The riparian woodlands have adapted to and are dependent on these fluvial geomorphological changes

Floods

In many areas, peak stream flows occur in spring, usually from mid-May to early June due to the spring melt of the mountain snow pack combined with spring rains. This spring peak is generally followed by a progressive decline in discharge during the summer and fall. The minimum flows often occur during the winter months of December through March (Rocchini et al. 1976a).

Periodic floods are responsible for the geomorphic transformations that occur at the riparian zone interface (Bull 1988). The major geomorphic transformations are channel shifts, channel size changes, erosion of floodplains and terraces, sediment depositions (the building up of floodplains), and vegetation removal and establishments (Brinson 1990, Rood and Mahoney 1990). These geomorphic transformations will affect the ecology of a stream by rearranging streambed habitats. The sediment deposition replenishes topsoils and nutrient supplies on the floodplains providing fertile ground for vegetation (Brinson 1990). Floods also recharge the water table which is important to the riparian groundwater supply (Rood and Mahoney 1990).

High flows and floods create nutrient rich shallow waters over the floodplains for a short period of time. This increases nutrients because floods scour away aquatic and riparian plants and leaf litter thereby increasing the drift of aquatic insects and nutrients. Aquatic animals migrate to this calmer water to feed and some species of fish, including various endangered fish species like the white sturgeon, use this as a cue for spawning (Gordon et al. 1992). Exceptional flood events create major modifications to the riparian landscape, accelerating all of these processes. The erosion and deposition levels increase with the increase of river discharge (Komar 1988).

There are a number of causes of floods in cold regions. Rapid snow melt, rainstorms, and a mixture of both (rain on snow) are the main causes of flooding. Mixed events can occur as spring rain on snow and autumn-winter rain on snow. Rain on saturated or frozen soils is also a common cause of floods. Ice jams during spring breakup on the river can also produce floods although these are not usually associated with annual peak flows. This study deals only with the floods that occur during the spring peak flows. The three main causes of these events are rapid snow melt, rainstorms and spring rain on snow and/or on frozen, or saturated soils. Spring rain on snow may yield a flood sequence somewhat greater than the mean flow associated with snowmelt (Church 1988).

Erosion

In many areas the spring peak flow is the driving force behind the fluvial geomorphic processes of erosion, transport and deposition which shape the riparian landforms and enable recruitment of pioneer vegetation. The magnitude and length of time of the flood influences the amount of erosion that occurs (Bull 1988).

Erosion by a stream is the progressive removal of mineral material from the floor and sides of the channel. Streams erode in various ways, depending on the nature of the channel materials and the 'tools' with which the current is armed. The hydraulic force of flowing water, exerts impact and a dragging action upon the bed, which erodes poorly consolidated materials such as gravel, sand, silt and clay (Strahler and Strahler 1973).

In an alluvial river, capacity for bedload movement increases sharply with the stream's velocity, because as velocity increases so does the turbulence and drag force on the bed. Bedload capacity increases up to the third or fourth power of the velocity (Strahler and Strahler 1973). As flood waters rise, they erode the most susceptible parts of the bed and bank. When the flood subsides, sediment deposits on the channel sides and floor filling the previously scoured areas (Gordon et al. 1992).

Stabilization

Vegetation plays an important role in the process of erosion. Scouring may not occur on vegetated banks with just moderately high flows as the vegetation stabilizes the banks (Gregory et al. 1991). Cottonwoods have a greater network of roots than grasses and stabilize the banks even in flood events. Above-ground stems of cottonwoods increase channel roughness during overbank flows, thereby decreasing the erosive action of floods and retaining material in transport (Strahler and Strahler 1973). There are limits to cottonwood stabilization. Even treed banks will slump from gradual undercutting and erode over time, losing the outside trees to high flows once the undercutting of the bank has dislodged the tree. Meander lobes with mature cottonwood stands need exceptionally large flood events to produce enough energy to remove large trees (Gregory et al. 1991).

Transport

Erosion adds sediment and woody debris to the river which then transports its new load. A river's ability to pick up and transport its sediment load, depends upon its energy. Much of the river's energy is lost due to friction on channel walls and bed (Morisawa 1968). However, flow resistance reaches a minimum at bankfull stage, and thus the channel operates most efficiently for the transport of water and its load at this level. Consequently, bankfull discharge is assumed to control the form of alluvial channels (Gordon et al. 1992).

Sediment transport in rivers occurs as a combination of bedload, suspended load, and washload. The coarsest sediments are found in the bedload and move along the river bottom not supported by the water. Finer sediments are lifted well above the bed by the flow's turbulence and comprise the suspended load. The washload is the finest-grained fraction of the suspension transport (Morisawa 1968). The ranges of sediment grain sizes that comprise these three transport modes are governed by the flow strength of the river -- its velocity, or power. Much of the increase in sediment transport during floods results from shifts in the grain sizes found within these three modes; grain sizes that normally move as bedload are transported at high rates during a flood as part of the suspended load, and coarser grain sizes than usual are found in the washload (Komar 1988).

Deposition

A stream carries its load until it lacks the energy to do so, at which time deposition takes place (Gordon et al. 1992). There are many factors which lessen the transporting ability of a stream. A loss of capacity and/or competence may be caused by decreased gradient, decreased volume, increased calibre of load, or damming of the channel. A stream gradient may change when the stream flows from one rock type to another. An increase in stream length with the same vertical fall, as in a meander, will result in a gradient which is gentler. Gradient is suddenly decreased when a stream bounces from a steep mountain front onto a plain or when it moves into a still body of water. In all these cases, a decrease in gradient causes a loss of transporting ability and deposition of the load (Morisawa 1968). The net effect is a vertical and horizontal gradation of sediment sizes, building a wide range of depositional forms referred to as bars (Knighton 1984).

Point bars are the main feature on alluvial river systems. They form on the inner bank of meanders and often create sandy or cobble bars which slope gradually into the water providing a bare, moist area with full sunlight exposure (Braatne et al. 1996). Point bars are one of the prime sites for cottonwood and willow recruitment. The higher elevation sites provide protection from extreme deposition, ice scouring and moderately high flows (Bradley and Smith 1984, Rood and Mahoney 1990).

Black Cottonwoods

The hydrologic and fluvial geomorphological processes that shape the meandering channel provide water and periodically repeated disturbance which *Populus trichocarpa* (black cottonwood) has adapted to and now depends on for successful recruitment and growth (Braatne et al. 1996).

The cottonwood found throughout most of B.C. are black cottonwood, *Populus trichocarpa*, except for the northeastern corner, where the balsam poplar, *Populus balsamifera*, is found. The genus *Populus* belongs to the willow family, Salicaceae, and is divided into five sections with *P. trichocarpa* and *P. balsamifera* belonging to the Tacamahaca Section (Dickmann and Stuart 1983). The taxonomic status of *P. trichocarpa* has been problematic for a century (Rydberg 1893, Critchfield 1960). The problem arises because the vegetative features are indistinguishable from those of *P. balsamifera* (Eckenwalder 1984). Where both poplar species overlap, hybridization occurs, further complicating the taxonomy. However the taxonomic treatment is not critical since black cottonwood and balsam poplar in British Columbia are very similar in ecological and physiological properties (Peterson et al. 1995). The sites under investigation in this study probably support only black cottonwoods.

Black cottonwoods occur on very moist sites, particularly along streams. They are well adapted to the dynamic riparian zones, since they are very tolerant of flooding (Brink 1954, Hosner 1958). However, cottonwoods are not tolerant of drought and are exceptionally vulnerable to drought-induced xylem cavitation (Braatne et al. 1992, Tyree et al. 1994, Weber 1995). Black cottonwoods are phreatophytic and are therefore dependent on the saturated water table for moisture (Mahoney and Rood 1991). Annual flooding recharges the riparian water table and is also important for the recruitment and maintenance of cottonwoods (Rood and Mahoney 1990).

Phenology

Black cottonwoods are dioecious; male and female flowers occur on separate trees. Flowering occurs from April through May. The pollen is dispersed by wind, and within 24 hours of landing on a female flower, fertilization typically occurs (Braatne et al. 1996). Seed dispersal typically coincides with declining river flows following spring high water or flooding, and usually lasts four weeks (Braatne et al. 1996). The majority of seeds germinate within 24 hours of landing on an appropriately moist substrate.

Sexual Reproduction

Through erosion and deposition spring peak flows and spring floods create suitable sites for black cottonwood recruitment. These sites are moist, barren sites with full sunlight exposure, the main requirements for seedling recruitment (Bradley 1982, Scott et al. 1996). Moisture requirements of new seedlings are largely supplied by residual moisture contained in recently flooded substrates, and are subsidized by rains, raised riparian water tables and capillary fringe levels associated with spring flooding (Bradley 1982, Bradley and Smith 1986).

Moist sites are important because the seeds of *Populus* species are 0.3 mg to 0.6 mg per seed (Braatne et al. 1996). This small size means that there is little or no endosperm present to sustain seedlings while leaves and roots development occurs (Bradley 1982). Viability of seeds is very short which is also related to their small size and lack of endosperm (Braatne et al. 1996). The seeds have fluffy, cotton-like hairs attached to them to aid in their dispersal by wind and water and this is responsible for the common name 'cottonwoods' for the trees.

The dispersal of seeds coincides with declining river flows which increase the probability of favorably moist microsites. Flooding also eliminates many potential flood-intolerant competitors from colonizing cottonwood and willow recruitment zones. This keeps the recruitment zones relatively open for shade-intolerant black cottonwood seedlings.

Asexual Reproduction

Black cottonwoods are also capable of asexual reproduction. A common form of asexual reproduction through clonal reproduction is the rooting of branch fragments (Peterson et al. 1995). Such fragments are often the result of wind and snow-related crown breakage and beaver browse. Trees swept into rivers experience strong turbulence resulting in the loss of most of their branches, another common source of branch fragments. Branch fragments that are transported by the river provide a mechanism of dispersal, usually only associated with sexual reproduction.

Suckering is another common form of asexual reproduction in the black cottonwood. Root suckers sprout from the parent tree's lateral roots which are generally shallow. Crown damage and fluvial disturbance (scarification) of shallow roots will promote such root suckering (Rood et al. 1994). Suckering can also be produced from the basal portion of the stem and these shoot suckers are sometimes known as coppice growth (Bradley et al. 1991). Coppicing commonly occurs following beaver-harvesting, ice scour, fire damage, or grown die-back. Shoot suckers often contribute to a pattern of multiple trunks in close proximity (Gom 1996).

Dams on Alluvial Rivers

Past studies indicate that downstream effects of impoundment vary greatly depending on the size, purpose and flow release regime of a dam. The geographical area in which it is constructed and how the dam is operated will also affect the results. From these previous studies, standard patterns emerge for alluvial river systems in general.

A reservoir acts as a sediment trap. Most of the suspended load is lost at the rivers entrance to the reservoir (Williams and Wolman 1984, Dunne 1988, Debano and Schmidt 1990, Rood and Mahoney 1995). Water leaving the dam is clear with little or no suspended load. This sediment-free water will pick up any unconsolidated material and carry it downstream. The size of material picked up will depend on the gradient of the system and the dam's discharge levels.

The sediment-free water discharged from dams induces channel erosion resulting in entrenchment (Graf 1988). With the downcutting and entrenchment of the channel and loss of sediment deposition, meandering is reduced or eliminated depending on the degree of narrowing and the amount of sediments added to the stream by tributaries downstream of the dam (Rood and Mahoney 1990, Johnson 1992, Rood and Mahoney 1995, Scott et al. 1996). Decreases in suspended load have been documented to occur from a few kilometers to hundreds of kilometers downstream of some dams (Williams and Wolman 1984, Rood and Mahoney 1990).

Dams that reduce or eliminate spring peak flows, decrease or eliminate erosion and deposition on meander lobes. With reduced erosion and deposition, meandering is reduced and cottonwood recruitment zones become deficient (Rood and Mahoney 1990, Johnson 1992, Rood and Mahoney 1995, Scott et al. 1996). The open bars left from the narrowing of the river are no longer inundated resulting in the loss of periodic recharging of the water table (Rood and Mahoney 1995). The meander lobe point bars, prime recruitment sites for cottonwood seedlings, dry out and consequently provide suitable sites for encroachment by grasses and unsuitable sites for cottonwood recruitment (Debano and Schmidt 1990). With the encroachment of grasses and other vegetation to the river's edge, suitable cottonwood recruitment sites are further lost (Bradley and Smith 1984, Williams and Wolman 1984, Rood and Mahoney 1990).

Conclusion

The reproductive ecology of black cottonwoods in a hydrological gaining mountain system is not fully understood. Many of the studies have occurred on semi-arid prairie systems and southwestern arid systems. The cottonwoods in these previous studies include *Populus balsamifera,* and *P. angustifolia* from the Tacamahaca Section and *P. deltoides* and *P. fremontii* of the Aigeiros Section. Much of the understanding of the reproductive ecology of these *Populus* species can be applied to the black cottonwood, but with different geomorphology, weather, and species, the understanding and applicability are incomplete. The lack of detailed knowledge for specific regions prevents comprehensive environmental impact analyses and analyses of costs versus benefits that are essential for informed environmental resource planning and management.

The reproductive ecology of the black cottonwoods in southeastern British Columbia has not been the focus of previous studies. Riparian cottonwoods are threatened by numerous human-induced impacts, including river damming, water diversion, cattle grazing and clearing for agricultural use, transportation corridors and other uses. In order to prevent the decline in black cottonwood ecosystems, the reproductive ecology of black cottonwood in the East Kootenay drainage needs to be more completely understood.

The present study has been divided into two interrelated investigations. The goal of the first is to clarify the role of flood disturbance and particularly the 1995 Elk River flood on black cottonwood reproductive ecology. The second study investigates the effects of flood flow attenuation by the Libby Dam on the ecology and reproduction of black cottonwoods along the Kootenai River. For these two related investigations, four adjacent river systems were studied, the Elk, the Upper Kootenay, the Fisher and the Lower Kootenai rivers.

The Elk River was chosen because it was the site of the 1995 'flood of the century'. This presented a rare opportunity to directly study the effects of a high magnitude flood on the geomorphology of the river valley and on the black cottonwood population. Baker (1988), Bull (1988), Kochel (1988), Ritter (1988), Patton (1988), and Gupta (1988) studied various aspects of floods and extreme flood events relative to geomorphic responses, erosion, sediment transport, and deposition, with these studies investigating the immediate effects of the flood incident. None of the previous studies investigated changes that occurred in the subsequent years following an extreme event. The present study investigated the impact of the 1995 Elk River flood event and the influence it had on the riparian zone in the following two years.

The first study involved the Elk River extreme flood event to investigate the following questions:

1) What were the geomorphological changes that occurred from this extreme event?

2) Were the changes restricted to 1995 or does a flood of this magnitude influence subsequent change for a number of years?

3) What effect did the 'flood of the century' have on the cottonwood populations and on cottonwood reproduction during the immediate and following years?

The results from the Elk River study will also be applied to the overall knowledge of black cottonwood reproductive strategies for the Kootenay River Basin.

The second investigation of flow attenuation on the Kootenay River involved four systems. The free-flowing Elk River (B.C.) was paired with the free-flowing Upper Kootenay River (B.C.) as they shared the northern geographic location, and the free-flowing Fisher River (Montana) with the flow-attenuated Lower Kootenai River (MT.) as they shared the southern geographic location. The Elk and Upper Kootenay river systems provided two unregulated systems to monitor black cottonwood reproductive strategies with slight differences between the two systems which provided a broader view of how processes relate to geomorphology. The Fisher River (MT) was used as a control site for the Lower Kootenai River to consider possible influences due to the geographic difference between the Upper and Lower Kootenay river valleys. The second study investigated the following topics:

1) condition of the riparian zone along the Lower Kootenai River after twenty years of flood flow attenuation,

2) the impacts of flood flow attenuation by the Libby Dam on cottonwood recruitment and riparian vegetation,

3) methods of mitigation that could help to restore the riparian woodlands along the Lower Kootenai River.

Chapter 2. The Elk River: After the 'Flood of the Century'

Introduction

Riparian habitat is especially important to the Elk Valley as it supports the highest abundance and diversity of plants and wildlife. The Elk River, the main drainage for the valley, also supports much of the easily accessible recreation in the area. This recreation includes sport fishing, kayaking, canoeing, rafting and other water related activities. The Elk River and its riparian area contribute exceptional aesthetic value that increase human enjoyment of many activities, including bird watching, hiking, wildlife appreciation and photography and driving through the valley.

The main riparian tree in the Elk Valley is *Populus trichocarpa* Torr. & Gray, the black cottonwood. However, riparian components and especially the black cottonwoods are impacted and even threatened by numerous human activities. The Elk Valley is quite narrow, varying in width from 1.6 km to 6.4 km, restricting much of the human use to the riparian zone (Rocchini et al. 1976a). The flood-formed terraces are used as transportation corridors with Highway 3 and a Canadian Pacific Railway on opposite sides of the Elk River. Most of the fertile and level land, suitable for agricultural use, is found on the flood terraces of the Elk River. Consequently, much of the cottonwoodland has been cleared for human settlement and farming. The largest town along the Elk River is Fernie and much of its development occurs on the flood terraces. Outside of towns, much of the clearing is for farming, particularly for hay crops and cattle and horse grazing. Some farmers have left floodplain areas of cottonwoods between their fields and the river while others have cleared the trees right to the river's edge.

The Elk River Basin is located in the southeastern corner of British Columbia, an extremely mountainous region, lying entirely within the Front and Border Ranges of the Rocky Mountains (Figure 1). The region is drained by the Elk River with its major tributaries being the Wigwam and Fording rivers and Michel Creek. The stream elevations range from 1650 m near the headwaters in the Front Range, to 720 m at the mouth where the Elk River enters Koocanusa Lake (reservoir).

The Elk River has three major differences from semi-arid systems which have been more thoroughly studied with respect to riparian cottonwoods. Firstly, the majority of the Elk River reach is in a humid region with a relatively uniform distribution of precipitation throughout the year. This climate contrasts with the semi-arid systems, which have less precipitation but higher proportions of precipitation occurring in winter relative to the summer months. Secondly, the humid reach of the Elk River is a hydrologically (effluent) gaining system (Figure 2a). The groundwater flows down the hillsides and then enters and adds to the river's flow. Groundwater is close enough to the surface to be available to sustain trees so that treed hillsides are a good indicator of a hydrologically gaining system. In prairie, semi-arid areas, stream systems are typically hydrologically (affluent) 'losing' systems (Figure 2b), where the groundwater slopes downward away from the river's edge. The surrounding plains are usually void of trees as the groundwater is too deep to sustain tree growth. The

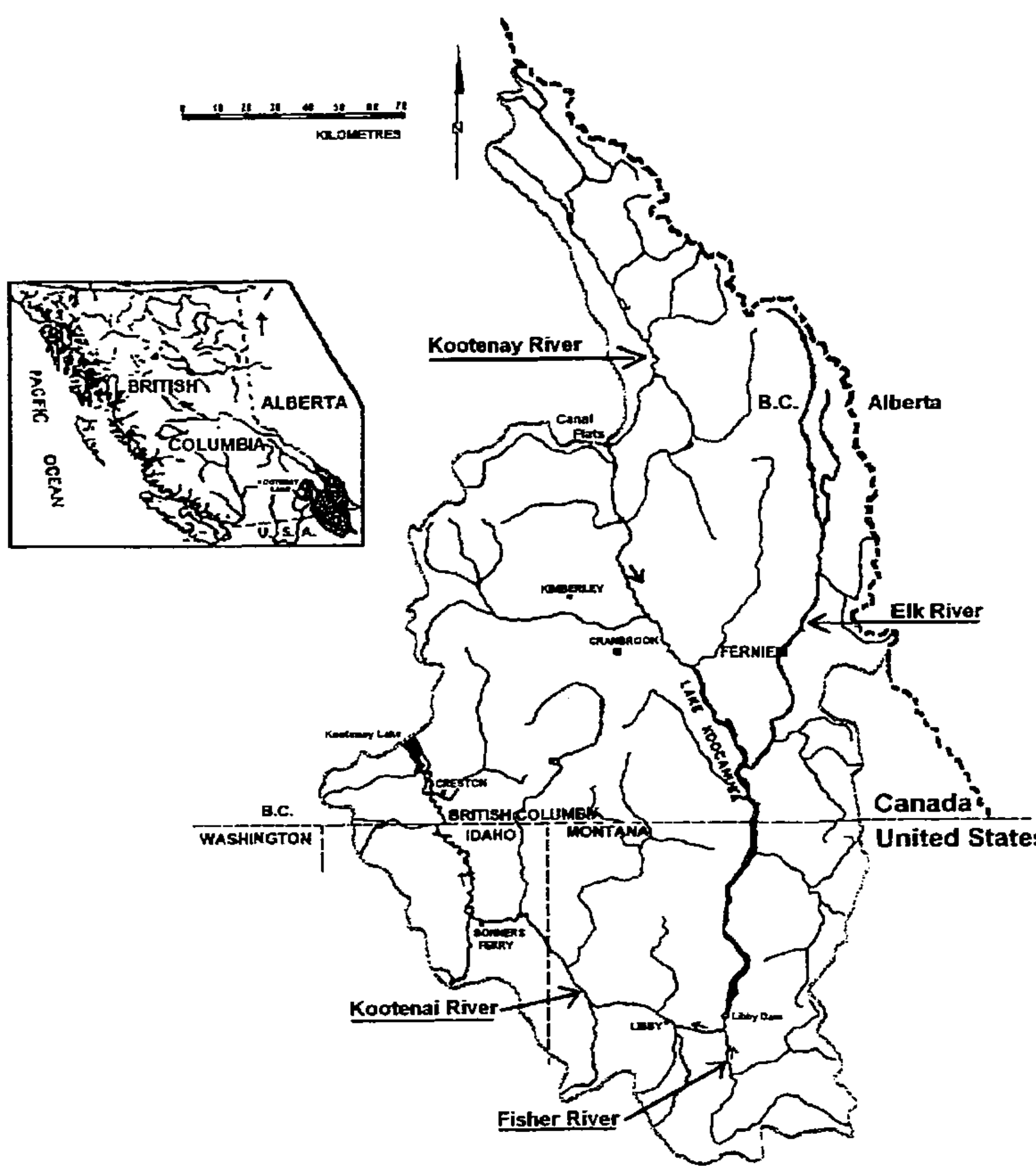


Figure 1. The Kootenay River Basin and Elk River Basin
(From Ken Knudsen Ecological Resource Consulting 1994)

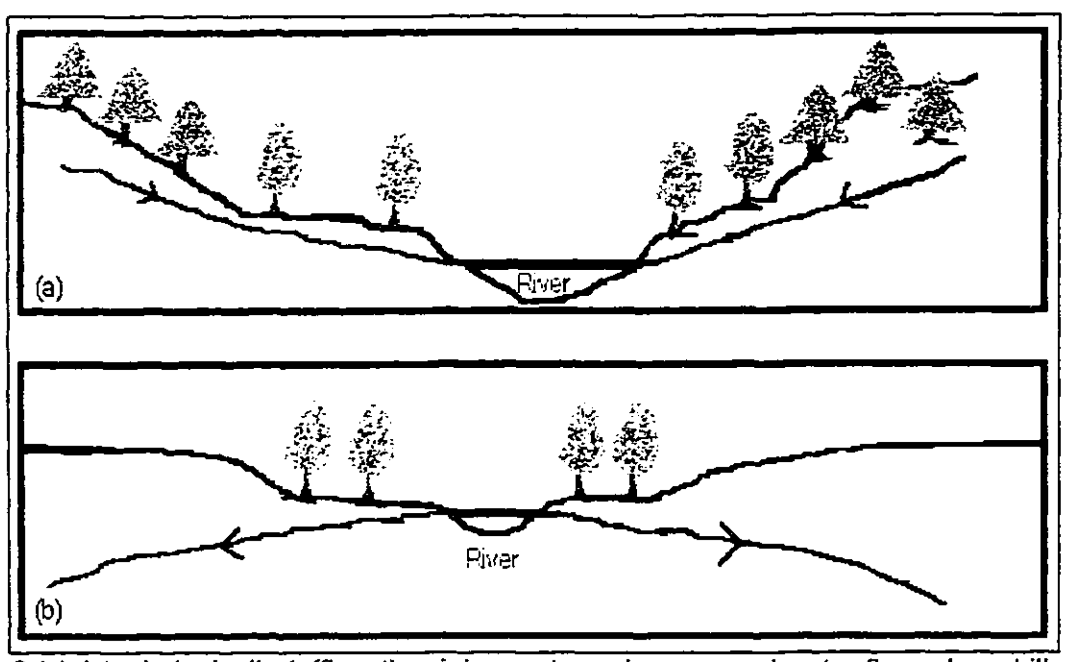


Figure 2.(a) A hydrologically (effluent) gaining system where ground water flows down-hill adding to the river and (b) a hydrologically (affluent) losing system where the ground water flows downward away from the river, so that the further away from the river the deeper the groundwater becomes.

substrate composition of the floodplain will dictate the degree or level of this slope (Rood and Mahoney 1990, Mahoney and Rood 1991, Mahoney and Rood 1992). Thirdly, a single cottonwood species, the black cottonwood, is found along the Elk River and the surrounding area. Some of the semi-arid systems studied had two or more *Populus* species and interspecific hybrids. Those *Populus* species were from both the Aigerios and the Tachamahaca sections further complicating reproductive strategies when comparing them to the single population of black cottonwoods along the Elk River.

The previous studies on semi-arid systems have shown that riparian cottonwood forests need dynamic stream flows with floods that provide physical disturbances which produce new recruitment sites for cottonwood seedlings (Bradley and Smith 1986, Rood and Mahoney 1990, Rood and Mahoney 1994, Scott et al. 1996). Flood events are responsible for successful establishment, resulting in arcuate banding of even-aged cottonwood trees in these systems (Bradley and Smith 1986 Braatne et al. 1996). Annual spring peak flows are also important in semi-arid systems to recharge the water table (Mahoney and Rood 1990, Mahoney and Rood 1991, Rood and Mahoney 1992).

This study will investigate black cottonwood seedling recruitment along the Elk River. As well, it will look into other reproduction strategies of the black cottonwood in a mountainous system. The study will monitor growth of seedlings and survival into the following year. In 1995, the flood of the century occurred on the Elk River. What effect did the flood of the century have on the cottonwood population and reproduction in the following years? What geomorphological changes resulted from this extreme event? Were the changes restricted to 1995 or does a flood of this magnitude continue to influence change in later years? Change in geomorphology will be investigated along the study reach of the Elk River following the flood of the century as well as historic changes since 1962. With this rare opportunity to study the effects of a flood of this magnitude, some of the questions surrounding floods of this magnitude in a humid reach may be answered.

Materials and Methods

Field studies were conducted along the Elk River from 8 km south of Fernie to about 8 km downstream (measured by the highway). These studies occurred from the beginning of May to the end of October 1996 and from April to the end of October 1997. Mean daily, monthly and annual discharge data from 1925 to 1997 at station #08NK005 (Phillips Bridge) and from 1968 to 1997 at station #08NK002 (Fernie) were taken from the Environment Canada, 'Hydat' data base. Streamflow analysis of the Elk River used data from 'Hydat' at station #08NK005 (Philips Bridge), as it was the largest data-set for the river. Flood recurrence data was analyzed using the log Pearson type III fit (Smada program analysis), a distribution favored by the United States Geological Survey and found to fit the Elk River data reasonably well.

Climate data at Fernie were gathered by Environment Canada for the years 1913 to 1992 at which point the weather station was discontinued. Sparwood provides the nearest continuous monitoring station, but Sparwood weather patterns are not identical to those in the Fernie area or at the river reach of the present study as it is considerably dryer than the Fernie valley.

For the present study, floodplain positions are expressed relative to a reference point corresponding to the estimated position of the river's edge at base flow. Base flow was established as the typical flow for late September into early October (20 m^3/s), at the end of the growing season. The base flow was then converted to a base stage using a discharge/stage ratings curve at the Fernie hydrometric gauging station.

Three meander lobes were selected for sampling sites according to certain criteria. These sites contained gradually sloping banks at the lobes, displayed minimal human impact, and were readily accessible. They were situated upstream from the Highway 3 tunnel and near the Elk River Institute (Figure 3). At each site, three or more transects were established by running a tape-measure from a metal-tag numbered cottonwood tree down to the river's edge and were perpendicular to the stream. One metre long, iron rebar stakes were pounded into the ground near the river's edge to enable exact repositioning of the transect. However, the majority of these bars were toppled by the spring high water in 1997. With the loss of the rebar, transect lines were not reestablished precisely, complicating the repositioning of the quadrats and staff gauge along the transect lines in the following months and year.

Seven transects were established at Site 1 along with three transects at each of Sites 2 and 3. Transect elevations were surveyed using a transit and staff gauge in May and July of 1996, in October 1996 and finally October 1997. Transect lines surveyed in May were used but the ones surveyed in July had to be corrected for error as the transit was not calibrated resulting in a slope error. Surface composition, type and texture and vegetation zones along the transect lines were mapped and described.

The seedling densities along the transect lines were measured within $0.1m^2$ quadrats. In total, 145 quadrats were established along 13 transects and the seedling heights of ten haphazardly chosen seedlings were measured in each. Both height and density counts were determined along the transect lines

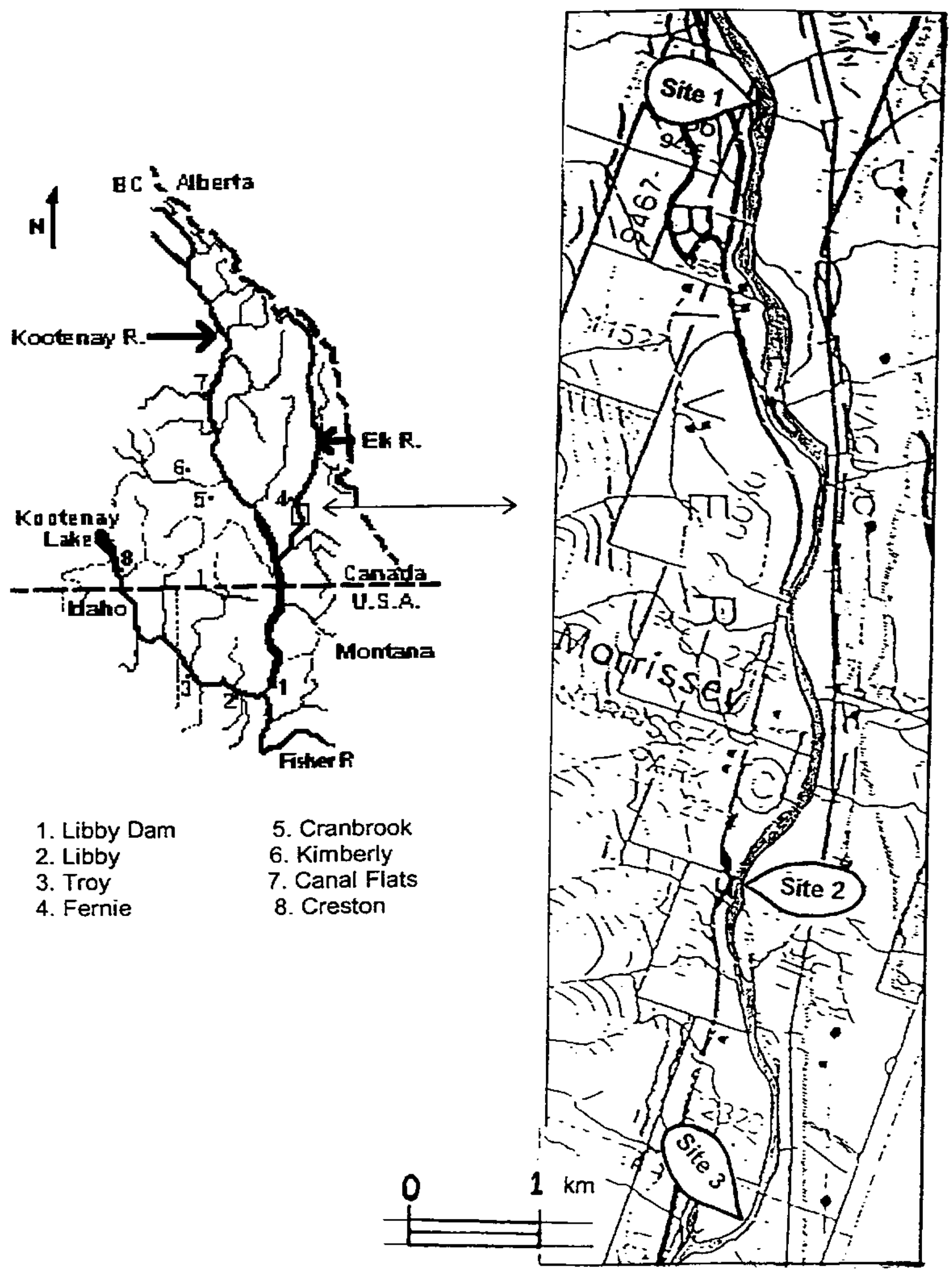


Figure 3. The figure on the left is the Kootenay River Basin where the Elk River is located. The figure on the right is an enlargement of where the study sites occurred from the topographical map 82G/SW scale 1:100,000 .

in positions where seed beds occurred. Beaver activity was noted by tracks, cut branches and felled trees. Evidence of ungulate and bird use of the sites was also noted.

Mature trees were aged by ring counts from cores extracted with an increment borer. Densities of saplings (juveniles) were determined in 2 m^2 quadrats along the transect where they occurred. Random aging of juveniles was performed by cutting down a sapling at ground level, removing a thin slice from the cut end and counting the rings under a dissecting microscope. When possible, juveniles were also aged by counting the annual growth scars on the tree stem.

Air-photos from 1962, 1981, and 1994 were analyzed for changes in geomorphology and are listed in Table 1 along with their date, site, air-photo number and scale information. Air-photo dates are presented since change in stream flow across each year would result in change in channel width and bar exposure. August 8, 1996 a flight over the river provided the opportunity to view the river valley and take oblique photographs for analysis of geomorphological impacts following the 1995 'flood of the century'.

Table 1. Summary of air-photos used in geomorphology analysis along the Elk River B.C.

DATE	SITE	AIR-PHOTO #	SCALE
Jul 23, 1962	1	BC4075:11	1:15,840
Jul 9, 1962	2	BC4057:163	1:15,840
Jul 9, 1962	3	BC4057:103	1:15,840
Aug 24, 1981	1	BC81103:045	1:40,000
Aug 24, 1981	2 & 3	BC81103:095	1:40,000
Aug 10, 1994	1	30BCC94124:155	1:15,000
Jul 22, 1994	2	30BCC94090:179	1:15,000
Aug 10, 1994	3	30BCC94125:059	1:15,000

Results and Discussion

Comparisons of River Stage Patterns at Study Sites Versus Gauging Stations

The Fernie gauging station stage data were then compared to the stages at all three sites, Figures 4, 5 and 6 and transect stages were found to be closely correlated with stages at the Elk River hydrometric gauging site. Thirteen transacts were analyzed and correlation coefficients of determination averaged 0.988. The regression slopes averaged 0.98 and thus, the magnitudes of stage changes at the sites and gauging station were very similar. The regression slopes ranged from 0.54 to 1.39 and, as expected, those sites with more gradual stage changes involved gradually sloping banks, while the steeper transect stage patterns occurred at sites with steeply sloping stream banks. Where the site's banks were steeper than the gauging site, the regression analysis slope was greater than one. More gradual banks at sites, had a regression analysis slope less than one compared to the gauging station (Figures 4, 5, 6).

The particular stage versus discharge pattern is primarily determined by cross-sectional geometry combined with channel gradient a product of longitudinal profile. The difference in specific stage-discharge patterns at the study sites reflect both cross-sectional and gradient difference and either or both would underlie the steeper stage response at the transect line with greater than 1 for their regression analysis slopes. Consequently, the stage at the Fernie gauging station was used for subsequent analyses. The base stage elevation was set to '0' and all surveyed elevations were zeroed relative to this base stage.

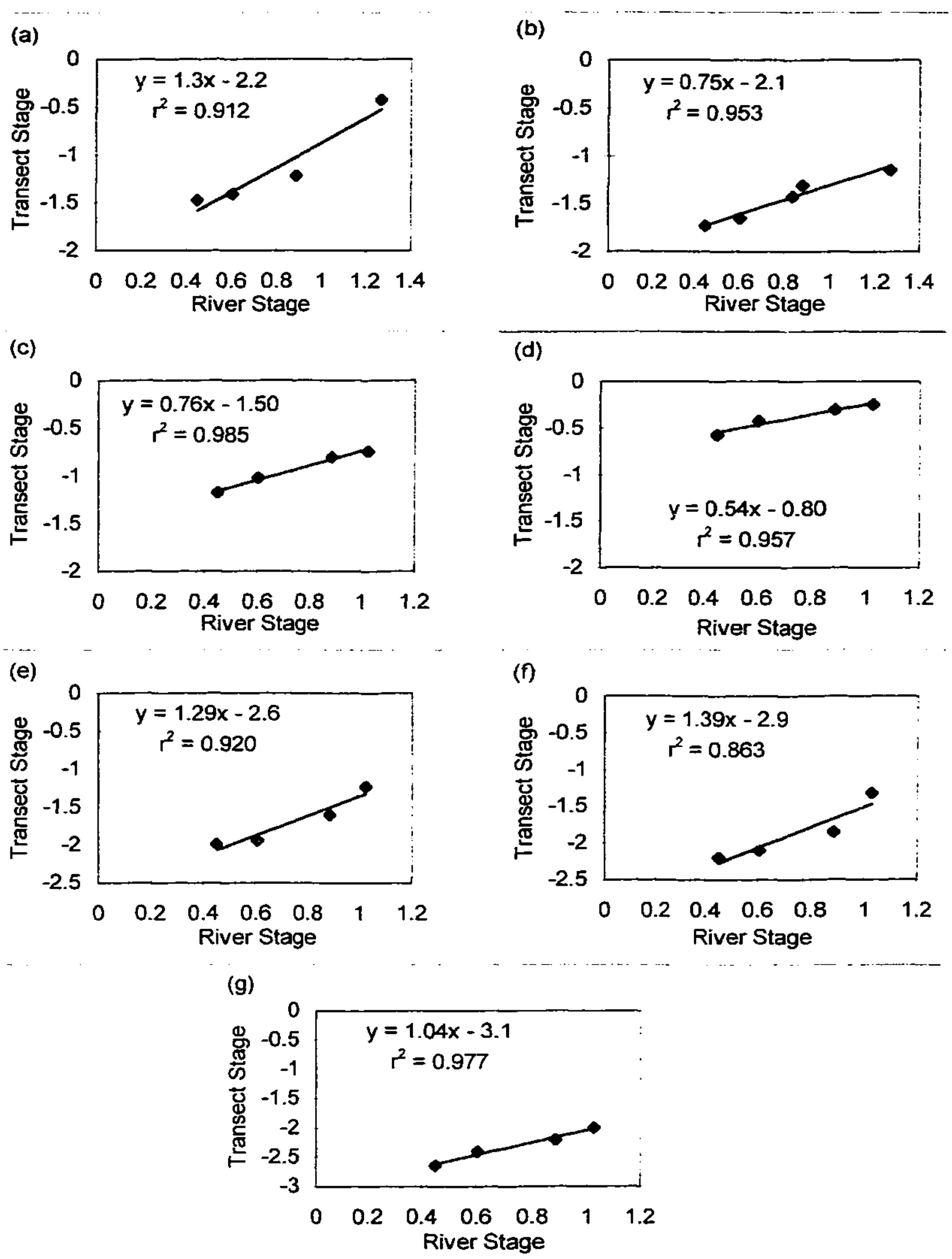


Figure 4. The gauging station stage at Fernie (#08NK002), compared to the stage measured at the Elk River Site 1 (49^0 25' N 115^0 02' W), transects (a) 0636, (b) 0637, (c) 0644, (d) 0645, (e) 0646, (f) 0647 (g) 0648.

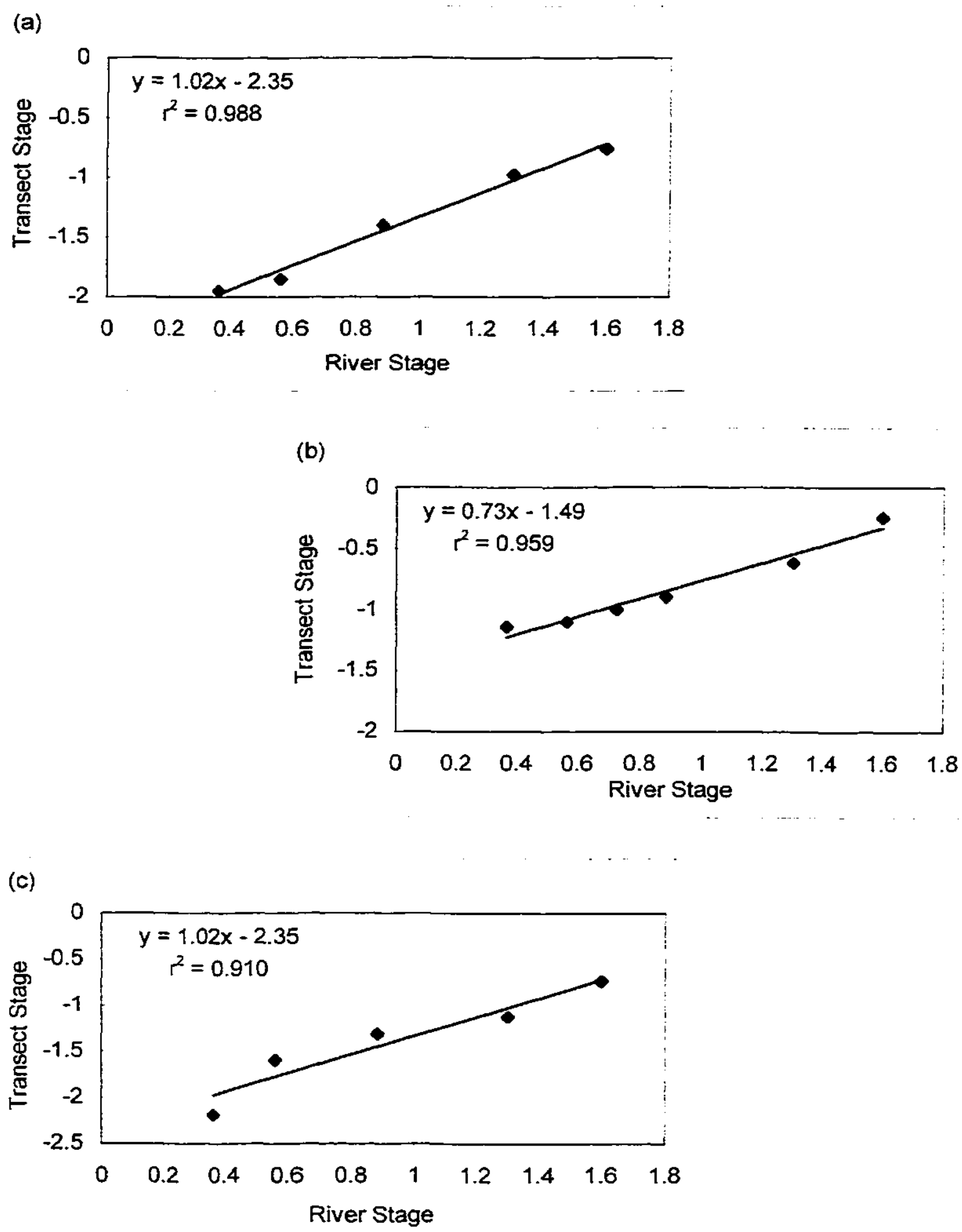


Figure 5. The gauging station (#08NK002) stage at Fernie, compared to the stage measured at the Elk River Site 2 (49^0 23' N 115^0 01'W), transects (a) 0633, (b) 0634, (c) 0635.

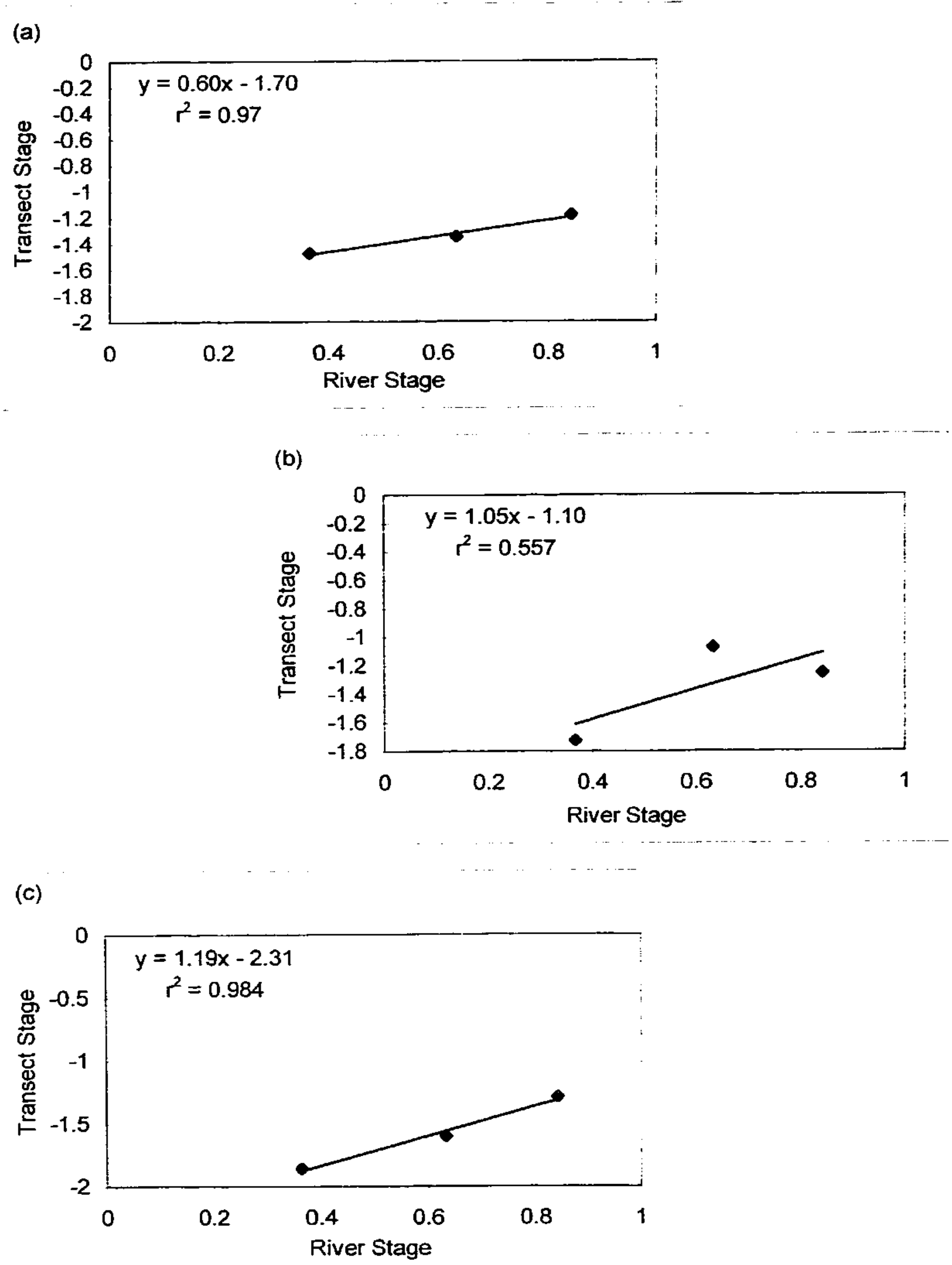


Figure 6. The gauging station (#08NK002) stage at Fernie compared to the stage measured at the Elk River Site 3 (49^0 21' N 115^0 00' W), transects (a) 0651, (b) 0652, (c) 0653.

<u>Hydrology</u>

The analysis of annual peak discharge involved data from gauging station 08NK005 at Phillips Bridge (Highway 93). This gauging station occurs just before the Elk River enters the Kootenay River (Koocanusa 'Lake' in the summer). This data-set was used since it was considerably larger (73 years) than the record at Fernie (29 years). A forty-year record is required to estimate mean annual flooding within +/- 10% of the true value with 95% confidence (Richards 1982). Even longer series are necessary for a satisfactory estimation of skewness used in fitting three-parameter distributions such as the log-Pearson type III analysis.

Figure 7a shows the annual peak discharges at Phillips Bridge and indicates the flood return periods. As the return interval increases, so does the standard deviation which indicates that the larger the return time, the greater the error associated with the estimation (Table 2). Table 2 also shows the actual discharge for flood events of significant magnitude and the dates they occurred. As indicated, most of the flood events occur in late May or early June although exceptions occur (Figure 7a).

Figure 7a shows that the 'flood of the century' which occurred on June 7, 1995 was between a 1-in-100 and 1-in-200 year recurrence event, but closer to the 200 year event based on the estimated return interval from the log-Pearson type III recurrence analysis. The 2 parameter log normal recurrence analysis puts the same flood event closer to the 1-in-100 year event which would have an estimated flow of 1086 m^3/s versus the actual 1995 discharge of 1130 m^3/s. The

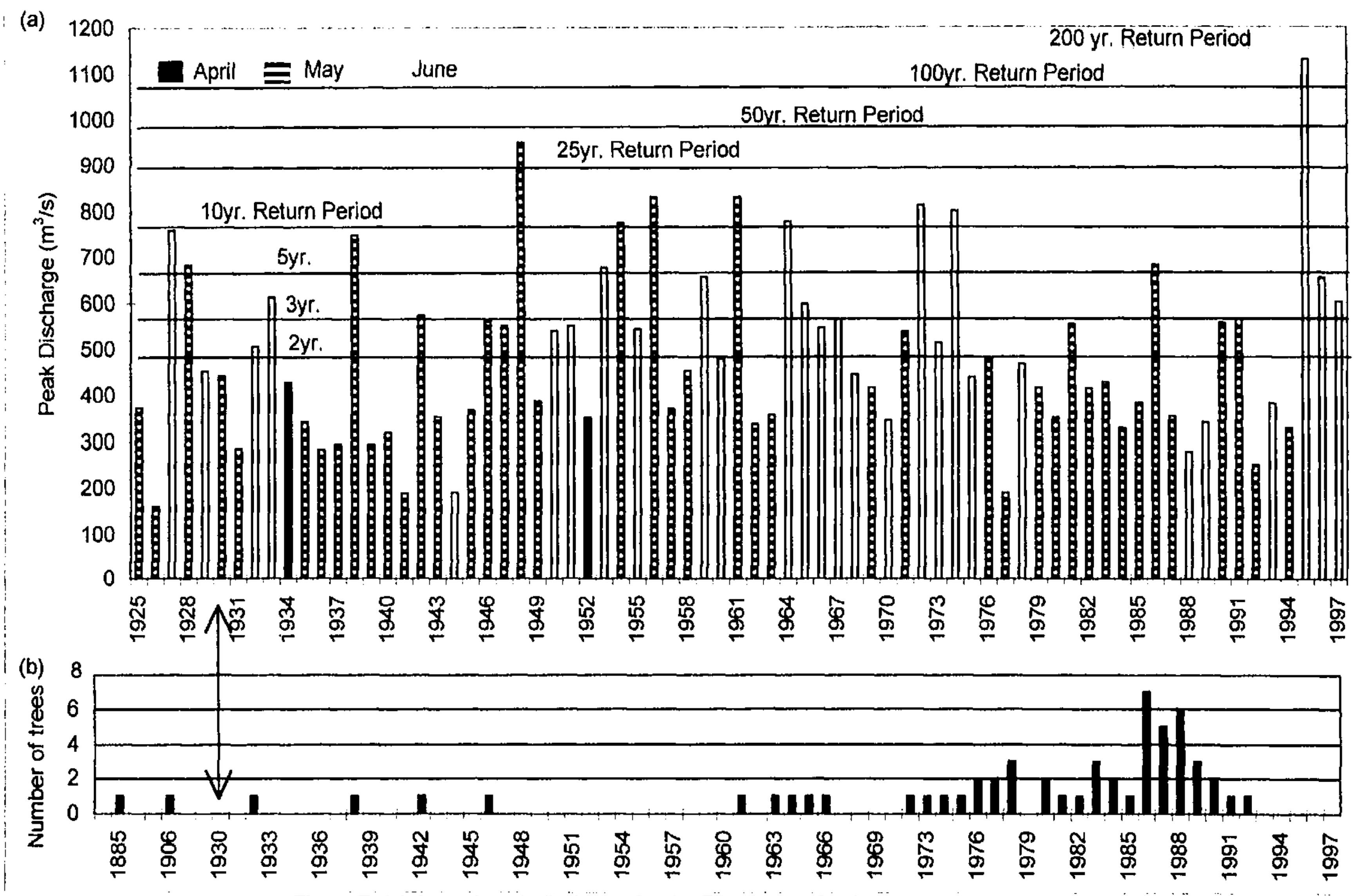


Figure 7. (a) Annual peak discharge for the Elk River at Philips Bridge (#08NK005) and (b) frequency distribution of cottonwood tree establishment years along the Elk River.

Table 2. Distribution analysis using Log Pearson Type III recurrence analysis

EXCEEDENCE PREDICTION	RETURN PERIOD	CALCULATED VALUE	STANDARD DEVIATION	ACTUAL VALUE	DATE
0.995	200	1150	140		
0.990	100	1070	110	1130	6/7/95
0.980	50	986	84		
0.960	25	897	63		
0.900	10	769	42	830	5/22/56
				830	5/28/61
				779	6/9/64
				813	6/1/72
				801	6/18/74
0.800	5	661	33		
0.667	3	569	28		
0.500	2	483	24		

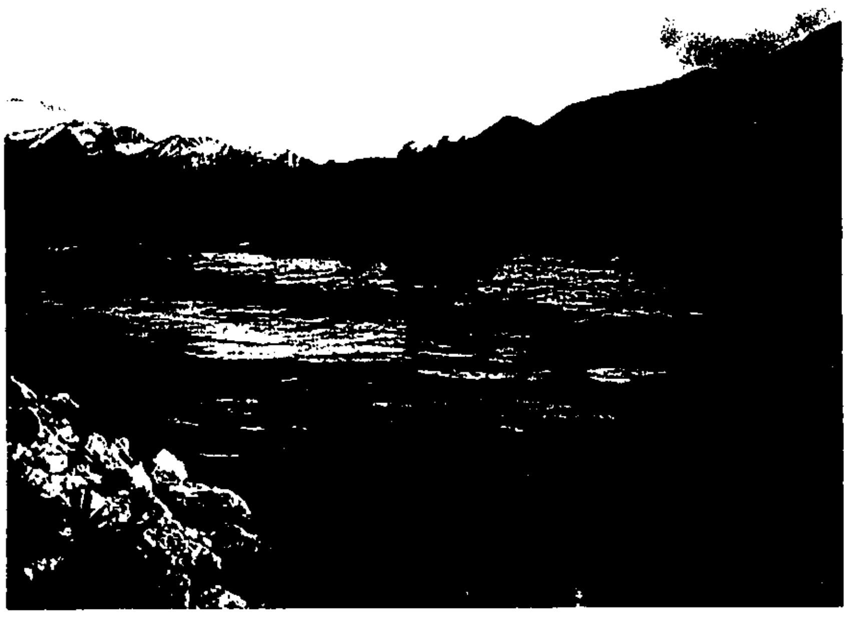
First Moment (mean) = 507.549
Second Moment = 3.707e04
Skew = 7.671e-01
of 1130.0 m^3/s

normal distribution analysis indicated that the 1995 flood exceeded a 1-in-200 year event that would have had a calculated return flow of 980 m^3/s. This reveals the variation that occurs when estimating a return period of a rare event. While a data-set of over one hundred years would give a more accurate assessment, the three analyses are consistent in assessing the 1995 flood as a 1-in-100 year event .

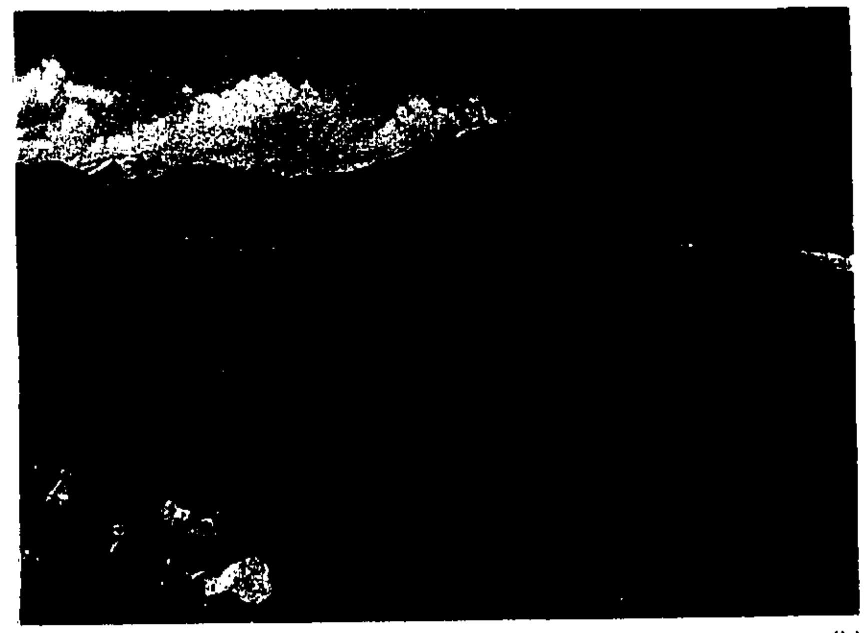
The 1995 'flood of the century' occurred the year prior to the study, but Site 1 did have a picture taken the morning after the crest of the 1995 flood (Figure 8a); the study island is completely under water in this photo. The extensive amount of sediment being transported is evident by the brown water in the photo. The Elk River on June 7, 1995 was thick with sediment, and it also transported huge trees which were constantly tumbling, breaking off many branches as they moved downstream.

Site 1 was revisited in July, 1995 and the submerged island in Figure 8a is shown in Figure 8b. The waters had receded but were still above average stage and were still murky. The discharge of the Elk River on July 5, 1995 was 166 m^3/s and the range for the month of July was 166 to 62 m^3/s (July 31). The same month in 1994 had a peak of 82.7 m^3/s on the first of July and declined to 38.9 m^3/s by July 31. By autumn, the Elk River had deposited considerable sediment and the island at Site 1 had a larger bar on the inside than shown in the photo (Figure 8b).

Following the 1996 spring peak which was a 1-in 4 year flood event (Figure 7a), the island at Site 1 had been linked to the river bank (Figure 8c).



(a)



(b)

(c)

Figure 8. Site 1 at 49^0 25' N 115^0 02' W along the Elk River, (a) June 7, 1995, (b) early July 1995, (c) and Aug 3, 1996.

The meander lobe upstream of the old island also experienced substantial deposition, increasing its size and connecting it to the former island.

Geomorphology

Flood events of the magnitude of the 1995 event, cause large scale geomorphological changes (Kochel 1988). One of the most noticeable is channel change. Once the flood waters receded in 1995, the Elk River returned gradually to its original channel. The previous high water left behind partially eroded channels, in some areas, scoured down to the large cobble substrate that was underlying the thick depositions of smaller cobble and fine. Both sites where scour occurred, which resulted in channel changes, were previously covered with grasses.

The first site of scoured grassland was the result of clearing for settlement and cattle grazing. This clearing extended to the river's edge and was adjacent to a small grove of juvenile cottonwoods left on the downstream corner of the meander lobe. The air-photo in Figure 9a was taken July 23, 1962; the meander lobe that is circled, shows the site before the future channel changed. Some of the meander lobe had already been cleared but a grove of cottonwoods was left on the inside edge of the meander lobe (A). In Figure 9b, the circled area shows the same meander lobe, August 10, 1994, with new settlement and the removal of most of the cottonwoods with a few left along Highway 3 and a small group of juveniles left along the river channel (B).

In 1996, a 1-in-4 year flood event occurred. This flood was insufficient to

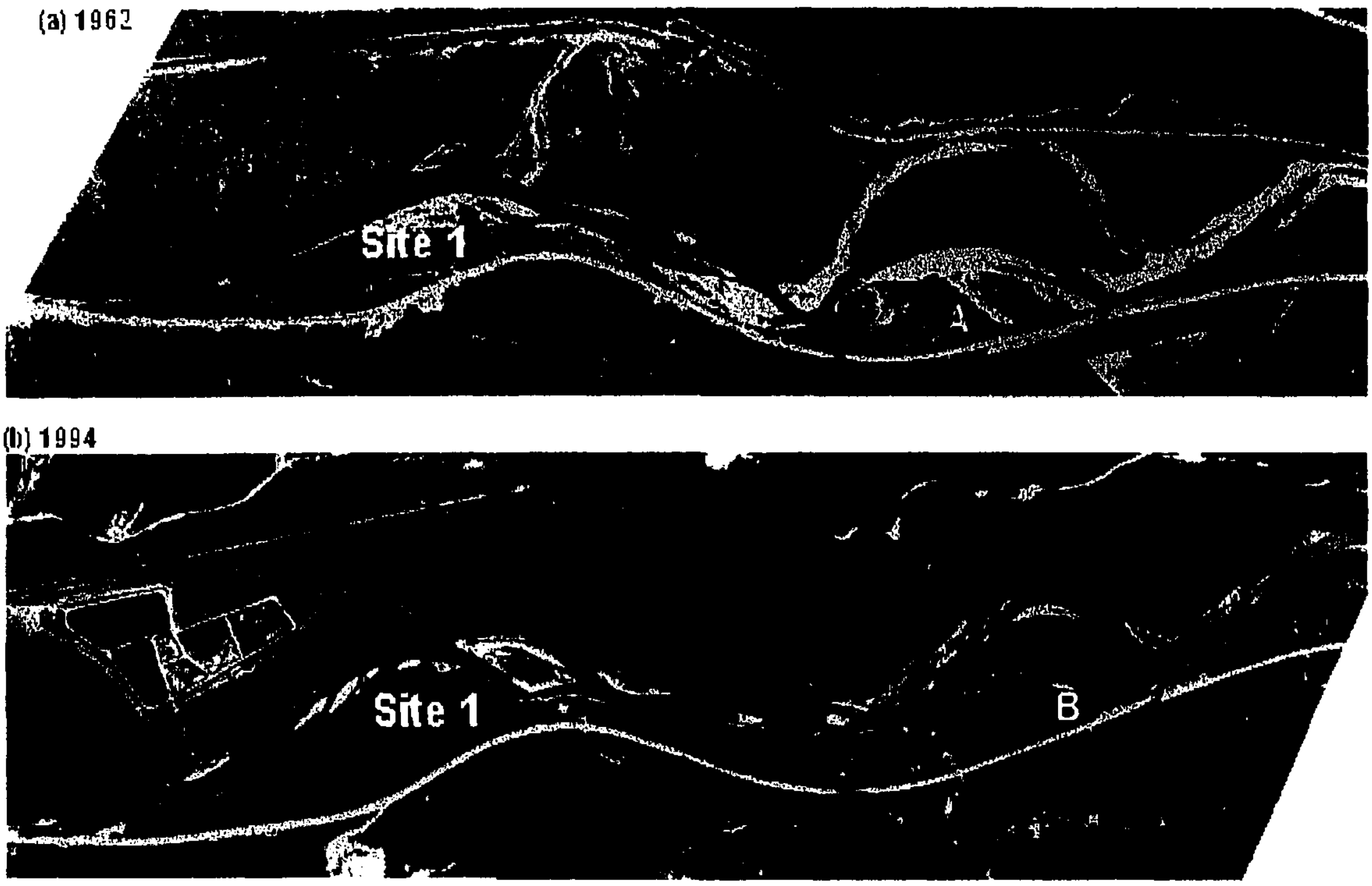


Figure 9. The circled site in (a) and (b) was one area where significant fluvial geomorphological change occurred over a 22 year period. Images are from air photo BC4075.11 (a) taken July 23, 1962 and air photo 30BCC94124 No. 155 (b) taken Aug. 10, 1994 both are approximately 1:15000 about 2 km downstream from Site 1 (49° 25' N 115° 02 W), A—black cottonwoods.

overflow the banks and flooded only lower elevations. When the 1996 flood waters receded, the previously scoured areas had become the new main channels. Figure 10 shows the new channel formed cutting across the grassland meadow. The old channel, to the right (Figure 10A), was abandoned for the new channel (Figure 10C). Figure 11a is a 1994 air-photo of the Elk River showing where the channel change would occur. Figure 11b is an enlargement of the meander lobe that was scoured to form the new channel. The overlay indicates approximate position and size of the new channel.

The second channel change occurred about 5 km further downstream. Air-photo Figure 12a, is the site on July 9, 1962, before the channel change occurred, circled. The fresh deposition and/or scour shows that an earlier event cleared this meander lobe of vegetation, except for the far corner (marked with an arrow). In 1948, a 1-in-25 year flood event occurred, which was the second largest disturbance flow on record for this reach (Figure 7a). This may have initiated the scouring of this meander lobe. For the next 12 years, several flood events occurred with 1-in-10 year flood return periods, the third occurring in 1961 (Figure 7a). This 12 year period of above average floods, may have kept this area cleared of vegetation.

By 1994, most of the meander lobe had been colonized by cottonwoodlands, but a grassy channel could still be seen running along the back of the meander lobe (Figure 12b). Water follows the path of least resistance, and subsequently the 1995 flood scoured this path of grasses, enlarging it by removing cottonwoods along its edges (Figure 13). The new

A – Old channel B – Old secondary channel C – New channel arrow – flow direction

Figure 10. The first site where the Elk River changed coarse, about 2 km downstream from Site 1 (49° 25' N 115° 02' W), in 1996. The main and secondary channels (A&B) were abandoned for the new channel (C) in 1996. Image recorded Aug. 3, 1996.

(a)

(b)

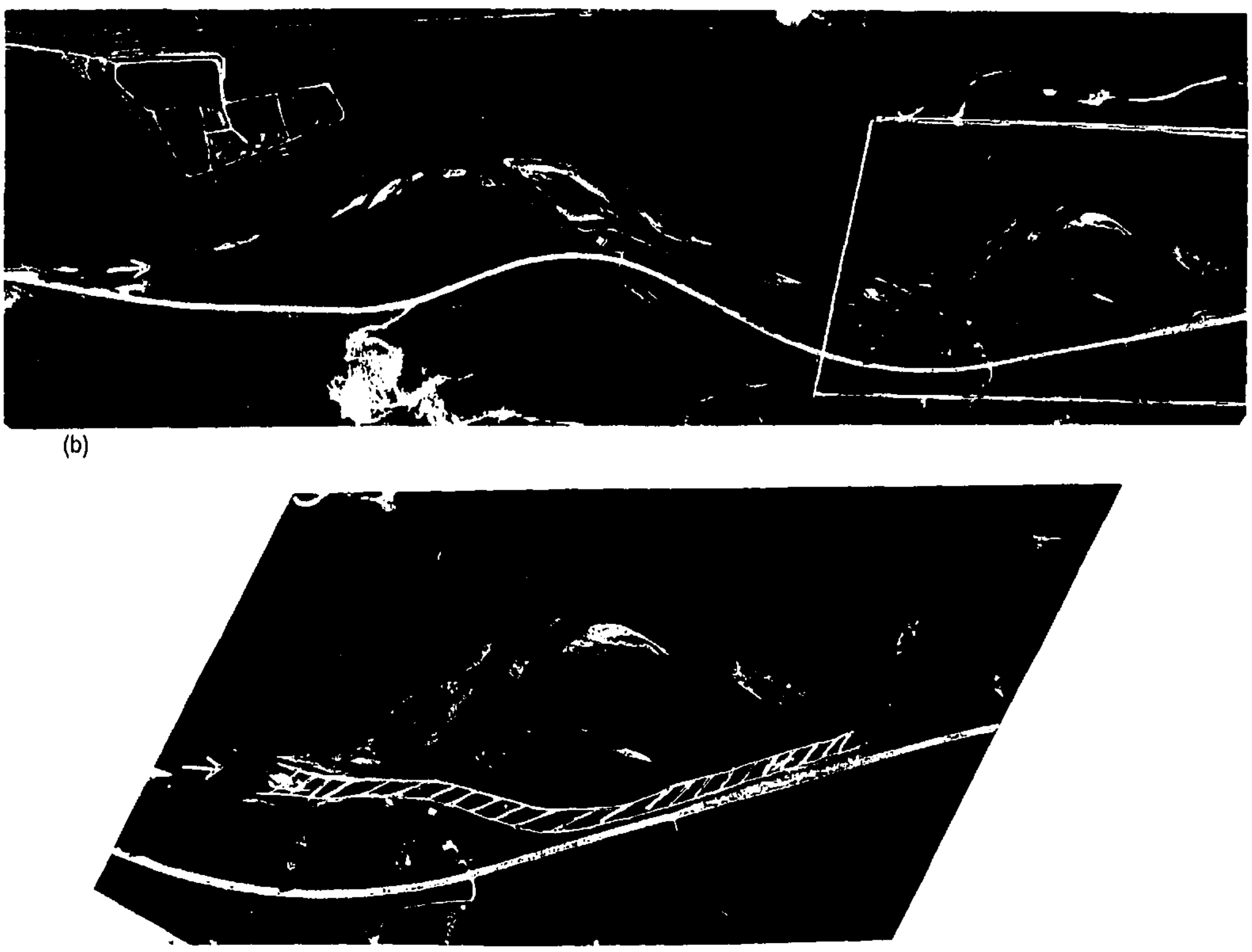


Figure 11. The Elk River, (a) image taken Aug. 10, 1994 air-photo 30BCC94124:155 prior to the channel change, scale 1:15,000. (b) The approximate new coarse of the Elk River (overlay) in 1996, the base image is a portion of the (a) 1994 air-photo at a scale of approximately 1:10,700.

(a)1962

(b) 1994

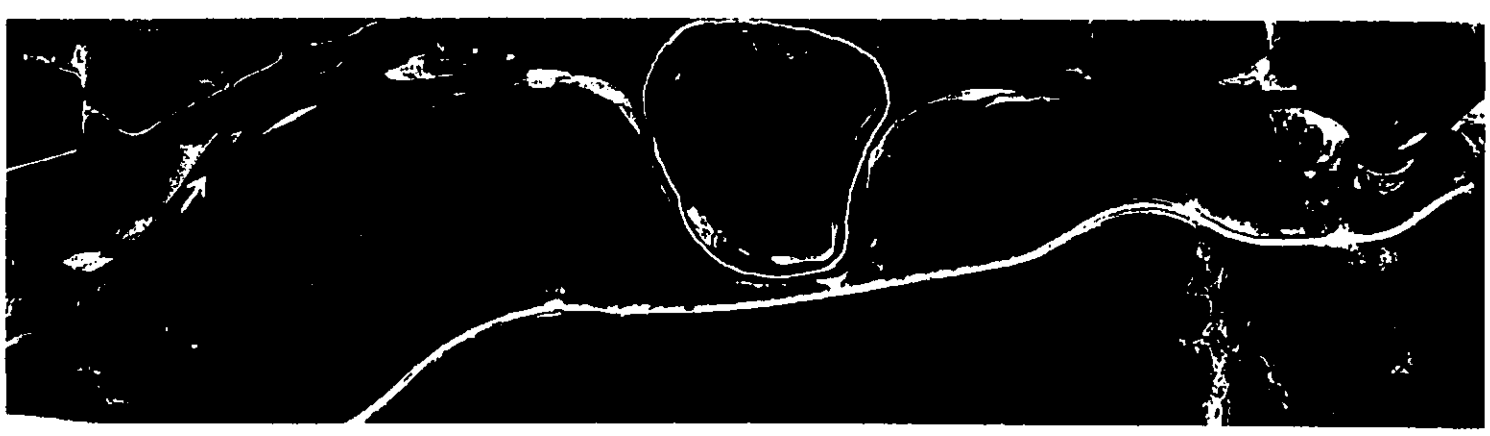


Figure 12. The circled site (a) and (b) was the second site of a channel change downstream from Site 3 (49° 21' N 115° 00' W). Images are from (a) air photo BC4057:103 July 9, 1962, and (b) air photo 30BCC94125:059 taken Aug. 10, 1994, both approximately 1:15,000 scale.

channel now runs along this old path of grasses.

In 1996, although the Elk River did not abandon the old channel for the new one, the flow to the old channel was reduced and a large island was created (Figure 12b). Both channel shifts were initiated through easily erodible grasslands rather than established cottonwoodlands. The second site of channel change included the removal of fringe cottonwood trees, but the rest of the cottonwoodland protected the majority of the meander lobe from being scoured away.

Large volumes of deposition are known to occur with extreme flow events like the 1995 flood (Kochel 1988). Most of the scour and deposition reported in previous studies occurred immediately following the decline of flood waters. Few studies have followed the events of scour and deposition for subsequent years.

The amount of deposition following the 1995 flood is not known since sites were not surveyed prior to the flood. However in May, 1996 at Site 1, transect line number 0637 elevations were recorded showing the elevation after the 1995 flood. New elevation measurements were made in July, 1996 recording the scour and deposition that occurred along this transect line from the 1996 1-in-4 year return flood event (Figure 14). In Oct. of 1997 elevation measurements were made on the same line to investigate changes that occurred following the 1997 peak discharge (Figure 14).

Substantial scour and deposition occurred in 1996 and 1997 even though these high flow events were minor compared to the 1995 flood. One possible

A – Site 3 B – New channel C – Original channel

Figure 13. The site of the second channel change adjacent to Site 3 (49^0 21' N 115^0 00' W) along the Elk River Aug. 3, 1996.

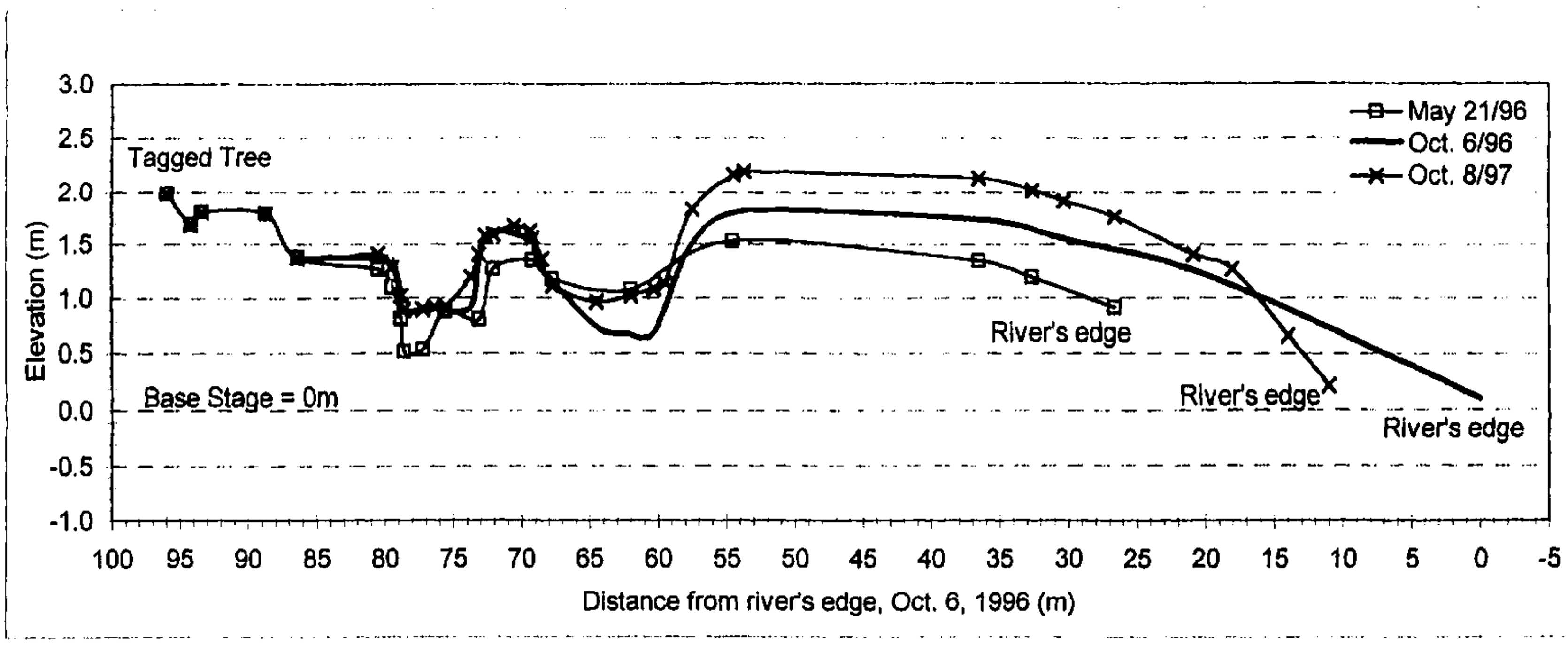


Figure 14. Changes in cross-sectional elevations relative to base stage that occurred along transect 0637 at the Elk River Site 1 from May 1996 to October 1997.

explanation for this erosion was because the 1995 flood left unconsolidated areas of substrate which required less energy for remobilization in the following years. The level of deposition should decrease with time as the new streambed substrate material becomes progressively stabilized.

Site One

Site 1 with transect line 0637, underwent noticeable geomorphological change in recent decades. Figure 15a shows the area (circled) in 1962. At that time, the site was on a meander lobe with considerable cottonwood recruitment sites apparently available. In 1981, the meander lobe had a section cut off from it forming part of a new island, and the river had eroded the opposite bank, shifting the river left (facing downstream) to accommodate the island (Figure 15b). By 1994, the island had cottonwood recruitment and had grown in size through deposition (Figure 15c). The continued erosion of the left bank increased the width of the river channel on the left side of the island (Figure 16). After the 1995 flood, the right channel had been reduced but still flowed. Following the flood of 1995, and the high flow of 1996, the right channel of the island was closed off to reconnect the island with the meander lobe. A partial back channel resulted that was fed by a small creek and the Elk River (Figure 17a). After the 1997 peak, the downstream edge of the meander lobe had elongated and approached the mainland with only a slightly submerged bar prevented the final connection (Figure 17b). This demonstrates the extent of deposition and the downstream advance of the meander lobe during the two years after the 1995 'flood of the century'.

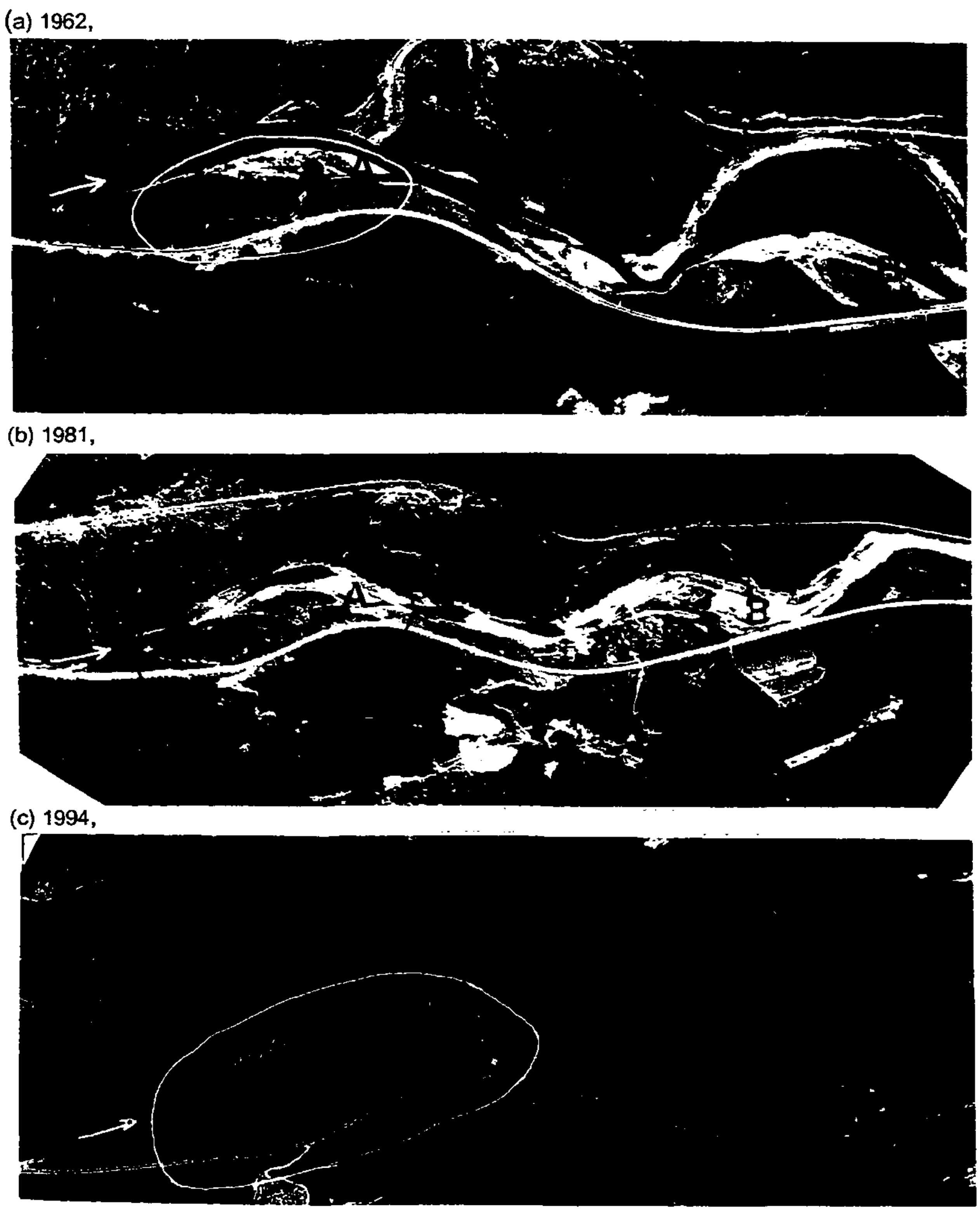


Figure 15. Elk River channel migration and formation of islands (A and B) from 1962 to 1994 at 49° 25' N 115° 02' W. Site 1 is circled and images are a scale ranging approximately 1:15,000 to 1:20,000.

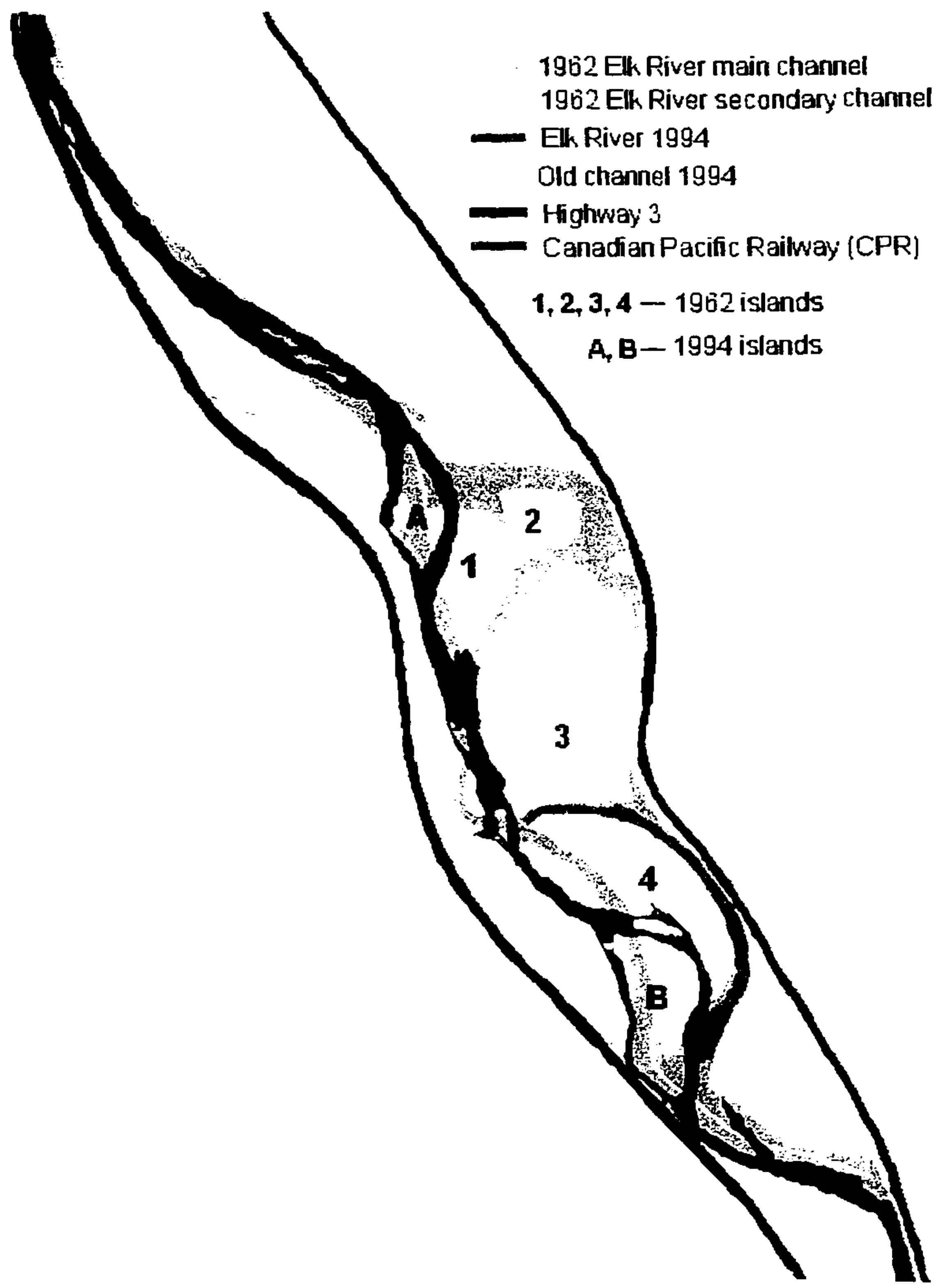
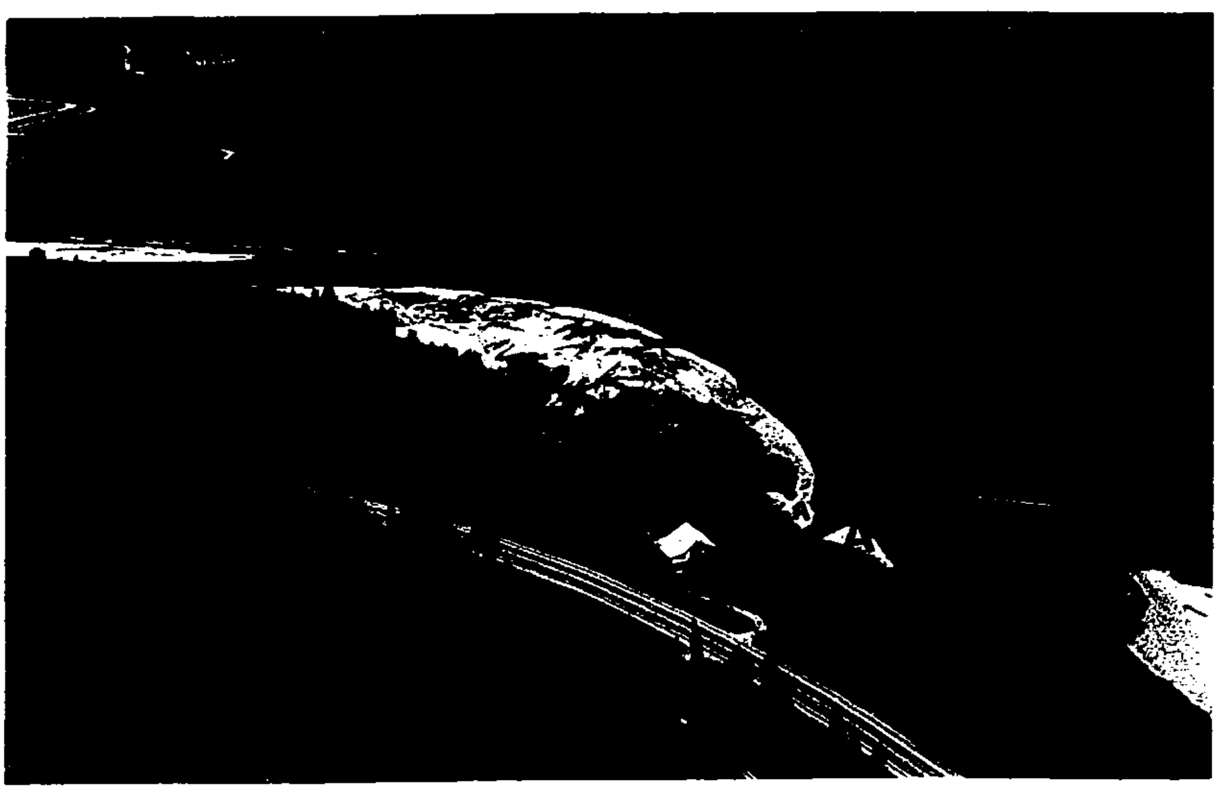


Figure 16. The Elk River channels in 1962 with an overlay of the Elk River channel in 1994 (approximately 1:15,000 scale at 49° 25' N 115° 02' W).

(a) 1996, A - bar



(b) 1997, A - bar

Figure 17. Elk River Site 1 (49^0 25' N 115^0 02' W), (a) oblique photo taken August 3, 1996 and (b) photo taken at ground level in 1997, extension of the bar.

The formation of the island (A) at Site 1 was not the only change which occurred along this stretch of the Elk River. Figure 16 shows the changes that occurred along this reach. These included the moving of Highway 3 as it was eroded away by the Elk River upstream of Site 1, the loss of three islands (marked 1, 2, 3) just downstream of the new island (A), and the formation of another new island (B). Figure 15b shows the start of island B in 1981 as a portion of the meander lobe which was latter cut off from the mainland.

Site Two

Substantial deposition and meandering occurred at Site 2 following the major 1995 flood. Figure 18a shows the meander lobe in 1962 with a small open bar shaded by mature cottonwoods and an island close to the opposite bank (circled). By 1981 the back of the meander lobe had been cleared, but a buffer strip of cottonwoods was left along the river (Figure 18b). The island across from the site had become connected to the left bank and large deposits existed (circled). By 1994, the whole meander lobe had been cleared, leaving a single row of cottonwoods along the edge (Figure 18c). The barren areas of 1981 (circled) had been colonized by the same types of vegetation found along the fringe that was left: black cottonwood, willow, red-osier dogwood, Columbia hawthorn, and a variety of grasses, wildflowers and sedges. A small bar occurred at the middle of the meander lobe and was chosen as Site 2 (Figure 18c arrow).

At Site 2, the small bar present in 1981 (Figure 18b), was enlarged by 1994 (Figure 18c arrow) and Site 2 continued to enlarge through 1997. Three

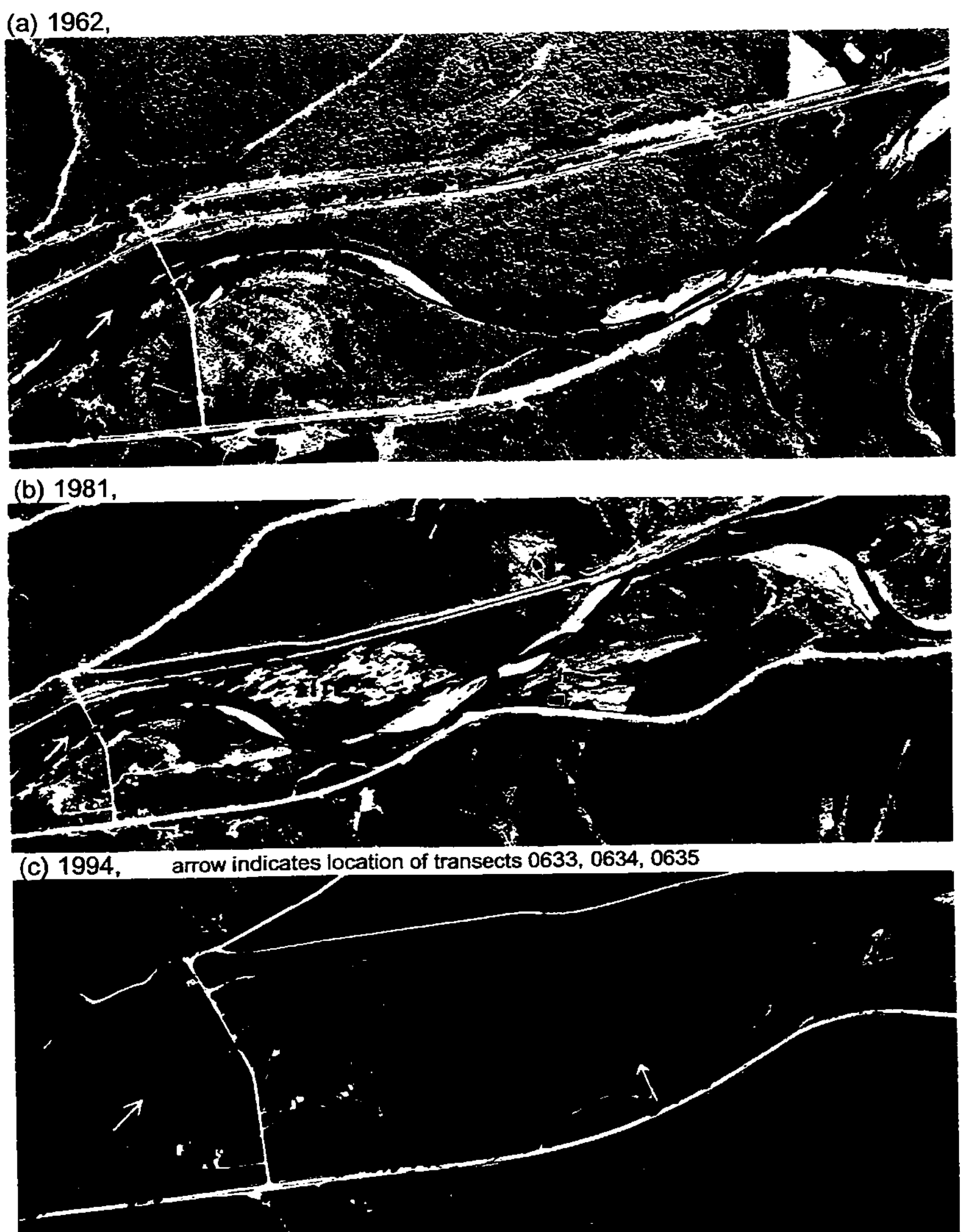


Figure 18. Elk River channel migration at 49° 23' N 115° 01' W from 1962 to 1994 leading to the merging of the island to the mainland. The images are a scale ranging approximately 1:15,000 to 1:20,000.

transect lines were established on the main portion of the meander lobe. In 1997, the meander lobe had shifted downstream, leaving the upstream transect (0635) on an eroding edge of the meander lobe. Transect 0635 decreased from 16.2 to 7.6 m in length from the tagged tree to the river's edge from 1996 to 1997. Transect 0634 underwent mixed changes from 38.4 to 41.1 m to the river's edge and had up to 0.4 m of new deposition (Figure 19a). The last transect line at Site 2 was 0633 which extended from 41.5 m (1996) to 45.7 m (1997) and received up to 0.6 m of new deposition (Figure 19b).

Site 2 is slowly being built up through deposition and is also shifting downstream. The new area deposited in 1981 had increased in size by 1994, showing the slow building of the meander lobe over 13 years. From the 1994 air-photo, the meander lobe appears to have increased more in the two years following the 1995 'flood of the century' than it had in the 13 year period between 1981 and 1994 air-photos.

Site Three

Site 3 involved a newly formed bar resulting from the scouring away of vegetation and the deposition of fines, and cobble, resulting in a barren, cobble site more than 100 m long. The 1962 air-photo (Figure 20a) shows Site 3 with the freshly deposited bar flanked by vegetation, probably consisting ofwillow and juvenile cottonwoods. By 1981, the bar had progressed towards the opposite bank. Erosion had carved the inside edge to form a sharp 'S' bend in the river (Figure 20b). By 1994, the point bar had expanded through deposition and cottonwoods had colonized the meander lobe (Figure 20c). When the transect

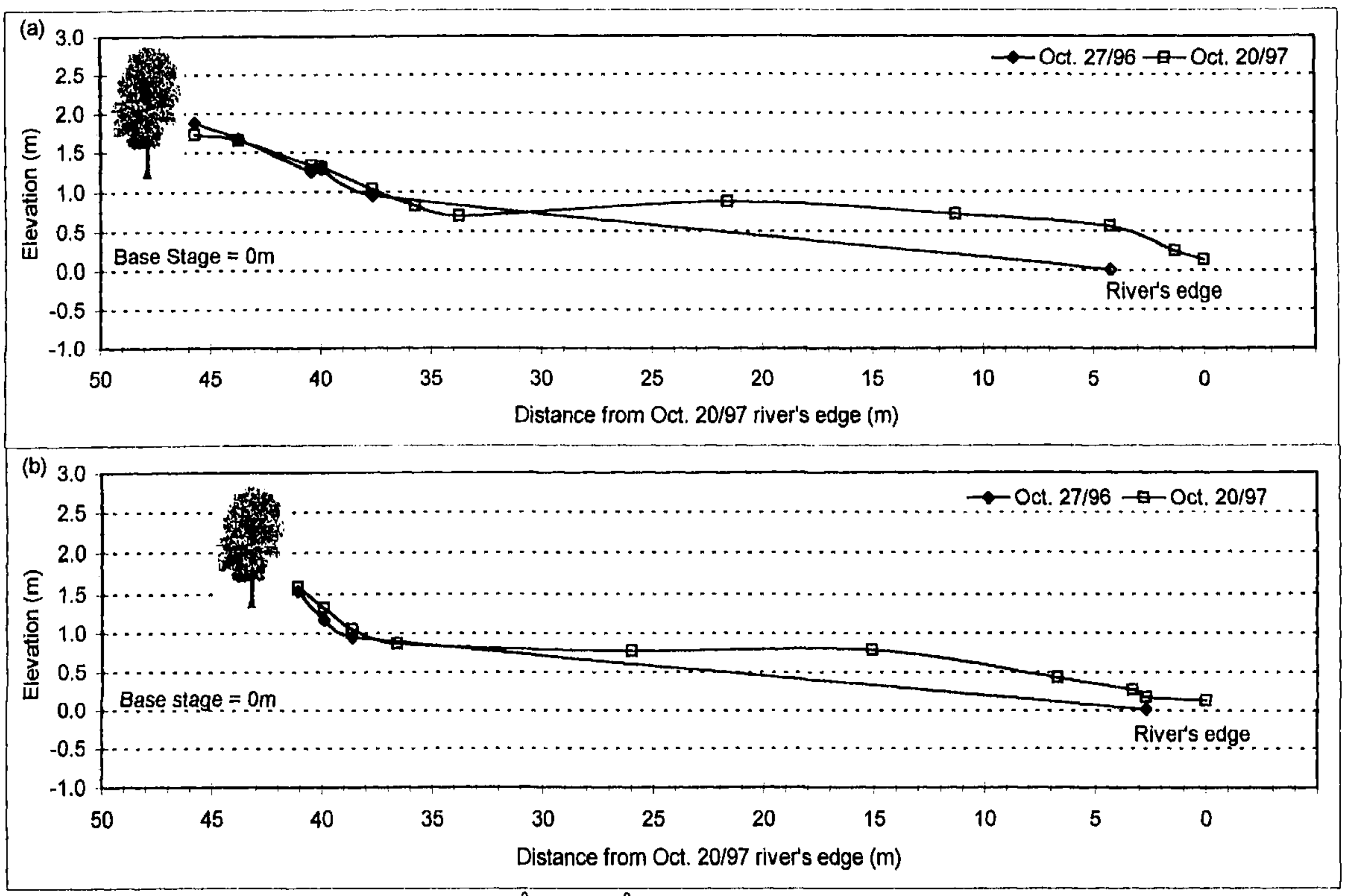


Figure 19. Gain in elevations along Elk River Site 2 (49⁰ 23' N 115⁰ 01' W) transects from deposition that occurred during 1997 spring flow (a) transect 0633, and (b) 0634.

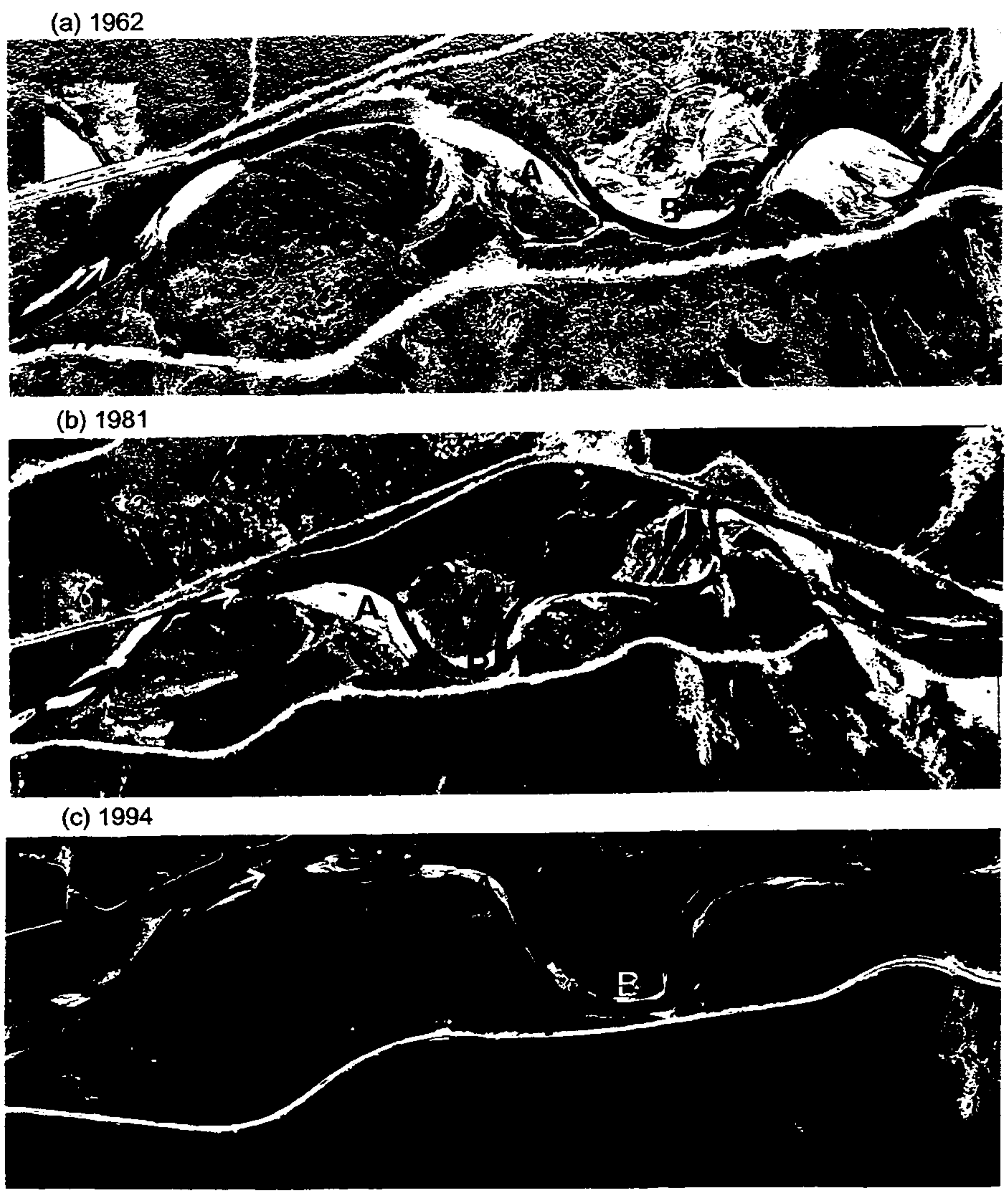


Figure 20. Elk River channel migration at 49^{0} 21' N 115^{0} 00' W (Site 3 [A]) from 1962 to 1994 causing change in sites labeled A and B and images are a scale ranging approximately 1:15,000 to 1:20,000.

lines were set up at Site 3, following the 1996 peak discharge, the meander lobe had increased in size considerably from 1994.

The changes that the Elk River experienced from 1962 to 1994 at and near Site 3 can easily be seen by overlaying the 1962 river channel with the 1994 channel (Figure 21). Site 3 (A) and the migration of the meander lobe, is also visible by 1994. As well as the change in meander lobe A, meander lobe B had changed shape considerably (Figure 21). The channel pattern along this whole stretch had changed substantially. The arrows mark major changes but very little of the river channel is unchanged from 1962 to 1994 (Figure 21). Site 3 in 1996 is shown in Figure 22 with transect lines drawn in at the approximate positions. The average length of these transects was 100 m. Following the peak flow of 1997, the Elk River had eroded a small channel through the meander lobe leaving part of the outside portion as a mid-channel bar (Figure 22b). On the opposite side of the river, which previously (1996) had an eroding bank (Figure 22a), was a point bar in 1997 (Figure 23a). The inside edge of Site 3 was greatly reduced, leaving transect 0651, which was previously well in from the edge, at the eroding edge of the meander lobe (Figure 23b). The previously 100 m long cobble bar was thus reduced to less than 30 m in length.

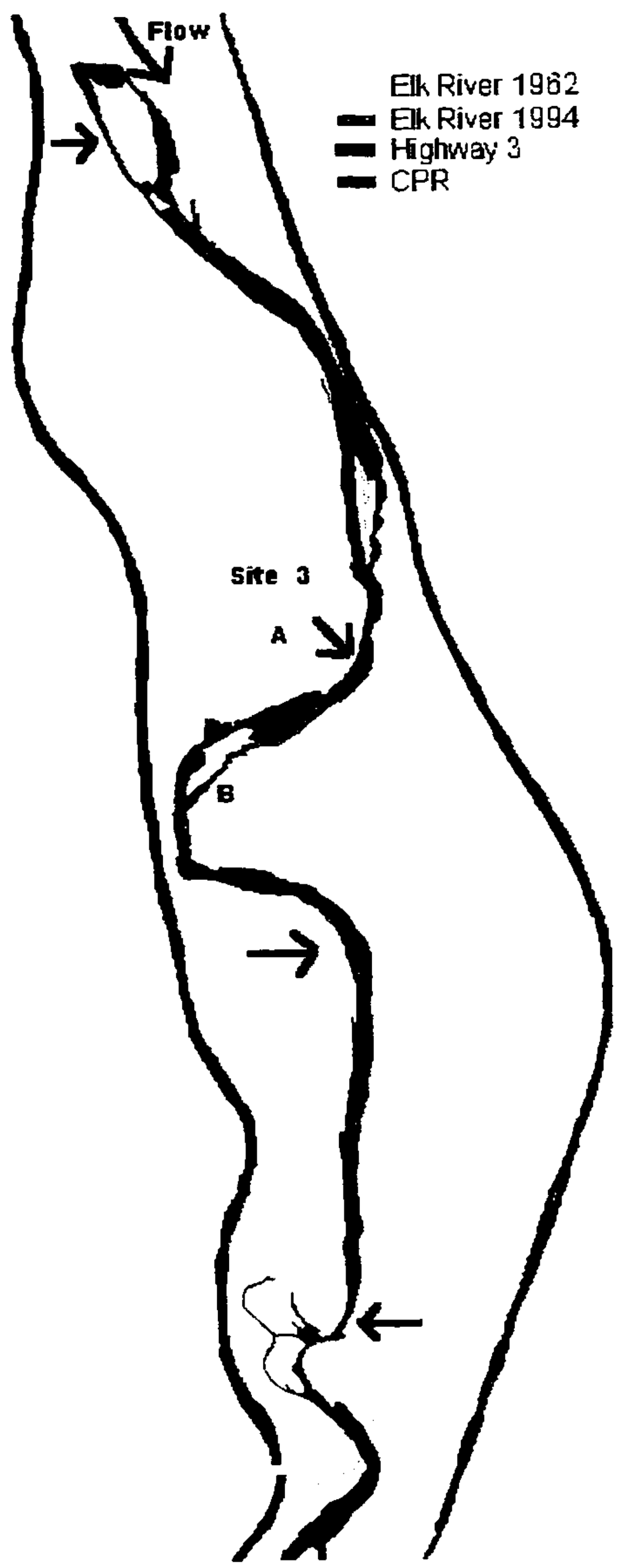
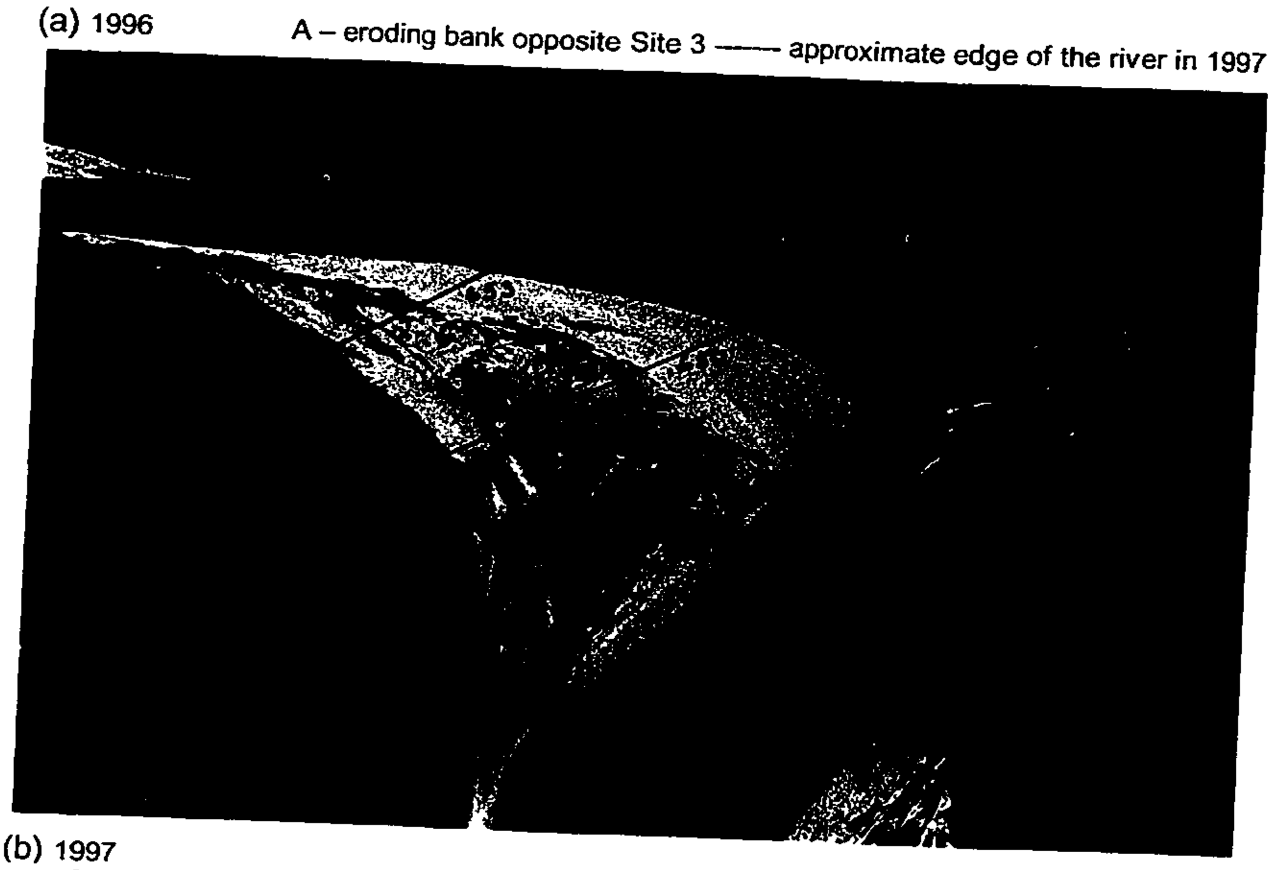


Figure 21. The Elk River channel in 1962, with an overlay of the Elk River channel in 1994 (approximately 1:15,000 at 49° 21'N 115° 00' W).

(a) 1996 A – eroding bank opposite Site 3 —— approximate edge of the river in 1997



(b) 1997

Figure 22. Site 3 (49° 21' N 115° 00' W) along the Elk River (a) Aug 3, 1996 with approximate positions of transects 651, 652, 653 and approximate new channel in 1997 marked,) (b) Site 3 (X) in September 1997.

(a)

(b)

Figure 23. Changes that occurred at and near Site 3 (49^0 21' N 115^0 00' W) along the Elk River 1997. (a) The previously eroding bank across from Site 3, transect 0653 became a new point bar A. (b) The new channel which reduced the size of Site 3, transect 0651is now on the eroding edge of the meander lobe, taken July 18, 1997.

Successful Black Cottonwood Recruitment of Site One

Recruitment can be inferred by examining the ages of trees in stands and relating them to records of flood events. Tree-ring core samples were taken on what previously was the island at Site 1. The earliest tree establishment apparently occurred in 1977, (Table 3). However, when dealing with increment-core samples it is impossible to determine exact tree age since the original root crown is usually buried. The samples were taken about 25 cm from the ground surface to permit the crank of the increment borer to be turned, and this resulted in an age underestimation of about 2 to 5 years. Additionally, since the rings are unclear and difficult to interpret, all tree establishment dates from table 3, 4, and 5, are approximate and do not attempt to compensate for error due to burial or the height that the core was sampled at.

All of the trees sampled, on the old island, were 20 years old or younger (Table 3). This is supported by the 1981 air-photo (Figure 15b) which shows a barren site. Small seedlings would be too small to show up on such an air-photo, however the air-photo does show other vegetation, such as grasses, had not colonized the site by 1981. The trees on the island (Figure 24b) were tightly clumped suggesting that these groups were of clonal origin (Gom 1996). Because of this, only the largest tree of the group was cored to best estimate the age of the original tree

The 1974 peak discharge had a 1-in-10 year return interval (Figure 7a) that may have been the event that scoured the new channel, creating the island as well as scouring away any vegetation that might have colonized this part of

Table 3. Year of establishment of cottonwood trees sampled from Elk River Site 1 (49^0 25' N 115^0 02' W), based on increment core samples.

NUMBER	CIRCUMFERENCE	YEAR OF ESTABLISHMENT	
1	83 cm	1980	↑
2	41.8 cm	1988	
3	83.8 cm	1984	
4	72.5 cm	1983	Old Island
5	94.0 cm	1977	
6	67.0 cm	1983	
7	35.0 cm	1986	↓
8	90.0 cm	1973	
9	96.4 cm	1977	
10	130.0 cm	1966	
11	58.8 cm	1986	
12	69.0 cm	1980	
13	63.0 cm	1986	
14	140.0 cm	1964	
15	160.0 cm	1961	
16	78.5 cm	1984	
17	86.0 cm	1981	
18	71.4 cm	1982	
19	49.0 cm	1986	
20	77.5 cm	1983	

the meander lobe since 1962. If trees were scoured by this event, some of the trees cored could have originated from root suckering, shoot suckering or coppice growth after the stem was sheared or buried. These clonal processes could have produced clumps of trees. The tree apparently established in 1977 could have been established through seedling or clonal origin in 1974 or 1975 after the moderate flood. The island may also have been formed during and following the 1974 flood. The frequency distribution of the trees sampled can be found in Figure 7b with the peak discharges associated with the years of establishment in Figure 7a.

The remainder of trees sampled at Site 1, were behind the edge of cottonwood trees of the old meander lobe (Figure 24b), and behind transect lines 0636 and 0367. The 1962 air-photo shows that this area had some vegetation but not mature cottonwoods, which were along the back of the meander lobe (Figure 24a). Table 3 shows the results of the tree-core samples taken in this area. There were a few trees established in the early 1960's but the majority were from the 1970's and 1980's. This confirms that the area in the 1962 air-photo which shows vegetation cover included some cottonwoods. The sample line would have to extend to the highway to determine the age of the mature stand that was evident in the 1962 air-photo and which is still present in 1997 (Figure 24).

The cottonwood trees on the old island were surrounded by a fairly dense stand of juvenile cottonwood trees. These juveniles had densities of 10 stems/m^2, standard deviation (sd) equaled 4.7 stems/m^2 and ranged from 4 to 7

(a)

(b)

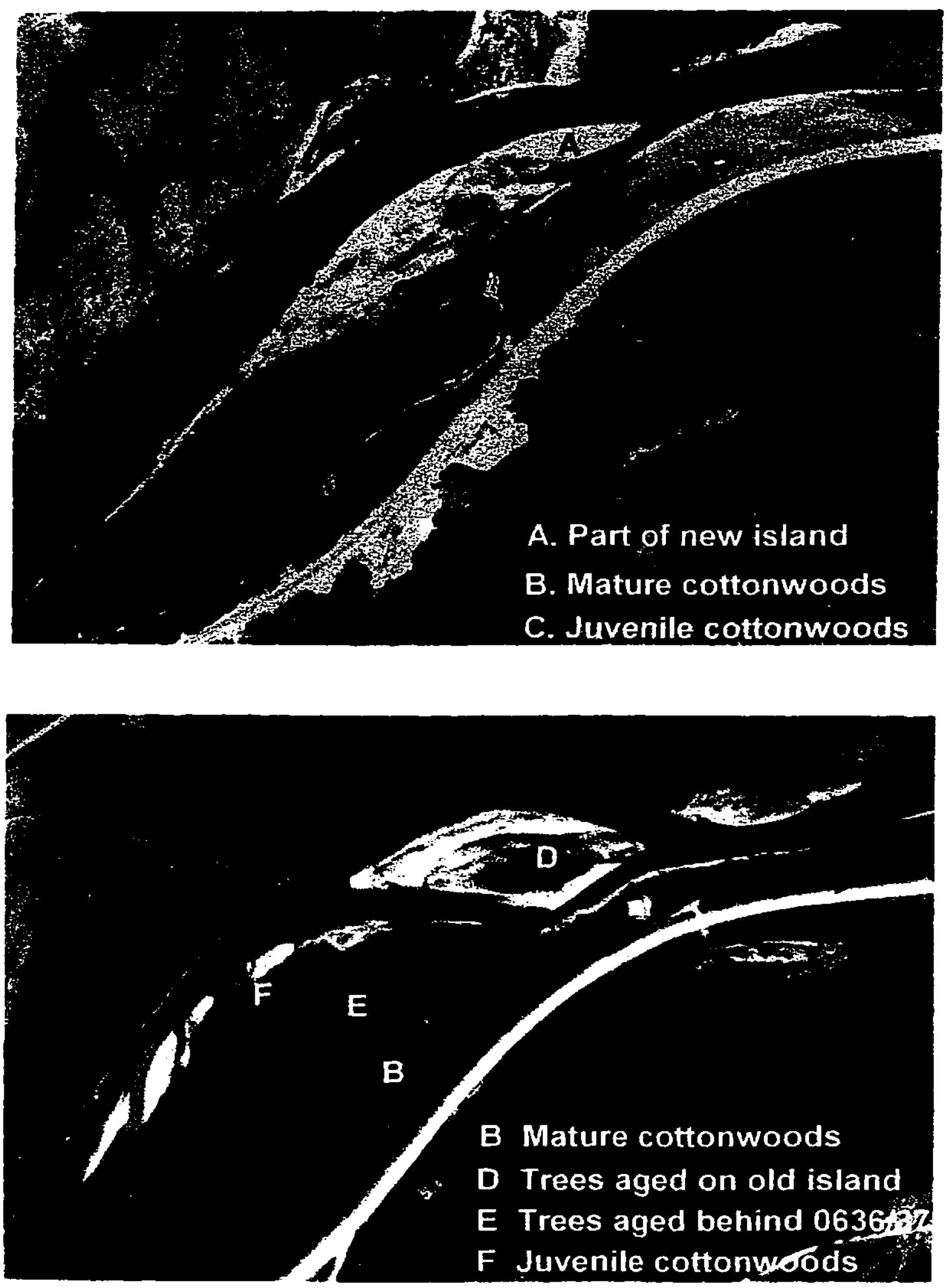


Figure 24. Age class structure at Site 1 along the Elk River. (a) and (b) Areas of sampled trees in (a) 1962 and (b) in 1994 that were increment bored in 1997. Images were from air-photos (a) 1962 and (b) 1994, at approximately 1:6,000.

years of age, with an average height of 187.8 cm, sd = 86.7 cm. Juvenile height ranged from 85 (browsed and some were flood trained) to 343 cm. Some of the older juveniles could have been the result of the 1991 flood event which had a 1-in-3 year return interval and some of the younger juveniles originated from the scour of the 1995 flood. The considerable height for their young age and the large size of some of the leaves suggest a clonal origin, probably root suckers in which the established root system enables favorable growth and shoot size for some of the juveniles in the group sampled.

The juvenile trees in front of the mature stand of cottonwoods on transect 0636 included 7.7 stems/m^2, sd = 2.37 stems/m^2. The average heights by June 30, 1998 were 182 cm, sd = 67.21 cm and ranged from 98 (flood trained and some were browsed) to 340 cm with ages ranging from 3 to 9 years. Many of these juveniles exhibited the same growth and density patterns as the juveniles in front of the cottonwood trees that were aged on the old island. Their origin was not known but some are clonal as evidenced by their growth rate and the size of some leaves. The same flood events may have been responsible for these juveniles as enabled the juveniles found on the old island.

Successful Black Cottonwood Recruitment of Site Two

Increment core samples were extracted from a few large trees along the edge of the Site 2 meander lobe. However, most of the trees at the site were juveniles growing back on the previously cleared field. The majority of the juveniles probably originated as root suckers, probably from the plowing of the field after the mature trees were removed. Table 4 shows the group sampled; numbers 1, 2, 6, 17 and 18 were taken from the mature stand along the edge. The rest of the samples were randomly collected in the abandoned cleared field. Some of those trees were probably of clonal origin since they had especially large leaves. The height of the three, four-year-old trees (19, 20, 21) implied that they were of cloned origin because seedlings of their age are considerably smaller. The two trees (22, 23) in their first year of shoot growth were also of clonal origin since their heights were more than 30 cm. In contrast, the tallest first year seedlings along the Elk River averaged only 1.5 cm. The three saplings with shoots from 1994 and the two from 1997 were excavated and were confirmed to be from root suckers. These root clones demonstrated the rapid growth capable of clonal saplings compared to seedlings.

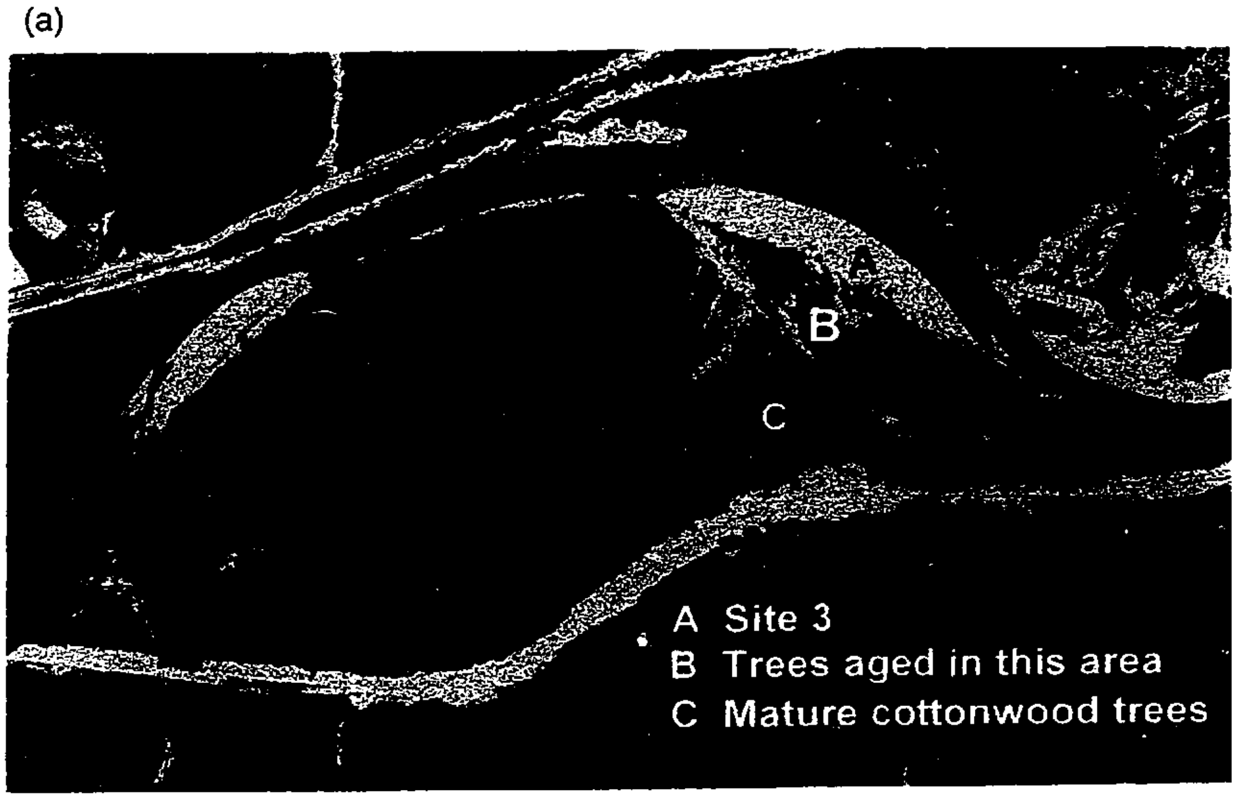
Successful Black Cottonwood Recruitment of Site Three

The trees sampled at Site 3 were mainly from the newly vegetated area shown on Figure 25b. One tree was sampled from the corner of the mature stand (B) and was found to have been established in about 1938 (Table 5). The rest of the trees sampled support the evidence from the 1962 air-photo (Figure 25a) which shows small vegetation, that would have indicated young cottonwoods (Table 5).

Table 4. Year of establishment of cottonwood trees sampled from Elk River Site 2 (49^0 23' N 115^0 01' W), based on increment core samples and growth scar counts for the saplings (*).

NUMBER	CIRCUMFERENCE	YEAR ESTABLISHED
1	190 cm	1942
2	175 cm	1946
3	30.5 cm	1988
4	45 cm	1985
5	30.4 cm	1990
6	193.8 cm	1932
7	39.1 cm	1989
8	30.0 cm	1988
9	28.5 cm	1991
10	34.3 cm	1992
11	40.0 cm	1990
12	31.8 cm	1988
13	4.2 cm	1989
14	7.1 cm	1988
15	12.3 cm	1987
16	6.5 cm	1987
17	335 cm	1906
18	122.5 cm	1885
19	51.7 cm tall	1994* clone
20	50.5 cm tall	1994* "
21	74.5 cm tall	1994* "
22	38.3 cm tall	1997* "
23	30.5 cm tall	1997* "

(a)



(b)

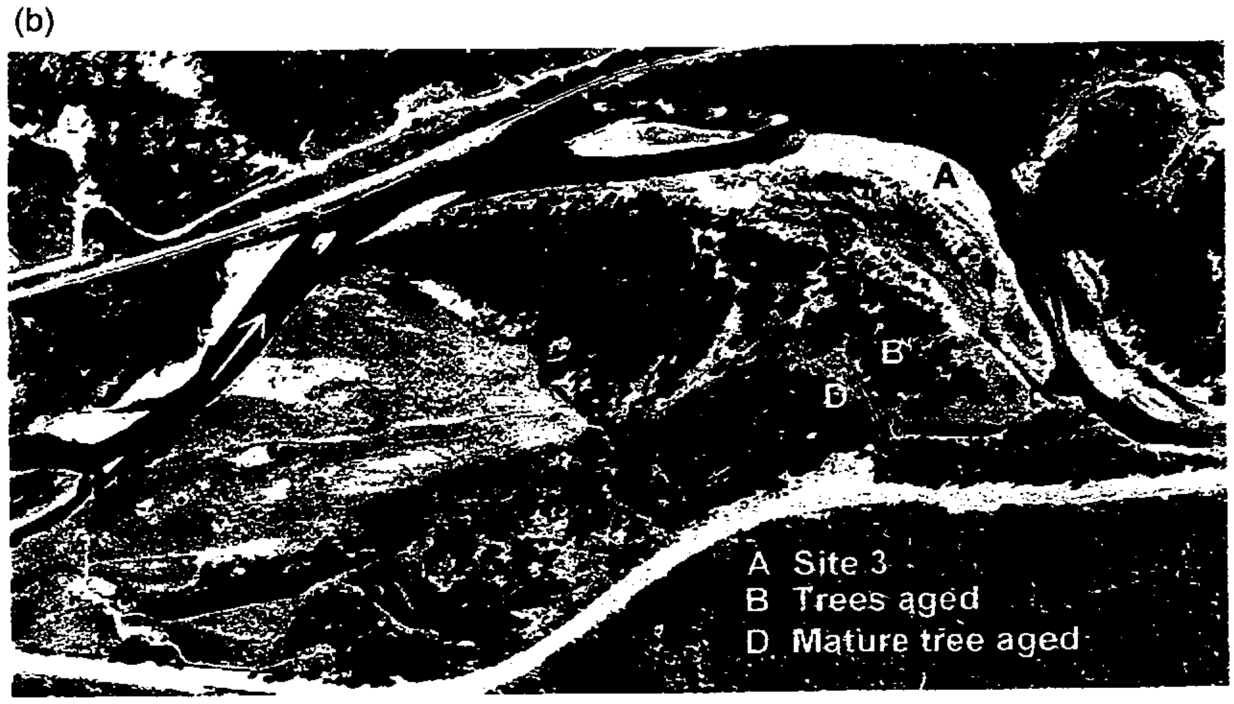


Figure 25. Ages class structure at Site 3 along the Elk River. (a) and (b) Areas were sampled trees were, in (a) 1962 and (b) in 1994, that were sampled in 1997. Images were from (a) 1962 air-photo was approximately 1:10,000 and (b) 1994 was approximately 1:7,000.

Table 5. Year of establishment of cottonwood trees sampled from Elk River Site 3 (49^0 21' N 115^0 00' W), based on increment core samples.

NUMBER	CIRCUMFERENCE	YEAR ESTABLISHED
1	263 cm	1938 mature stand
2	95.0 cm	1974
3	75.0 cm	1976
4	137.0 cm	1963
5	88.0 cm	1978
6	50.0 cm	1976
7	118.2 cm	1971
8	68.8 cm	1978
9	18.0 cm	1989
10	34.6 cm	1987
11	102.5 cm	1965
12	5.4 cm	1988
13	4.9 cm	1987
14	4.6 cm	1987
15	9.4 cm	1986
16	11.9 cm	1986
17	----------	1975
18	-----------	1986
19	------------	1978

Tree Ages and Peak Flows

Figure 7b includes all of the trees sampled from the three Elk River Sites. With the minimal number of older trees the pattern of recruitment did not appear to be clearly correlated with high peak flow years. The lack of sampling in older stands and the small data size (62) limit the confidence of analysis. Further sampling is needed but in contrast to some other studies, this data set does not indicate a close correlation between cottonwood establishment and flood events along the Elk River.

Trees were not arranged in clear arcuate bands and no dominate age cohorts of trees were found. The lack of arcuate banding, which is found on prairie and other semi-arid systems where tree establishment is more closely tied to flood events, also supports the interpretation that recruitment is not always linked to flood events along the Elk River, a humid, hydrologically gaining, mountainous river reach. However, black cottonwoods freely sprout root suckers, and this complicates the association of establishment and flood events and the lack of arcuate banding. The original parent trees may have been established following a flood event but subsequent cloning makes it difficult to establish the sources of origin of ramets in mature stands and would contribute multiple ages in a cottonwood clone.

Black Cottonwoods

Phenology

Black cottonwood male catkin emergence generally occurs from late March to early May with specific times varying geographically with regional climate and across years due to weather and particularly temperature of a particular year (Braatne et al. 1996). Along the Elk River between Fernie and the Highway 3 tunnel, male catkins (which emerge prior to female catkins) had started to emerge by May 7, 1997. Across western North America, black cottonwood seed dispersal generally occurs from late May through June and into July (Braatne et al. 1996). Seed release near Fernie had just started by June 23, 1997 but had commenced by June 7, in 1998 following a warm spring. The annual growth period is terminated with leaf senescence that had just started by September 1997 in the middle Elk valley.

The flushing phenology in 1997 seems to be at the end of all of the typical times for black cottonwoods across North America. Conversely, senescence times along the Elk River appeared to be at the beginning of the normal timing for black cottonwoods. In the adjacent and warmer Kootenay valley, trees had not started to show any sign of senescence in early September. This compressed phenology provides the seedlings established along the Elk River with a shorter growth period than along some other river systems where bud flush and seed release are earlier and senescence is later. With a reduced growth period, the black cottonwood seedlings would be expected to be smaller than along other river systems with a longer growth period.

Sexual Reproduction

Seedling Establishment and Growth for 1996 and 1997 Cohorts

Black cottonwoods, like all cottonwoods, are prolific seed producers (Braatne et al. 1996). Consistent with this, abundant initial seedling establishment occurred on all of the meander lobes in this study in 1996, 1997 and 1998. The seeds that landed and germinated in areas of grasses and/or other dense vegetation along transect lines, usually died by mid-summer (personal observation along study site transect lines). This confirmed previous studies; seedlings are noncompetitive probably largely due to shade intolerance (Braatne et al. 1996).

The seedlings that survived the first summer had been established on initially barren areas. No banding was evident in 1996 or 1997, but rather, a broad scattering occurred across the open areas. Some banding did occur following the 1995 flood, with a broad scattering of seedlings between dense bands. Low elevations close to the river's edge lacked seedlings as these areas were submerged during seed release.

Seedling densities and heights were recorded along seven transect lines at Site 1 and three transect lines at each of Sites 2 and 3, producing thirteen total transects along the middle Elk river. Initial seedling heights for 1996 are shown in Figure 26a for Site 1, with a mean of 9.1 mm and a range of means for each transect line from 5.4 to 16 mm. Individual heights ranged from 2 to 118 mm by September of 1996. Figure 27a shows the mean heights from quadrats for Sites 2 and 3, with an overall mean of 13.6 mm for Site 2 and

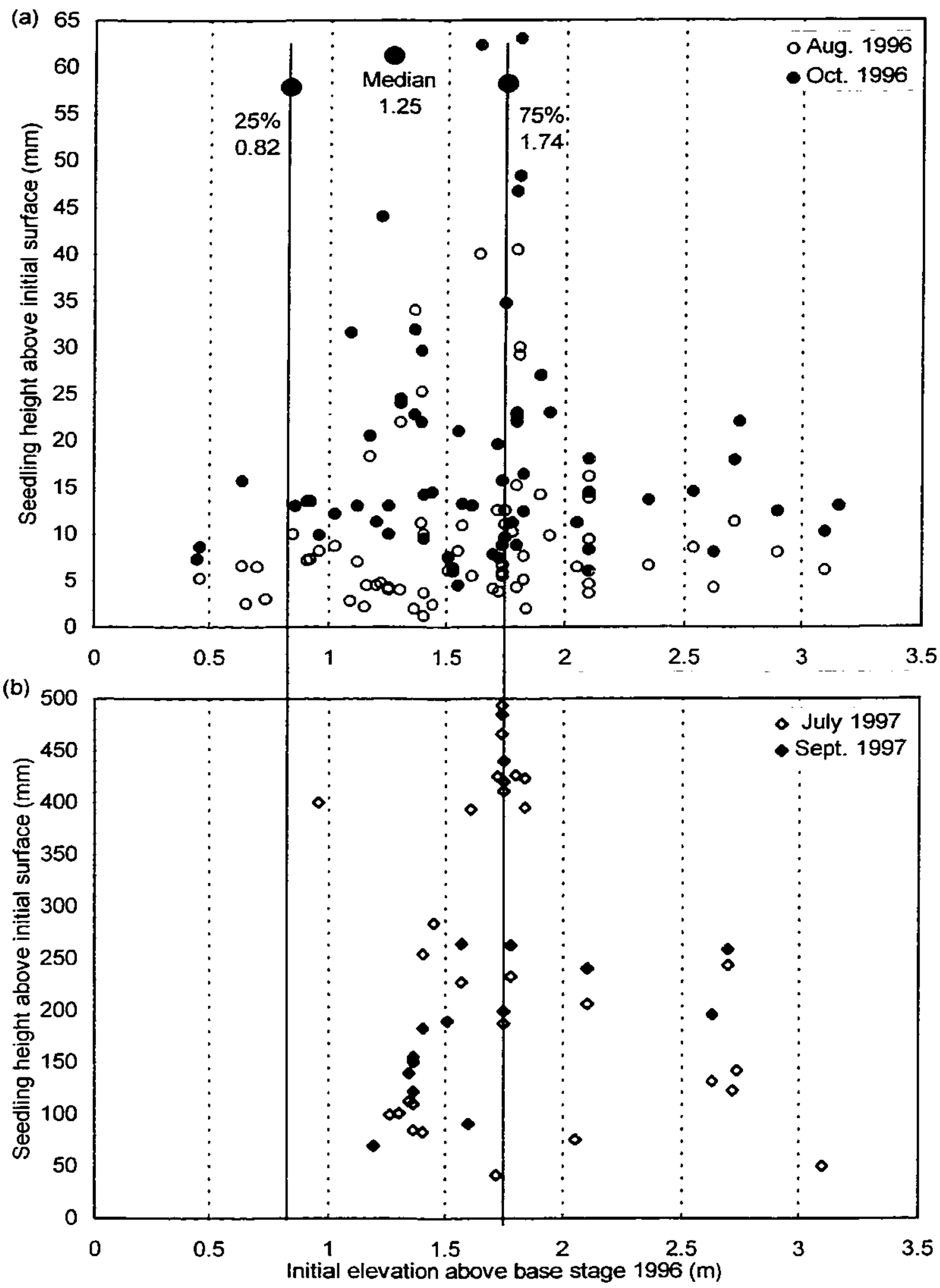


Figure 26. Elk River Site 1, heights for 1996 seedlings (a) in 1996 and (b) in 1997 with 25%, median and 75% values for seedling position from all transects along the Elk River in 1996.

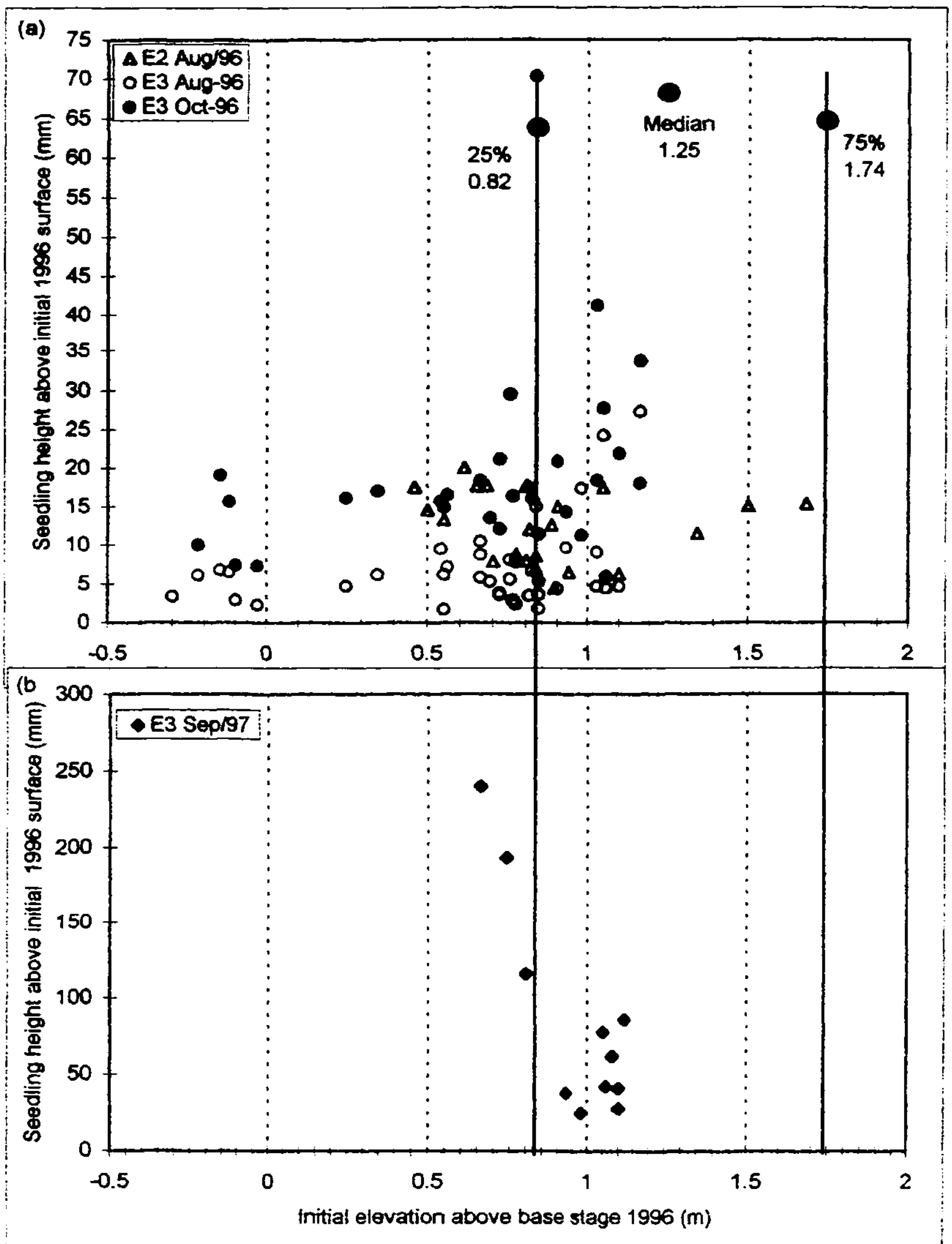


Figure 27. Elk River Sites 2 and 3 heights for 1996 seedlings (a) in 1996 and (b) in 1997 with 25%, median and 75% values from seedling position from all transects along the Elk River.

19.2 mm for Site 3. Site 2 had a seedling height range from 2 to 30 mm while Site 3 seedling heights ranged from 2 to 81 mm by October, 1996.

Both Figures 26 and 27 show the median, 25% and 75% values for the three meander lobes with respect to elevation of seedling occurrence. Site 1 had more seedlings at higher elevations than Sites 2 and 3. With all three sites taken together, the median elevation of seedling establishment was 1.25 m, with the majority of seedlings occurring between 0.82 to 1.75 m above the base, late summer, stage. Site 1 taken alone would have the middle 50% falling between 1 and 2.1 m. while Sites 2 and 3 would have 50% occurring between 0.5 and 1.2 m. The 1996 seedlings that survived to 1997 occurred between 1 to 3 m above base stage for Site 1. Seedlings that survived to 1997 at Site 3 occurred between 0.6 to 1.15 m and no 1996 seedlings survived to 1997 at Site 2.

Both sites which had 1996 seedlings survive into 1997 had large reductions in seedling densities. Mean seedling densities for 1996 were 105/m^2 for Site 1, 120/m^2 for Site 2, and 235/m^2 for Site 3, (Figure 28a and 29a). By the fall of 1996, overall seedling densities dropped by 54% of initial establishment (Figure 28b and 29b). May, 1997 seedling densities were measured and little change was noted from the fall densities. Therefore no ice scouring of seedlings occurred in the 1996/1997 winter on Sites 1 and 3. Site 2 was not investigated so it was not known if it experienced seedling loss over the winter. After the 1997 high water, seedling densities were measured again. The overall density was 18% of the early density in 1996. The majority of the loss of seedlings was due to burial by deposition and scour removal by erosion that occurred in 1997.

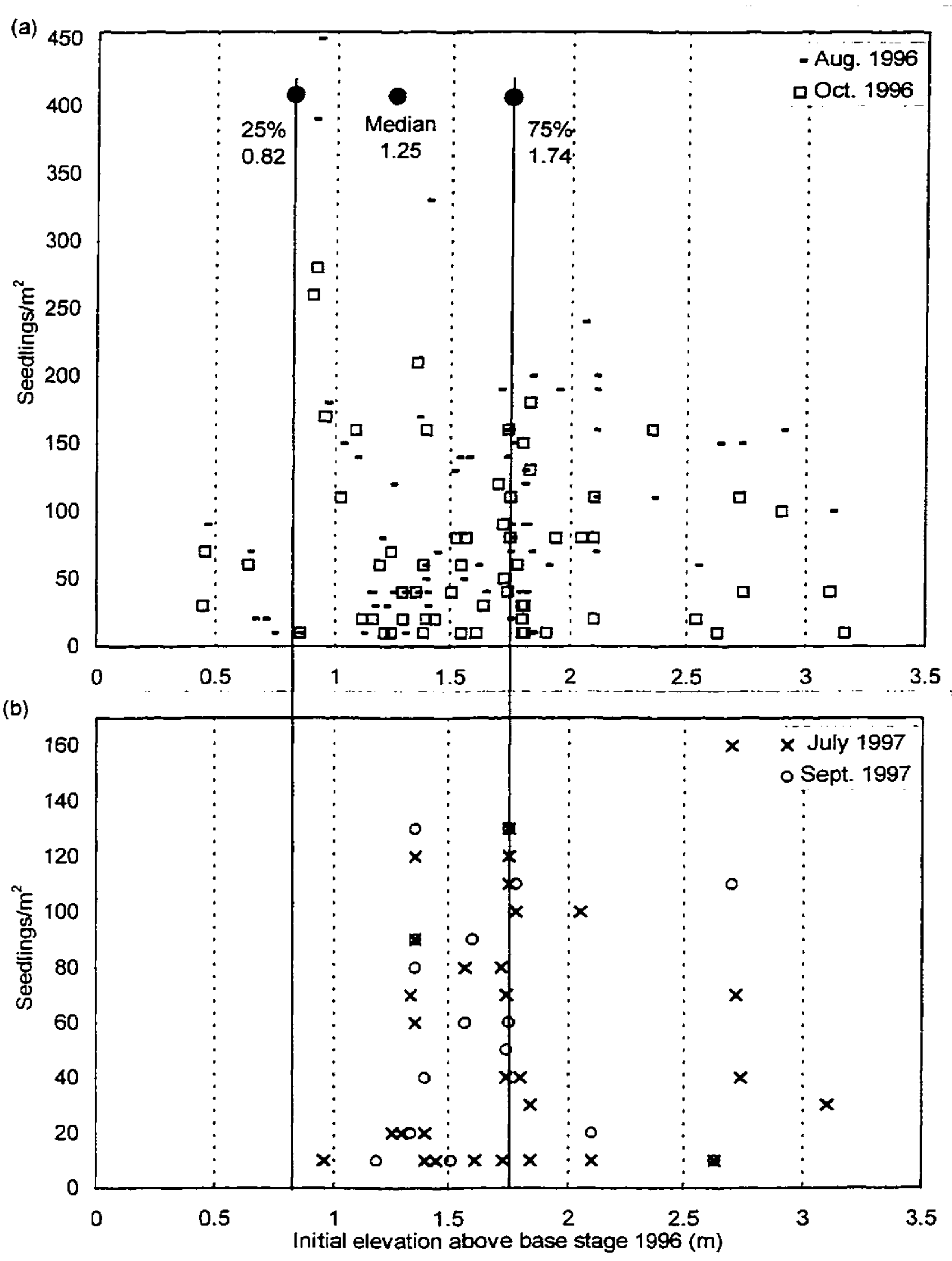


Figure 28. Elk River Site 1 densities for 1996 cottonwood seedlings (a) in 1996 and (b) in 1997 with 25%, median and 75% values for seedling position from all transects along the Elk River.

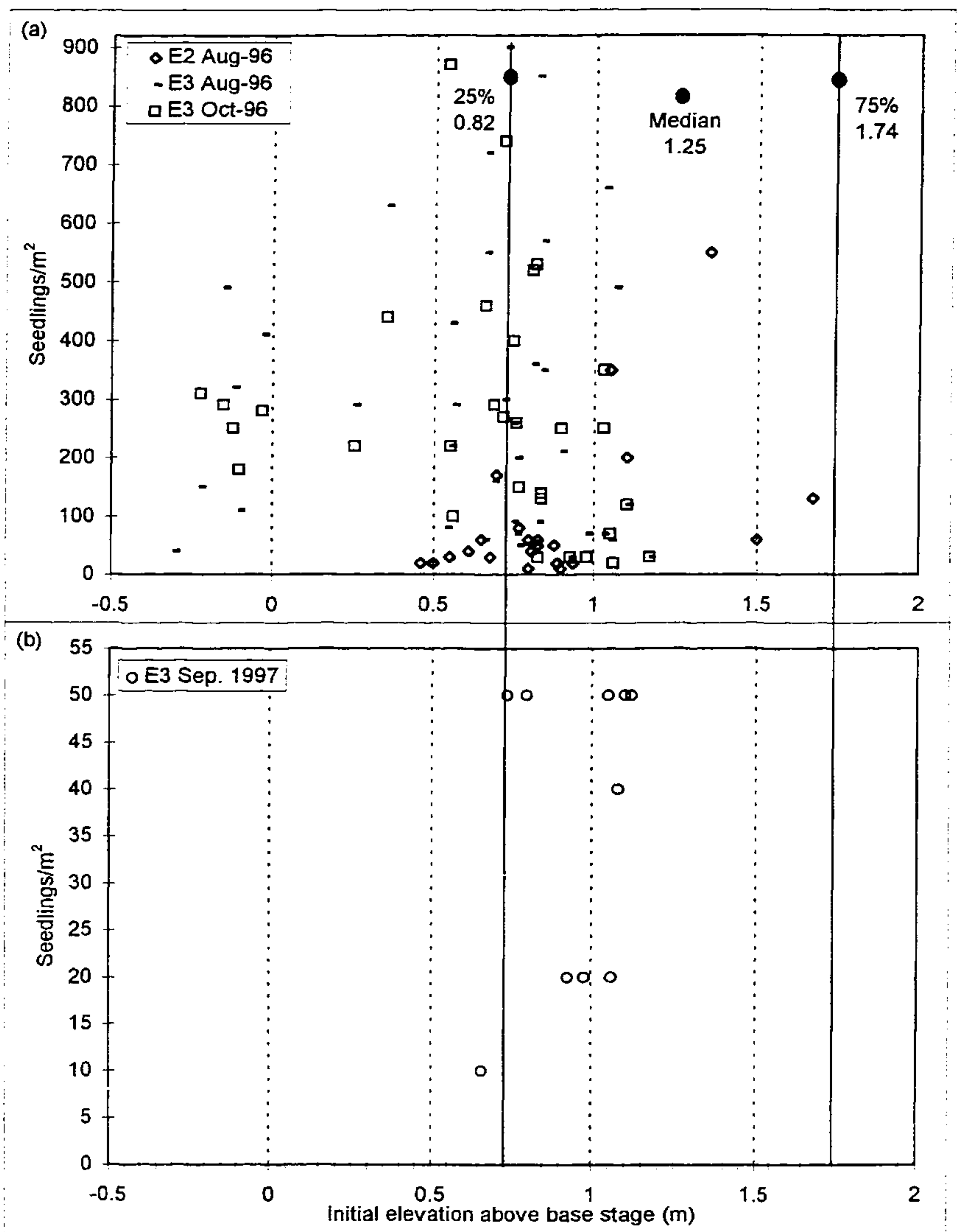


Figure 29. Elk River Sites 2 and 3 densities for 1996 cottonwood seedlings (a) in 1996 and (b) in 1997, with 25%, median, and 75% values for seedling position from all transects along the Elk River.

The extents of scour or deposition that occurred at all three sites relative to the initial elevations where seedling establishment took place are shown in Figure 30.

Site 1 experienced the greatest deposition with most zones being covered to depths from 0 and 0.5 m (Figure 30). All quadrats that had more than 50 cm of deposition had no seedling survival from 1996 through 1997. Some of the 1996 black cottonwood seedlings did survive 40 cm of deposition but only the tallest seedlings from 1996. Even in these, all of the 1996 growth was buried in 1997 with differing amounts of the 1997 growth prior to inundation, being buried as well. Some seedlings which experienced less deposition were buried to the growth scar (1996 growth tip) in 1997. The initial elevation at which 1996 seedlings survived to 1997 can be seen in Figures 26b and 27b, with the amount of deposition added to the mean height.

Peak discharge occurred on June 2, 1997, giving the 1996 seedlings about a month of growth in 1997 before being flooded. At the extreme, the 1996 seedlings grew up to 11 cm in a month in 1997. During the initial establishment, seedlings probably put more energy into the growing of roots than into their shoot growth (Mahoney and Rood 1991). In 1997, the 1996 seedlings already had the roots established and thus more resources could be diverted to the shoot growth. The 1996 seedlings that survived deposition in 1997 had to grow 1 to 10 cm before deposition took place which was easily attainable for the tallest seedlings in 1996. In contrast, the seedlings of average height of 1996 could not grow the 10 to 30 cm they required to survive the deposition. This

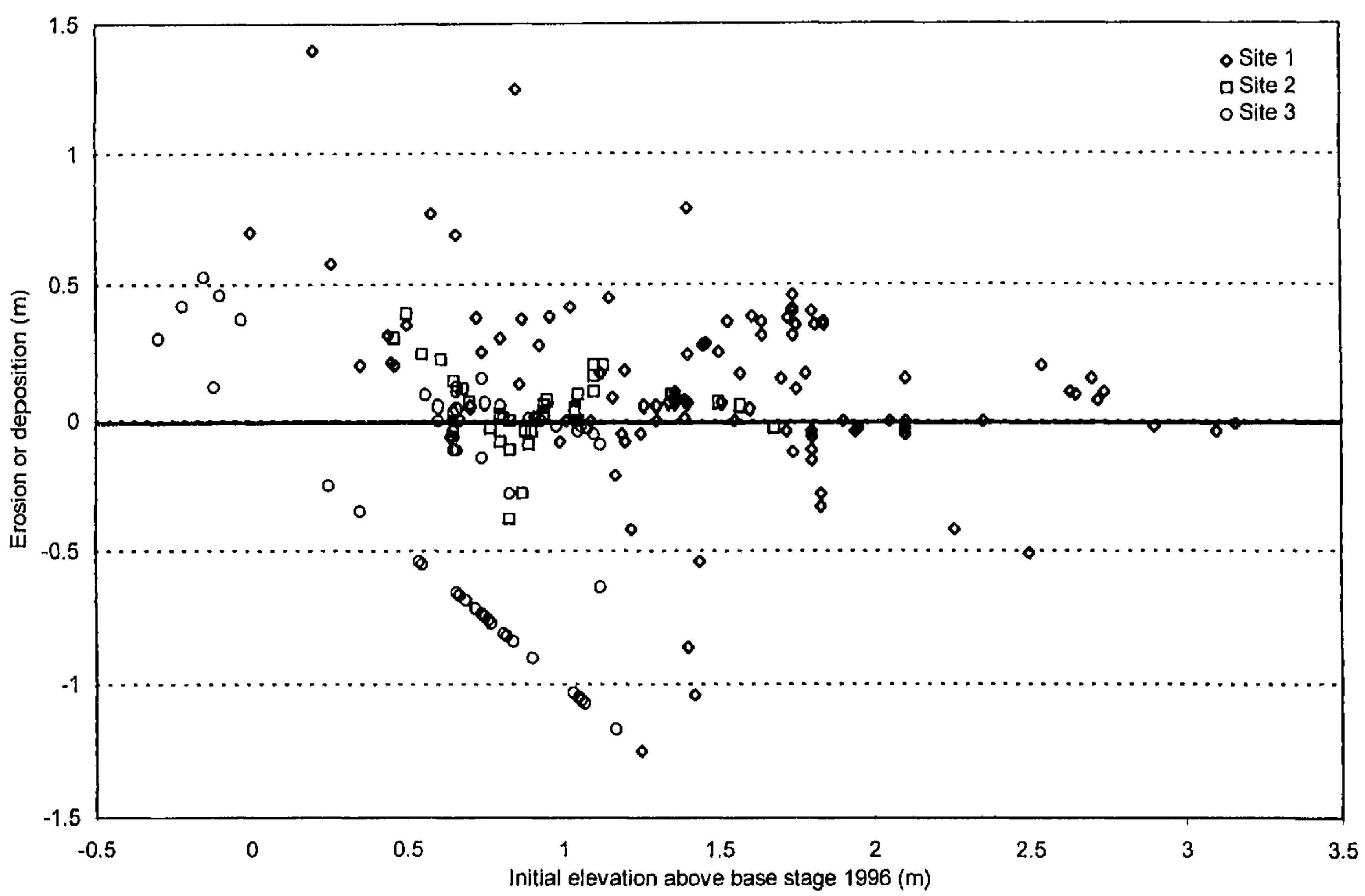


Figure 30. The amount of deposition (positive) or erosion (negative) for the three sites along the Elk River, which resulted from the 1997 spring high flow.

resulted in the extreme drop to 18% in densities from the initial establishment levels of 1996 (Figure 28b)

Sites 1 and 3 experienced more deposition than Site 2 but no seedlings from 1996 survived to 1997 at Site 2. The range of seedling heights at Site 2 were from 2 to 30 mm, well below the 2 to 110 mm and 2 to 118 mm from Site 1 and 3, respectively. Deposition at Site 2 was considerably less than Site 1 but the shorter 1996 seedlings could not grow sufficiently in 1997 to survive burial.

Site 2 was a newly enlarged meander lobe deposited after the 1995 flood. Because it was new, it was at a very low elevation. New meander lobes depend on deposition each year to gradually build up the elevation. With the growth of a new lobe the seedlings have less chance of survival for the first few years because of the extensive erosion and deposition that occur. Once the meander lobe is built up to the elevations found at Sites 1 and 3 the newly established seedlings will have a better chance at survival.

Seedling Establishment in 1997

Seedling heights were first measured July 16, 1997, a month earlier than the first measurement of seedlings in 1996. Because of these earlier measurement, the average heights were only between 2 to 10 mm for Sites 1, 2, and 3 (Figure 31a and 32a); the seedlings had just recently emerged. The 1997 seedlings were later measured on September 29, 1997, and quadrat samples averaged from 7 to 44 mm at Site 1, 7 to 24 mm at Site 2, and 4 to 21 mm at Site 3. The 1997 growing season did not produce the same seedling height results

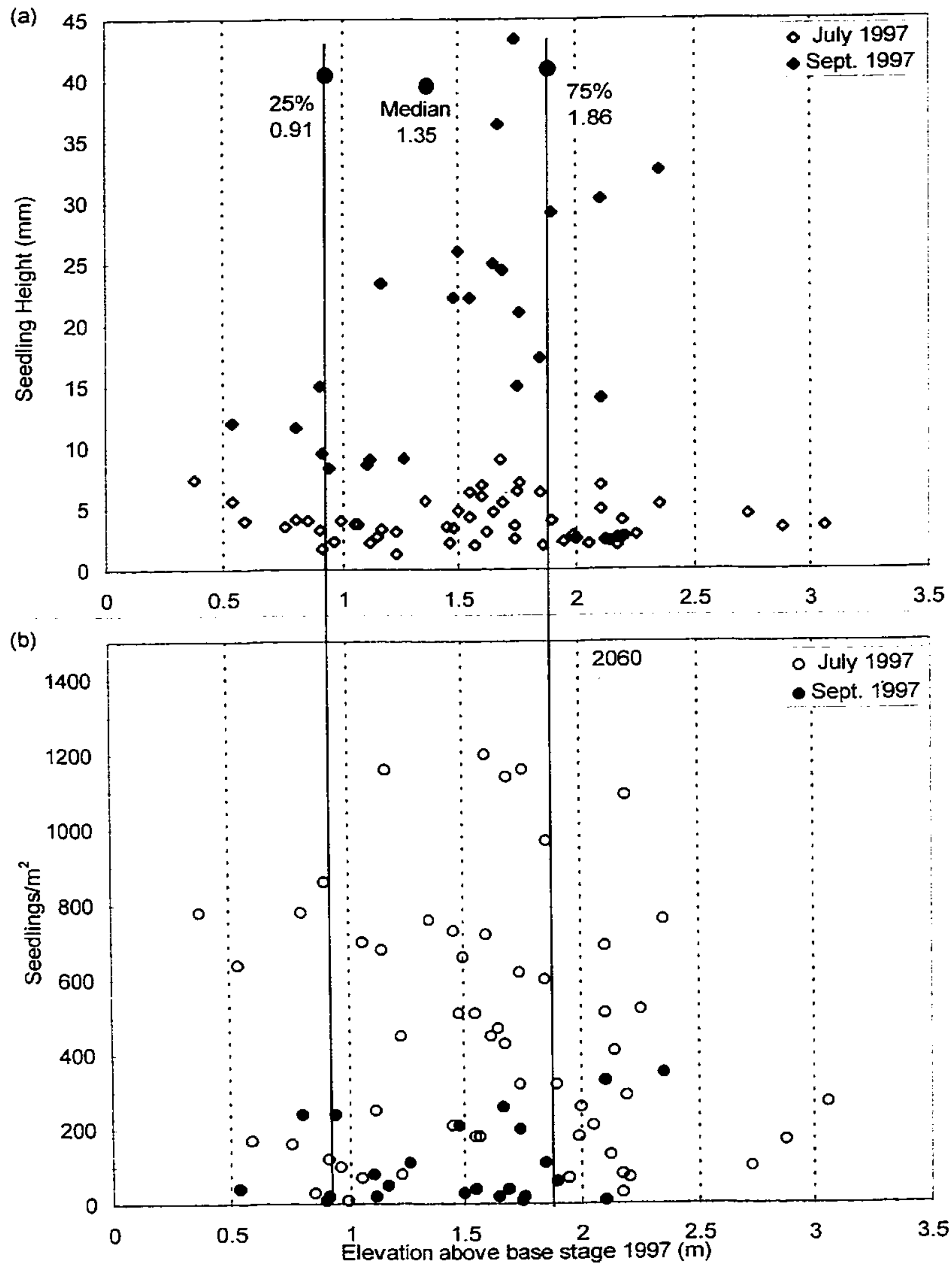


Figure 31. Elk River Site 1, 1997 cottonwood seedlings (a) heights and (b) densities with 25%, median, and 75% values from all transects along the Elk River.

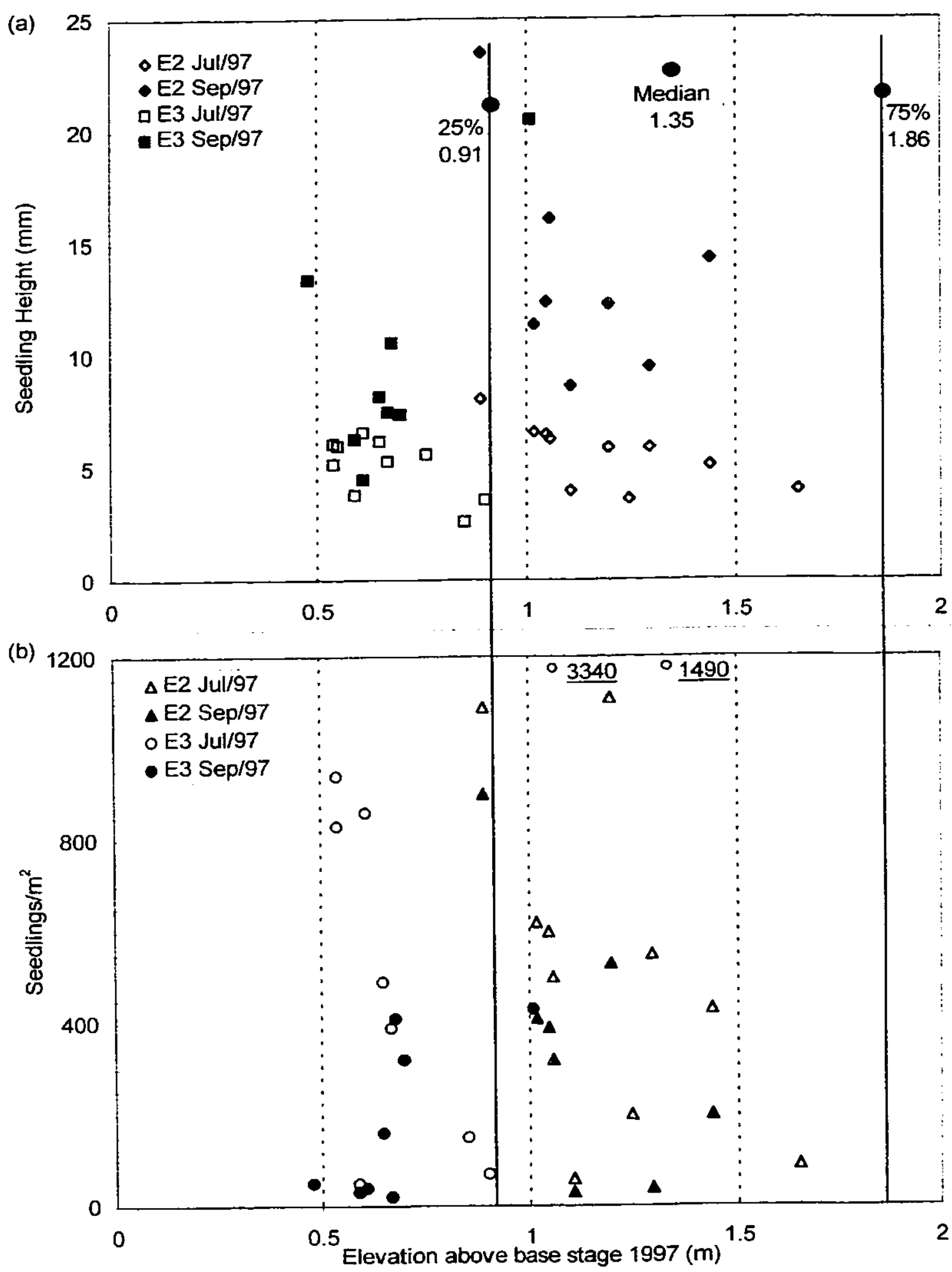


Figure 32. Elk River Sites 2 and 3, 1997 cottonwood seedlings (a) heights and (b) densities with 25%, median and 75% values from all transects along the Elk River.

as in 1996, with 1997 seedling significantly less than the first year growth of the 1996 seedlings (Anova F-Value 19.232, P-Value < .0001, appendix 2-259). The range of heights was also less in 1997 with Site 1 ranging from 4 to 75 mm, Site 2 ranging from 5 to 23 mm, and Site 3 ranging from 2 to 21 mm. At Site 1, only one measured seedling was above 50 mm in height. Smaller seedlings would have reduce chances of survival, especially if there was substantial deposition in 1998. Conversely, the 1997 seedlings have an advantage over the 1996 seedlings in that they were established at higher elevations than the 1996 seedlings. Consequently they might not have to survive the levels of deposition to which the 1996 seedlings were exposed. Figures 31 and 32 show the median for recruitment elevations in 1997. The median and the middle 50% were calculated for all three sites together. The 1997 middle 50% had increased by 10 cm above the 1996 middle 50% elevation.

The initial establishment densities of seedlings were higher in 1997, than in 1996. The 1997 seedling mean density was 570/m^2 for the Elk River sites, with the highest density of 3340/m^2 at Site 3 in 1997, compared to the highest seedling density of 900/m^2 at Site 3 in 1996 (Figure 31b and 32b). The density decline for the 1997 seedlings by the fall was also higher when compared to the 1996 densities. The density in the fall of 1997 was only 28% of initial establishment. The 1996 seedlings had only a drop to 54% of initial establishment, but a initial mean of 153 seedlings/m^2 meant a drop to 83 seedlings/m^2 which was lower than the mean fall density for 1997 of 160 seedlings/m^2. The survival percentages had a significant difference between

1996 to 1997 with Anova F-Value 18.264 and P-Value < .0001 (appendix 2-260). The high initial establishment of 1997 helped to reduce the impact of the loss of seedlings by the fall of 1997.

The difference in survival of the 1996 versus 1997 seedlings might be attributable to weather. The summer of 1997 was hotter and drier than that of 1996. Many of the new seedlings of 1997 probably did not grow roots fast enough to maintain moisture contact and this probably resulted in drought stress and some mortality. The seedlings that did survive showed evidence of drought stress in the form of their stunted growth rate. In the late summer of 1997 many of the 0.1 m^2 quadrats were filled with dead seedlings that were the same heights as when they were measured in July (Figure 33). Transect lines 0644 and 0645 at Site 1 had no survival of 1997 seedlings by the fall.

The 1996 seedlings that survived to 1997 did not experience drought stress in 1997 to the extent experienced by the new 1997 seedlings. Very few 1996 seedlings were found dead at the end of the 1997 growing season. With many of the 1996 seedlings established as much as 40 cm below the 1997 substrate surface, their roots were well established and much deeper than roots of the new 1997 seedlings. It is thus noteworthy and interesting that cottonwood seedlings in suitable deposition zones grow their roots downwards while sediment deposition raises the substrate surface upwards. These two processes combine to improve the seedlings' moisture access since the new fine deposition will retain some moisture and even draw moisture upwards through capillary rise.

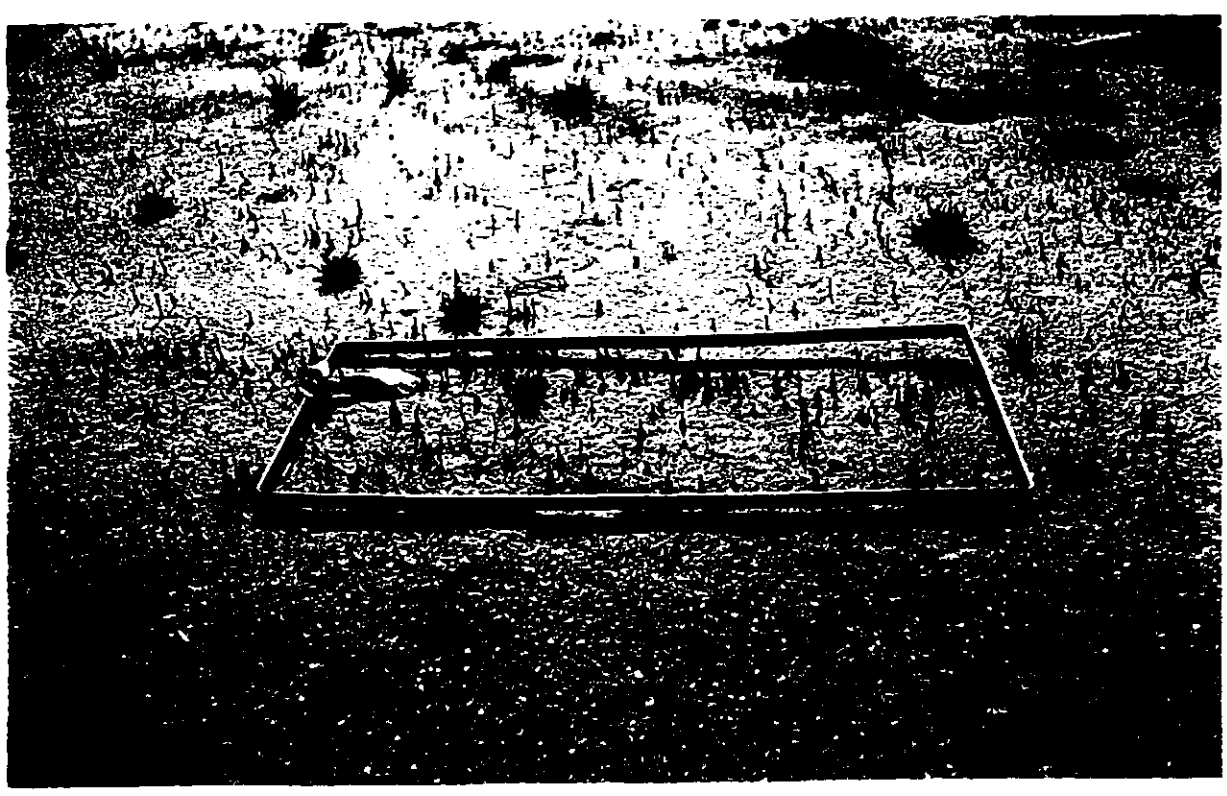


Figure 33. A 0.1 m^2 (20 X 50 cm) quadrat with 1997 cottonwood seedlings from Site 1 that had died from drought in 1997.

It is because of this extensive deposition and the ability of cottonwoods to produce adventitious roots from buried stems that many mature trees appear to have established 3 to 4 m above the base stage of the river. These mature trees were probably from seedlings established when the surface of that position of the meander lobe was at substantially lower elevation. With each year, added deposition buries some of the previous years growth and the trees appear to be established at higher elevations. This is an advantage to the juvenile since each year the tree keeps its roots in contact with the riparian water table and new roots can be produced from the buried stem. The gain in elevation reduces the chances of scour by high water and ice, further benefiting the saplings. However this is one reason why aging cottonwoods using increment core samples is inaccurate, since the 'breast height' position of the tree will often actually be much higher than 1.2 m above the root crown.

Cobble Versus Fine Substrates

The old island at Site 1 presented an opportunity for a comparison of how substrate texture affects seedling growth since both cobble and fine substrate areas were found on the island. The island had cobble substrate on the river's edge and fine substrate on the shore edge. Figure 34 shows the transect lines and the corresponding substrate. Comparisons of seedling densities for each line were made in 1996 (Figure 35a). No significant difference was found between seedling survival in the cobble versus the fine substrate in 1996, with each showing a 54% decrease by the fall of 1996 (Anova F-Value .417, P-Value

.5218 appendix 2-261). However, the same comparison was performed on the 1997 seedlings and although no significant difference occurred (P-Value .1539), a dramatic difference occurred with no seedling survival on the cobble substrate by the fall (Figure 35b). There was no significant difference because even on the fine substrate their were 20 quadrates which had no survival (histograms found in appendix 2-262).

This comparison implies that when sufficient moisture is available such as through summer rain, substrate has little affect on the survival of seedlings. However, with a hotter, drier summer (no data available as weather station for Fernie had been discontinued, personal observation only), fine substrate is beneficial since it has a greater capillarity to bring moisture up to the seedlings. Seedling roots may also be able to grow faster in fine than in cobble. However, the cobble substrate made it very difficult to excavate first year seedlings with intact roots and thus, no comparison of root lengths was made.

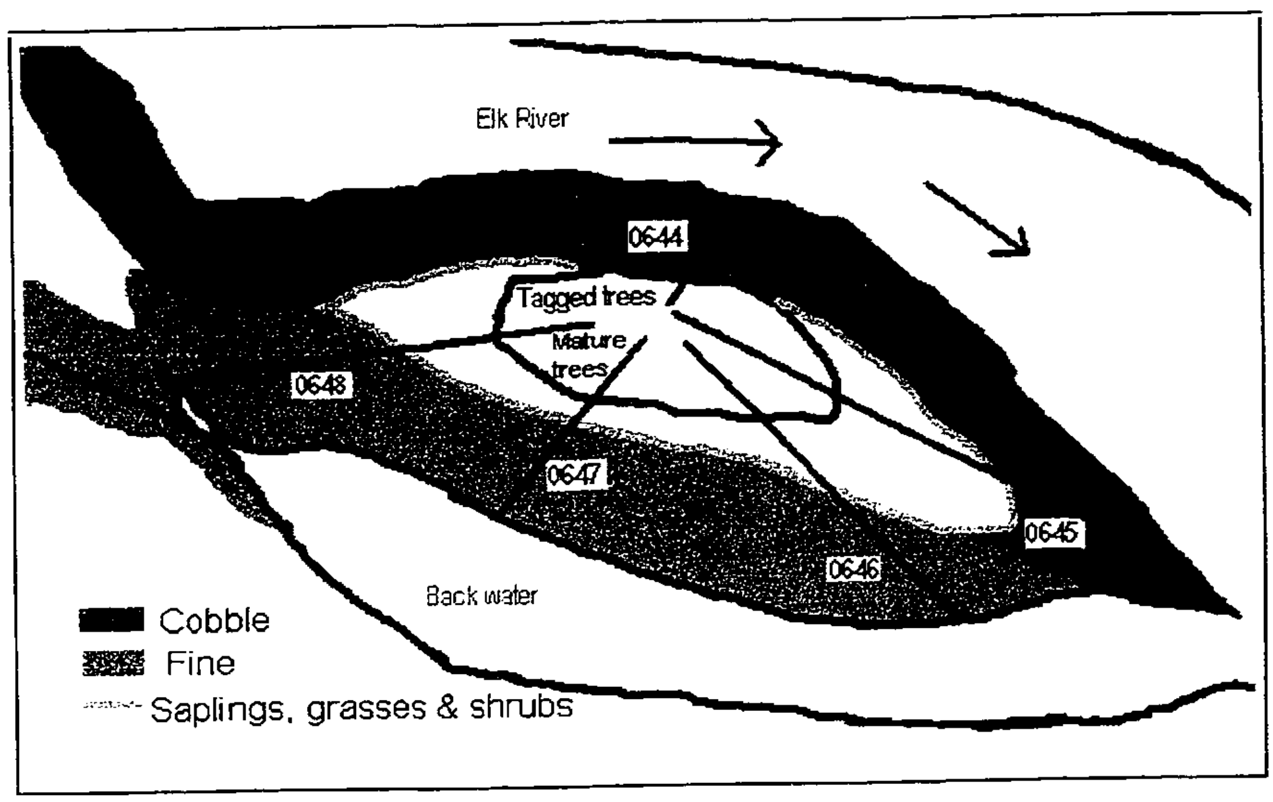


Figure 34. The 'old island', at Site 1 along the Elk River showing transect lines and the surface substrate and cover.

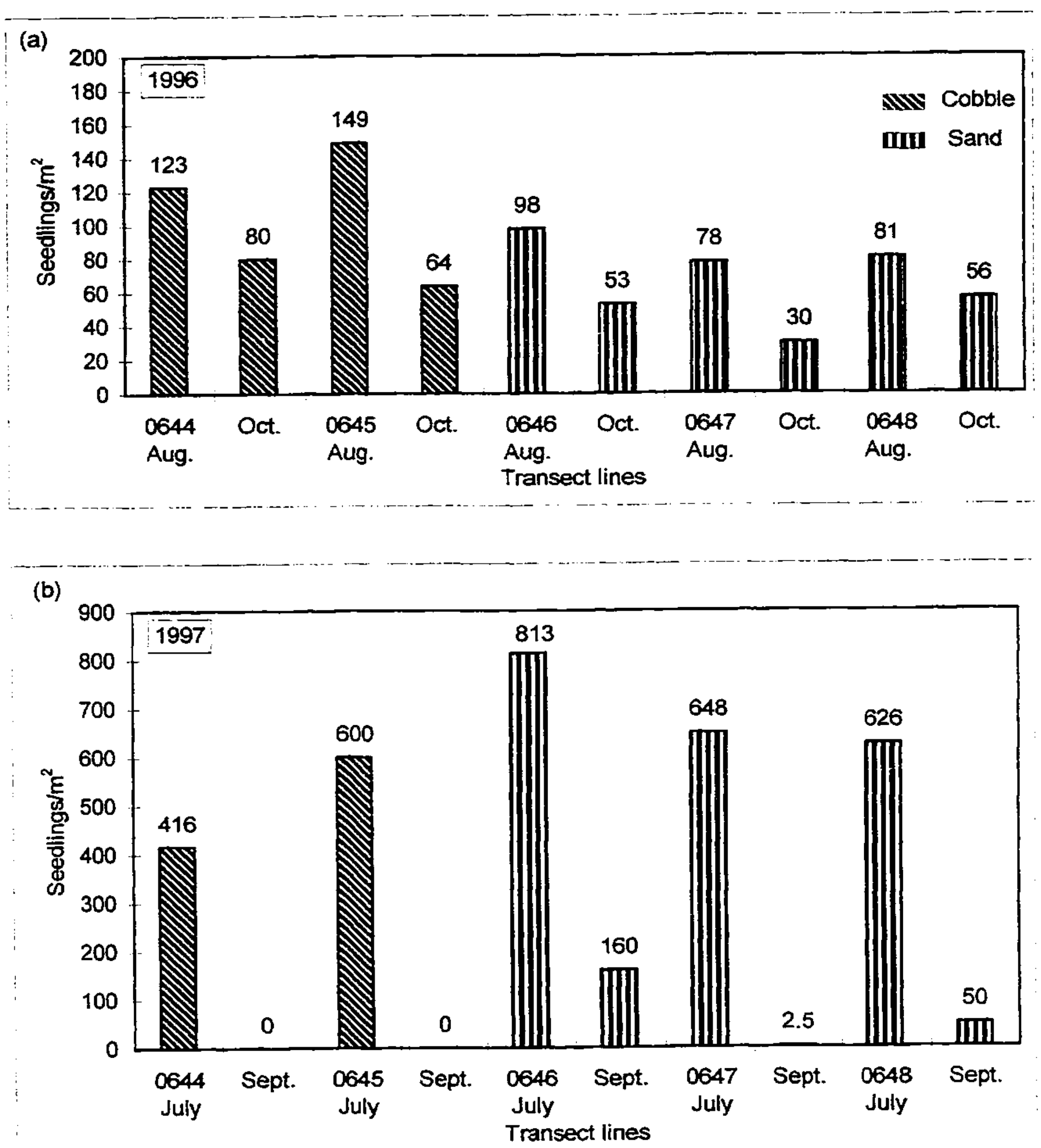


Figure 35. The mean densities of black cottonwood seedlings for (a) seedlings in 1996, and (b) seedling in 1997, on the 'old island' at Elk River Site 1.

Shoot and Root Length of Seedlings

On August 27, 1997, shoot and root lengths were measured for seedlings on a flood zone terrace at Site 1. This location was chosen because of the fine substrate which made it possible to excavate seedlings without damaging the roots. Seedling excavation was attempted at Site 1 near transect lines, but where cobble occurred, excavations resulted in severed roots. The seedlings that occurred on the fine were suffering from severe drought stress, many were dead and the ones still alive were relatively short. The root lengths of these would not indicate root growth potential during the first month of establishment. The seedlings on the small bench appeared to be in good health and showed no signs of drought stress. Seedlings were larger than the ones lower on the meander lobe at Site 1 and there were few dead seedlings.

One probable reason that these seedlings were doing better than the ones at the lower elevation on the meander lobes had to do with this river reach being hydrologically gaining. Even though the seedlings were at a higher elevation than the ones at Site 1, they were on the edge of the hillside where the groundwater was quite shallow before flowing into the river. The river fine substrate also helped by bringing some of the moisture towards the surface through capillary action.

The higher elevation seedlings also resulted from earlier seeding establishment since this area would have been exposed above the river stage earlier after the spring peak flow, compared to the lower elevation areas of Site 1 that would have been submerged at that time. This gave the higher elevation seedlings a week or two of additional growing time, accounting for some of the taller stature.

The upper terrace (Figure 36a) had thirty nine seedlings sampled. One density count was taken (Figure 36b) which yielded 760 seedlings/m^2 with an average height of 30.9 mm. The average heights of seedlings sampled was 35.3 mm with the individual heights shown in Figure 37a. The correlation between root length to shoot height was positive with a coefficient of determination (r^2) of 0.36 (Figure 37b). The first year 1997 seedlings had substantially deeper roots than their shoot heights, which is consistent with the expectation that new seedlings allocate more photosynthate into root than shoot growth during the establishment year.

One 1996 seedling and one 1995 seedling were sampled but the deeper substrate turned to cobble and the roots were severed during excavation. The 1995 and 1996 shoot portions were buried with fines and had adventitious roots along the old stem. The roots were tapering so it was concluded that they were seedlings but since these were broken the total root length was unknown.

Asexual Reproduction

Branch Fragments

Black cottonwood stems are physiologically totipotet which enables artificial propagation by branch cuttings and natural asexual clonal propagation by shoot fragments. There was an abundance of branch fragments along the

(a)

(b)

Figure 36. The terrace at Elk River Site 1, (a) where 1997 seedling were excavated for shoot and root length analysis and (b). a 0.2 X 0.5 m quadrat sample for a seedling density count in 1997.

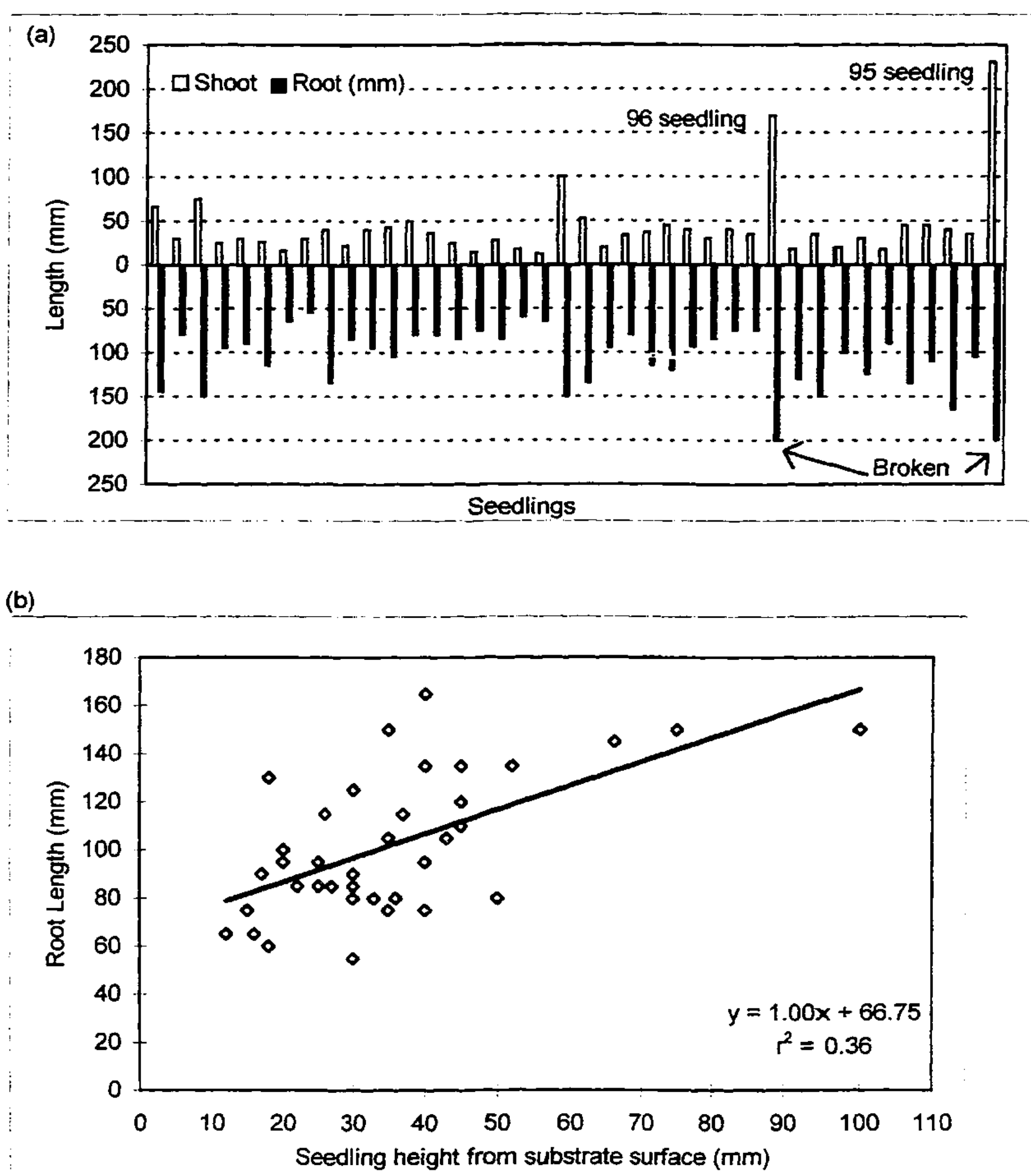


Figure 37. Cottonwood seedlings of the first year, shoot heights and root lengths on the terrace along the Elk River Site 1, August 1997.
(a) individual seedling shoot heights and root lengths, (b) regression analysis.

Elk River and one source of these was from beaver browse as evidenced by teeth marks.

Evidence of beaver activity was noted at Sites 1 and 3. Cut branches, harvested saplings and beaver tracks were observed at both sites. Numerous branches left by beavers are picked up by the spring high-water, transported downstream, and deposited on meander lobes and other shallow sites during stream flow recession. This allows dispersal of the clonal fragments.

A second source of branch fragments comes from wind, snow and ice damage of cottonwood trees. These branches are also picked up by spring flood waters, carried downstream and deposited. The branches broken from the previous winter or early spring storms are likely to be viable. It is likely that the longer the branches have been laying on the ground the less viable they become.

The third source of branch fragments is produced by the spring floods themselves. The slow undercutting of wooded banks eventually topples trees into the river during high water. Many of the branches are broken by the impact of landing. The fallen trees are rolled and churned by the flood waters, resulting in further branch excision. Due to this tumbling, trees in the Elk River flood plains were observed to consist of a root 'ball' and relatively barren truck (bole) after most branches had been sheared off. The excised branches are likely to travel further than the main tree because of their smaller size and consequent increased mobility.

Once the branch fragments have been deposited, shoots can flush from the surface buds and adventitious root development follows. If the area where the branch fragment was deposited dries out before roots develop, the branch fragment dies. When moisture levels remain high, roots can successfully grow into the substrate and the shoot growth of these branch propagules usually exceeds the growth of first year seedlings. The leaves produced on branch fragments are larger than leaves of seedlings and branch fragment roots may be able to grow faster than seedling roots, maintaining contact with more rapidly dropping water tables.

The exceptional flood in 1995 contributed vast numbers of branch fragments along the Elk River. The percentage of branch fragments that produce trees is unknown as is the quantitative contribution of this form of reproduction to the black cottonwood populations along streams.

Root Suckers

Cottonwood shoots that were aged by annual stem scar counts were in their first or second year of growth but had thick stems, large leaves and were more than 10 cm in height, were excavated to determine their origin. The saplings falling into the above category were sampled away from the transect lines so that excavation would not interfere with recruitment studies along the transect lines. The saplings with these growth characteristics were determined to be root suckers and were linked to lateral roots from adjacent larger trees. These suckers often occurred from the drip line of parent trees out towards the river. These clonal saplings were established in vegetated areas with mainly grasses that would retard seedling recruitment due to the shade intolerance of cottonwood seedlings. The root suckers are so much faster growing than seedlings that they are able to grow above the grasses allowing access to sunshine. First year root suckers were from 10 to 50 cm compared to first year seedlings which were from 1 to 10 cm. Root suckers were found at all three sites along the Elk River in the vegetated zone just away from the start of open, sandy or cobble bars.

Reproduction through root suckering does not disperse genotypes like branch fragments can, but it does increase the black cottonwood population. The root suckers have some advantages over seedlings in that they are more drought tolerant since the root suckers are linked to the older parent tree which has established extensive roots, that provide reliable access to moisture. The roots of the new clonal saplings also grow at accelerated rates compared to seedlings, enabling the clones to reach deeper groundwater more quickly than seedlings.

Root sucker propagation can increase the density of successful cottonwood recruitment. Young trees produce lateral root clones and consequently even if the seedling density is low and the recruitment site is no longer barren, recruitment can still continue through root cloning. Clonal root suckering complicates the forest structure and is one reason why arcuate banding along the Elk River is not conspicuous.

<u>Coppice Growth</u>

Coppice growth (or shoot sprouts) is new shoot growth that follows trunk harvesting or damage. The process can be induced by fire, beaver, scour from floods or ice and/or logging. The main stem is killed or removed by one of the these causes and the remaining stump produces shoot suckers, enabling tree survival. When the damage is the result of ice or flood, the remaining stem is often toppled and buried, resulting in what appears to be a group of juvenile cottonwoods. Initially it is quite apparent that the shoots originate from a central point (the buried stem). However, as further deposition occurs, the shoots appear further apart and their origin is less clear. As with branch fragment growth and root suckers, coppice shoot growth is much faster than seedling growth. Coppice and root sucker growth rates are also faster than shoot growth from branch fragments.

Sites 1 and 3 displayed signs of coppice growth. Site 3 had beaver browse on a flood terrace that would not be flooded except during extreme events. Here, shoots were apparently originating from the stumps of juvenile trees that were felled by beavers. The beaver damage occurred after the 1995 'flood of the century' so the remaining stumps were still above ground level and visible. It was unclear what the origin of older juveniles were, there was some clonal activity as evidenced by the large leaves on saplings but without direct excavation it was unknown if these were from root suckers, branch fragments or shoot suckers of coppice growth.

Site 1 was another possible site of shoot suckering but no recent coppice growth was observed. The juvenile trees surrounding the mature trees on the old island may have been the result of flood damage or ice scour and subsequent stumps were buried after the damage occurred. The band of juveniles between the mature trees and the open bar at transect line 0636 might have resulted from the same event that formed the old island. However none of the saplings were excavated to determine the possible type of clonal origin.

Coppice growth reduces the negative effects that beavers, floods and ice scour have on black cottonwood trees. Coppice growth generally produces bushy tree types that provide continued food supplies for the beavers. In situations were the main tree trunk was felled and the stump is buried, the resulting coppice growth can grow into a mature tree that might be indistinguishable from seedling- or other asexual-originated trees.

Conclusion

Periodic spring floods are important on the Elk River system to produce new cottonwood seedling recruitment sites. Age analysis of mature cottonwood indicated that successful establishment had occurred in many years even if the spring floods were below a 1-in-2 year event. Annual spring high flows also exclude flood-intolerant upland plants from the recruitment zones providing another role for high flows.

Dynamic flows created the actively meandering channel along the Elk River. In recent decades, meander lobes were constantly changing and in some cases have moved downstream. Extreme events like the 1995 'flood of the century', changed channel courses and scoured and deposited large volumes of material, resulting in abundant new areas for cottonwood recruitment.

Extreme flood events can result in differing degrees of change depending partially on what events occur in subsequent years. The 1995, 1-in-100 year event was followed the next two years by a 1-in-4 and then a 1-in-3 year high-flow event. These two smaller flood events were able to erode and deposit substantial amounts of substrate, probably because the vast quantities of substrate moved by the 1-in-100 year event did not have time to become as consolidated by 1996 and 1997. These smaller floods would probably not have caused this degree of channel change and material transport and deposition if they had not followed the 1-in-100 year event.

The effects of the 1-in-25 year flood of 1948 may have been similar to those of 1996 and 1997 floods. However, a set of air-photos prior to 1948 and another from the early 1950's would be necessary to confidently analyze the extent of disturbance following that flood. During the next thirteen years, three, 1-in-10 year events occurred which may have kept the meander lobes free of vegetation, as evident in the 1962 air-photos. Some of the scoured meander lobes had a few remaining large cottonwood trees which suggests that these lobes were completely covered with mature trees prior to 1962.

Spring peak flows are the principle driving forces behind the geomorphology of many alluvial systems. High energy of spring flows permits the river to change its position. The 1995 'flood of the century' resulted in extensive flood plains scouring. In 1996, a 1-in-4 year high flow event further scoured areas initially scoured in 1995, sometimes resulting in new courses or abandonment of old courses. The 1997, 1-in-3 year high flow event caused the migration of some meander lobes downstream and the formation of some smaller channels that cut into large lobes creating channel bars.

Extensive piles of woody debris deposited in 1995 were increased in 1996. Logs deposited in 1995, trapped sediment from 1996 and/or 1997 and deposited it on top of the cobble stream-bed. Where the logs stayed in place during high flow in the following year, the fine deposits grew in size and depth. Some logs were moved downstream in 1996 and 1997. This was observed as the debris piles left after a flood event acted as fine traps which help to create and increase elevations of the mid-channel bars and meander lobes.

As hydrology shapes stream geomorphology it likewise dictates the distribution of riparian vegetation. Annual peak flow causes physical disturbance which results in barren, low elevation, moist bars. These are prime nursery sites for pioneer plant species. With inundation occurring annually at these low elevations, flood intolerant plant species are excluded.

Black cottonwoods possess all the characteristics of ecological pioneers. They are an early successional species, because they are shade intolerant. They also have a positive regenerative response to disturbance, rapid juvenile growth, and prolific reproductive potential. Black cottonwoods are also flood tolerant adapting them to dynamic riparian zones, such as those along the Elk River. These trees can be especially long-lived in these areas. In one old growth stand along the Elk River, 30- year-old cottonwoods, with circumferences of up to 6.4 m, still survive (Personal sampling, tree aged was approximately 320 years old).

The 1995, 'flood of the century' along the Elk River created many new seedling recruitment sites. However, new seedlings often had to survive extensive deposition in the following years. This deposition led to selective population thinning of the black cottonwood seedlings. Only the fastest growing seedlings, that made it through the initial establishment summer, had a chance to succeed through the following years of deposition. Each year, some seedlings survived into the next and thus, resulted in new stands with multiple age groups as are found in the mature stands previously established.

Continued deposition at seedling recruitment sites has helped to protect those seedlings from subsequent floods by increasing their elevation. Some

1995 seedlings survived the next three years in areas where the elevation was raised 70 cm above the initial establishment surface.

The extreme 1995 flood event along the Elk River was responsible for large scale geomorphic responses of erosion, sediment transport and deposition in the flood year 1995. The following two-year study along the Elk River found a continuation of these events which was driven by annual high flows. This resulted in continuous meander lobe and channel migration, formation of mid-channel bars and islands, and substantial deposition which increased bar elevations and created new seedling recruitment sites. These geomorphological changes affected the black cottonwoods by increasing the loss of mature trees to undercutting and scour, promoting clonal recruitment through suckering (root and shoot) and, in places, selected for taller seedlings that could survive the extensive deposition that occurred. It is likely that the geomorphological effects will diminish with time as the stream and riparian substrate become progressively more consolidated.

Chapter 3: The Kootenay River: Twenty Four Years after the Completion of the Libby Dam

Introduction

There are at least three spellings for the river and watershed discussed in this chapter. "Kutenai" is often found in documents describing the Native Americans of the watershed (Knudsen 1994). The Canadian spelling is "Kootenay" and will be used when referring to the river system in general since it primarily occurs in Canada. When referring to the study sites in Canada the "Upper Kootenay" will be used. The American spelling is "Kootenai" and this will be used when discussing the sites and area in the United States to be referred to as the "Lower Kootenai".

The Kootenay River originates in the Rocky Mountains of British Columbia in Kootenay National Park and Mount Assiniboine Provincial Park (Figure 38). The river enters the Rocky Mountain Trench near Canal Flats. Upstream of Canal Flats the Kootenay River is a reasonably steep gradient mountain stream with mainly coarse cobble beaches and a confined valley that limits the meandering of the river. South of Canal Flats to Lake Koocanusa (reservoir) the river occupies a wide valley bottom with a shallow gradient channel. Here, the river is not confined by steep mountain sides and the deep sandy silt bares contrast sharply to the cobble substrate found above Canal Flats.

South of Canal Flats the Kootenay River Basin straddles the Rocky Mountain Trench which divides the region into two halves. The Purcell

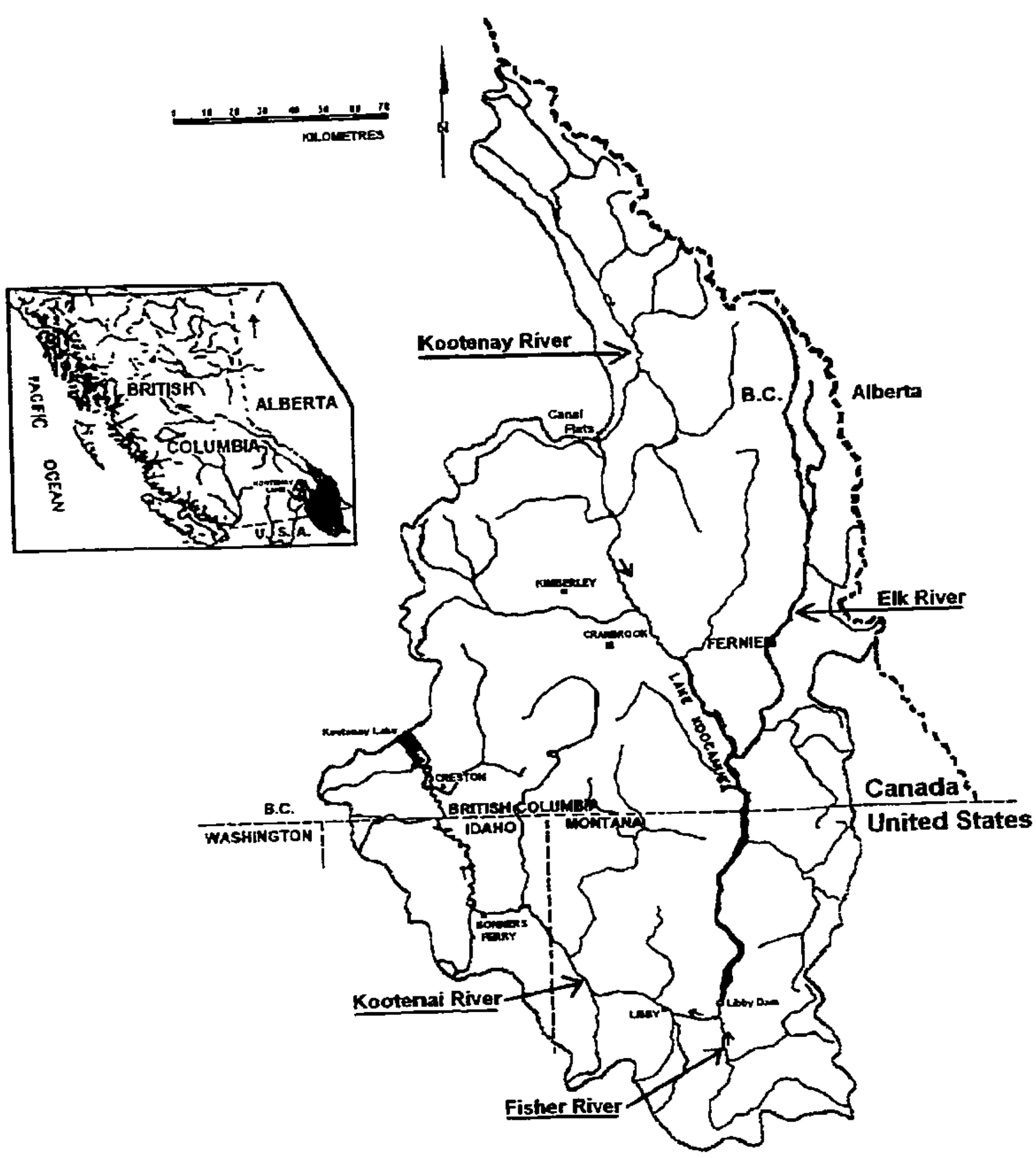


Figure 38. The Kootenay River Basin and Elk River Basin
(From Ken Knudsen Ecological Resource Consulting 1994).

Mountains occupy the western half and the Rocky Mountains occupy the eastern half. The Trench has a northwest-southeast orientation and lies at an elevation of 750 to 900 m (2475 to 2970 ft) (Rocchini et al. 1976b).

Topographically steep mountain canyons and valleys dominate the Kootenay River Basin. Consequently, all of the major tributaries to the river, including the Elk, Bull, St. Mary, Lussier, White, Palliser, Cross and Vermillion rivers have steep channel gradients, particularly in their headwaters (Table 6). The highest peak in the Kootenay River Basin is 3618 m. (1 1,867 ft.). When the Kootenay River enters Kootenay Lake, the river's elevation is 532 m. (1 745 ft.), more than 3,000 vertical metres (nearly 1 0,000 vertical feet) below its high mountain origins. In contrast to the tributaries and initial reach of the Kootenay, the mainstem of the Kootenay River has a fairly shallow channel gradient after entering the Rocky Mountain Trench near Canal Flats. The river drops less than 305 m (1,000 ft.) in elevation from Canal Flats to Kootenay Lake, a distance of more than 480 km (300 miles) (Rocchini et al. 1976 b, Knudsen 1994).

Along the mainstem's slow meandering course, the river valley bottom widths vary from 4.8 to 27.2 km (3 to 17 miles) (Rocchini et al. 1976 b). The widest areas are in the valley bottoms in the final reach of the Bonners Ferry, Idaho, to Creston B. C. area. The Rocky Mountain Trench is primarily a longitudinal depression filled with very thick sedimentary and glacial deposits. These deposits vary in depth from 450 m (1,500 ft.) near the St. Mary River to 1350 m (4,500 ft.) at the mouth of the Elk River (Rocchini et al. 1976 b). The Kootenay River has carved a valley 60 m to 90 m (200 to 300 ft.) deep into these

Table 6. The Upper Kootenay River and its main tributaries length, gradient and mean monthly discharge from Environment Canada 'Hydat' data base.

RIVER	LENGTH	GRADIANT	MEAN MONTHLY DISCHARGE
Vermilion River	58 km	6.03 m/km	75 m^3/s
Cross River	38 km	30.26 m/km	no information available
Palliser River	58 km	20.69 m/km	51 m^3/s
White River (Main)	85 km	14.12 m/km	58 m^3/s
Lussier River	69 km	19.13 m/km	19 m^3/s
St. Mary River	118 km	11.44 m/km	52 m^3/s
Wild Horse River	29 km	36.21 m/km	no information available
Bull River	98 km	12.55 m/km	107 m^3/s
Elk River	212 km	5.24 m/km	193 m^3/s
Upper Kootenay River	230 km	2.3 m/km	620 m^3/s

deposits and the floodplain is 0.8 to 3.2 km wide (0.5 to 2 miles) (Rocchini et al. 1976b).

The riparian habitat along the Kootenay River is important to the East Kootenay valley as this supports the region's greatest abundance and diversity of plants and wildlife. The Kootenay River supports recreational fishing and boating with the mountainous reach north of Canal Flats particularly supporting kayaking, canoeing and rafting activities. The Kootenay River and its riparian areas contribute aesthetic values that increase human enjoyment of many activities such as bird watching, wildlife appreciation, and photography. Tourism and especially ecotourism, are growing industries in the west Kootenay region which rely on healthy natural landscapes aesthetic values and wildlife.

Studies from across Western North America have revealed steady declines of riparian habitat (Bradley et al. 1991). Two major causes of the declines have been woodland clearing and impacts due to damming and diversion. Much of the clearing along the Kootenay River occurred in the late 1800's to early 1900's and Montana's Lower Kootenai was more impacted by clearing than British Columbia's Upper Kootenay. The Upper Kootenay also flows through a wider valley bottom than the Lower Kootenai so human settlement and development was not as restricted to the floodplain as it was along the Lower Kootenai River.

The Pre-historical and Historical Use and Development of the Kootenai Valley

The Native American the Kutenai inhabitants of the Kootenay basin lived a nomadic existence, with members scattered in small groups to hunt and gather food. Preference for either fishing or hunting divided the Kutenai tribe, or nation, into two harmonious segments that gathered once a year for religious festivals at Grasmere, British Columbia (Hungry Wolf and Hungry Wolf, 1989). The "Upper Kutenai" tribes lived closer to the Rocky Mountains, maintained larger horse herds and made trips to the Great Plains once or twice a year to hunt buffalo. Their surplus buffalo and horses were traded to their "Lower Kutenai" relatives, who preferred canoes over horses and staying near home waters to trap and spear fish or hunt birds and small game (Knudsenl994).

The Kutenai people used the sweet cambium layer of the black cottonwood as a food source, but it was only eaten when fresh in the spring (Campbell 1914). The cottony seed fluff of the cottonwood trees was used as a stuffing for pillows. The inner bark was used to make soap and a medicinal tea. The sticky resin on the buds has a pungent odour in spring and was used as an ointment for small cuts or as a makeshift glue. The Secwepemc used large cottonwood trees to make dugout canoes (Antos et al. 1996), but their Kutenai natives built their canoes with a frame of red cedar. The Indians on the west side of the Rockies also used spruce bark after soaking it in water, stretched to a frame with pitch to hold the seams together. The Indians on the east side used the bark from the birch tree with their canoes fashioned in a similar way (Campbell 1914).

The Kutenai natives used "sweat houses" extensively to cure ills, aches and pains. Sweat houses were constructed along the Kootenay River by bending saplings to make a rounded roof (Campbell 1915). It was probable that cottonwood saplings were used for small sweat houses ranging from one to three metres in basal diameter to accommodate six or seven people at one time. Sweat houses were always constructed near streams for the building material (saplings) and the cold water of the stream, which they jumped into after sweating profusely in the house. The remains of sweat houses, the bent saplings out of the frames were sometimes found in 1915, but more often the only remains were piles of rocks, burned by fire and broken by the water thrown upon them while they were hot (Campbell 1915).

Hungry Wolf and Hungry Wolf (1989) states that the upper Kutenai tribes traded buffalo with the lower Kutenai tribes but if they did not have buffalo robes they used reeds to cover their teepees with and these were quite common around the Libby area (Figure 39) (J. Gruber, personal communication, March, 1997). The Kutenai Indians also used wicker baskets made of cedar roots, for boiling meat (Campbell 1914). Cedar trees are a late successional plant of the Kootenay Basin riparian zone. Cottonwood was used for hide-scraping poles, tanning sticks, and frames (Antos et al. 1996). Another important plant fibre used by the natives from the riparian habitat was *Apocynum cannabinum,* hemp dogbane, also called Indian hemp, used to make a fibre that was spun into rope or twine used for fishing nets, fishing line, and bowstrings as well as other purposes. Hemp dogbane occurred in only a few locations, making it a much- desired

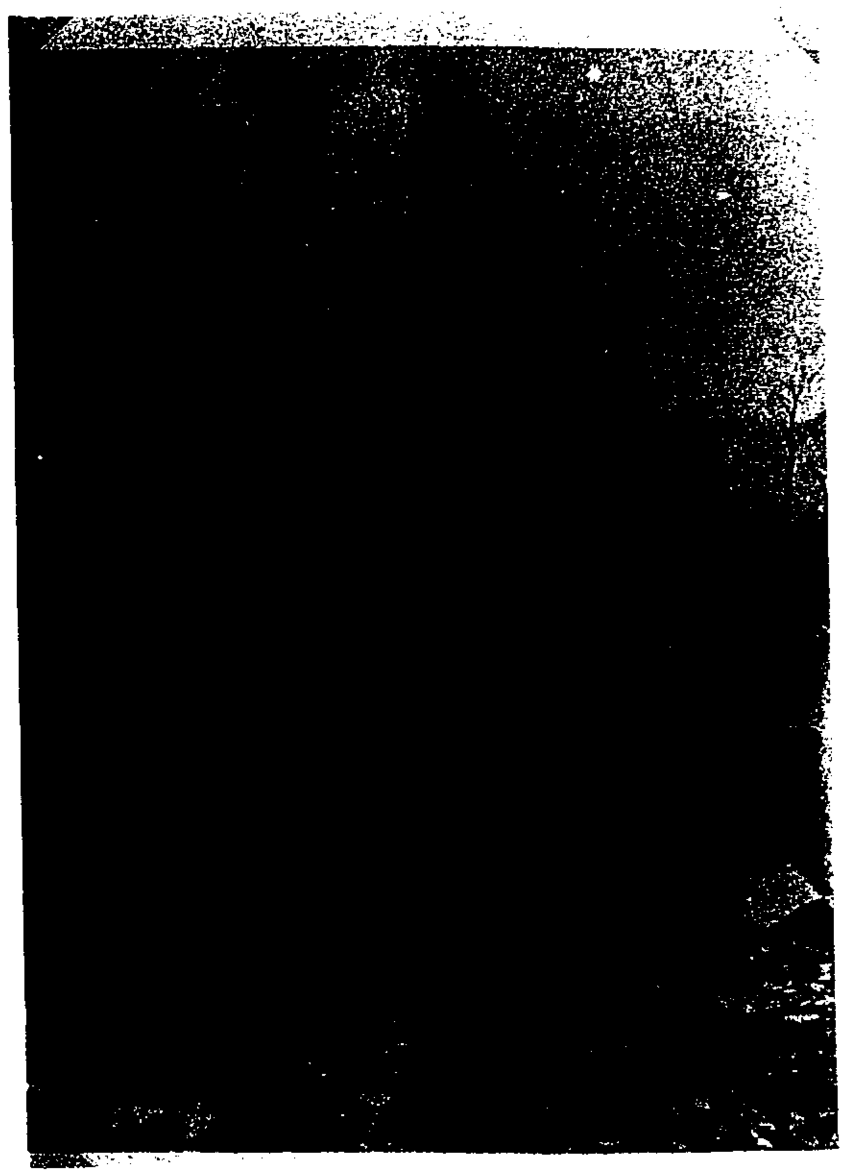


Figure 39. A Kutenai teepee near Libby, Montana
(from Gruber's personal collection 1997).

trade item throughout the area (Antos et al. 1996). Thus, much of the food, medicines and raw materials the Kutenai natives used came from the wet-lands and riparian zones of the Kootenay River.

The natives in the area had very little impact on the riparian ecosystem. Fires were set by the Kutenai in the spring, every 5 to 7 years if a fire did not naturally start, in the Baynes Lake area south to and including the Tobacco Plains which kept this area clear of small trees, with only large *Larix occidentalis* (tamarack or western larch) and *Pinus ponderosa* (Ponderosa pine) widely spaced with grasslands over most of the area (Kay, personal communication, Dec, 1996). The early surveys of this area noted that the riparian habitat was dense along the Kootenay River with no mention of fire damage and consequently the fires started by the Kutenai Natives probably did not substantially impact the riparian zones (Mumbrue 1893).

<u>European Arrivals</u>

David Thompson arrived in the Libby area in May of 1808 financed by the North West Fur Company. In his journals he comments on the abundance and types of trees found in the area (M. White, personal communication, March 1997). The following year Thompson and his French-Canadian crew built a structure called the "Kootenay Post" near present-day Libby. Three years later the post was relocated further upstream where it became a major fur trading post until closing in 1847 (Malone and Roeder 1976). By 1821 the trading post was absorbed by the Hudson Bay Company. The area was relatively quiet up to and including the 1850's with only fur trappers, and the occasional prospector (M. White, personal communication, March, 1997).

A mission station was established on the Tobacco Plains, located between Grasmere, B.C. and Eureka, Montana in 1845 by Father DeSmet, a Jesuit priest (Knudsen 1994). Settlers preceded Campbell who arrived in 1854 from what was then called the Red River Settlement (Campbell 1914). Most of the settlers of the Tobacco Plains brought in cattle and/or farmed. Because of this relatively flat, fertile land of the Tobacco Plains, the meander lobes along the adjacent part of the Kootenay River were not cleared and farmed. By 1866 the Flathead Lake valley was generally well settled by ranchers and farmers, with settlement extending from the Flathead to the Kootenay Basin (Campbell 1914).

During the 1860's an increase in activity and people in the Libby area and along the Kootenai River occurred due to an increase in gold prospecting. The town of Libby was established in 1862, largely in response to this activity (M. White, personal communication, March, 1997) In 1864 the Wild Horse River gold rush brought a further influx of miners to work the Wild Horse River, a tributary of the Kootenay River in British Columbia. In 1867, the Libby Creek (Montana) gold rush was on and in 1868 the Yaak River was another site of a gold fined, both streams are tributaries of the Lower Kootenai River. During the 1870's many of the gold sites had been exhausted so most of the prospectors left the area. However, in 1885, another gold rush occurred along Libby Creek which reestablished the population. At that time, there were no roads in this area with the only access being a series of trails. Because of the lack of access, there were few homesteaders near Libby, Montana by the mid-1 880's (M. White, personal communication, March, 1997).

The United States government sought to increase settlement in Montana, and to encourage this the Timber and Stone Act of 1878 was passed to allow people to acquire homesteads for timber value. The homesteaders claimed large tracts of timbered land which was not suitable for agriculture and these were generally not riparian zones.

In 1891 some timber homesteaders near Libby moved down to the floodplains by the mouth of Libby Creek and established claims with the hope that the railway would come through their land. This area is now part of Libby and includes a large meander lobe of the Kootenai River that was cleared for this settlement. An early picture of Libby taken by Libby Creek, Figure 40, shows what is left of the cleared cottonwoods in spring at the turn of the century. Cottonwoods were left along the Libby Creek (foreground of Figure 40) at that time.

Population remained low and relatively little development occurred between gold rushes. While the Timber and Stone Act of 1878 brought in a few more residents, a great influx followed the arrival of the railways (M. White, personal communication, March, 1997). Accessibility was the main reason for the slow population growth of the Kootenay Basin which was limited until the completion of the Great Northern Railroad in 1893 and the Canadian Pacific

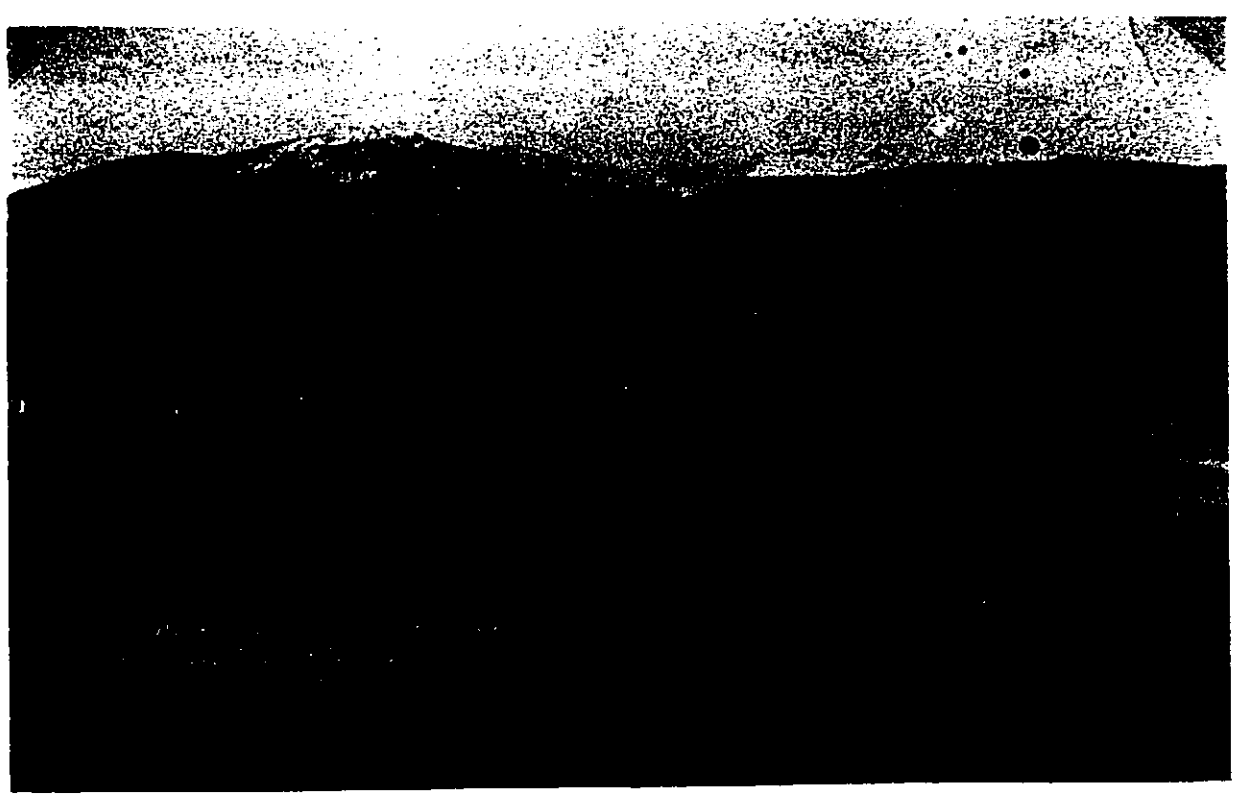


Figure 40. The town of Libby, Montana at the turn of the century before the construction of the Libby bridge which was completed in 1911 (from Gruber's personal collection 1997).

Railroad in 1898, the year Cranbrook, British Columbia was established. Steamboat travel also helped from 1892 to 1900 operating from Jennings, a small town upstream of the present Libby site, to Fort Steele, British Columbia, an older and larger settlement than Cranbrook at that time.

Surveys of the Libby area began in 1893 with timber cruises starting in 1903 to survey marketable timber. The surveyors also took note of the homesteads they came across. It was not until 1905 to 191 0 that the Kootenai area was promoted for agricultural development. The timber homesteaders were interested in the marketable timber and few of these homesteads were on the floodplains of the Kootenai River. Conversely, it was the floodplains of the Kootenai River that were cleared by agricultural homesteaders for orchards and farming. The Kootenai Valley in the United States is very restricted by the mountains so that the only relatively flat, fertile land was on the floodplains. By 1930, the meander lobes that are utilized today had been cleared.

From Jennings upstream to the international border there was less activity along the Kootenai River because the nearby Tobacco Plains offered larger tracts of agricultural land and had been settled before the railways were established. The settlement of Rexford, along the Kootenai River just west of Eureka, was on a large meander lobe much like the early Libby site and offered a dock for shipping and receiving goods by ferry, linking the Tobacco Plains by the Kootenay River to Jennings and Fort Steele.

Historic Flooding of the Lower Kootenai River

The Kootenay River, like all natural river systems, experienced floods of different magnitudes prior to the Libby Dam. The earliest reported flood occurred in 1893 and an extreme flood event occurred in 1896 when a train was washed off its tracks and over Kootenai Falls (M. White, personal communication, March, 1997). No flow records exist for this event so it could not be compared to the flood of 1916 which was about a 1 -in-1 00 year flood event (Log Pearson Type III recurrence analysis). On June 22, 1916, The Western News, Libby's paper reported:

> "Rivers Run Riot
> Floods Reported from all Sections of the State — Bridges and Telegraph Poles Are Down—
> Traffic Blocked by the Raging Floods — No Casualties."

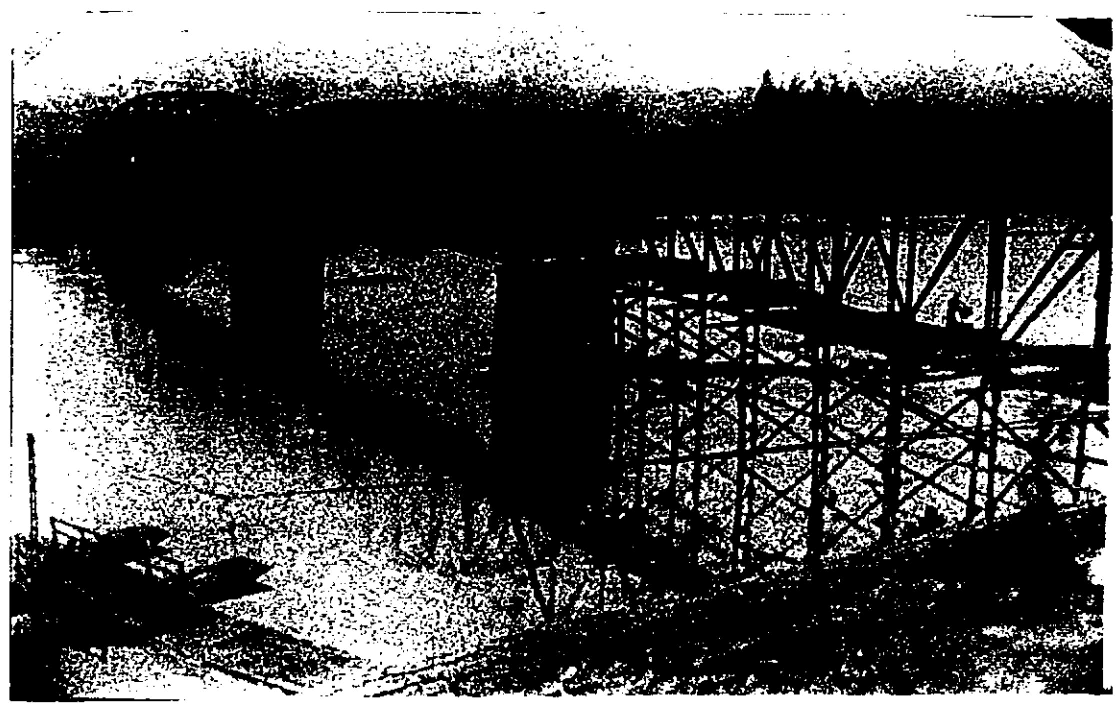
The news article states that the mail service and the trains had been shut down since June 18, 1916. The cause of the flood was attributed to two weeks of extremely hot weather which caused an abrupt and extensive snow melt. The normal, slow spring melt of snow had not occurred because of an unusually cold April and May. Rivers and creeks had been rising rapidly for several days prior to the June 17 and 18 peak flows which washed out portions of the railroad, many bridges, telephone poles and threatened the new bridge to Libby which was saved by blasting apart a log jam (The Western News 1916). Figure 41 provides a photograph of the 1916 flood but it was published in The Western News in 1948, so the original date and estimated discharge are unknown. Figure 42a shows the Libby Bridge near completion in 1911 demonstrating the water level when the Kootenai River is not in flood. Figure 42b shows the same bridge some time during the 1916 flood.

IT WAS A BIG FLOOD IN 1916

This picture shows Old Libby Depot in 1916 Flood; taken south of depot looking east. From picture belonging to Mrs. Bertha Kienitz.

Figure 41. Libby Montana during the flood of 1916
(from the 1948 Western News, unknown date).

(a)



(b)

Figure 42. Libby bridge near completion in 1911 (a) and some time during the 1916 flood (b) (from Gruber's personal collection 1997).

The next large flood occurred in 1948 which was approximately a 1-in-50 year event as analyzed by a log Pearson Type III recurrence distribution. The flood waters peaked on May 28, 1948 and The Western News reported on the rising waters on May 27, 1948 with the headline:

"Kootenai Floods Cause Damage From Fernie to Bonners Ferry"

The Western News states that the 1948 flood was the highest flood in the history of the Kootenai Valley, but the peak flow records show that this was a 1-in-50 year flood event, and was smaller than the 1916 flood. Sudden warm weather and rapid snow melt was proposed as the cause the 1948 flood. In Canada, flood damage occurred across the St. Mary and Elk rivers, tributaries of the Kootenay, and at Grand Forks, downstream from Kootenay Lake. The Bull Dam, on the Bull River just upstream from the Kootenay inflow, was washed out in the 1948 flood, adding to the flood waters flowing into Montana and Idaho. Figures 43,a and b were taken during the 1948 flood in Libby, Montana, but exact dates are unknown.

A flood in l956 was between a l-in-10 and l-in-25 year event. In l961, a slightly higher peak flow was also between 1 -in-1 0 and 1 -in-25 year event (Figure 44). Subsequently, the Libby Dam was proposed to provide flood control for the Kootenai Valley.

(a)

(b)

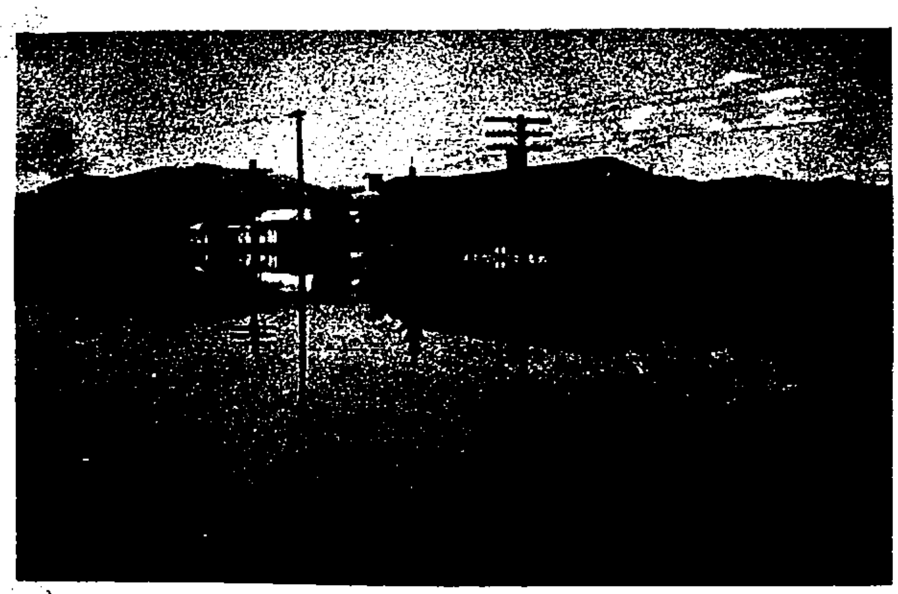


Figure 43. The town of Libby, Montana during the flood of 1948 (a) and (b) (from Gruber's personal collection 1997).

SITE OF EARLY CAMPS OF THE LOWER KUTENAIS, DURING FLOOD IN JUNE 1961
Looking east, up-river, to Bonners Ferry. Ditches and dikes have now tamed the area for farming; spring flooding such as this, typical in older times, is now infrequent.

Figure 44. The Lower Kootenai River during the flood of 1961 near Bonners Ferry, Idaho (photo by Winton Weydemeyer).

Libby Dam

The Libby Dam is situated on the Kootenai River, 27.2 km upstream of Libby, Montana (Figure 38). The impoundment named 'Lake' Koocanusa, extends 145 km upstream to Wardner, British Columbia. The reservoir name includes the first three letters of Kootenay and Canada and then USA. Koocanusa reservoir has a maximum depth of 113 m (370 ft) and covers an area of 188 km^2 (46,000 acres) at maximum pool (USACE 1983). The Libby Dam was completed in 1972 and reached full pool in June, 1974 (Storm et al. 1982).

The three main purposes of the Libby Dam are: 1) flood control to protect downstream developments in British Columbia, Montana, Idaho, and along the Columbia Basin in Oregon and Washington; 2) hydroelectric power generation; and 3) to provide public recreation (Rocchine et al. 1976b and USACE 1983). The regulated releases of water at the Dam augment flows in the Columbia River for power generation at downstream plants, navigation, irrigation, fish migration and water quality (USACE 1983). Because the Libby Dam is managed primarily for power generation and flood control, the reservoir undergoes substantial annual fluctuations in lake elevations (Hamilton et al. 1990).

Lake Koocanusa's surface area at maximum pool accounts for less than 1% of the drainage basin area (26, 505 km^2) and therefore, the water budget is controlled almost exclusively by inflow from the Kootenay and Elk rivers (Hamilton et al. 1990). The Libby Dam has successfully attenuated flooding along the Kootenay River, allowing 110 km (70 miles) of fertile land on the floodplains between the Dam and Kootenay Lake to be farmed (Knudsen 1994).

The flood control benefits of the Libby Dam also extend to the lower Columbia River because the Kootenay River historically contributed 10% of the total spring flows of the Columbia River at The Dalles, Oregon (Knudsen 1994).

Benefits of the Dam have not come without cost. Since its completion, Libby Dam and its reservoir have impacted the water quality, fisheries and recreational values of the Kootenay River and Kootenay Lake to a greater degree than any other single facility or pollution source in the Basin (Knudsen 1994). The reservoir inundates 144 km of river valley and 44 km along its tributaries (Knudsen 1994). This area formerly supported some of the most productive populations of westslope cutthroat (*Salmo clarki* Richardson) and bull trout (*Salvelinus confluentus* Suckley) in North America (Knudsen 1994). Both of these species still exist in the reservoir, but the cutthroat population is declining despite intensive planting of hatchery cutthroats (Knudsen 1994).

The unusual white sturgeon (*Acipenser transmontanus* Richardson) of the Kootenai River experienced declines in population and of juvenile fish after the Dam was completed. In 1994 the Kootenai River population of white sturgeon was declared endangered and research is underway to restore the spawning of white sturgeon through controlled releases from the Dam during the spawning periods (USACE 1996)

As well as disrupting native fisheries, the Dam and reservoir inundated and thereby destroyed all of the riparian habitat along the reservoir portion of the Kootenay River valley. In Canada and the United States, the area flooded by the reservoir supported the largest stands of cottonwoodlands in the Basin.

Most of the earlier clearing occurred downstream of the impoundment which further diminished the downstream resource.

The reservoir also eliminated an important winter range area for wildlife and especially the ungulates of the area. In the United States, congress authorized up to $2 million to replace wildlife winter range lands. More than 971 ha (2,400 acres) were selected to serve as wildlife rangeland near Eureka and Libby (USACE 1983). The Canadian side had no compensation because there was no water license granted in this area of British Columbia. This was changed in 1996 when compensation for the East Kootenay area was consolidated within the Columbia Treaty. This did not provide direct funds but the Canadian side now has access to the money from the combined Columbia Basin Fish and Wildlife Compensation Program to be used in the East Kootenay.

For optimal power production, the reservoir goes through an annual cycle of filling in spring and subsequently a gradual drawdown that typically exceeds 30 m (100 ft) (USACE 1974). As well, fluctuation between 140 and 570 m^3/s (5, 000 to 20,000 cfs) in river discharge rates during summer months is common. Fluctuations of this magnitude hinder river floaters and other recreational water users.

From studies on other river systems, it is known that dams that attenuate spring peaks have a number of impacts on the river and riparian system with the extent of impacts largely dependent on the reservoir size and pattern of flow regulation. The main effects that may occur include: 1) the reservoir acting as a sediment trap, resulting in outflows being depleted in suspended sediment,

2) down-cutting of the downstream channel, 3) downstream channel narrowing, 4) reduced channel meandering, 5) reduced downstream sediment deposition, 6) encroachment of flood-intolerant plant vegetation, 7) loss of cottonwood and willow seedling recruitment sites, and 8) reduced water table recharge. Some or all of these effects have occurred along western streams with variations unique to individual systems (Bradley and Smith 1984, Williams and Wolman 1984, Debano and Schmidt 1990, Rood and Mahoney 1990, Rood and Mahoney 1995, Scott et al. 1996). Because flood attenuation by dams has particularly impacted downstream cottonwoods, the potential impact of the Libby Dam on the Lower Kootenai River was a focus of the present study.

Black Cottonwoods along the Kootenay River
[adapted from Jamieson et al.1997, Appendix 1, written by M.L. Polzin]

The black cottonwood is the largest of North America's native poplars and is one of Canada's fastest growing hardwoods. Black cottonwoods occur principally in Pacific drainages from Alaska to southern California. In Canada, black cottonwoods occur in the southern Yukon Territory and across all of British Columbia except for the northeastern part which is populated by the closely related balsam poplar, *Populus balsamifera* L. The black cottonwood is the principal and possibly exclusive native cottonwood in most southern regions of B.C. (Brayshaw 1965).

Cottonwoods occur on moist sites and particularly along streams. They are well adapted to the dynamic riparian zones, since they are very tolerant of flooding (Brink 1954, Hosner 1958). However, cottonwoods are not tolerant of drought and are exceptionally vulnerable to drought-induced xylem cavitation (Mahoney and Rood 1991, Tyree et al. 1994). Black cottonwoods are phreatophytic and are therefore dependent on the saturated water table for moisture (Mahoney and Rood 1991). Annual flooding recharges the riparian water table and is also essential for the recruitment and important for the maintenance of cottonwoods.

Black cottonwoods are dioecious; male and female flowers occur on separate trees. Seed dispersal often coincides with or follows spring flooding, and usually lasts for about four weeks. Seed dispersal is by wind and water (Peattie 1950, Maini 1967, and Braatne et al. 1996). The three main requirements of newly germinated seedlings are sufficient water, a stable substrate, and full sunlight (Bradley 1982, Rood and Mahoney 1990, Mahoney and Rood 1991, Braatne et al. 1996). Cottonwood seedlings are poor competitors because shading reduces their growth rates, and photosynthetic limitation may even prevent their roots from growing fast enough to remain in contact with moisture from the receding river (Braatne et al. 1996). Their faster growing competitors might also deplete soil moisture and nutrients, further slowing cottonwood seedling growth (Fenner et al. 1984).

Floods contribute a number of factors to enable cottonwood reproduction. Flooding eliminates many potential competitors, keeping the recruitment zones relatively open for new seedlings. However, where cottonwood establishment has occurred at low elevations or if flows are very high, flooding may scour or bury cottonwood seedlings from previous years (Bradley and Smith 1986, Rood and Mahoney 1990). Annual spring floods provide some of the moisture requirements of cottonwood seedlings through inundation and recharging of the riparian water table. They also provide one dispersal mechanism, the deposition of the water transported seeds at suitable positions on the point bars.

Black cottonwoods are also capable of asexual reproduction. Common forms of clonal reproduction including, the rooting of branch fragments, root suckering from lateral roots of parent trees, and basal stem suckers or coppice growth (Galloway and Worrall 1979, Bradley et al. 1991, Rood et al 1991, Gom 1996). Only the asexual reproduction through branch fragments allows for dispersal of genetic material, when branches or fragments are swept downstream during floods. Clonal recruitment and seedling establishment of riparian cottonwoods require specific sequences of hydrological conditions and are often promoted by flood events (Moss 1938, Mahoney and Rood 1993, Scott et al. 1993).

Cottonwood replenishment is adapted to, and dependent upon a dynamic hydrological system (Bradley and Smith 1984, Rood and Mahoney 1990, Rood and Mahoney 1995, Braatne et al. 1996, Scott et al. 1996). Since black cottonwood trees are relatively short lived, with life spans of about 200 years, ongoing replenishment is essential to the health and the continuation of the cottonwood. When cottonwoods are chronically water stressed their survival can also be greatly reduced (Braatne et al. 1992 and Weber 1995)

Previous studies on semi-arid river systems have shown that riparian cottonwood forests need periodic flooding that provides the physical disturbance required to produce new recruitment sites for cottonwood seedlings (Bradley and Smith 1986, Rood and Mahoney 1990, Rood and Mahoney 1994, Scott et al. 1996). Flood events are responsible for successful cohort establishment, resulting in arcuate banding of even-aged cottonwoods (Bradley and Smith 1986 Braatne et al. 1996). Annual spring peak flows are also important in semi-arid systems to recharge the water table, ensuring health and growth of established trees (Rood and Mahoney 1990, Mahoney and Rood 1991, Mahoney and Rood 1992).

Summary

The retardation of seedling recruitment that results from river damming and flow attenuation has contributed to the decline of cottonwood forests along various streams in Southeastern Alberta and in numerous areas of the western United States (Johnson et al. 1976, Bradley and Smith 1989, Rood and Heinze-Milne 1989, Rood and Mahoney 1990, Snyder and Miller 1991, Johnson 1992, Rood et al. 1995). River systems that support the prairie cottonwood (*P. deltoides* Marsh), and Fremont cottonwood (*P. fremontii* Wats.), are especially vulnerable to stream flow manipulation since these are from Section Aigeios species and generally unable to reproduce through root suckering (Fenner et al. 1985, Rood et al. 1994). Decline of black cottonwoods and balsam poplars downstream from dams has also been reported (Stromberg and Patten 1992), although the differing reproductive strategies may underlie differences in vulnerability to damming and instream flow regulation (Stromberg and Patten 1991, Rood and Bradley 1993).

The present study will investigate the condition of the riparian woodland, with emphasis on the black cottonwoods, along the Kootenay River upstream and downstream of the Libby Dam. A comparison between upstream and downstream of the dam and reservoir will be done as they are the same water system. No inventory of riparian vegetation was conducted prior to the Libby Dam construction, complicating the analysis of what the riparian habitat was before the Dam. No other studies of the riparian habitat downstream of Libby Dam have been subsequently conducted (to my knowledge) although studies of water quality, fisheries and recreational impacts from the Dam have been completed and/or are underway. Because of the lack of detailed studies before the dam, inference from historical records was relied upon.

This study will examine the condition that cottonwoods and the riparian habitat in general are in today. It will investigate the changes that have occurred after damming and attempt to deduce the causes of these changes.

The Fisher River, a tributary of the Lower Kootenai River which inflows at the 'Big Bend', shortly downstream of Libby Dam will be evaluated as a control river since it is free-flowing and shares the regional climate with the Lower Kootenai. The Upper Kootenay River will be compared to the Lower Kootenai to interpret what impacts have occurred after more than twenty years of summer flow stabilization and spring peak attenuation. If flood attenuation and flow stabilization have resulted in a decline in black cottonwood recruitment, possible flow prescriptions and site amendments will be proposed for conservation and restoration of the riparian woodland. These recommendations may help to mitigate further damage to the riparian habitat and would seek to reverse some of the negative impacts already experienced by the riparian habitat below the Dam.

Methods and Materials

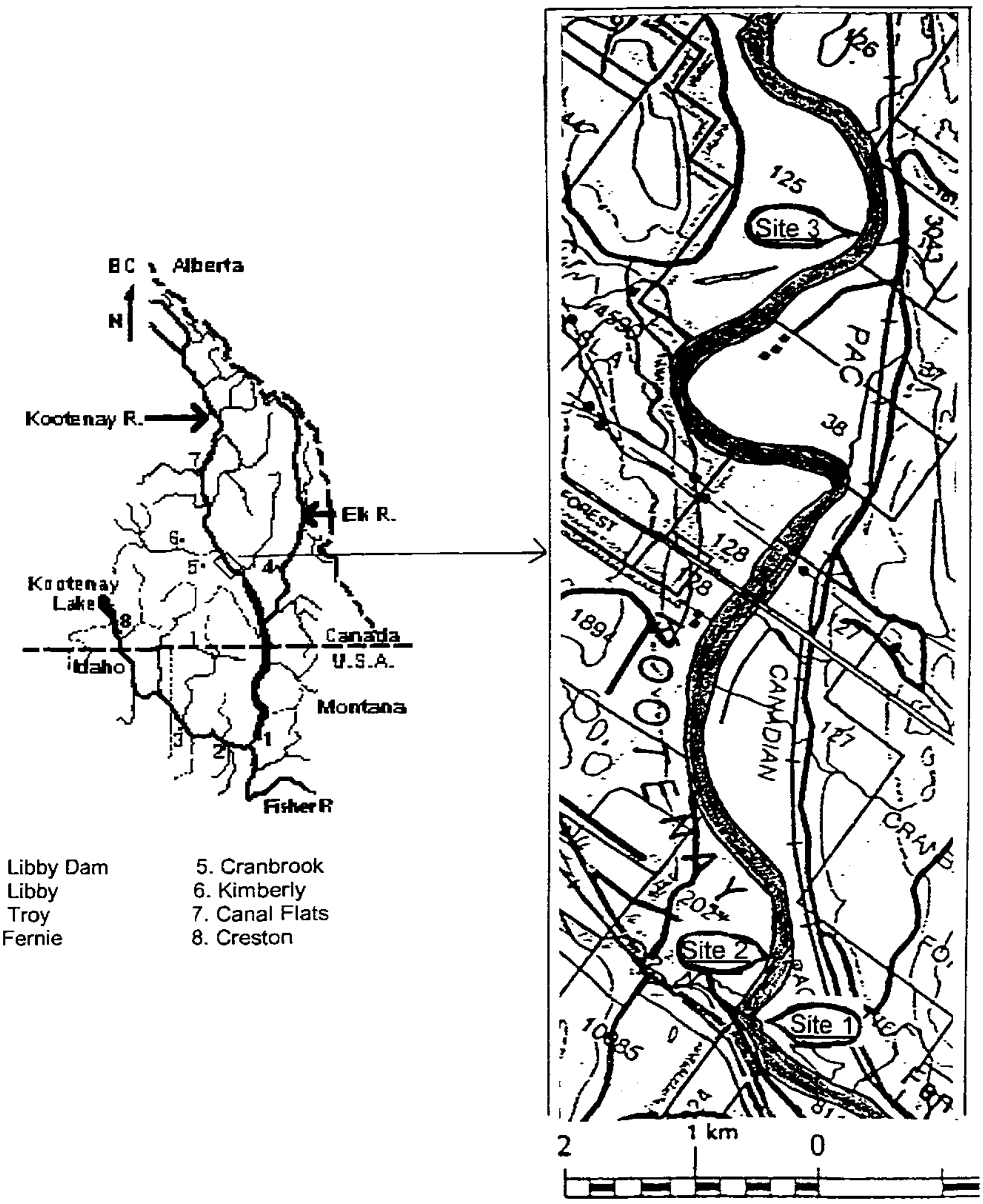
Field studies were conducted along the Kootenay River starting about 12 km south of Fort Steele, British Columbia and ending 5 km upstream of Troy, Montana. These field studies occurred from May to October, 1996 and from April to October, 1997. Mean daily, monthly and annual discharge data from 1963 to 1997 at station # 08NG065 (Kootenay River at Fort Steele) and from 1914 to 1972 at station # 08NG005 (Kootenay River at Wardner) were taken from Environment Canada's 'Hydat' data base. Mean daily, monthly and annual discharge data from 1911 to 1991 at station #12303000 (Kootenai River at Libby) and 1968 to 1994 at station #12301933 (Kootenai River below Libby Dam, near Libby) were obtained from 'Earthinfo's USGS Peak and/or Daily Values, data base and 1996 to 1997 discharge data were obtained from US Army Corps of Engineers internet web site. Flood recurrence data was analyzed using the log Pearson type III fit, a distribution favored by the United States Geological Survey and found to fit the Kootenay River data reasonably well. The program Smada was used to analyze the log Pearson type III flood recurrence data.

The Fisher River in Montana was used as an adjacent control for the Lower Kootenai River. Study sites along the Fisher River were 5 km upstream from where the Fisher River joins the Lower Kootenai River at the 'Big Bend' just upstream of Jennings, Montana. Mean daily, monthly and annual discharge data from 1969 to 1994 at station #12302055 (Fisher River near Libby) were from 'Earthinfo's' USGS Peak and/or Daily Values, data base and 1996 to 1997 discharge data were from US Army Corps of Engineers internet web site.

Climate data were gathered by Environment Canada for the years 1914 to 1957 and 1968 to 1997 at the Cranbrook, B.C., Airport. Climate data at Libby, Montana were gathered by U.S. D.A Forest Service Libby Ranger Station for the years 1912 to 1997.

For the present study, floodplain positions are expressed relative to a reference point corresponding to the estimated position of the river's edge at 'base flow'. Base flow was established as the typical flow for mid-October ($80.7 m^3/s$ for the Upper Kootenay River and $170 m^3/s$ for the Lower Kootenai River), the end of the cottonwood growing season along the Kootenay River. These base flows were then converted to base stages using discharge/stage ratings curves at Fort Steele, B.C. and Libby, MT. gauging stations (Upper Kootenay River 0.505 m and Lower Kootenai River 5.6 m). These base stage elevations were set to '0' and all surveyed elevations are calculated relative to these base stages.

Along the Upper Kootenay River three meander lobes for sampling sites were selected with certain criteria. The sites contained gradually sloping banks on the point bars, displayed minimal human impact, were situated downstream from the anastomosing channels near Fort Steele and upstream of the end of the full supply level of the reservoir, and were relatively easily accessible (Figure 45). At each site, three transects were established by running a tape measure from a metal tag-numbered cottonwood anchor tree down to the river's edge



1. Libby Dam
2. Libby
3. Troy
4 Fernie
5. Cranbrook
6. Kimberly
7. Canal Flats
8. Creston

Figure 45. The figure on the left is the Kootenay River Basin. The figure on the right is an enlargement where the Upper Kootenay study sites occurred from the topographical map 82G/NW scale 1:100,000.

with these lines extending perpendicular to the direction of stream flow. One metre long, iron rebar stakes were pounded in near the river's edge to enable exact repositioning of the transect. However, many of these bars were toppled or buried by the spring peak in 1997. With the loss of the rebar, transect lines could not be re-established precisely, and this complicated the exact repositioning of the quadrats and staff gauge along the transect lines in the following months.

Three meander lobes were chosen along the Lower Kootenai River using similar criteria as for the Upper Kootenay River sites. These sites were situated downstream of 'Big Bend' and upstream of Troy, Montana (Figure 46). Three transects were established at Sites 1 and 3 and two transects at Site 2. Rebar was used on the Lower Kootenai River sites except for two transect lines where it could not be pounded in due to large sub-surface cobble and boulders. All rebar stakes established on the Lower Kootenai River stayed in place into the following year.

Two meander lobes were chosen along the Fisher River using similar criteria. These were situated about 4.8 km upstream from the outflow of the Fisher River. Two transects were established at Site 1 and three at Site 2. All rebar used was buried or toppled by the peak in 1997 and both tagged trees at Site 1 were scoured away by the 1997 peak flow.

These twenty two total transects were surveyed for elevation using a transit and staff gauge, in the spring of 1996 (May, Upper Kootenay and June and July, Lower Kootenai) and in the following September and October of 1997.

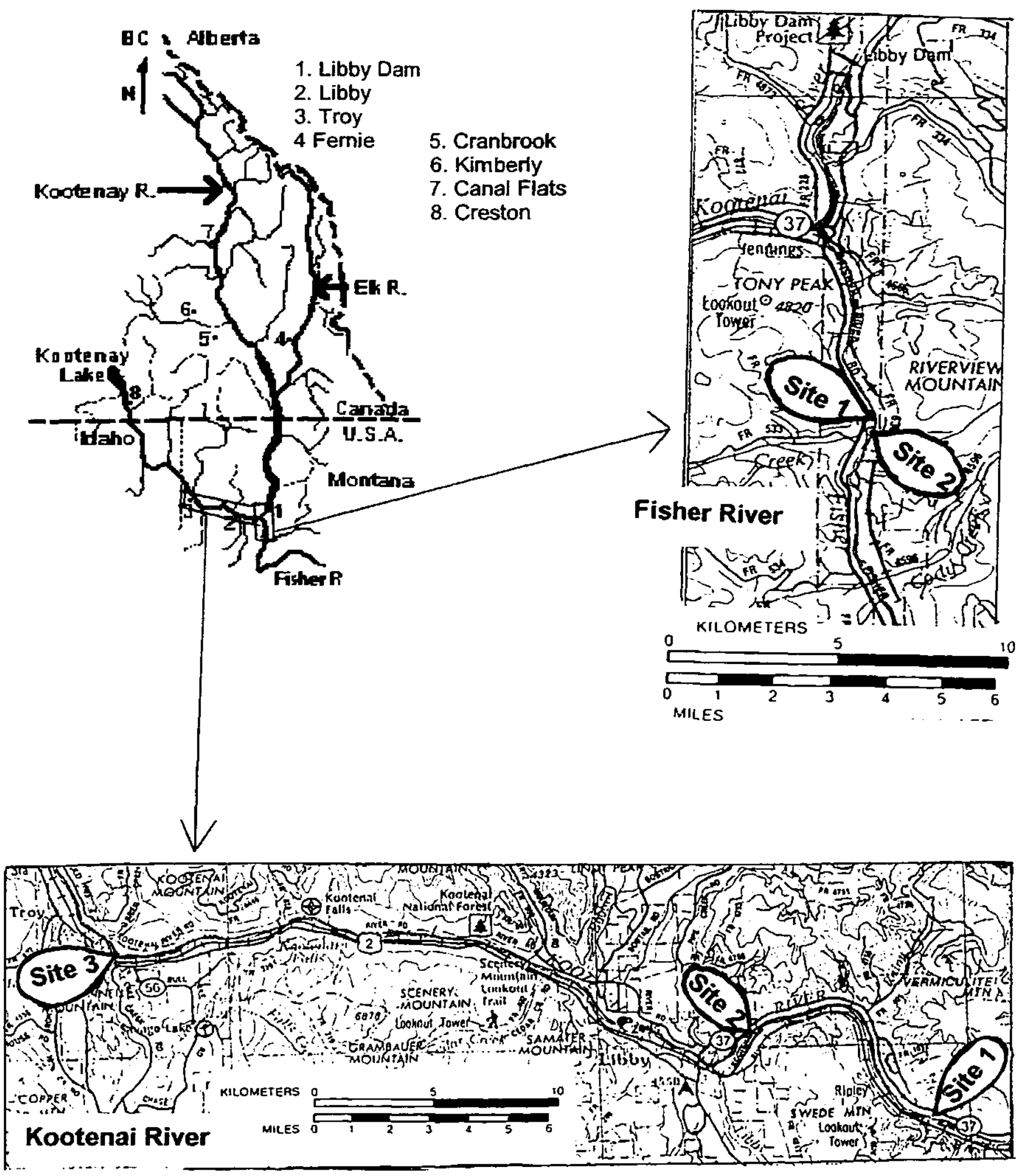


Figure 46. The figure on the left is the Kootenay River Basin. The figure on the right is an enlargement where the Fisher River study sites occurred and the figure on the bottom is an enlargement of where the Lower Kootenai River study sites occurred from Montana Atlas and Gazetteer maps 81 and 82 scale 1:250,000, 1994 DeLorme Mapping .

Transects surveyed in May 1996 were used but the transects surveyed in June and July 1996 had to be corrected for error as the transit was not properly calibrated resulting in a slope error. Surface composition type and texture and vegetation zones along the transect lines were mapped and described.

The seedling densities along the transect lines were measured within a 20 cm X 50 cm quadrat. In total, 87 quadrats (56 along the Upper Kootenay and 31 along the Fisher River) were established along 14 transects. Seedling heights of ten randomly chosen seedlings were measured in each quadrat at each site visit. Both height and density counts were determined along the transect lines in positions where seedlings occurred in low and high numbers. Beaver activity was noted by tracks, cut branches and felled trees. Evidence of ungulate and bird use of the sites was also noted.

Mature trees were aged by ring counts from cores extracted with an increment borer with auguring about 26 cm above the surface to allow room to rotate the bore crank. Densities of saplings (juveniles) were determined in 2 m^2 quadrats in areas along the transects where they occurred and/or where patches occurred on the study site meander lobes. Aging of juveniles was performed by cutting down the saplings at ground level, removing a thin slice from the cut end and counting the rings under a dissecting microscope. When possible, juveniles were also aged by counting the annual growth scars along the stem.

Air-photos for the Upper and Lower Kootenay River were analyzed for changes in channel position and pattern with the date, site, air-photo number and scale information found in Table 7. Air-photo dates are presented since

Table 7. Summary of air-photos used in channel position and pattern analysis along the Upper Kootenay (B.C.) and the Lower Kootenai (MT.) River.

SYSTEM	DATE	SITE	AIR-PHOTO #	SCALE
Upper	Jul 23, 1962	1 & 2	BC4076:9	1:15,840
Kootenay	Jul 23, 1962	3	BC4076:190	1:15,840
	Jul 23, 1962	between 2 & 3	BC4076:95 BC4076:115	1:15,840
	Jul 23, 1962	downstream of 1	BC4075:197	1:15,840
	Aug 6, 1975	1 & 2	BC7770:110	1:15,840
	Aug 6, 1975	3	BC7774:018	1:15,840
	Aug 6, 1975	between 2 &3	BC7770:143	1:15,840
	Aug 10,1994	1 &2	30BCC94124:016	1:15,000
	Jun 22, 1994	3	30BCC94020:166	1:15,000
	Aug 10,1994	between 2 & 3	30BCC94019:080	1:15,000
	Aug 10,1994	downstream of 1	30BCC94124:062 30BCC94124:063	1:15,000
Lower	1930	1	2869	
Kootenai	1930	2	2846	
	1930	3	2796	
	Aug 7, 1963	1	EMG-13-255	
	Aug 8, 1963	2	EMG-14-26	
	Aug 17,1963	3	EMG-18-63	
	Jul 26,1982	1	USDA 12611140 481-201	
	Jul 27, 1982	2	USDA 12611140 881-15	
	Jul 28, 1982	3	USDA 12611140 1381-53	
	Jul 17, 1992	1	USDA 12611140 992-112	
	Jun 22, 1992	2	USDA 12611140 292-225	
	Aug 2, 1992	3	USDA 12611140 1692-23	

change in stream flow across each year would result in changes in apparent channel width and bar exposure. On August 8, 1996 a low elevation (180 m) flight over the Upper Kootenay River provided the opportunity to take oblique aerial photograph for analyses of the geomorphological changes after 1994.

The Lower Kootenai River had air-photos from 1930, 1963, 1982 and 1992. A series of 1930 air-photos was analyzed from number 2787 (Troy) to 2876 (Big Bend), but the exact scales and dates were unknown. Air-photos numbering, 2900, to 2999 were upstream of the present day impoundment and were used for analyses of the extent of the cottonwoods compared to the 1963 stands of cottonwoods that were inundated by the Libby Dam impoundment. The air-photos used at individual sites are listed in Table 7.

Results and Discussion

Comparisons of River Stage Patterns at Study Sites Versus Gauging Stations

Riparian zones are primarily affected by the stage (elevation) changes rather than discharge, of the adjacent streams. Consequently, it is important to understand how water levels change with changing discharge. Hydrometric gauging stations are established at sites that are conveniently accessible and often have artificial channel geometries with relatively steep banks near bridges. This results in non-typical stage versus discharge patterns or ratings curves.

The non-typical stage-discharge relationship is especially relevant to riparian ecology since seedling recruitment sites particularly occur on meander lobes which have more gradually sloping banks than the steep banks near many bridges. Steep banks result in steeper increases of stage relative to discharge changes as compared to a gently sloping bank where a greater increase in discharge is required to produce the equivalent increase. Because virtually all records of stage and discharge are from these gauging sites, it is important to know how the stages actually change at recruitment sites. The cross-sectional transects of the present study enabled such an analysis.

The actual stage changes at the transect study sites along the Upper and Lower Kootenay River were compared with stage changes at hydrometric gauging stations near these particular sites. Stages along the transects were always found to be very closely correlated with stages at the gauging sites and coefficients of determination (r^2 values) generally approached 1 (Figures 47and 48).

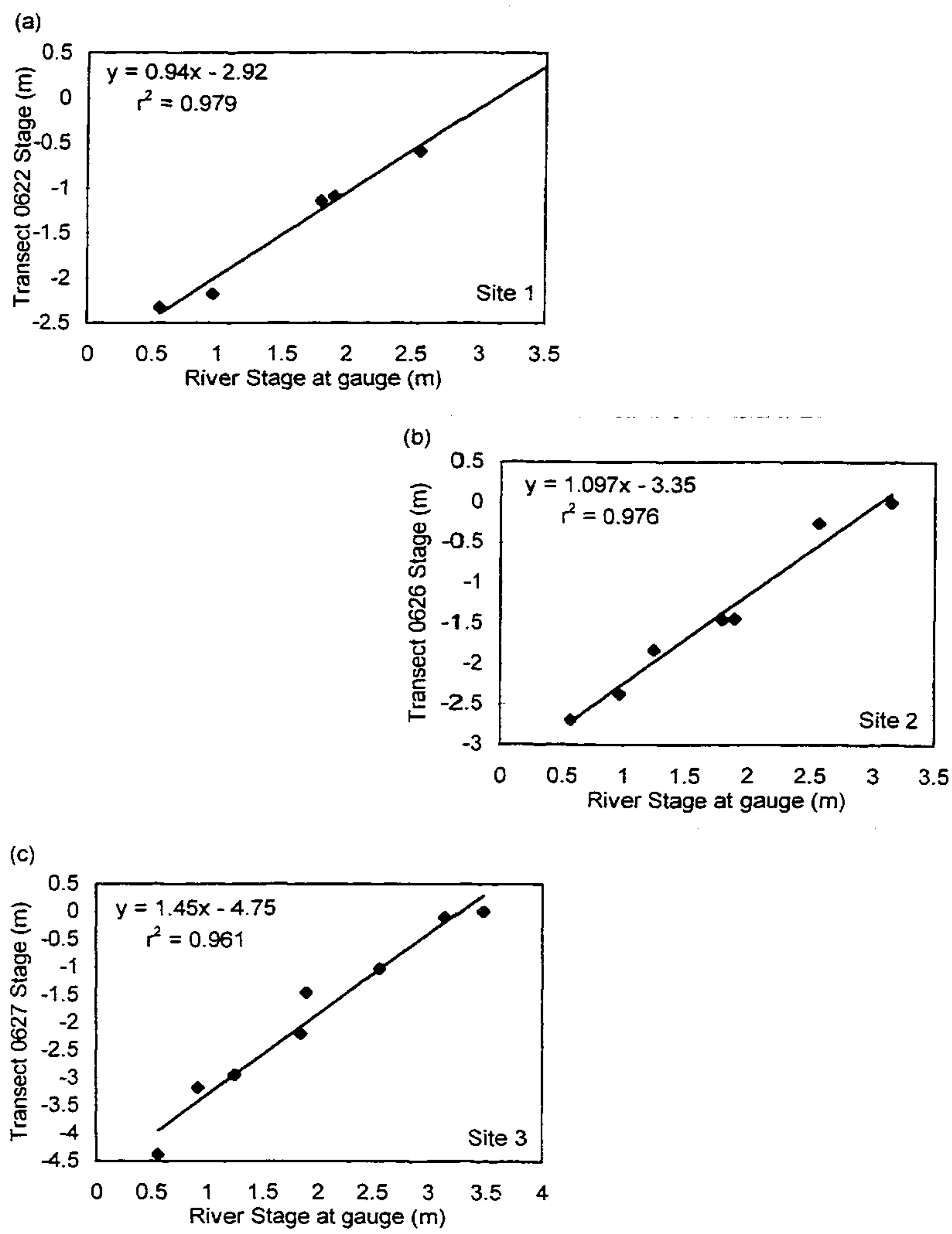


Figure 47. The Fort Steele gauging station (#08NG065) stage changes compared to the stage changes along the Upper Kootenay River Sites 1, 2, & 3. Transects (a) 0622, (b) 0626, (c) 0627.

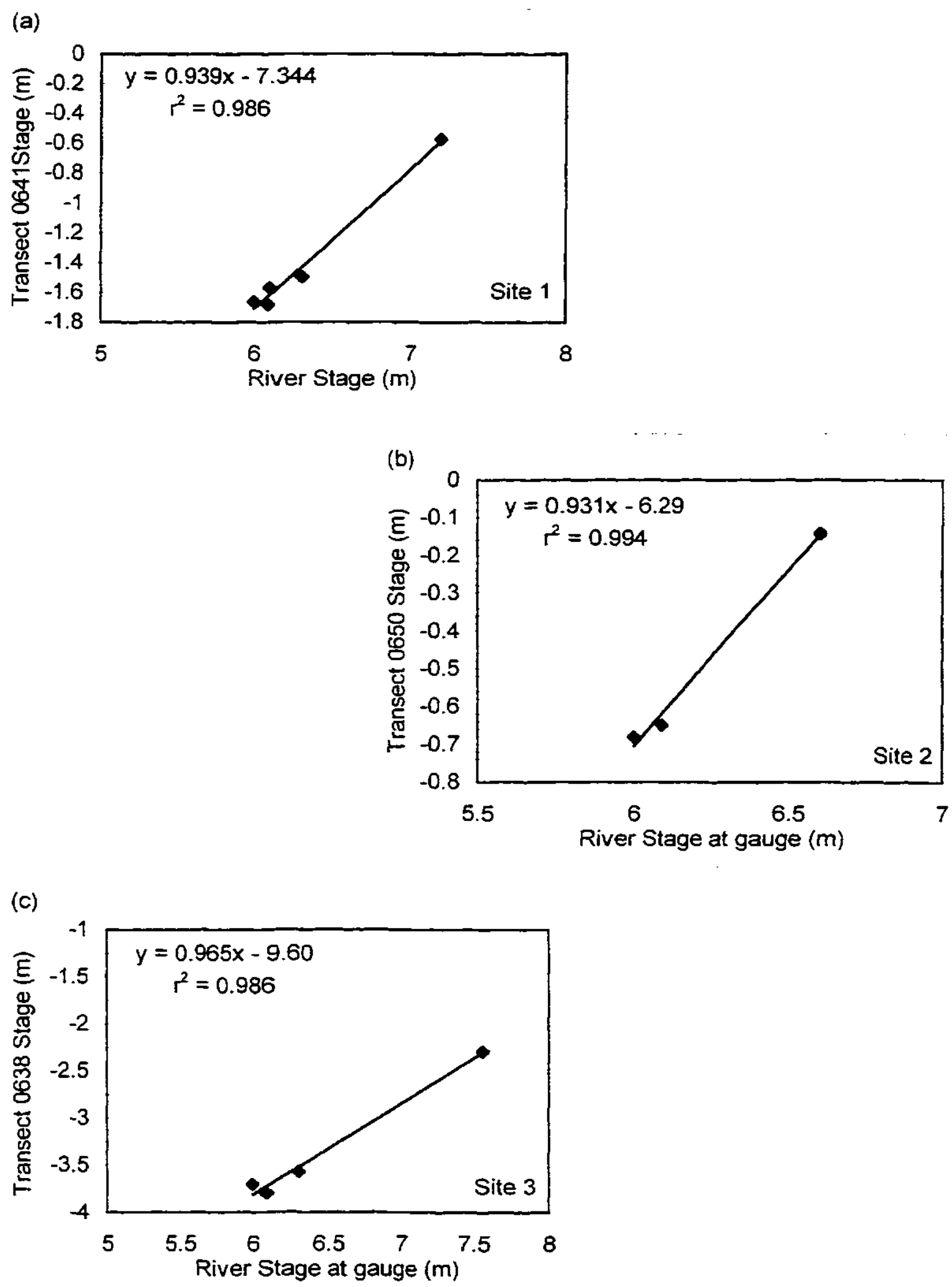


Figure 48. The Libby, MT. gauging station (#12303000) stage changes compared to the stage changes along the Lower Kootenai River Sites 1, 2, & 3.

Upper Kootenay River Site 1 had an r^2 of 0.979, and the regression slope was 0.94; thus, for each 1 m of stage change at the Fort Steele gauging station there was approximately 0.94 m stage stream change at Site 1 (Figure 47). This indicates that the transect was on a slightly more gradually sloping bank than the bank slopes at the gauging station. Site 2 had an r^2 of 0.98, and a slope of 1.1 and thus, stage changes at Site 2 were actually slightly greater than at the gauging station. Site 2 did have steeper banks than Site 1. Site 3 had an r^2 of 0.96, producing a regression slope of 1.45; for every 1 m of stage change at the gauging station there was a 1.45 m stage change at Site 3 (steepest banks).

The Lower Kootenai River study had fewer site visits than Upper Kootenay study and only 1 visit during substantially different flows. This produced data that were less complete than the Upper Kootenay River but there was still a very close correlation between the individual site stage changes and Libby gauging station stages (Figure 48). The r^2 values were very similar between sites, ranging from 0.986 to 0.998, and the Lower Kootenai Sites had apparently slightly gentler sloping banks compared to the gauging stations banks with regression analysis slopes ranging from 0.93 to 0.99. These less than unity values were expected and are probably more typical of gauging site versus meander lobe patterns.

This analysis confirmed the general suitability of the gauging sites which were used for subsequent analyses and base stage calculations. The results from both the Upper Kootenay and Lower Kootenai stage comparisons suggest that neither of these gauging station stage patterns would be exactly typical of the meander lobe patterns but they would be close enough for the subsequent analyses. The particular stage versus discharge pattern is primarily determined by cross-sectional geometry combined with channel gradient, a product of longitudinal profile. The difference in specific stage-discharge pattern at the study sites reflects both cross-sectional and gradient difference, and either or both would underlie the steeper stage response at Upper Kootenay Site 3.

Streamflows Upstream and Downstream from the Libby Dam

To examine the degree to which the Libby Dam decreased downstream flows a number of comparisons were made. First, the annual flows prior to the dam were compared with annual flows following the dams completion. Second, upstream and down stream flows were compared during flood events. Third, the timing of peak flows pre-dam were compared to post dam peak flows.

Upstream Versus Downstream Annual Peak Flows

Between the two gauging stations at Wardner, B.C., and Libby, Montana, the Elk River is the major contributor to the Kootenay River. Consequently, river discharge at the Libby Station were higher than at Wardner prior to the installation of the Libby Dam (Figure 49). This pre-damming comparison suggests that historic river patterns were very similar with the only differences being increased discharge downstream due to the inflow of rivers and creeks.

Operation of the Libby Dam has had a large impact on the annual pattern of discharge. From 1973 to 1995 there were greatly increased fall and winter discharges and greatly decreased spring and summer discharges. This artificial

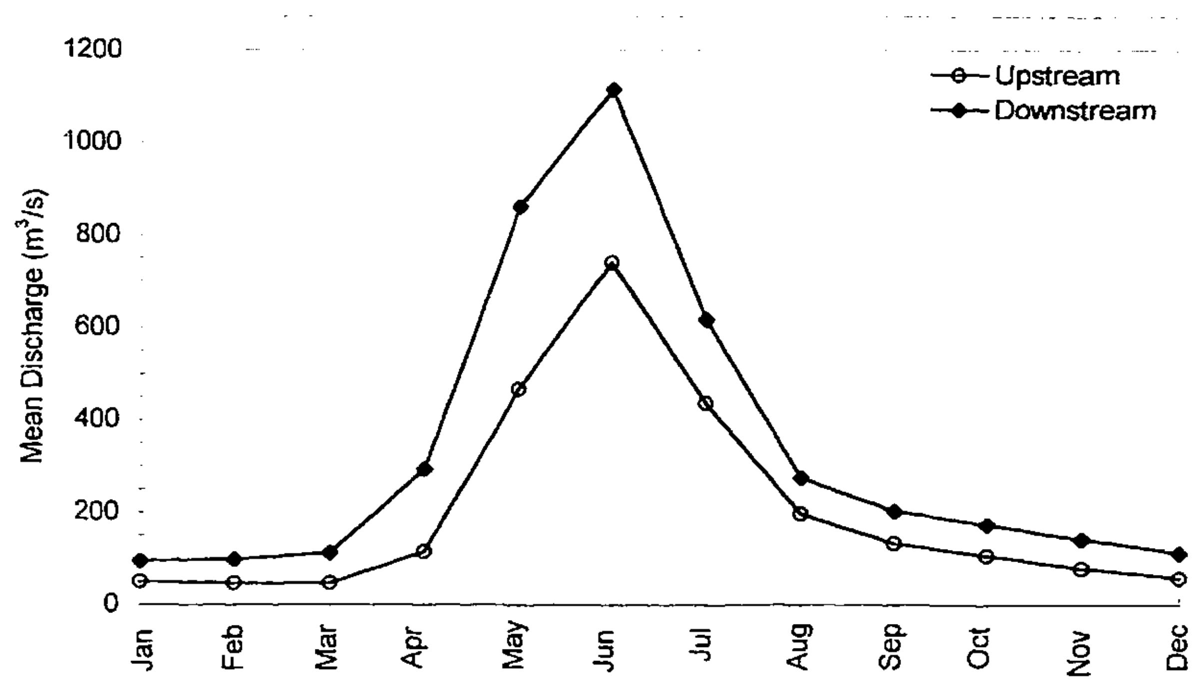


Figure 49. Mean monthly discharge (m3/s) of theupstream
(Wardner gauging station #08NG005) and downstream
(Libby, #12303000) along Kootenay River for the period 1914 to 1972.

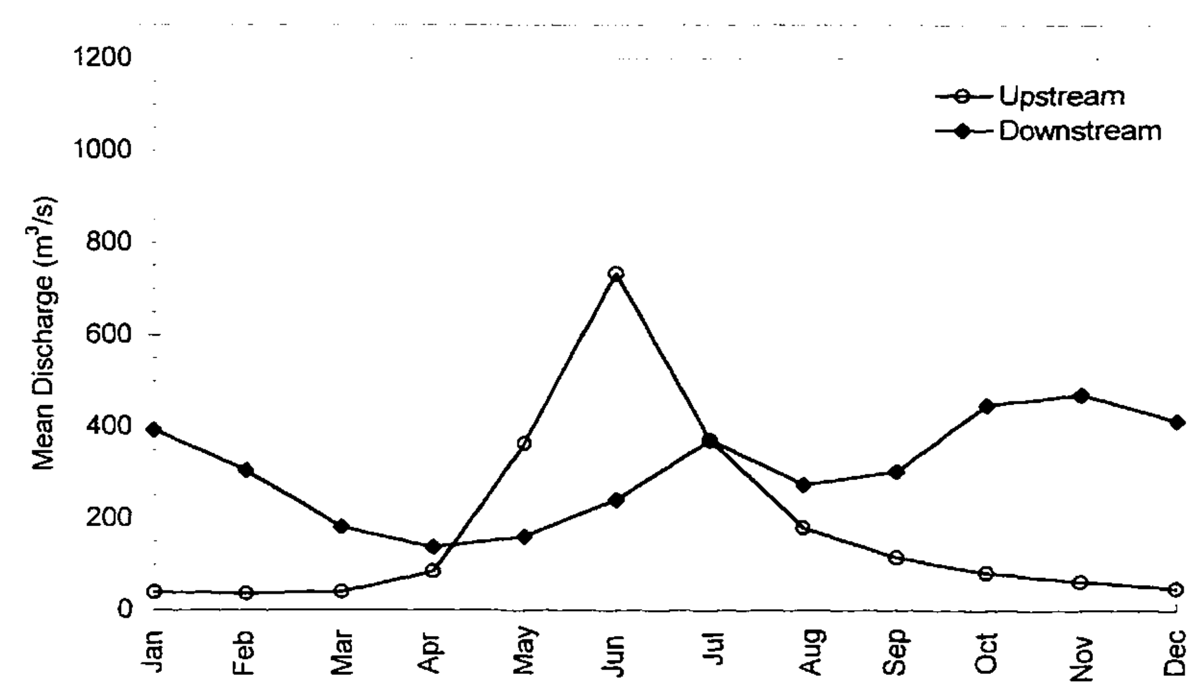


Figure 50. Mean monthly discharge (m3/s) of the upstream (Fort Steele, # 08NG065)
and downstream (below Libby dam near Libby, #12301933)
Kootenay River for the period 1973 to 1995. The dam was completed in 1973.

pattern reversed the natural fluctuation of river discharge (Figure 50).

The Upper Kootenay River had a 1-in-200 year flood event in 1974 (Figure 51), and the Dam virtually eliminated this peak which demonstrates its capacity to attenuate extreme flood events. Figures 52 and 53 show the daily discharge for a 1-in-2 year and 1-in-10 year flood events. Both of these events resulted in downstream peak discharges that were considerably less than the mean annual peak discharge prior to the Dam's completion of about 1150 m^3/s.

The present flood analysis of the Upper and Lower Kootenay River used gauging stations with the longest data sets. The Wardner, B.C., gauging station 08NG005 had a 49 year record and the Libby MT., gauge 12303000 had an 81 year record. The flood return periods were calculated using the Smada program for the log Pearson Type III distribution, a distribution favored by the United states Geological Survey and found it to fit the Kootenay River data reasonably well. The Fort Steele, B.C., gauging station had 34 years of record, falling short of the forty years required to estimate mean annual floods within +/- 10% of the true value with 95% confidence (Richards 1982). An extrapolation using regression analysis of the Wardner versus Fort Steele discharge, which differs by the Bull River inflow was conducted to enable a flood return analysis for the years 1973 to 1997 at the Fort Steele gauging station (Figure 54). There was a 9 year period of overlap for the Wardner and Fort Steele gauging stations which produced a regression coefficient of determination of 0.874 suggesting that the extrapolation would be reasonably accurate (Figure 55).

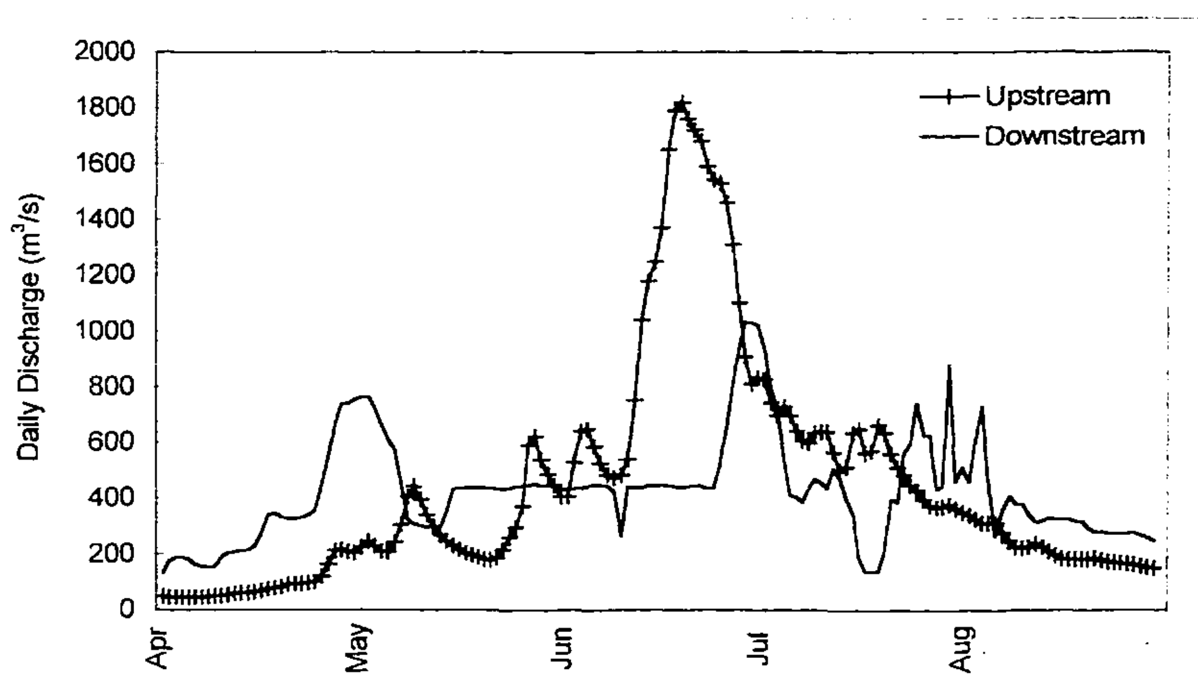


Figure 51. Daily discharge (m^3/s) for the upstream and downstream reaches of the Kootenay River for the periods April through August 1974, a 1-in-200 year flood event for the Upper Kootenay River.

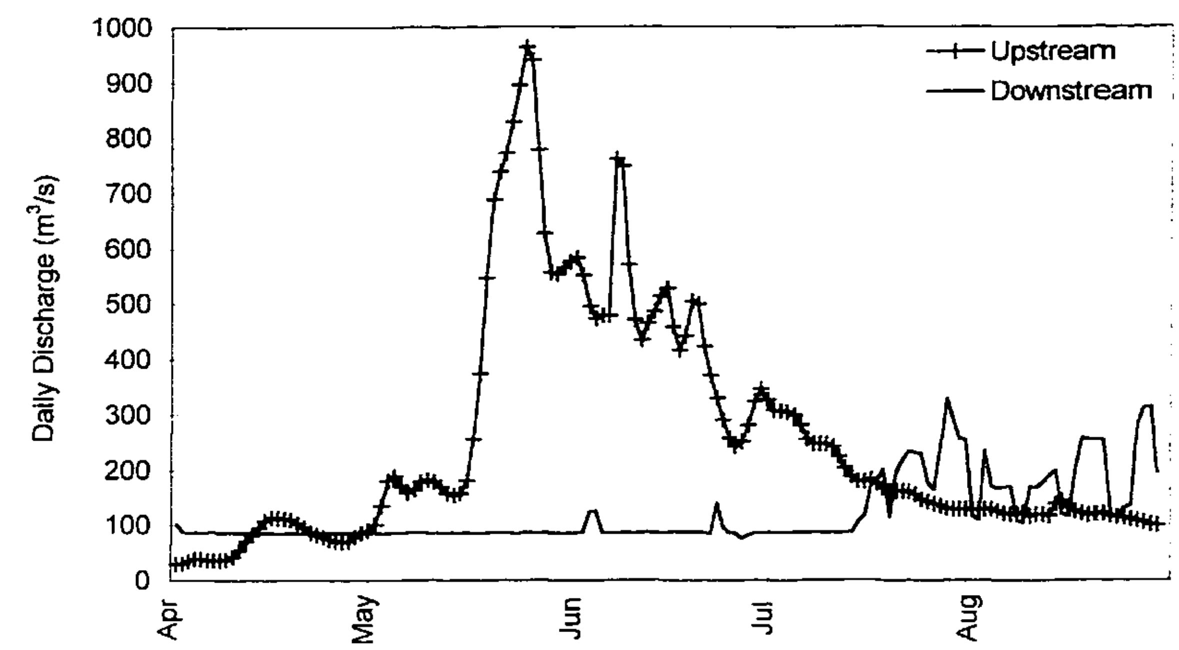


Figure 52. Upstream and downstream daily discharges (m^3/s) for the Kootenay River for the periods April through August 1985, a 1-in-2 year flood event for the Upper Kootenay River.

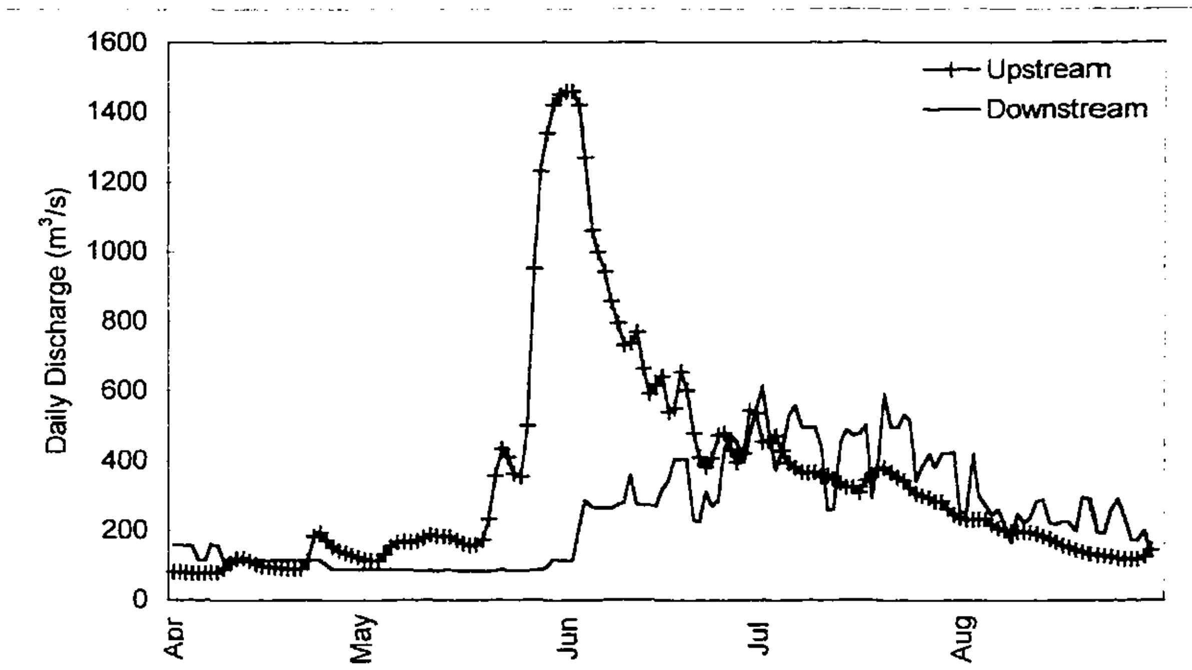


Figure 53. Upstream and downstream daily discharges (m^3/s) for the Kootenay River for the periods April through August, 1986, a 1-in-10 year flood event for the Upper Kootenay River.

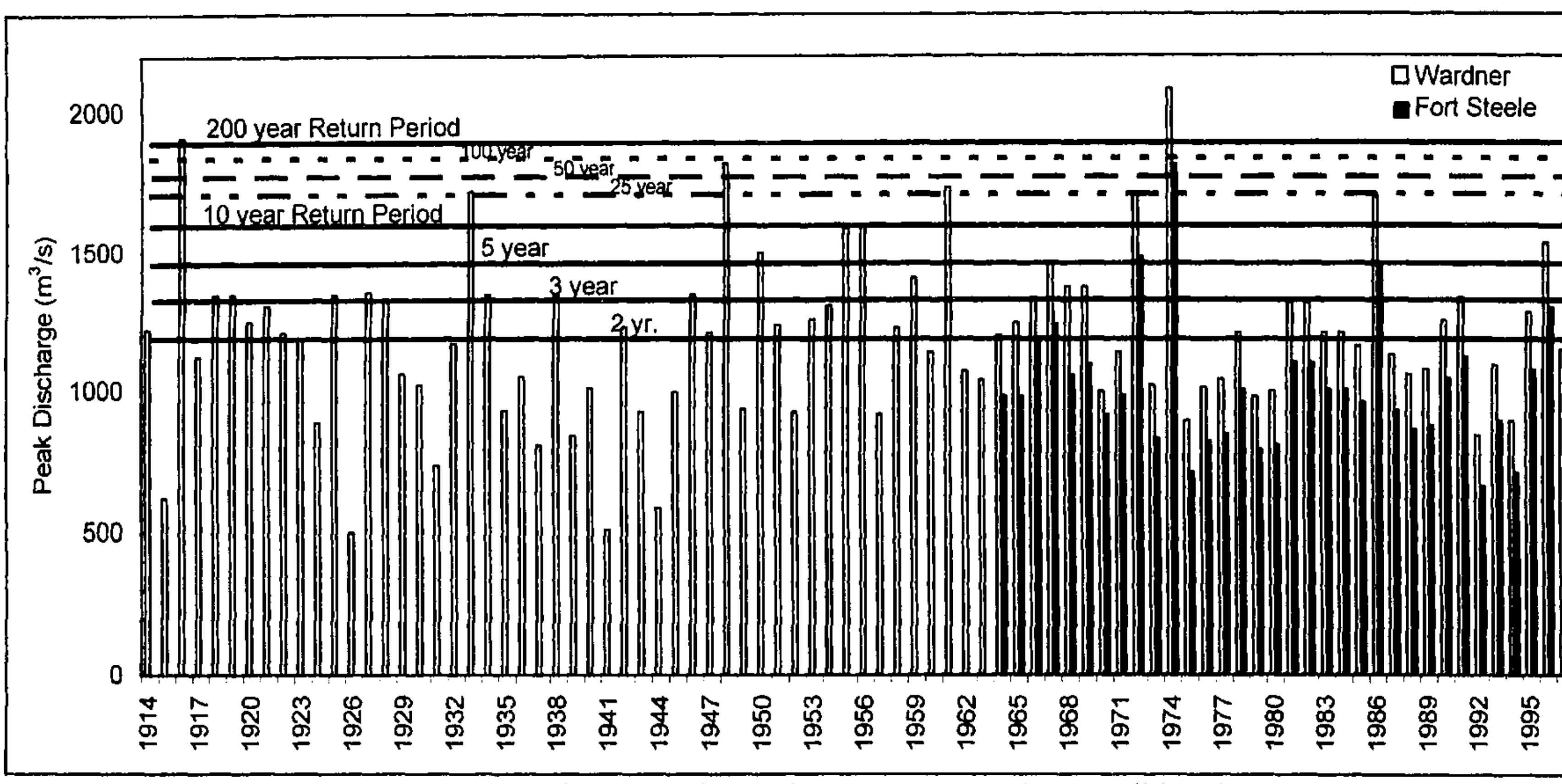


Figure 54. Historical annual peak discharge for the Upper Kootenay River at Fort Steele, (#08NG065) and the Wardner, (#08NG005), the Wardner station for the years 1973 to 1997are approximate flows, and flood recurrance analysis.

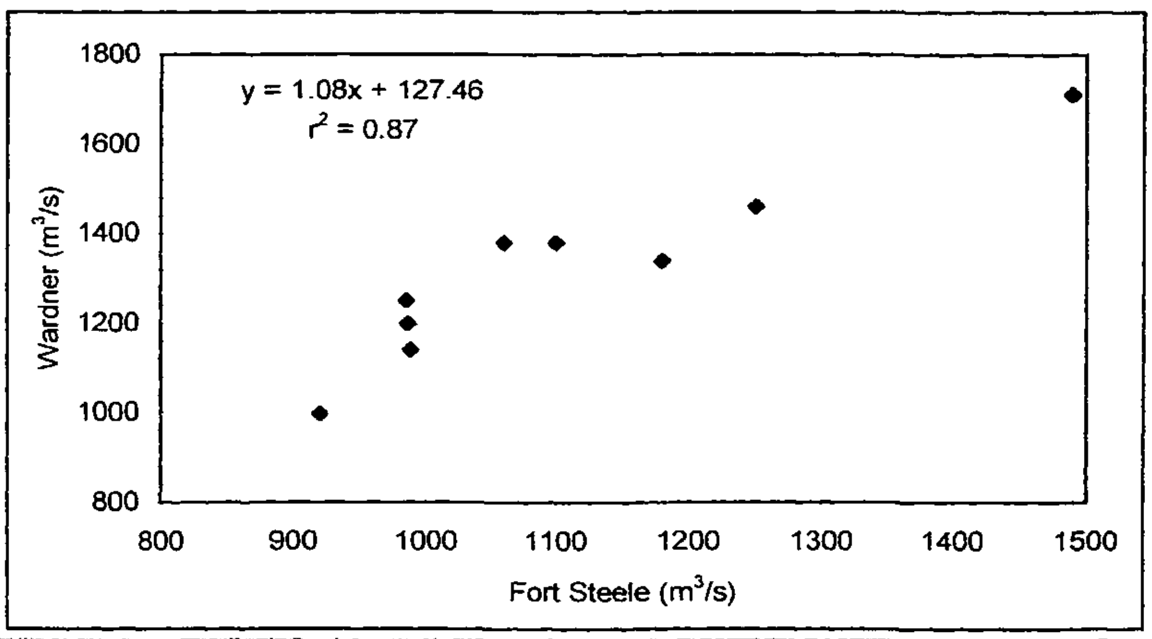


Figure 55. Regression analysis of the Fort Steele versus Wardner gauging stations peak annual discharges for the period 1963 to 1971.

Upstream and Downstream Flood Events

Prior to the Libby Dam completion the Lower Kootenai River had similarly timed annual spring peaks with extreme flood events occurring in the same years as the Upper Kootenay River (Figure 56). The 1916 flood was recorded as a 1-in-200 year flood event at Wardner, B.C., but the same event was estimated at just under a 1-in-100 year event at Libby, Montana. The 1948 flood was over a 1-in-50 year event at Wardner but under a 1-in-50 year event at Libby. The 1974 flood which was well over a 1-in-200 year flood event at Wardner would probably have been slightly over a 1-in-100 year event at Libby, and would probably have been larger than the flood of 1916 without flow attenuation by the Koocanusa Reservoir. Thus, Libby Dam was completed in 1972 and was tested in 1974 and showed that the Dam could 'protect' the downstream lowlands from extreme flood events.

The Timing of Peak Flows Downstream

The annual peak discharges prior to the completion of Libby Dam occurred in late May to early June with occasional peaks occurring early May and mid-June. In contrast the annual peak daily discharges since the completion of the Libby Dam usually occur during the late fall or winter months with the average being late November to early December (Figure 56). The mean peak discharge during the post dam spring peak period was about 250 m^3/s, (Figure 50) which is approximately one-half of the winter peak discharges since the Libby Dam completion. This reversal of peak discharge timing coupled with the extremely low mean discharges during the natural spring peak period results

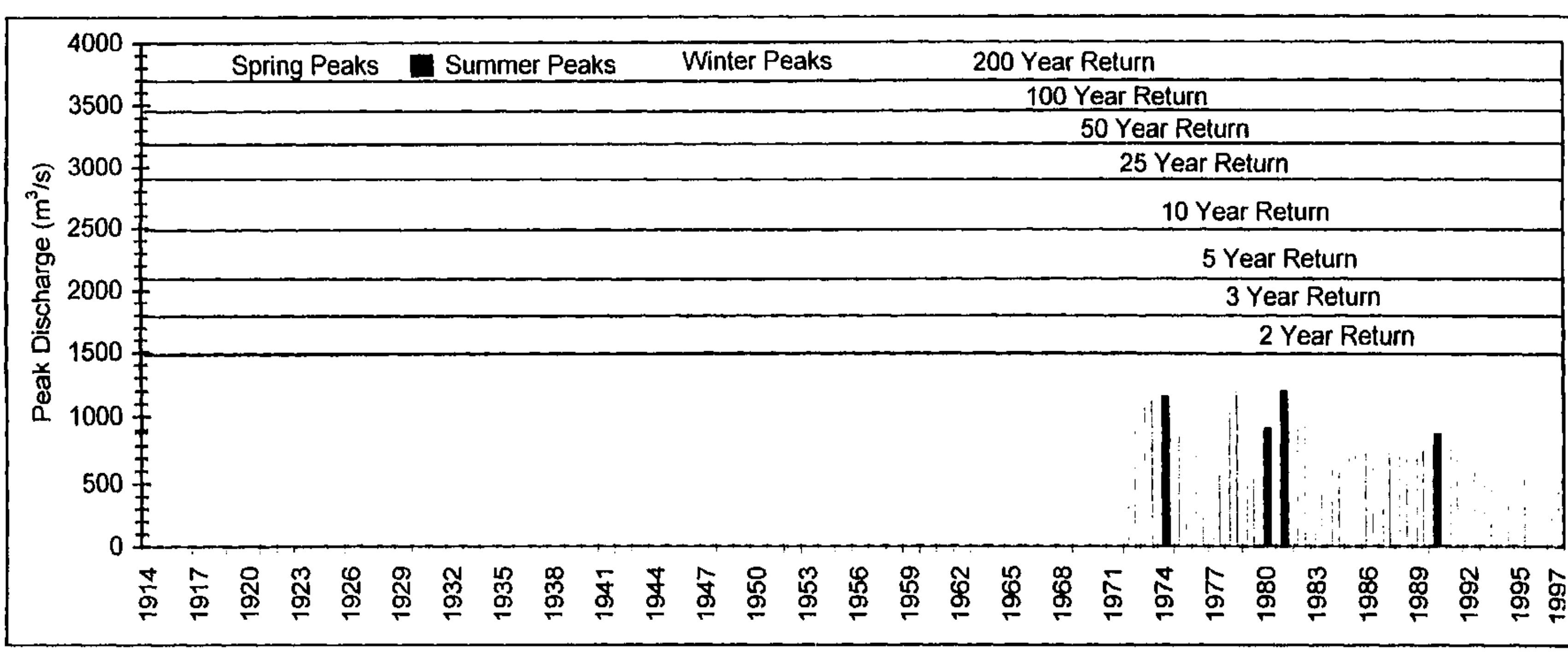


Figure 56. Historical peak discharges for the Lower Kootenai River at Libby, MT. gauging station #12303000 (1914 to 1991) and near Libby gauging station #12301933 (1991 to 1997), along the Lower Kootenai River, with flood recurrence analysis (log Pearson Type III) for the period 1914 through to 1997.

in a severely altered hydrologic regime along the Lower Kootenai River.

Flood Attenuation and White Sturgeon

Since the completion of the Dam, white sturgeon numbers have been declining along the Lower Kootenai River and their present population structure does not include the normal representation of juvenile fish (USACE 1996). In September, 1994, the Kootenai River population of white sturgeon was declared endangered (USACE 1996). Because some of the hydroelectric power needs were purchased from alternate sources since 1992, the Bonneville Power Administration has allowed the U.S. Army Core of Engineers (Corps) to store water behind Libby Dam in the winter so that it can be released in the spring to promote sturgeon spawning. These experimental flows have changed from year to year according to water availability and the increased understanding of the requirements of the white sturgeon (Figure 57). However these increased spring and summer flows did not surpass the annual peak flows that still occur mainly in November or December (Figure 56). There was one exception with a spring peak June 13, 1996, but it was only 8.5 m^3/s above the peak December discharge and lasted only part of one day and then dropped below the December peak.

The estimated sturgeon spawning dates were compiled from research by the Army Corps who were represented by a fish biologist on the Kootenai River White Sturgeon Recovery Team. This group has the task of developing a strategy to recover the sturgeon population (USACE 1996). The Corps is also

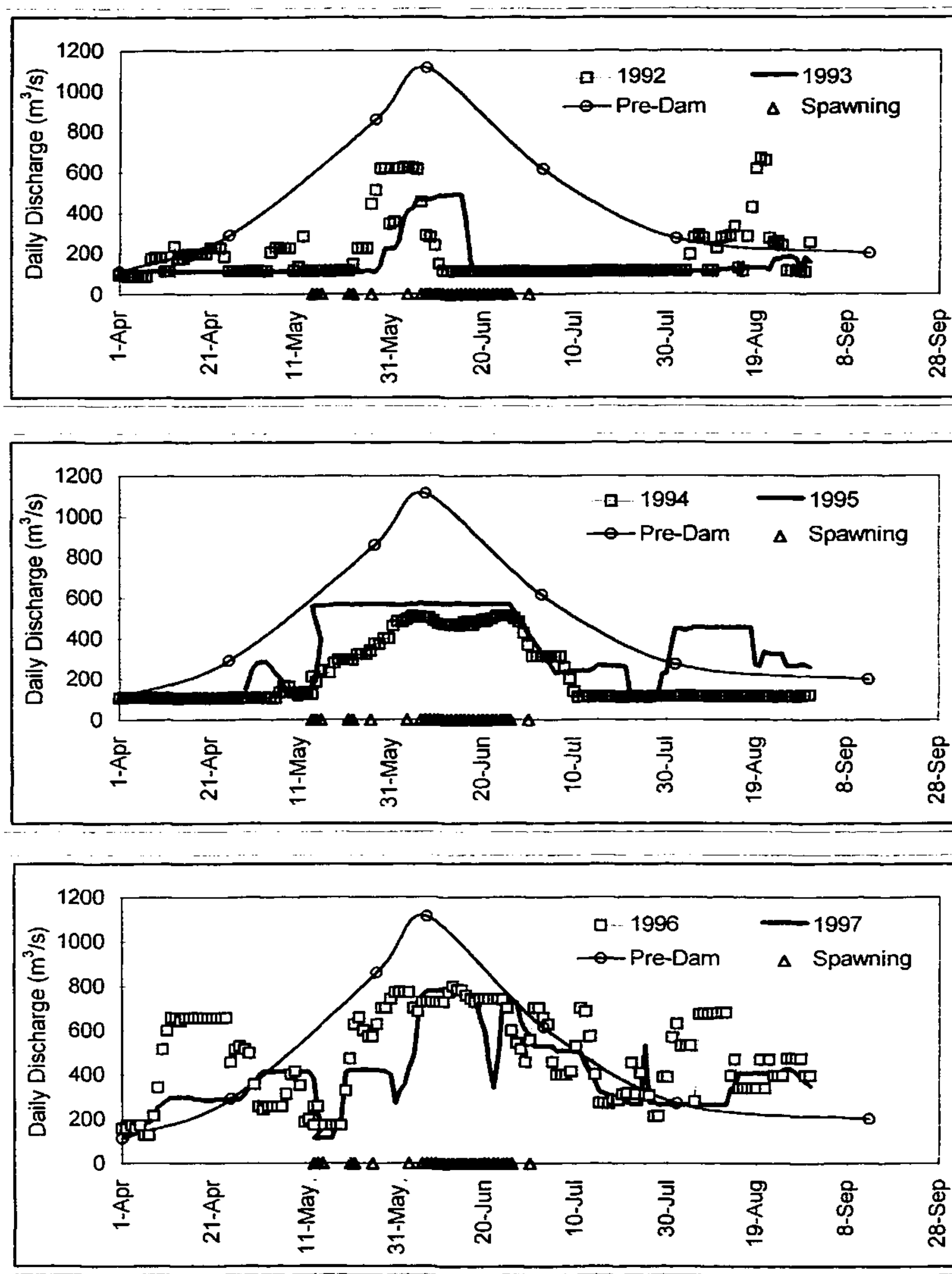


Figure 57. Libby, MT. (#12301933) daily discharges for the period April through August, 1992 to 1997 with pre-dam mean discharges for this period and estimated sturgeon spawning dates from USACE 1998.

working with the National Marine Fisheries Service to determine how stored water can best be used not only for sturgeon, but additionally to aid the downstream migration of salmon smolts in the Columbia River, to which the Kootenay River is a major tributary (USACE 1998).

Geomorphological Changes along the Kootenay River

Studies of other cottonwood-dominated river systems have shown that dams that attenuate spring peaks impact the downstream channel systems. The main changes to the geomorphology of the systems generally include: 1) channel narrowing, 2) loss or reduced meandering of channel, 3) sediment trapping by reservoir resulting in outflow water being sediment free, that produces and 4) a loss of downstream sediment deposition (Bradley and Smith 1984, Williams and Wolman 1984, Debano and Schmidt 1990, Rood and Mahoney 1990, Rood and Mahoney 1995, Scott et al 1996). Since the Libby Dam is operated to attenuate spring flooding similar geomorphological changes would be expected (Figure 50).

The free-flowing Upper Kootenay River experiences slow meandering with erosion of the outside bank accompanied by deposition on the inside edge of meander lobes or point bars. Both study Sites 1 and 2 along the Upper Kootenay experienced this shifting of meander lobes downstream over a 30 year period (Figure 58). The discharges for the days the air-photos were taken were different with the 1994 flow at 143 m^3/s and the 1962 flow at 280 m^3/s. Since the 1962 air-photo was taken at a higher discharge, the shallow waters marked would probably be exposed sandy bares at a flow equivalent to that of the 1994 air-photo.

Site 3 along the Upper Kootenay River experienced the same downstream movement of the meander lobe but the next meander lobe downstream experienced little change (Figure 59). This shows that in an

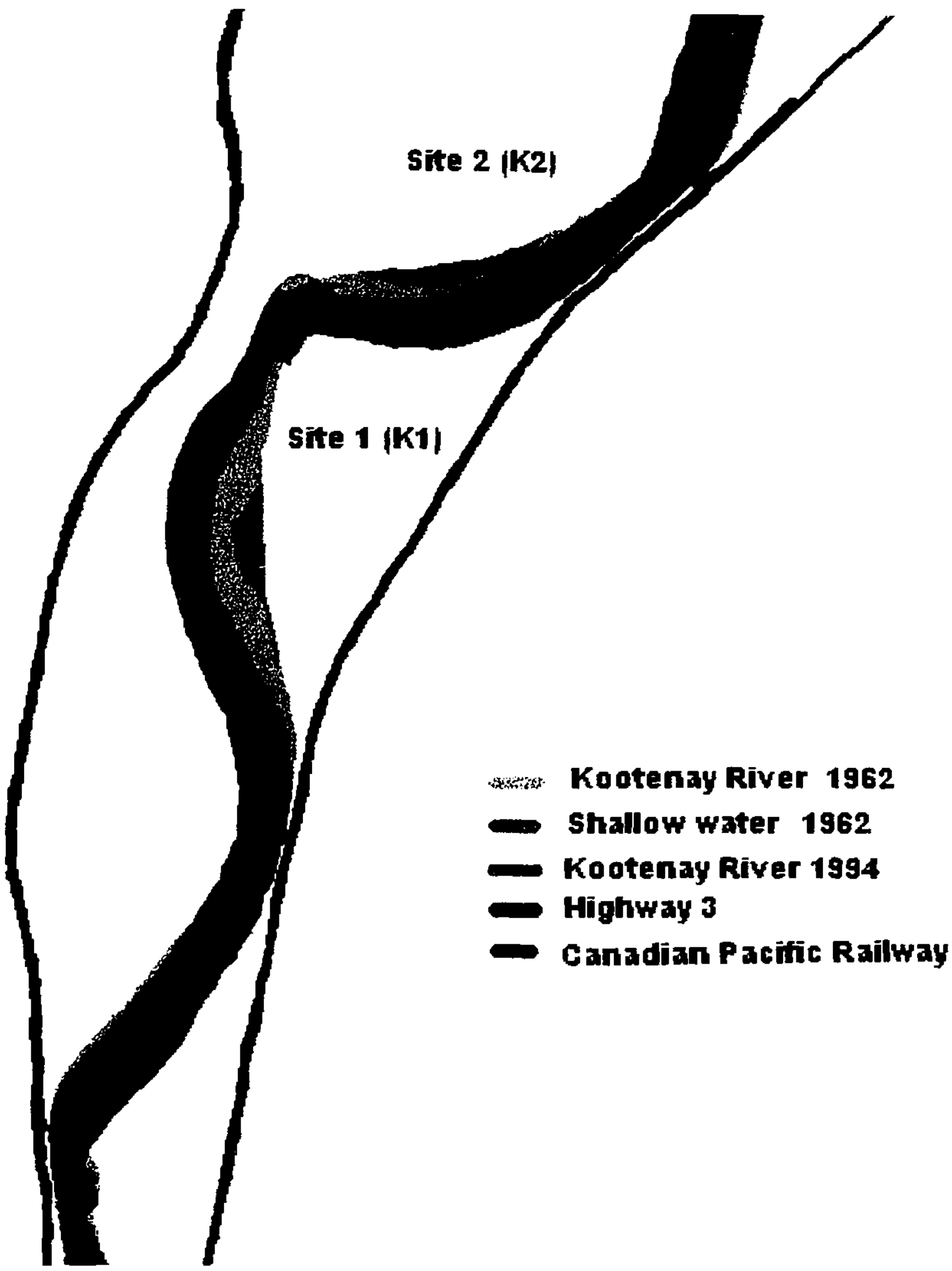


Figure 58. The Upper Kootenay River channel in 1962 with an overlay of the channel in 1994 (Sites 1 & 2 marked, approximately 1:15,000 scale at 49° 28' N 115° 30' W).

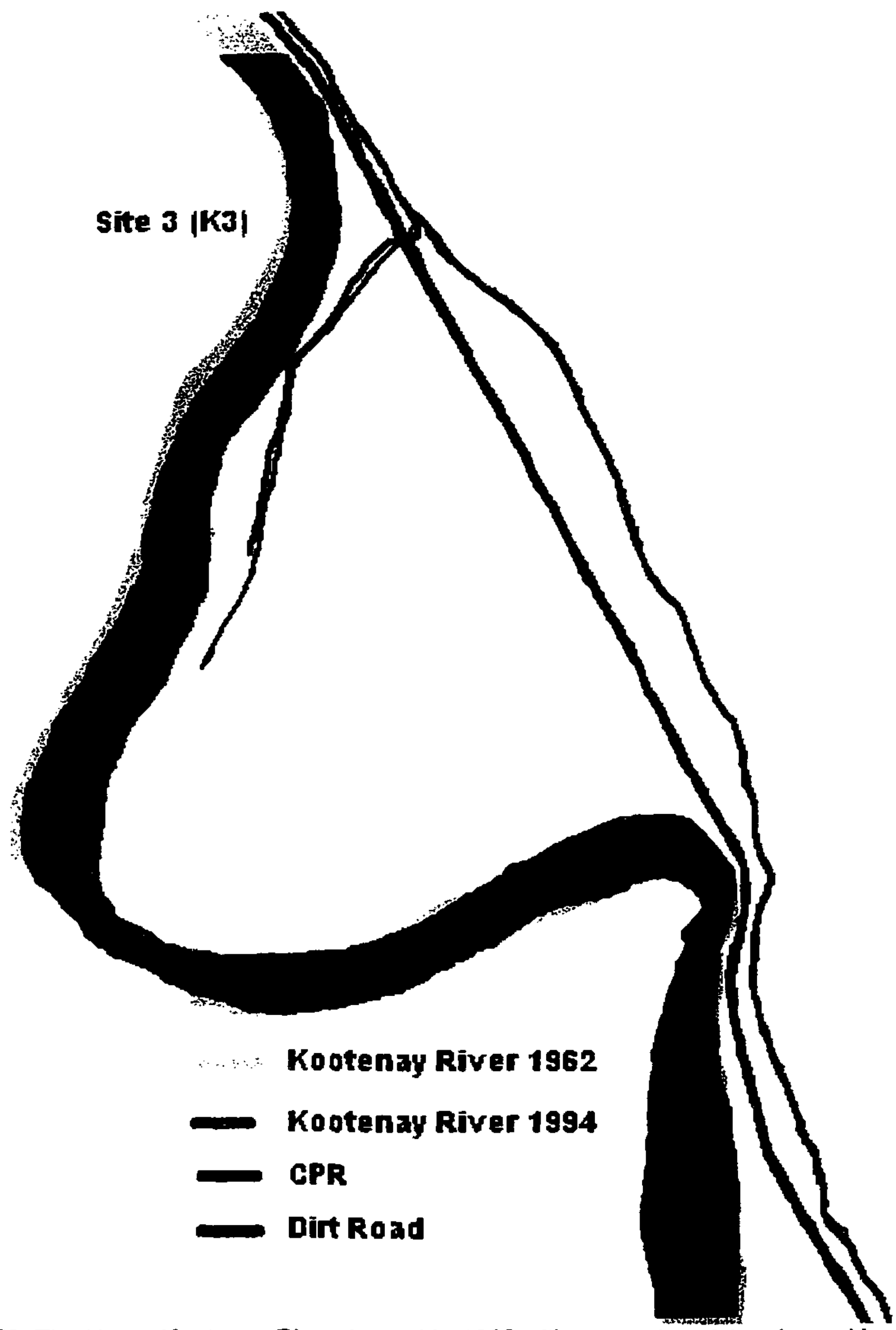


Figure 59. The Upper Kootenay River channel in 1962 with an overlay of the channel in 1994 (Site 3 marked, approximately 1:15,000 scale at 49^0 31' N 115^0 33' W).

unregulated system not all meander lobes behaved exactly the same but there may be a general shifting of meander lobes downstream.

The Lower Kootenai River channel has been more restricted in movement by the highway and railway running along both sides for Sites 1 and 2. The Upper Kootenay had both the railway and highway for Sites 1 and 2 but these were more distant from the stream allowing more channel movement. The Lower Kootenai River with its limited room for movement still showed some active meandering with an island apparently being altered downstream of Site 1 between 1930 and 1963 (Figure 60).

Lower Kootenai River Site 2 was situated on the upstream portion of the eroding edge of a meander. From 1930 to 1963 this site experienced erosion and deposition on the inside edge of the adjacent meander lobe (Figure 61). The island of 1930 was eroded on the inside, enlarging the channel between the island and the mainland with deposition occurring on the outside of the island resulting in a shifting of the island further into the main channel (Figure 61).

The Lower Kootenai Site 3 shows some erosion on the outside edge of the meander (Site 3) and a small amount of deposition along the inside edge (Figure 62). The island upstream of Site 3 was decreased in size and a small mid-channel bar downstream of Site 3 was gone 30 years later.

Thus, prior to damming, the three study sites along the Lower Kootenai River experienced similar but more gradual meandering as was observed along the Upper Kootenay River. More activity apparently occurred with mid-channel bar and island formation and/or elimination compared to the Upper Kootenay

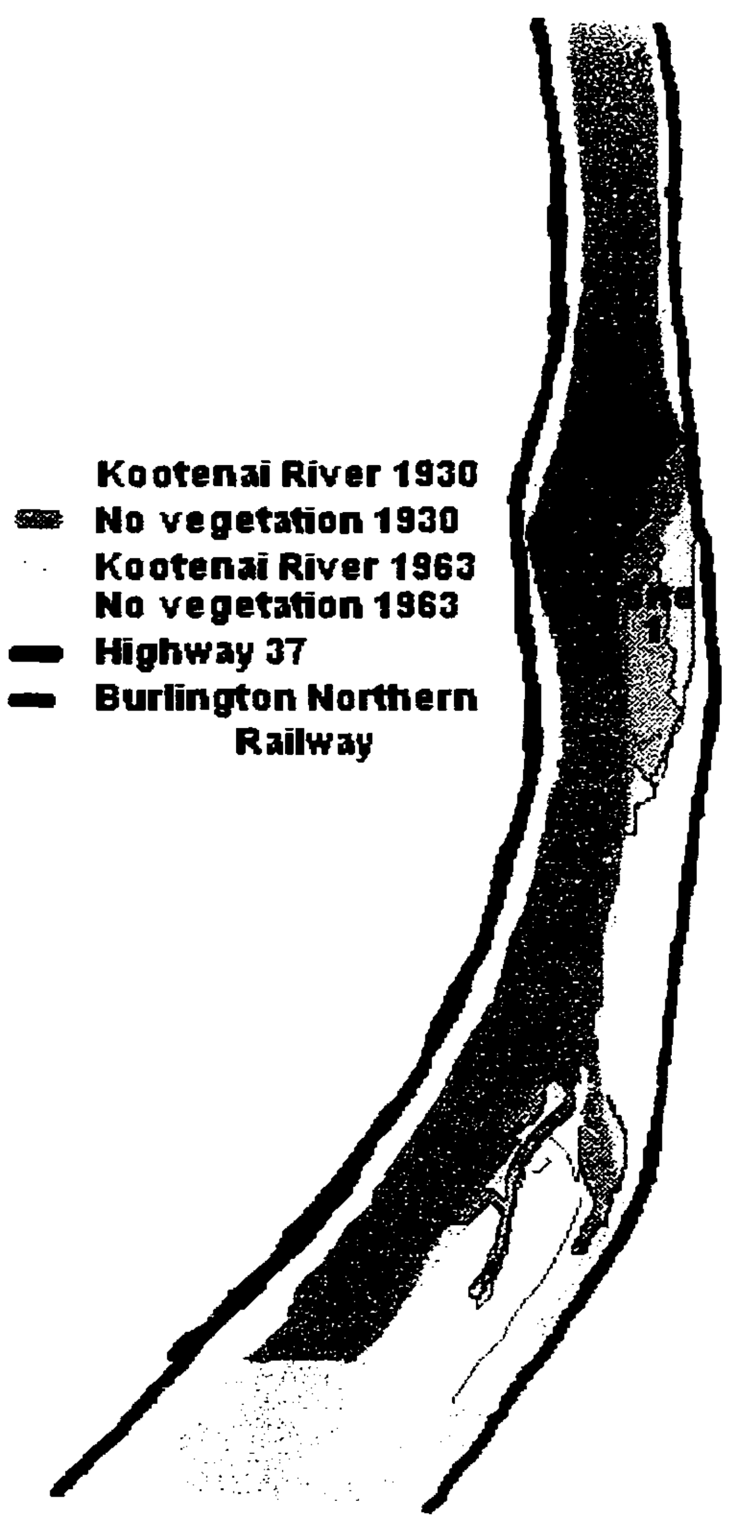


Figure 60. The Lower Kootenai River channel in 1930 with an overlay of the channel in 1963 (Site 1 at 48° 21 N 115° 22' W).

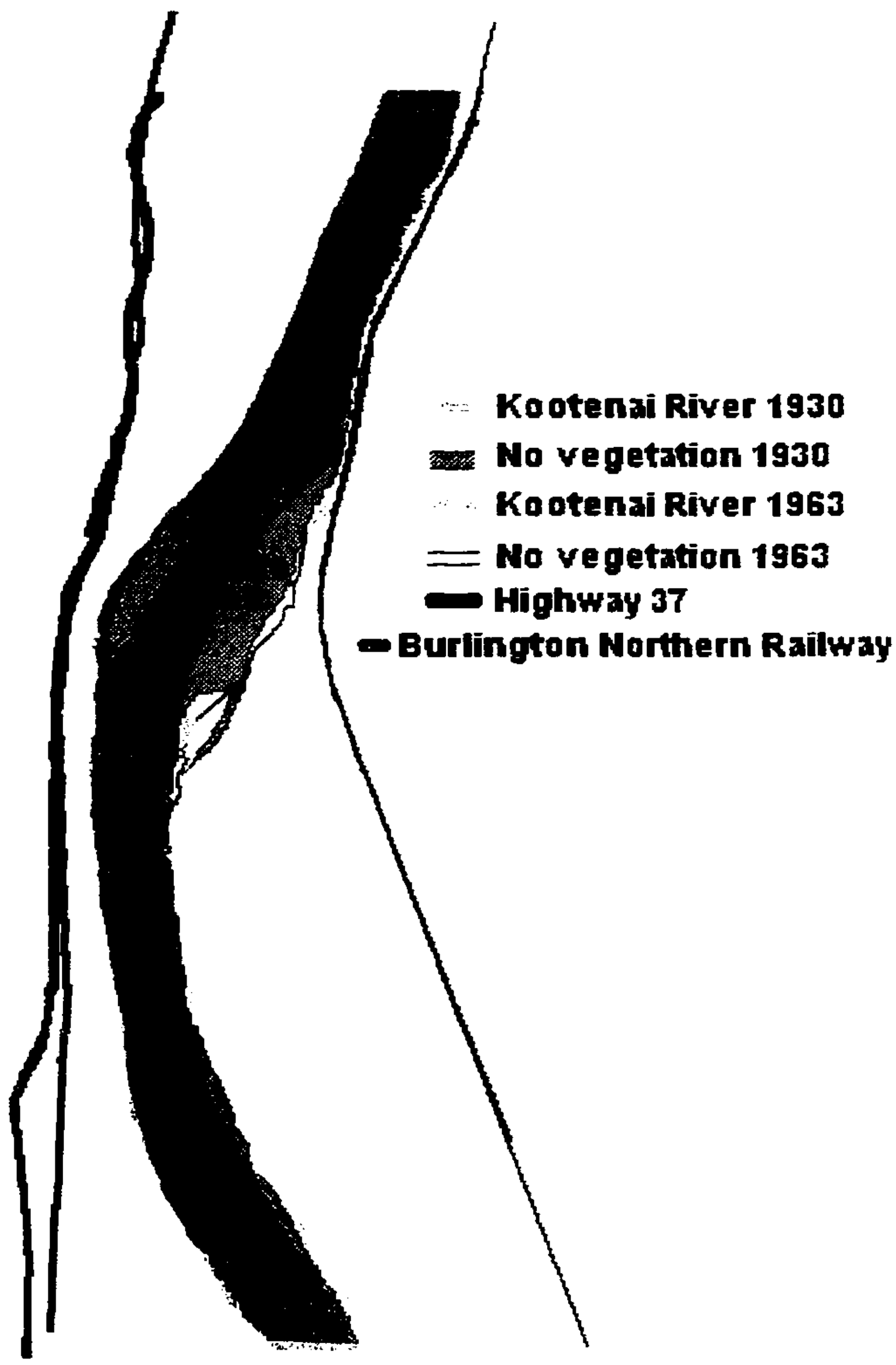


Figure 61. The Lower Kootenai River channel in 1930 with an overlay of the channel in 1963 (Site 2 at 48° 26' N 115° 31' W).

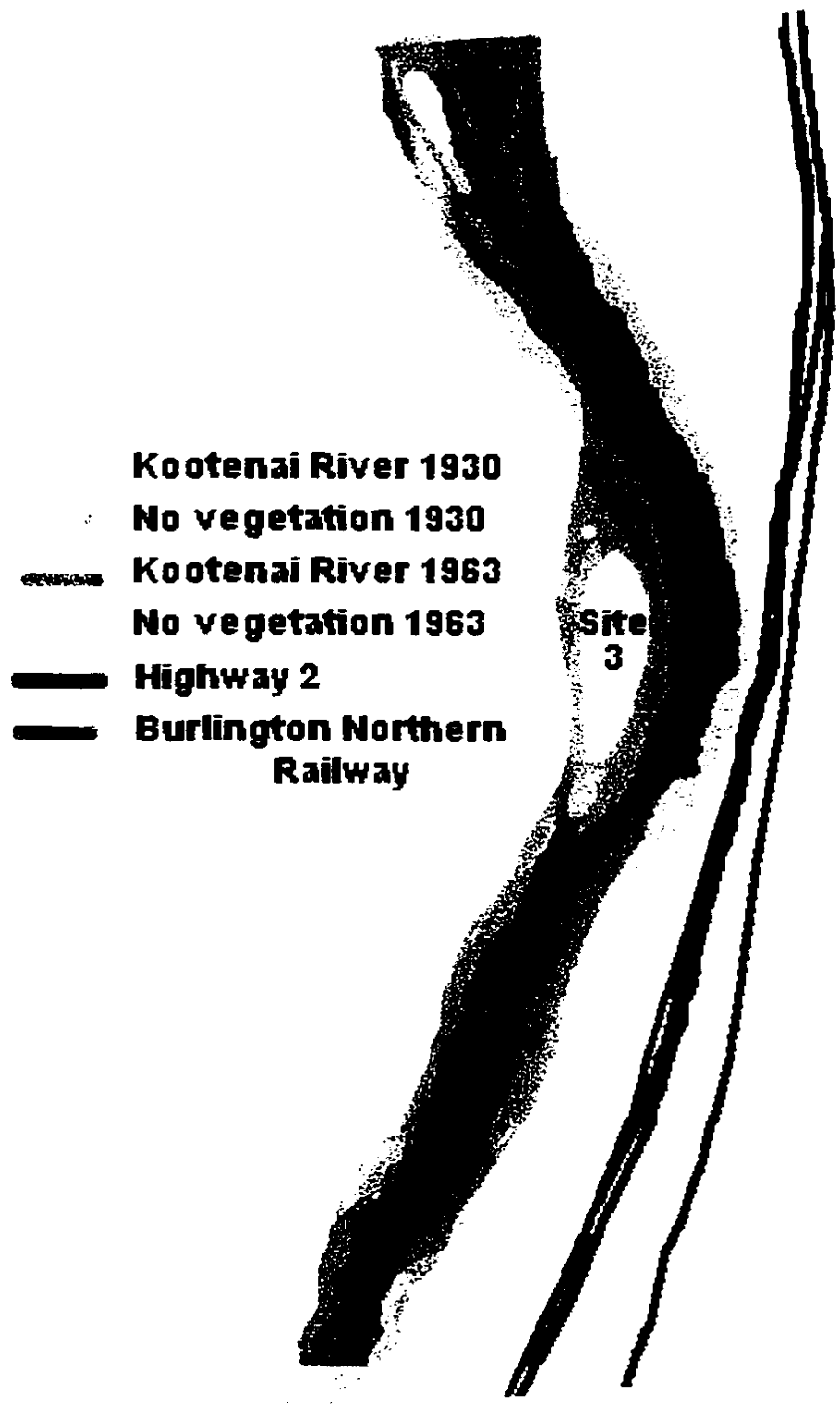


Figure 62. The Lower Kootenai River channel in 1930 with an overlay of the channel in 1963 (Site 3 at 48^0 26' N 115^0 50' W).

River which had few mid-channel bars.

The comparison of the 1963 air-photos to the 1992 air-photos of the same study sites for the Lower Kootenai River reveals a different pattern following the completion of the Libby Dam in 1972. The three study site areas show a narrowing of the river which involved mid-channel bars and islands becoming attached to meander lobes, and a lack of active meandering (Figures 63, 64, 65). There was a ten year period involved in these air-photo comparisons prior to regulation but changes that might have occurred during this interval had apparently been eliminated with the subsequent narrowing of the channel. The 1992 air-photos were taken on June 21 and 22, and July 17, for Sites 1, 2, and 3, respectively, with similar discharges of 115 m^3/s for the three dates. Even with this low discharge, only very small barren areas were exposed at the three study sites in June and July, 1992 during cottonwood seed release.

With the higher late spring flow releases from the Libby Dam for sturgeon spawning studies, these areas would have been submerged in years during the period of cottonwood seed release from 1993 through 1997. On field site visits, Sites 1 and 2 did have the barren areas similar to the 1992 air-photos but not until after August 11, 1997, well after seed release was complete. Similarly, Site 3 had barren exposed area in the 1992 air-photo view, but did not have barren areas even by September of 1997. During the field season of 1996 no barren areas were present at any of the Lower Kootenai River study sites.

Figure 63. The Lower Kootenai River channel in 1963 with an overlay of the channel in 1992 (Site 1 at 48° 21 N 115° 22' W).

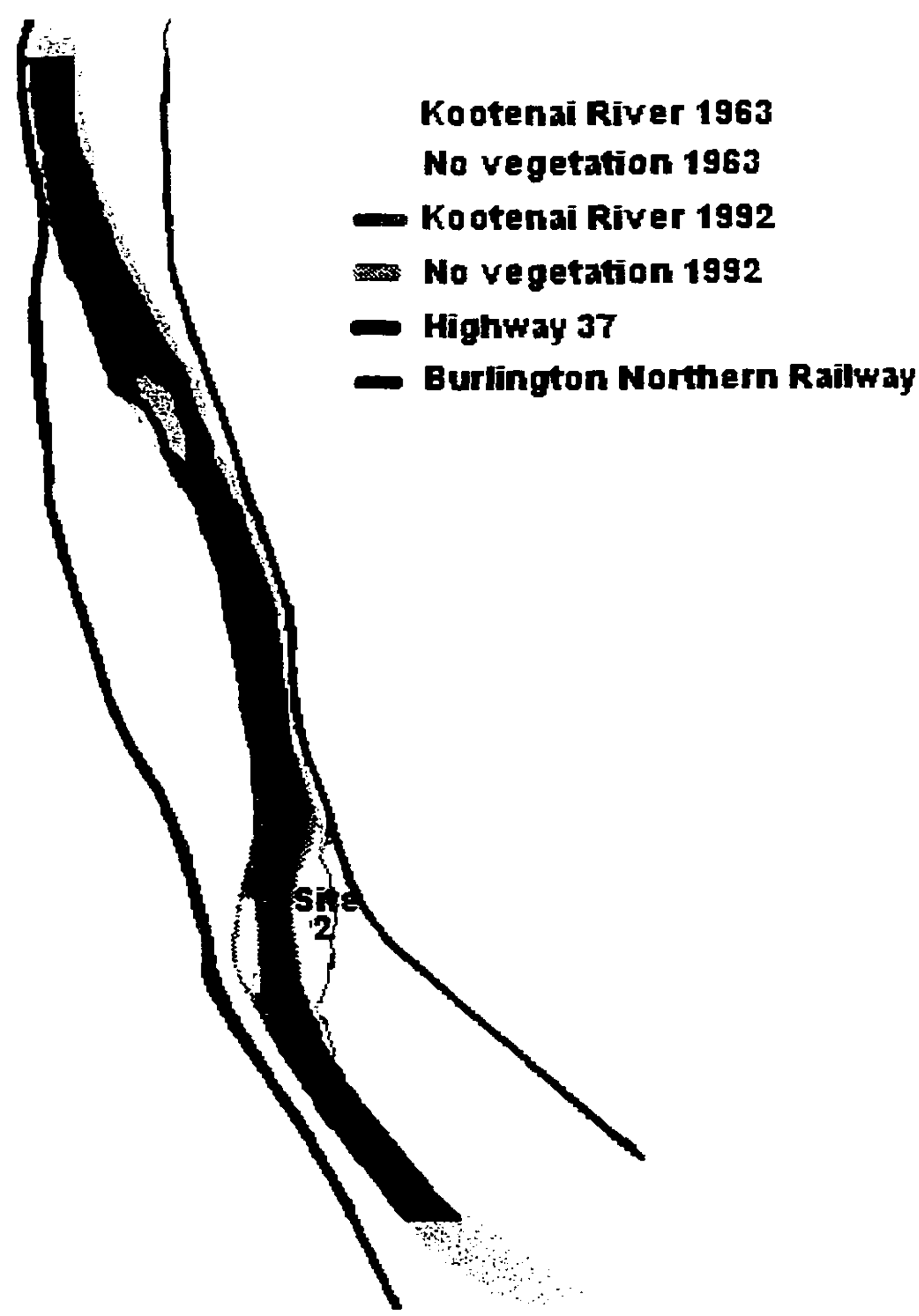


Figure 64. The Lower Kootenai River channel in 1963 with an overlay of the channel in 1992 (Site 2 at 48^0 26' N 115^0 31' W).

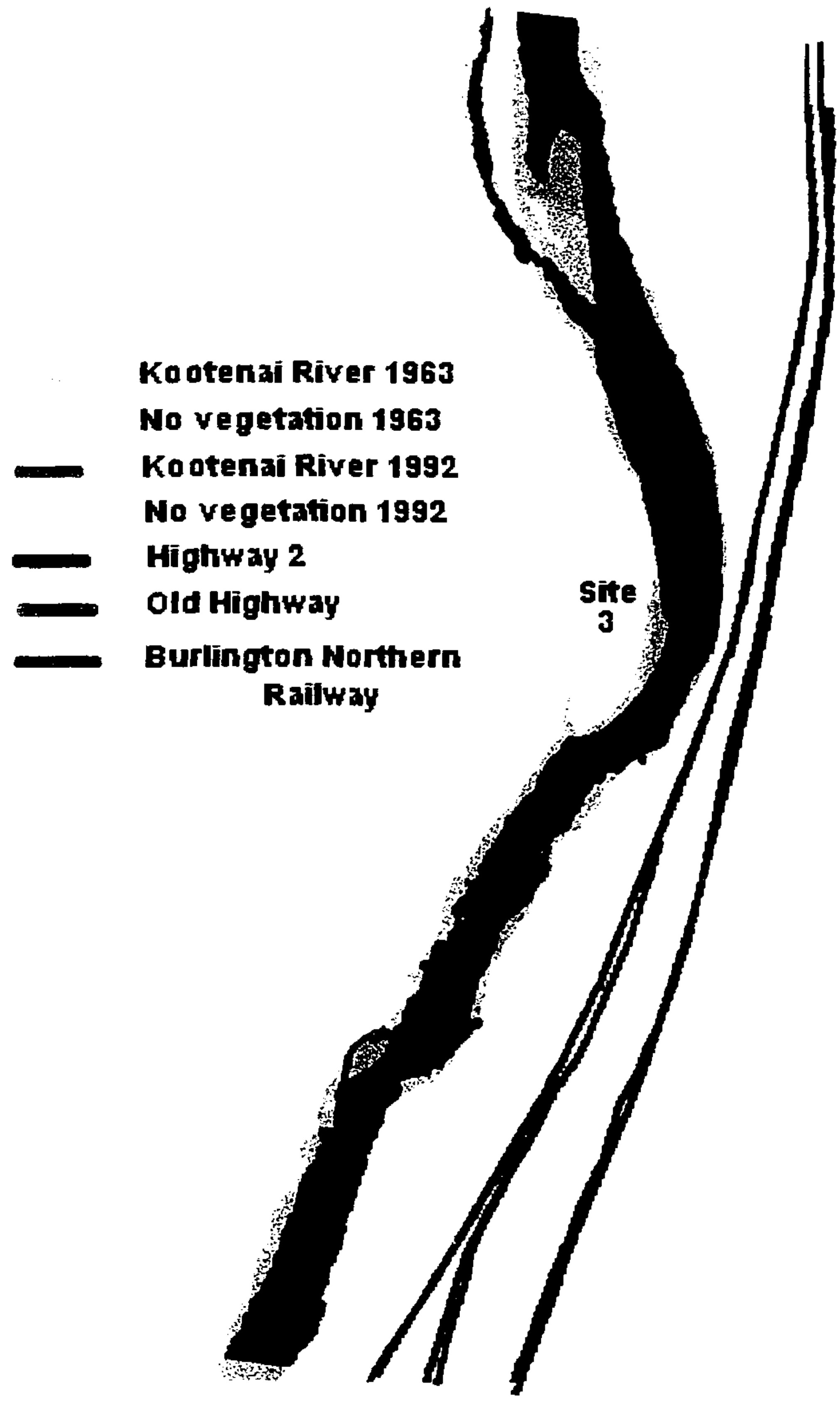


Figure 65. The Lower Kootenai River channel in 1963 with an overlay of the channel in 1992 (Site 3 at 48° 26' N 115° 50' W).

Substrate Comparison

The sites along the Lower Kootenai River possessed a striking difference in the surface substrate particle size relative to the free flowing Upper Kootenay reach. The Upper Kootenay River had fine substrate (sand and silt) bares with no exposed cobble or rocky sites along the entire study reach. The Lower Kootenai had only cobble sites with no fine substrate bars observed from the Libby Dam to Troy Montana (Figure 66).

Historical surveys in 1893 by D. P. Mumbrue report sandy beaches at the three Lower Kootenai River sites chosen for the present study. However, Mumbrue also noted that some areas with cobble and rocky beaches were also present along the reach a century ago. Mumbrue and later surveyors reported placing flags and markers on sandy beaches, with more sandy beaches than cobble or rock being reported along the reach. Judy Lundstrom of Libby, Montana, (Personal communication, March, 1997) grew up along the Kootenai River in the Libby area and from 1955 to 1960 used to go swimming in the river from a large sandy beach upstream of Libby. She also reported other sandy beaches in the area and reported that prior to damming, sandy beaches were abundant. Walt Zimmerman of Libby, MT., (Personal communications, March 1997) fished the Kootenai River since the 1920's and he also confirmed the abundance of sandy beaches prior to the Dam's completion but he also noted that there were some rocky beaches as well. His memory of the few rocky beaches corresponded to the same rocky beach areas reported by the earlier surveyors.

(b)

Figure 66. Site 1 along the Upper Kootenay River (49° 28' N 115° 30' W) (a) had a deep sandy substrate point bar compared to (b) Site 3 along the Lower Kootenai River (48° 26' N 115° 50' W) which had coarse cobble substrate.

Since all reservoirs act as sediment traps, the clear waters released have a high potential to scour and transport sediment. With low flows released during spring and summer months, the flow would only be competent to remove small particles, including sand and silt and thus would leave cobble covered sites downstream of the Libby Dam. The clear waters released from the Dam have a high competence to scour small particle size substrate and transport this material in the suspended load, resulting in the progressive loss of fine substrate from the low lying areas of meander lobes along the Lower Kootenai reach. This suspended load is apparently transported downstream past Troy. The present study did not investigate at what distance the silt shadow, the zone of suspended sediment depletion, ended, but it did reveal a deficiency of finer substrate downstream to Site 3 near Troy Montana.

Sediment and Woody Debris Trapped by the Reservoir

The Koocanusa reservoir acts as a sediment trap which has been well documented, but it also traps woody debris washed downstream from its tributaries and the main river upstream. Black cottonwoods reproduce asexually through branch fragments which makes up much of the spring debris (personal observations). The reservoir stops the flow of this material from entering the Lower Kootenai, blocking one form of propagation which was a source of genetic diversity for the lower river system. The branch fragments and logs also act as sediment traps when they are deposited with receding flow stage. Large logs and trees are deposited first resulting in localized flow barriers which slow the water velocities down and result in sedimentation occurring behind the new obstructions. Minor tributaries of the Lower Kootenai River and the Fisher River add relatively little debris to the Lower Kootenai River and no trees, logs or branches were left after spring flows on the study sites along the Lower Kootenai River in 1996 or 1997.

One of the major sources of debris for the Kootenay River is the Elk River. The high gradient and narrow Elk Valley results in many trees being undercut and toppled into the river each spring. The Elk River enters Lake Koocanusa which traps this debris, eliminating it from the Lower Kootenai River. After spring high-water, the floating woody debris on Koocanusa is collected to rid the reservoir of hazards to boaters and stored in piles to be burned in the late fall when the reservoir recedes.

The proportion of cottonwoods that are successfully recruited through branch fragments is unknown and this topic deserves further study to investigate its contribution to population recruitment and the extent of the impact of eliminating this reproduction mechanism by artificial reservoirs. The loss of the woody debris which act as sediment traps may also compound the loss of fine substrate along the Lower Kootenai since the toppled trees would have formerly provided current breaks, and created localized sites of deposition.

Depletion of Erosion and Deposition

The loss of sediment deposition has been a major geomorphological change noted on dammed systems with attenuated spring floods. The Lower Kootenai River has apparently lost virtually all net sediment deposition with almost no change occurring in cross-sectional elevations along the eight study transect lines. One sample transect line from each site is presented in Figure 67 with similar lack of change on the other five transect lines (found in appendix 1). Most of the small change that occurred in the cross-sectional elevations was due to staff gauge repositioning errors.

In contrast to the static bank cross-section along the flow-attenuated Lower Kootenai reach, the free-flowing Upper Kootenay demonstrated substantial bank change. One sample transect line from each of the Upper Kootenay sites is presented in Figure 68, and these reveal considerable deposition and some scouring. Similar dynamic patterns occurred along all of the nine transect lines of the upstream reach (the other six can be located in the appendix 1).

The amount of change that occurred along the Upper Kootenay River through scour and deposition were compared to the amount occurring along the Lower Kootenai River. There was a significant difference between the two reaches with a F-Value 51.392 and P-Value <.0001 (appendix 2-263). When transects were analyzed for the Upper Kootenay no significant difference was found F-Value .319, P-Value .7277 which suggests that transects were similar (appendix 2-265). Transects were similar along the Lower Kootenai as well with F-Value .920, P-Value .4029 (appendix 2-265). Transects were therefor excluded from the analysis. The reach, site comparison shown no significant difference but there were some difference between sites with an F-Value 2.666 and P-Value .0720 (appendix 2-263).

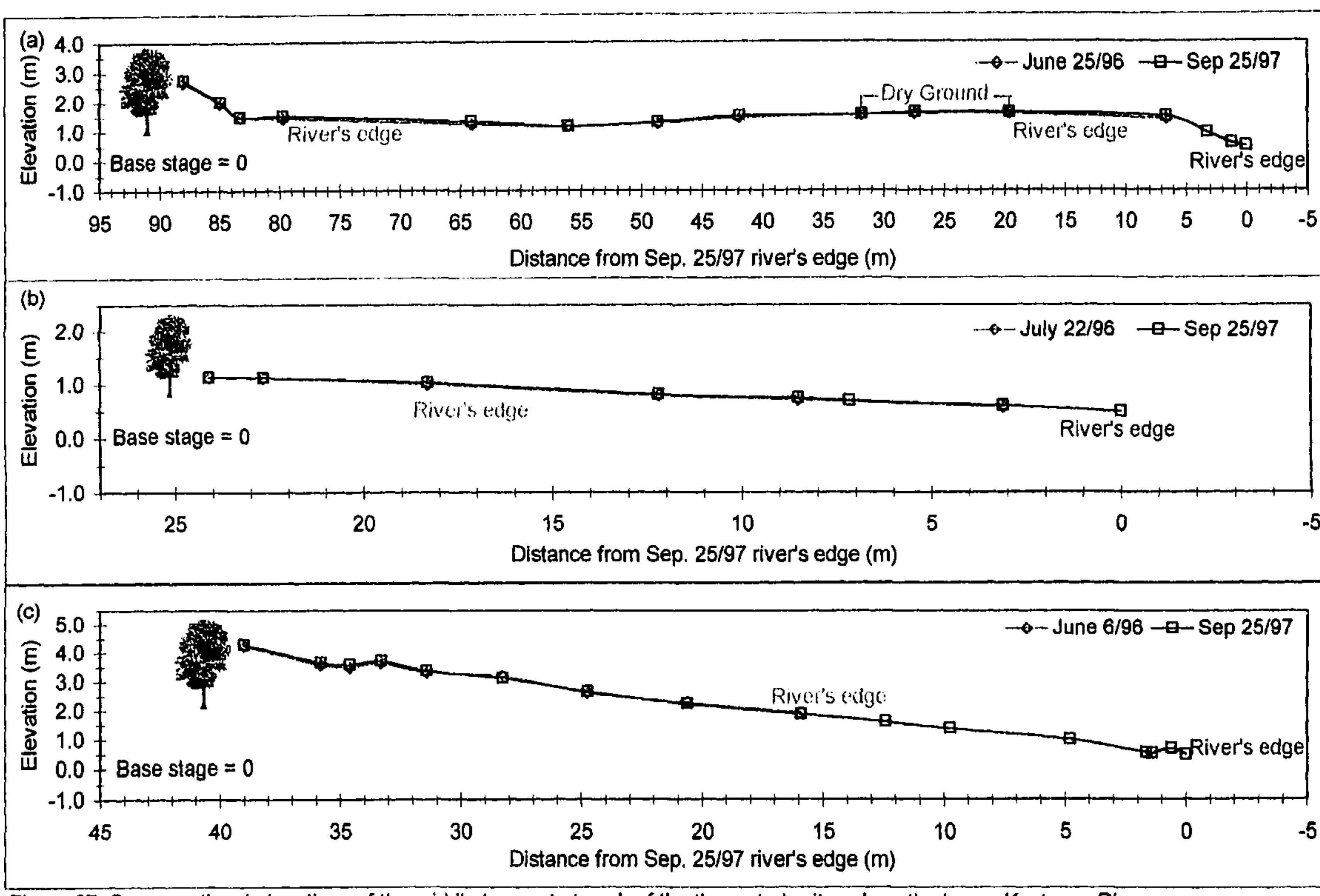


Figure 67. Cross-sectional elevations of the middle transect at each of the three study sites along the Lower Kootenay River, (a) Site 1 transect 0642 (b) Site 2 transect 0650 (c) Site 3 transect 0638.

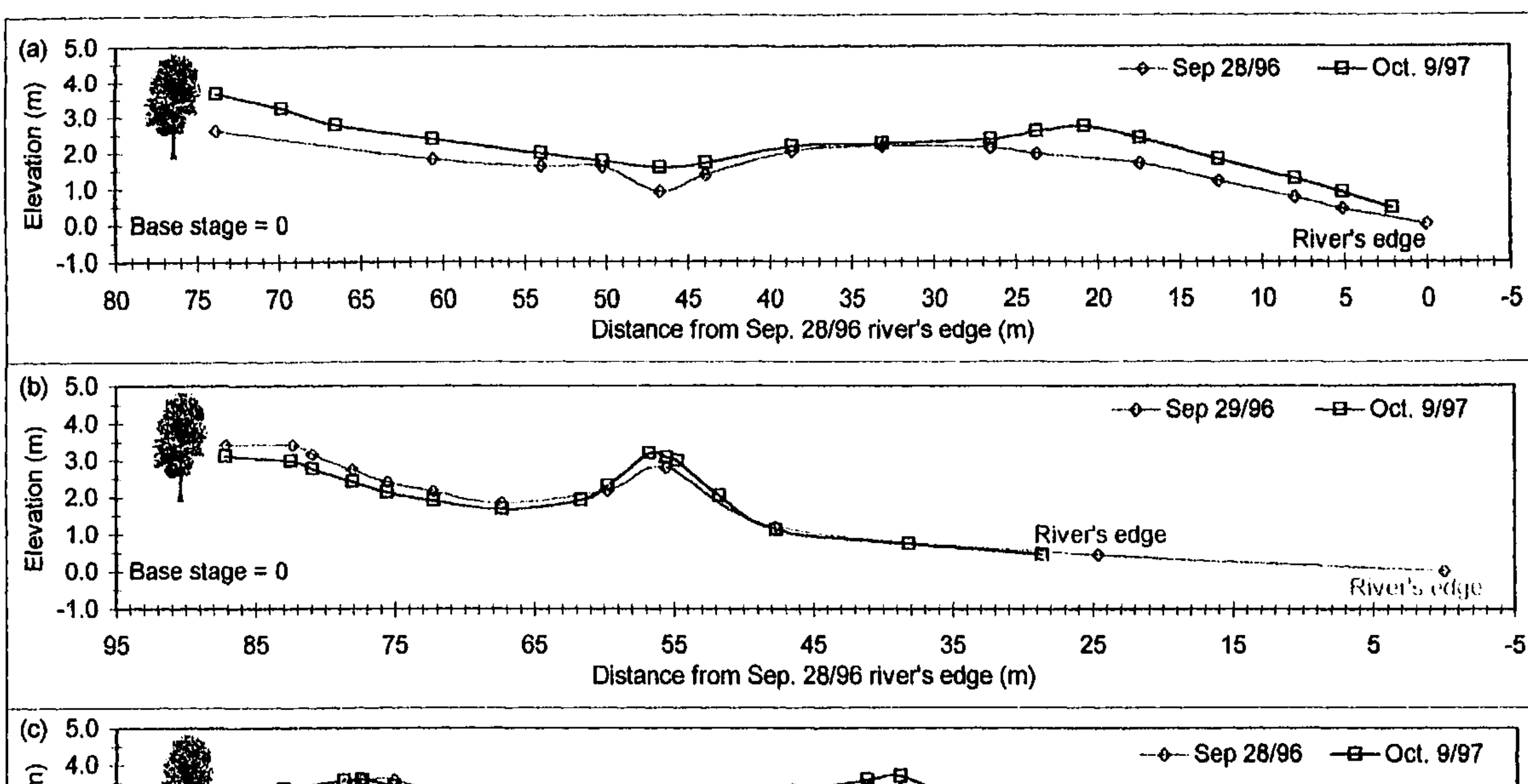


Figure 68. Cross-sectional elevations of the middle transect at each of the three study sites along the Upper Kootenay River, (a) Site 1 transect 0622 (b) Site 2 transect 0625 (c) Site 3 transect 0628.

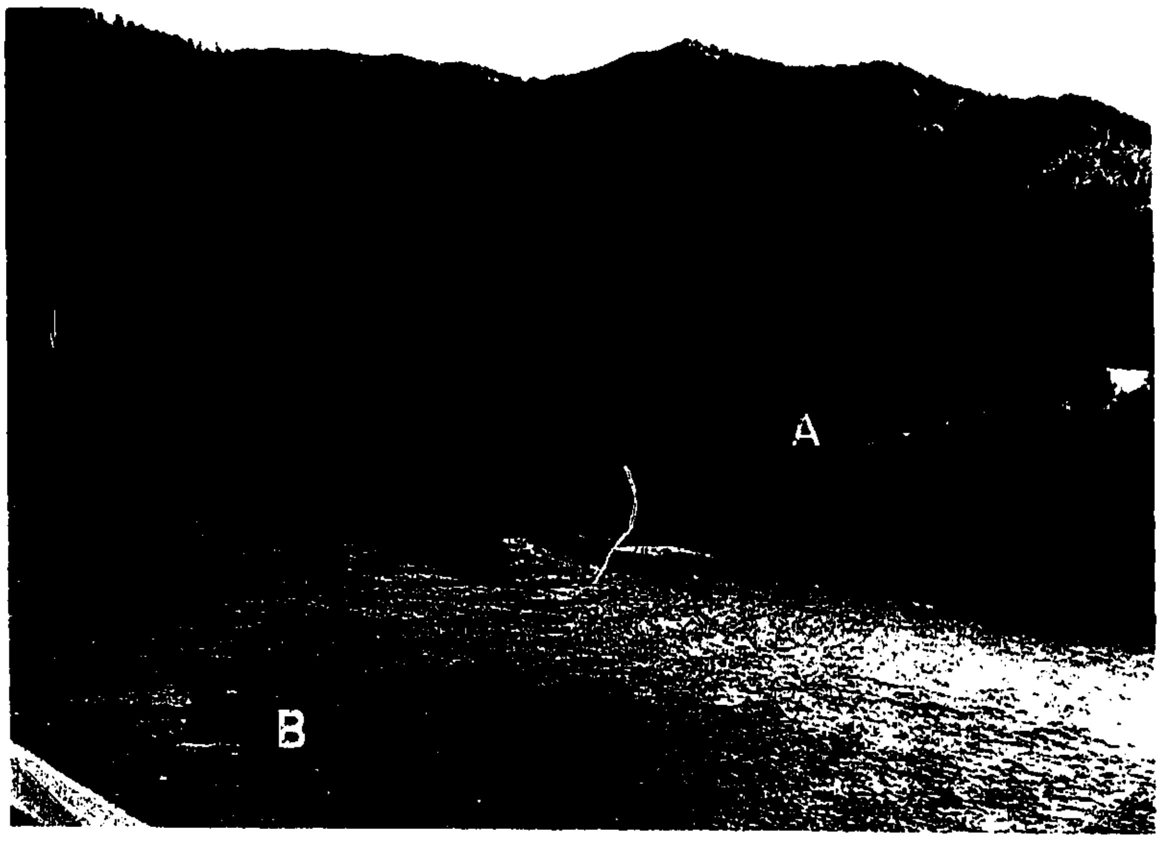


Figure 69. The Fisher River (A) entering the Lower Kootenai River (B). Some of the sediment in the suspended load is deposited at the meander lobe at the river's junction point, direction of flow indicated by arrows.

In some systems a sediment equilibrium is established downstream of an impoundment by the added sediment from tributaries. The Lower Kootenai River has a number of tributaries along the study reach, but these were unable to add a sufficient amount of sediment to restore the downstream sediment equilibrium. The Fisher River is one such tributary but the suspended load entering the Lower Kootenai River was deposited at the entrance as seen in Figure 69.

Cottonwood seedling recruitment along the Upper Kootenay River

Cottonwood seedling replenishment is dependent on a dynamic hydrological system (Bradley and Smith 1984, Rood and Mahoney 1990, Rood and Mahoney 1995, Braatne et al. 1996, Scott et al. 1996). Dynamic flow patterns with flood events provide the physical disturbances that produce barren and moist recruitment sites for cottonwood seedlings (Bradley and Smith 1986, Rood and Mahoney1990, Rood and Mahoney 1994, Scott et al. 1996). River damming that attenuates spring flooding has contributed to the decline of cottonwood forests along various streams in Alberta and southwestern United States as seedling recruitment has been particularly impacted (Johnson et al. 1976, Bradley and Smith 1989, Rood and Heinze-Milne 1989, Johnson 1992). These studies have shown that flow stabilization reduces cottonwood recruitment on hydrologically losing, semi-arid systems.

The Lower Kootenai River no longer has a naturally dynamic hydrologic and geomorphic system. As shown in Figure 67, virtually no deposition or scour has occurred on the typical seedling recruitment sites during the two years of the present study. This loss of disturbance and lack of periodic inundation has led to the encroachment of flood intolerant vegetation along the Lower Kootenai River, contrasting sharply with the vegetation free zones along the Upper Kootenay River (Figure 70).

It was the vegetation free zones along the unregulated Upper Kootenay River that had cottonwood seedlings established in 1996 and 1997. Site 1 seedlings were established between 0.94 and 1.7 m in elevation above the base stage in 1996, and between 1.8 and 2.7 m in 1997 (Figure 71). The zone of recruitment elevation and distance from the tagged tree overlapped between the two years with the 1996 seedlings growing closer to the river's edge.

No seedlings from 1996 survived the high water of 1997. The 1996 seedlings were investigated in May, 1997, and had survived through the winter and appeared to be in very good shape with no sign of ice scour. However, after the high water of 1997, no 1996 seedlings survived the scour and deposition that occurred during and after the spring peak flow of 1997.

The transect line 0623 had the elevation of the zone from 82 to 91 m (distance) apparently remaining the same but no 1996 seedlings survived to 1997 in this area after the spring peak discharge. However, during high water, the stream bank may have been scoured and after the water velocity slowed with the decreasing discharge, re-deposition may have occurred. The substrate at Site 1 is sandy silt less than 600 μm in size which was not a sufficient anchor to withstand the scouring that occurred. Thus, 1996 seedlings could have been scoured away with the initial scour of sediment.

(a)

(b)

Figure 70. Contrasting river-side zones of (a) Site 1 along the Upper Kootenay River illustrating barren recruitment areas and (b) Site 1 along the Lower Kootenai River illustrating vegetation encroachment to the river's edge.

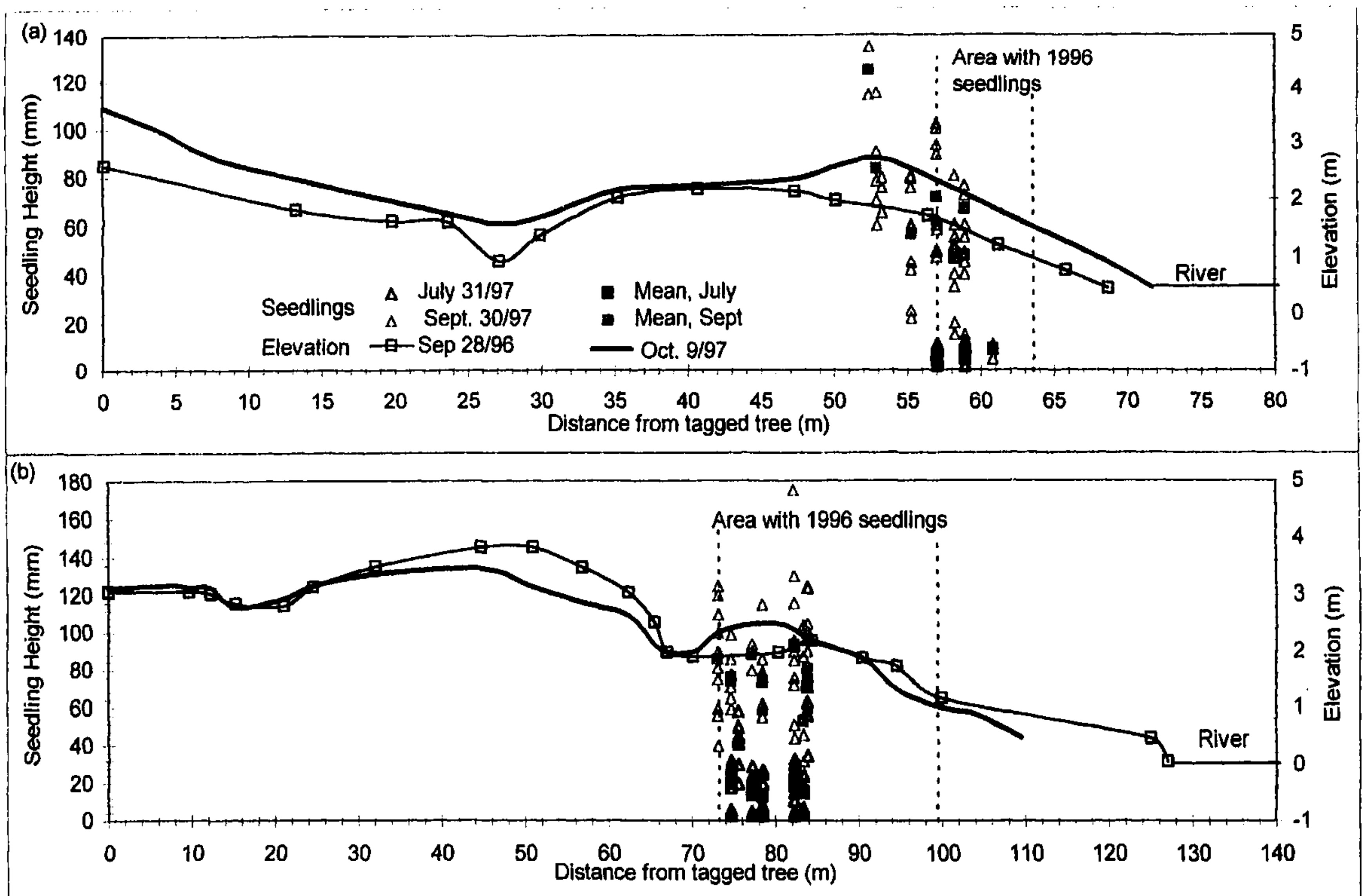


Figure 71. The Upper Kootenay Site 1, transects 0622 (a) and 0623 (b) at (49° 28' N 115° 30' W), illustrating 1997 seedling heights and locations, and 1996, 1997 cross-sectional elevations of these transect lines zeroed to base stage.

For Site 1 along the Upper Kootenay River, the average height of 1996 seedlings was 2.4 mm on August 16, 1996, and the seedlings ranged from 0.5 to 10 mm tall. By September 28, 1996, seedling heights averaged 24.8 mm and ranged from 1 mm to 102 mm. The average height of seedlings on July 31, 1997, was 11 mm and ranged from 2 to 30 mm. By September 30, 1997, the mean height was 70.5 mm and ranged from 5 to 175 mm (Figure 71).

In their first year, 1997 seedlings were significantly taller (70.5 mm) than the first year 1996 seedlings (25.8 mm) (Anova F-Value 26.767, P-Value < .0001, appendix 2-267). The peak flow of June 9, 1996 was 1310 m^3/s, which was a 1-in-5 year flow event, while the peak flow of June 6,1997 was 952 m^3/s, which was under a 1-in-2 year flow event. Flows remained high in June and July of 1996, during the time of seed release, resulting in most of the suitable recruitment zones being submerged. It was not until July 22, 1996 that the stage of the Upper Kootenay dropped to the stage on June 22, 1997, when recruitment zones were exposed (Figure 72). Thus, the seedlings were established a month earlier in 1997, resulting in an extra month of growth and larger seedling size of the first year seedlings in 1997.

The later seedling establishment in 1996 also affected seedling densities. Mid-July is near the end of the heavy seed release period. The overall initial seedling densities for the three Upper Kootenay Sites were significantly higher in 1997 (F-Value 57.823, P-Value < .0001, appendix 2-268). The fall seedling densities (survival through the summer) was also significantly higher in 1997 (F-Value 23.656, P-Value < .0001, appendix 2-269). This resulted in low seedling

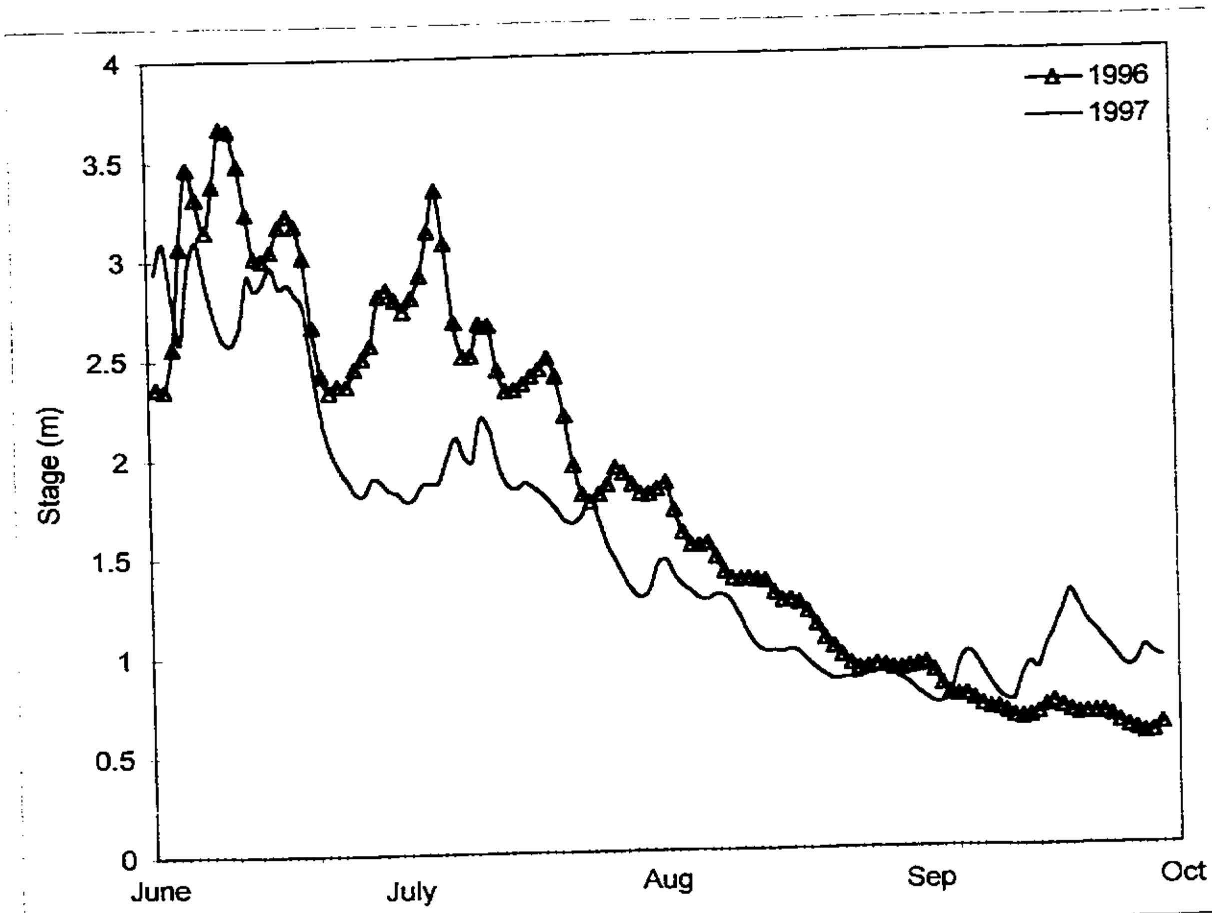


Figure 72. The daily stage from June through September, along the Upper Kootenay River at the Fort Steele gauging station (#08NG065), 1996 and 1997.

densities in 1996 as seen in Figure 73 compared to the seedling densities at Site 1 in 1997.

Seedling survival rates of the first autumn were also higher for 1997 seedlings at Site 1, however there was no significant difference between 1996 and 1997 survival rates when looking at the total sites (F-Value .022, P-Value .8834, appendix 2-270). At Site 1, there was 77% survival from the initial establishment in 1997 compared to 51% survival for 1996 seedlings (Figure 73). The 1996 seedlings were established at lower elevations than the 1997 seedlings and the weather for 1997 growing season was drier than the 1996 growing season (Figure 74). However, seedlings did not show signs of drought stress in 1997. Both a drier season and higher elevation of establishment should have made the 1997 seedlings more susceptible to drought stress but survival was still higher in 1997.

The earlier date cottonwood seedling establishment in 1997 allowed a longer growing period than for the 1996 seedlings. There was a significant difference in heights between 1996 and 1997 seedlings (F-Value 26.767, P-Value < .0001, appendix 2-265). Much of the initial growth of the first year is directed to root development and the longer 1997 growth season probably enabled greater root production. Cottonwood seedlings were excavated at Site 1 and root and shoot lengths measured on Aug 27, 1997. The majority of the first year seedlings had longer roots than shoots Figure 75 a. Regression analysis reveals a very slight positive correlation of shoot height to root length and thus, taller seedlings tended to have slightly longer roots (Figure 75 b).

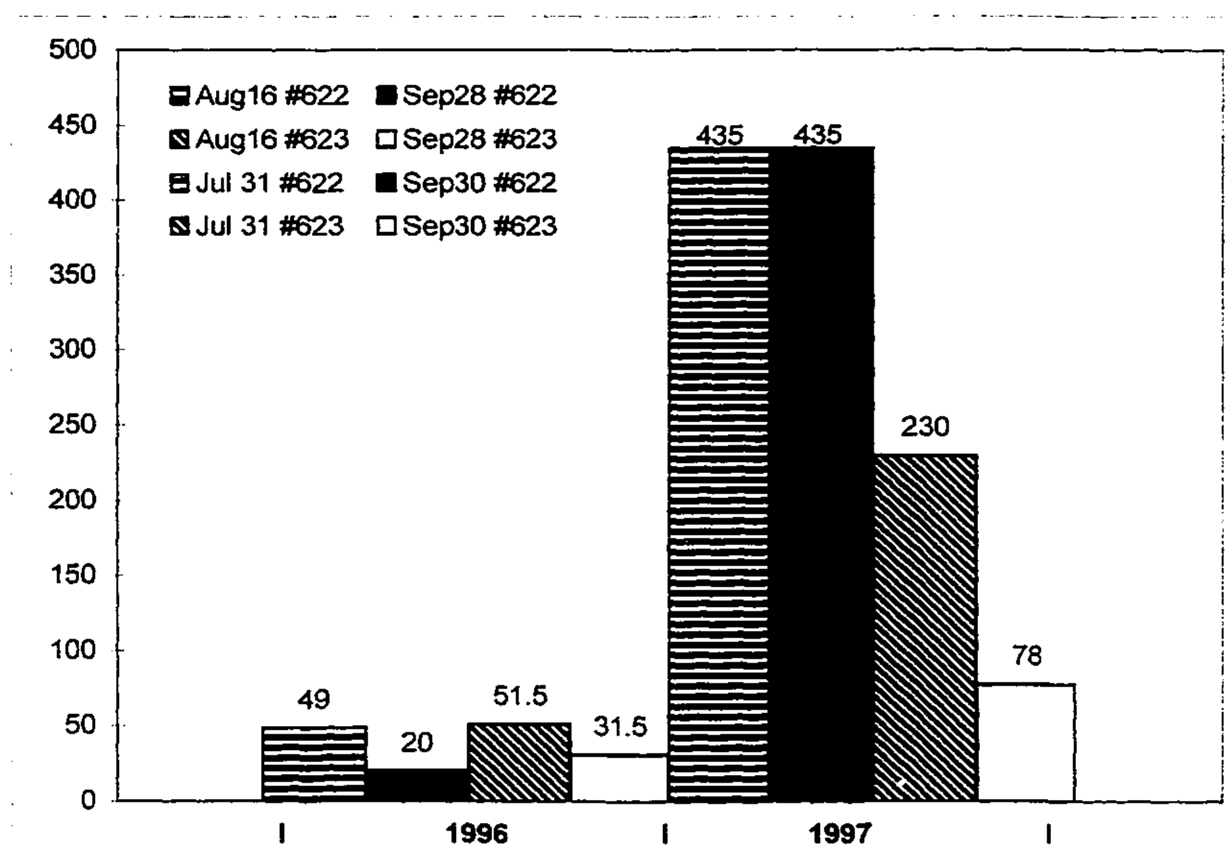


Figure 73. Cottonwood seedling densities at Site 1 at 49^0 28' N 115^0 30' W, transect 0622 and 0623 along the Upper Kootenay River.

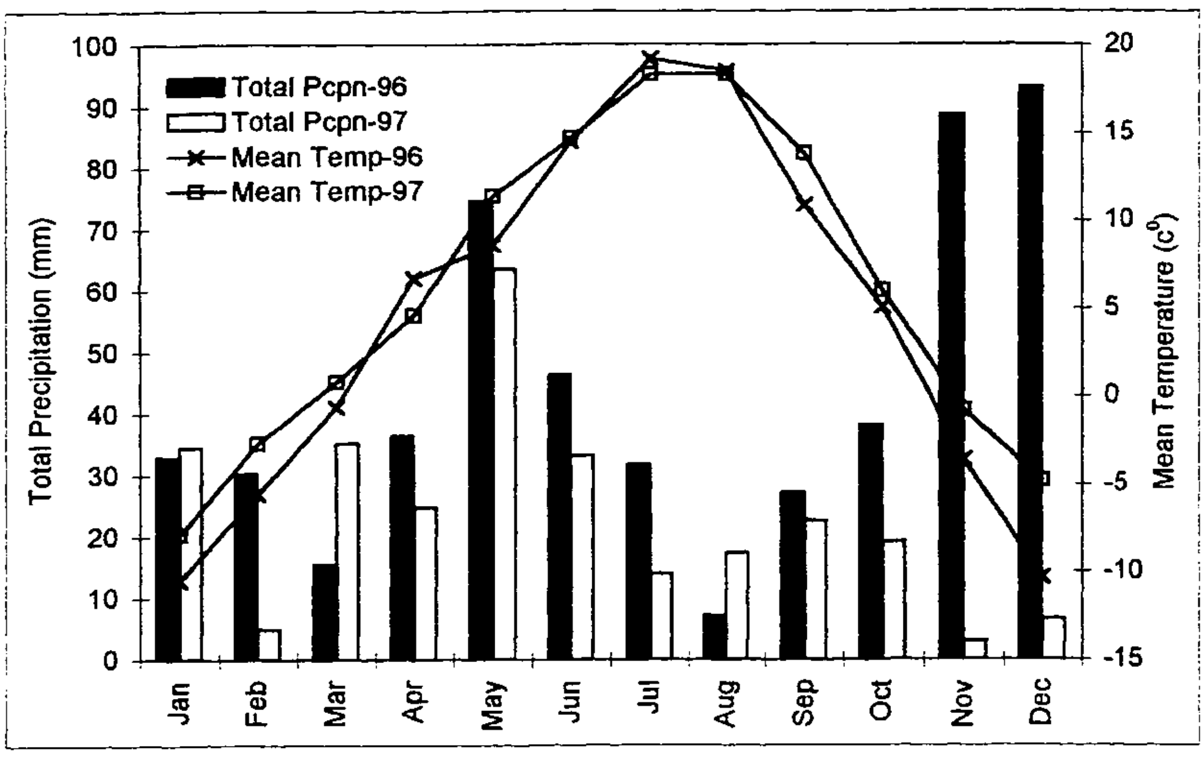
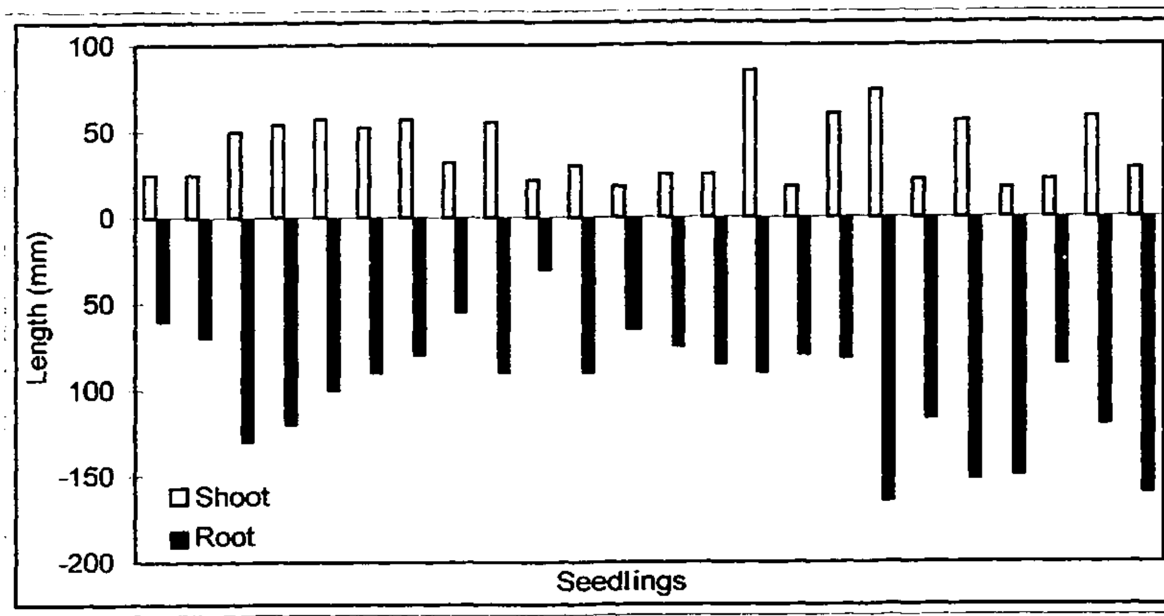


Figure 74. Total monthly precipitation and mean temperature for Cranbrook B.C., near the Upper Kootenay River for 1996 and 1997.

(a)



(b)

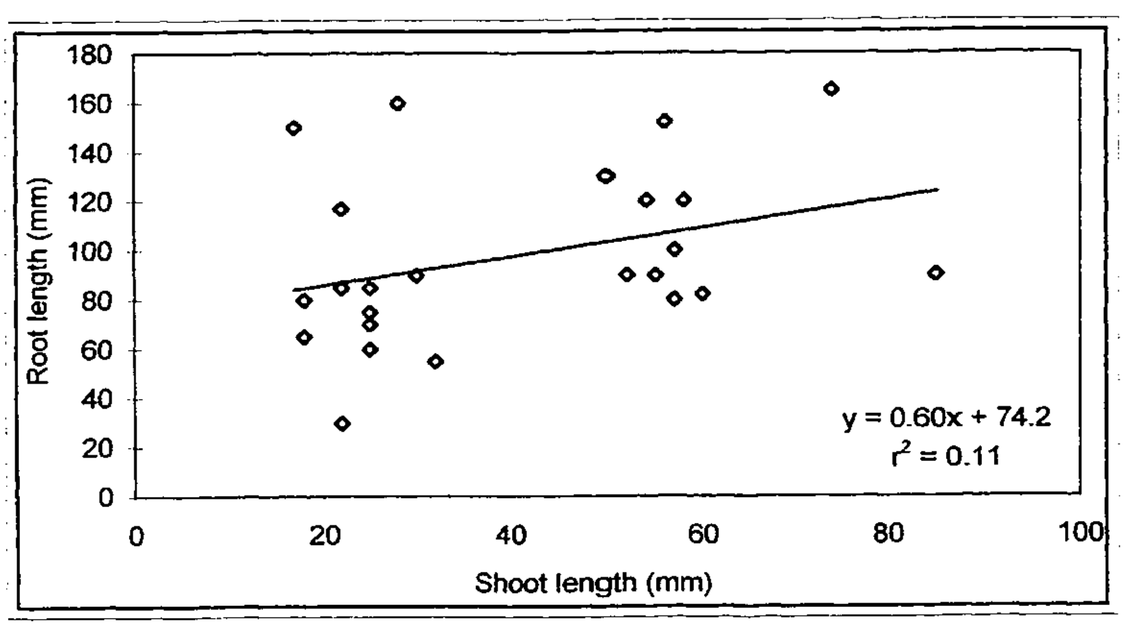


Figure 75. Cottonwood seedlings of the first year, shoot heights and root lengths of Upper Kootenay River Site 1 at 49^0 28' N 115^0 30' W, August, 1997.
(a) Individual seedling shoot heights and root lengths and (b) regression analysis.

The additional growing month in 1997 was accompanied by a period of stabilized flows with a stage between 1.9 m above the base stream stage on June 23 and 1.8 m on July 23 (Figure 72). During the equivalent period of 1996, the recruitment zone was still inundated so the newly established 1996 seedlings did not have a month of stable intermediate flows. It is expected that this would have lead to shorter root systems compared to the 1997 seedlings. This may have contributed to the observed lower first year survival rate in 1996.

In 1997, the apparent seedling survival rate at Upper Kootenay River Site 1 transect line 0622 was 100% while that at line 0623 was only 34% (Figure 73). However, some of the apparent loss of seedlings along 0623 was because the cottonwood seedlings were mixed with willow seedlings. Initially, young black cottonwood seedlings were indistinguishable from willow seedlings. By September, the willow seedlings were easily distinguished from cottonwoods. Consequently, many of the seedlings counted in July were actually willow seedlings which were not counted in September. Transect 0622 did not have the population of willow mixed with cottonwood seedlings and consequently these data were not distorted by this influence.

The results from Site 2 along the Upper Kootenay River mimicked those of Site 1 with shorter seedlings (6.8 mm on August 15 and 35.1 mm on September 28) for 1996 than in 1997 (14.9 mm on July 15 and 67.2 mm on September 30). The seedling establishment elevation was 1.6 to 2.7 m in 1996 and 1.9 to 3.1 m in 1997. The 1996 seedlings occurred at relatively the same distances from the tagged trees as the 1997 seedlings but the elevation of this area had increased by an average of 0.4 m due to sediment deposition (Figure 76). The seedling density was lower in 1996 (208/m^2 on August 16 and 52/m^2 on September 28) than in 1997 (643/m^2 July 29 and 265/m^2 on September 30) resulting in a 27% survival rate for the 1996 seedlings compared with 46% survival for the 1997 seedlings.

The lower survival rate in 1997 of Site 2 (46%) compared to the (77%) for Site 1 was mainly attributed to seedlings along transect 0624 which were established between 7 to 23 m from the tagged tree (Figure 76a). This area had a 50% cover of grass and other vegetation which shaded the cottonwood seedlings resulting in complete mortality by September of 1997. The seedlings in this area had thin elongated steams resulting from the shading experienced. This area was quite moist so the mortality was contributed to the shading not to drought. This same area did not have any seedlings in 1996 so it did not contribute to a lower average density for 1996 seedlings. All of Site 2 had more willow than Site 1, complicating survival densities by artificially lowering these due to initial counts of willows plus cottonwoods.

Site 3 along the Upper Kootenay River had different results from Site 1 and 2 because cattle were introduced annually at the beginning of September. This impact was not anticipated when the site was chosen. Site 3 was part of the fall pasture and the cattle's access to the river for water was through cottonwood seedling recruitment zones.

The cattle reduced fall seedling densities and decreased survival levels to 13.8% in 1996 and 13.7% in 1997. However, because the initial seedling

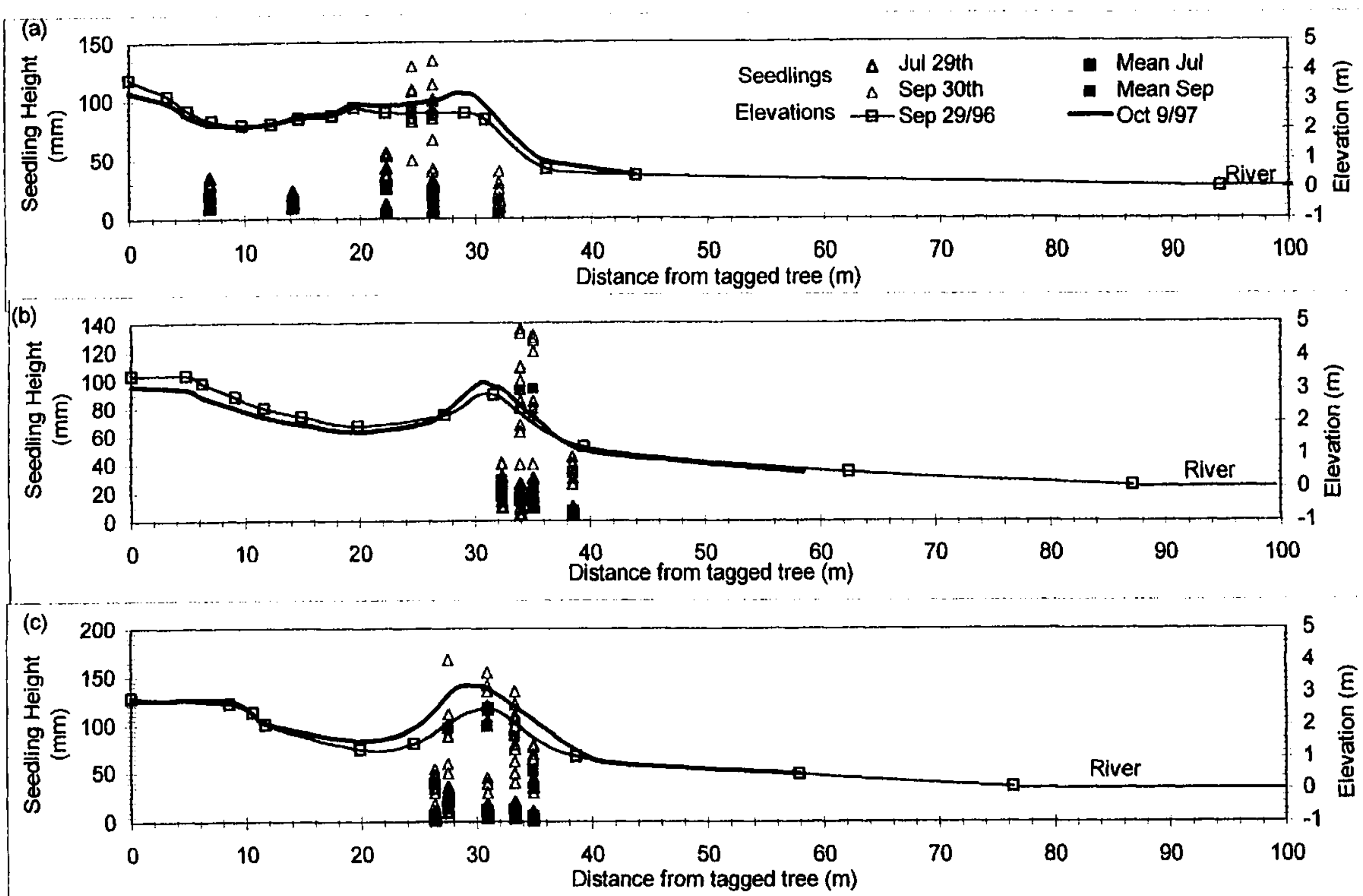


Figure 76. Cottonwood seedling heights and positions and 1996 and 1997 transect cross-sectional elevations above the basse stage for the Upper Kootenay Site 2, transects 0624 (a), 0625 (b) and 0626 (c) are at 49° 28' N 115° 30' W.

densities were higher in 1997 (632/m^2) than in 1996 (36/m^2) there were more seedlings surviving to October, 1997 than in 1996 even though the percentage survival was similar. Most of the mortality was due to trampling by the cattle. Since the substrate is sand and silt of less than 600 μm particle size, it did not provide a secure anchor and the seedlings were uprooted when animals walked on or near the seedlings.

Also, unlike the other sites, seedling heights at Site 3 did not have an increase in size in 1997 relative to the 1996 seedlings. Many of the seedlings that were not uprooted were browsed and this resulted in fall mean heights that were similar for the two years (43.1 mm for 1996, and 43.5 mm for 1997). The fall 1997 seedlings were taller, with heights of 5 to 135 mm, than the 1996 seedlings which ranged from 12 to 61 mm (Figure 77).

At Site 3 the elevations of seedling establishment increased in 1997 as was found for Site 1 and 2, the average increase was 0.31m with a range of 0.1 to 0.4m (Figure 77). There were some seedlings recorded in 1997 as 1996 seedlings, but these contained buried growth scars. All of the initially assumed 1996 seedlings excavated in 1997 were actually older, with two to four years of growth buried.

Transects were compared along the Upper Kootenay River with the data for the quadrates with willow seedlings removed. This resulted in no significant difference occurring between transects (F-Value 1.731, P-Value .1853 appendix 2-271), which indicates that transects were similar. When a site comparison was done, no significant difference was found (F-Value 5.375, P-Value .0070,

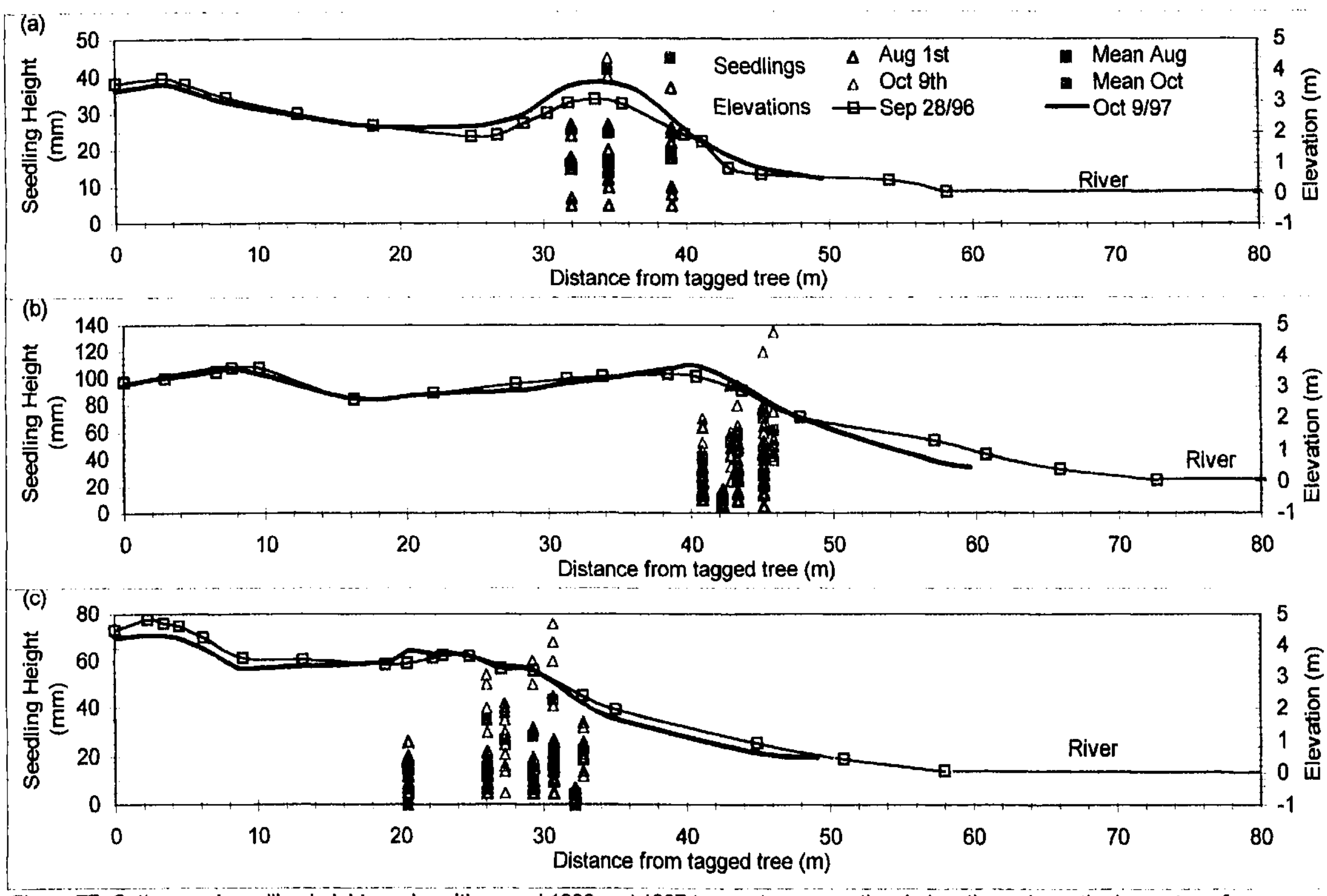


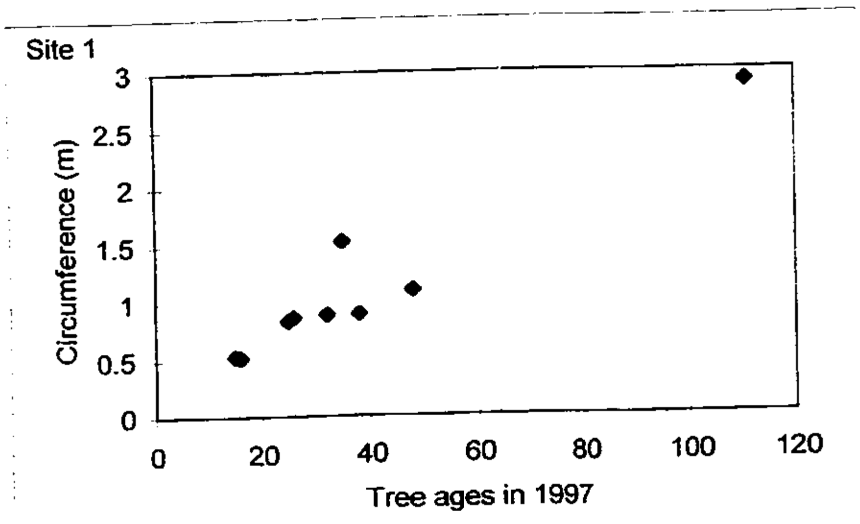
Figure 77. Cottonwood seedling heights and positions and 1996 and 1997 transect cross-sectional elevations above the base stage for the Upper Kootenay Site 3, transects 0627 (a), 0628 (b) and 0629 (c) are at 49^0 31' N 115^0 33' W.

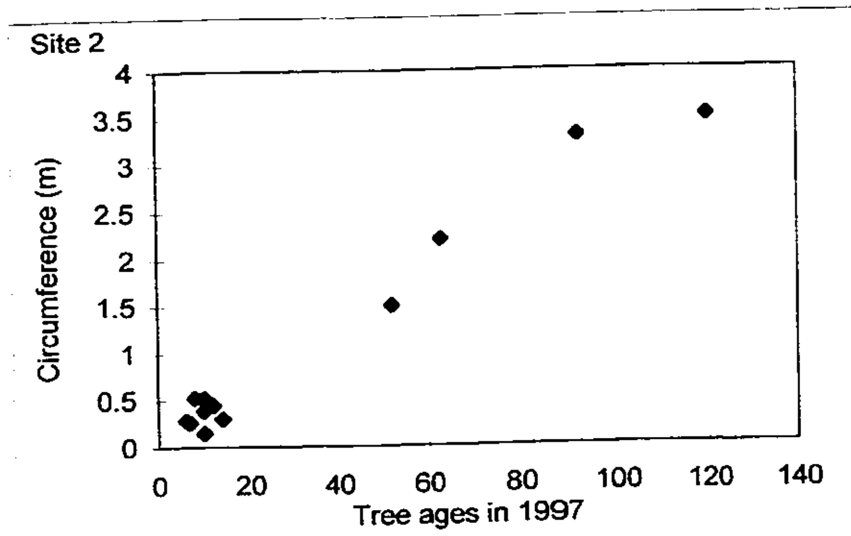
appendix 2-273), but it was very close to being significantly different. When a Fisher's PLSD analysis was done there was a significant difference found between Site 1 and 3 (P-Value .0173) and with Site 2 and 3 (P-Value .0028), and no significant differences found between Sites 1 and 2 (P-Value .6333, appendix 2-274). This suggests that the cows at Site 3 did impact black cottonwood seedlings.

Cottonwoods along the Lower Kootenai River

Mature cottonwood trees at the three sites along the Lower Kootenai River were increment cored to obtain ages. These trees were restricted to narrow bands (6.5 to 26 m wide) along the back of the meander lobes at Site 1 and 2 and in the center of Site 3, and the mature trees had largely all been established before the Libby Dam was completed.

Site 1 had nine mature cottonwoods with two trees, 15 and 16 years old, growing near a 48 year old tree (Figure 78). These young trees were probably were root suckers since the band of vegetation would have been too dense to permit seedling recruitment. The band of vegetation where the mature cottonwood trees were found consisted of water birch *Betula occidentalis* Hook., alder *Alnus crispa* ssp. *sinuata* (Regel.) Hulten, red-osier dogwood *Cornus stolonifera* Michx., Douglas maple *Acer glabrum* Torr. and white clematis *Clematis ligusticifolia* Nutt.. This was the same composition as found along the Upper Kootenay River. However, along the Upper Kootenay River, there were much wider bands of mature trees with more red-osier dogwood, and more





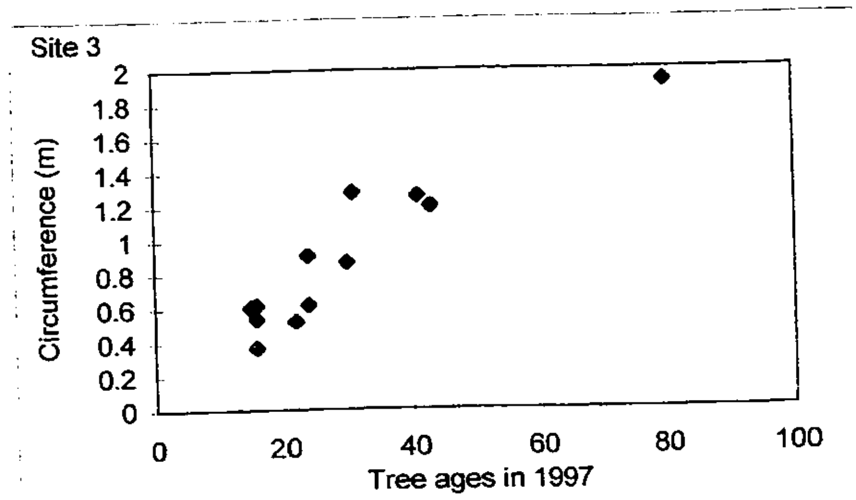


Figure 78. Circumferences of trees as a function of tree ages on 3 sites along the Lower Kootenai River.

abundant willows, including Mackenzie's willow, *Salix prolixa* Anderson, Sandbar willow, S. *exigua* Nuttall, Pacific willow *S. lucida* ssp. *lasiandra* (Betham) E. Murray and willow hybrids. Dense bands of juvenile willows and juvenile cottonwoods occurred along the river side of the groves of mature trees at the Upper Kootenay sites, and there were no equivalent bands along the Lower Kootenai River.

The Lower Kootenai sites had mature cottonwood trees and abundant seed release occurred in both years of the study (Figure 79). However, the Lower Kootenai Sites did not have the full range of age (size) classes of cottonwoods found in healthy riparian populations. The Lower Kootenai had a narrow band of mature trees with the band often being only a single tree wide with or without shrubs and low vegetation and especially grass to the river's edge. No bands of juvenile cottonwoods occurred between the mature trees and the recruitment zone and no cottonwood or willow seedling were observed along the stream edge (Figure 80).

In contrast, the Upper Kootenay River had mature trees furthest away from the river, with ages from 40 to 100+ years for the trees sampled; juveniles in front of the mature trees with ages decreasing from 30 to 5 years of age, and seedlings along the non-vegetated zones near the river's edge (Figure 80).

Historical survey notes by D.P. Mumbrue (1893) noted cottonwood trees with 45 to 100 cm (18 to 40 inch) diameters on meander lobes and that most of the banks along the Kootenai River had cottonwood groves mixed with cedar and alder. Mumbrue also always noted dense underbrush of willow, cedar and

Figure 79. A mature female black cottonwood tree near Site 1 (48^0 21' N 115^0 22' W) at the start of seed release along the Lower Kootenai River.

(a)

M – Mature black cottonwoods J – Juvenile cottonwoods S – Seedling recruitment sites

(b)

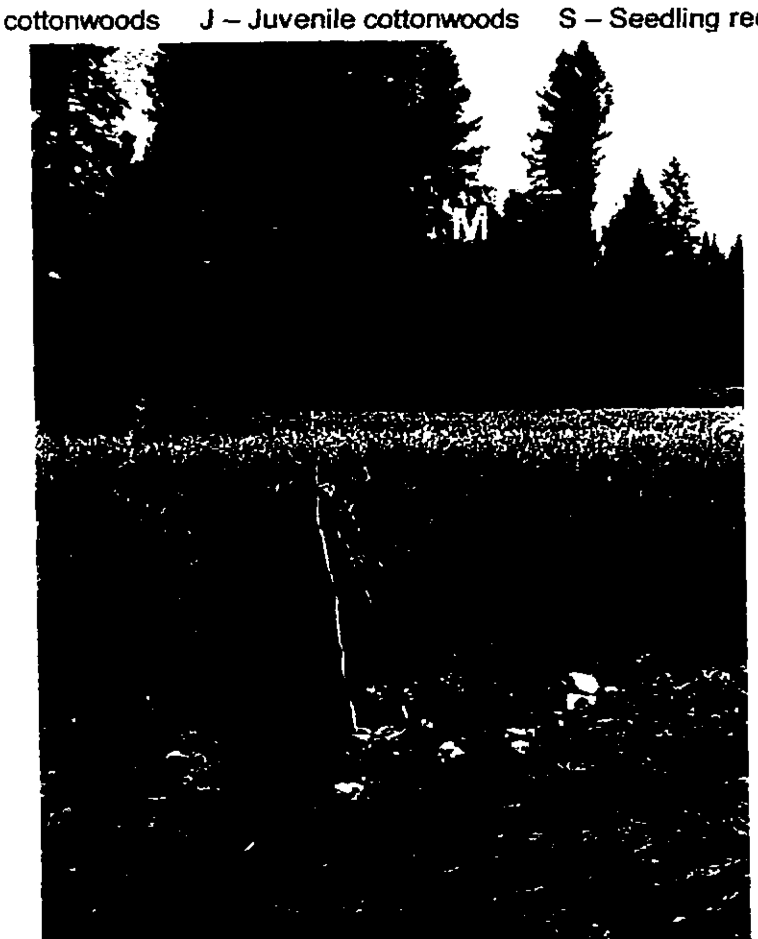


Figure 80. The population structure of black cottonwoods (a) along the free-flowing Upper Kootenay River, Site 1 and (b) the lack of a population structure of black cottonwoods along the flow-attenuated Lower Kootenai River, Site 3.

cottonwood saplings. These species assemblages are no longer found in the narrow bands of understory vegetation and the majority of the meander lobes had sparse understory during the present study. Bickel surveyed the area in 1898, and mentions cottonwoods by the river along the Lower Kootenai with dense underbrush of willow and cottonwood saplings. This historical vegetation association on the Lower Kootenai meander lobes, before the Libby Dam was completed, closely resembles that found in this study on Upper Kootenay meander lobes.

There were a few cottonwood juveniles of root sucker origin at the three study sites along the Lower Kootenai River. Site 1 had very few such clones with saplings ranging in age from 1 to 6 years with heights from 0.36 m (1 year) to 2.4 m (4 years). Many of the clones were browsed and all of the clones were in bands within about one metre from the drip line of a mature cottonwood tree. The clonal saplings were surrounded by dense grasses and no older juveniles were found at Site 1.

Site 2 along the Lower Kootenai River had a more extensive population of root suckers on the downstream end of the meander lobe. While it was not determined conclusively that all the older juveniles were of root clone origin, ten young juveniles were excavated and all were linked to lateral roots. Known clones ranged from 1 to 9 years of age with heights from 0.4 to 3.4 m. Clonal stem densities averaged 5.7 stems/m^2 with a range from 4 to 8 stems/m^2. The larger juveniles were also probably clones since these had large leaves and large shoots for their age. Those with large stems were cored, and circumference and age included in Figure 78.

Site 3 along the Lower Kootenai also had an extensive population of juvenile root suckers at the upstream end of the meander lobe. One of the three transect lines (0640) was established at this location. The other transect, 0639 included root sucker clones but these occurred just outside of the drip line of mature trees and clonal stems were 1 to 3 years of age. Transect 0638 had no juvenile clones.

The average densities of stems on and near transect 0640 was 3.3/m^2 with a range of 1.5 to 5.5/m^2. Ten smaller juveniles were excavated and all were found to be root suckers (Figure 81). Clonal saplings varied in height from 0.37 to 1.6 m. The larger juveniles were probably also of clonal origin as evidenced by their large leaves and the large stem size for the age. One 3 m tall tree 6 years old, which exhibited signs of clonal origin, was excavated and found to be a root sucker. Those trees with large stems were cored and are represented in Figure 78. The trees under 20 years of age probably all originated from root-suckers and the rest of the trees at Site 3 were established before the Libby Dam was completed, some of these probably originated from seedlings.

The Upper Kootenay River sites also had root suckers and these were often found along narrow bands about a metre from the drip line of the mature trees. The larger juveniles were not excavated but showed typical clonal growth form, with large leaves and large annual stem growth increments. The tightly grouped, older juveniles at the sites were also very probably clones. Some of

(a)

(b)

Figure 81. An excavated black cottonwood root sucker from Site 3, along the Lower Kootenai River (a) sapling before excavation (b) after excavation.

the younger juveniles (5 to 7 years) near the open beaches were excavated and were found to be mainly of seedling origin with one four year old root sucker originating from a slightly older tree that was in turn, of seedling origin. The excavated saplings had 1 to 3 years of stem growth buried. The Upper Kootenay juveniles not only had a different patterns of establishment, increasing in age as the distance from the river increased, and origins being mainly seedlings, but they were also growing with coyote willow (*Salix exigua*), Mackenzie's willow (*S. prolixa*) and Pacific willow (*S. lucida* ssp. *lasiandra*) and willow hybrids. Juvenile cottonwood populations at the Lower Kootenai Sites 2 and 3 were found at the low elevation end of the meander lobes with little willow and including instead, small fir, pine and larch trees.

Seedling recruitment along the Lower Kootenai River was never observed in the two years of the present study. No juvenile trees of seedling origin were identified and this further indicates that seedling have not been successfully recruited since the completion of the Libby Dam.

Vegetation Encroachment and Cottonwood Seedling Recruitment

The vegetation encroachment that has occurred along the Lower Kootenai River (Figure 82) provides one reason for the lack of cottonwood seedling recruitment. Successful seedling recruitment along the Upper Kootenay River occurred from 0 to 40 m from the river's edge in areas with vegetation cover of less than 20% and was most extensive in areas with no vegetation cover.

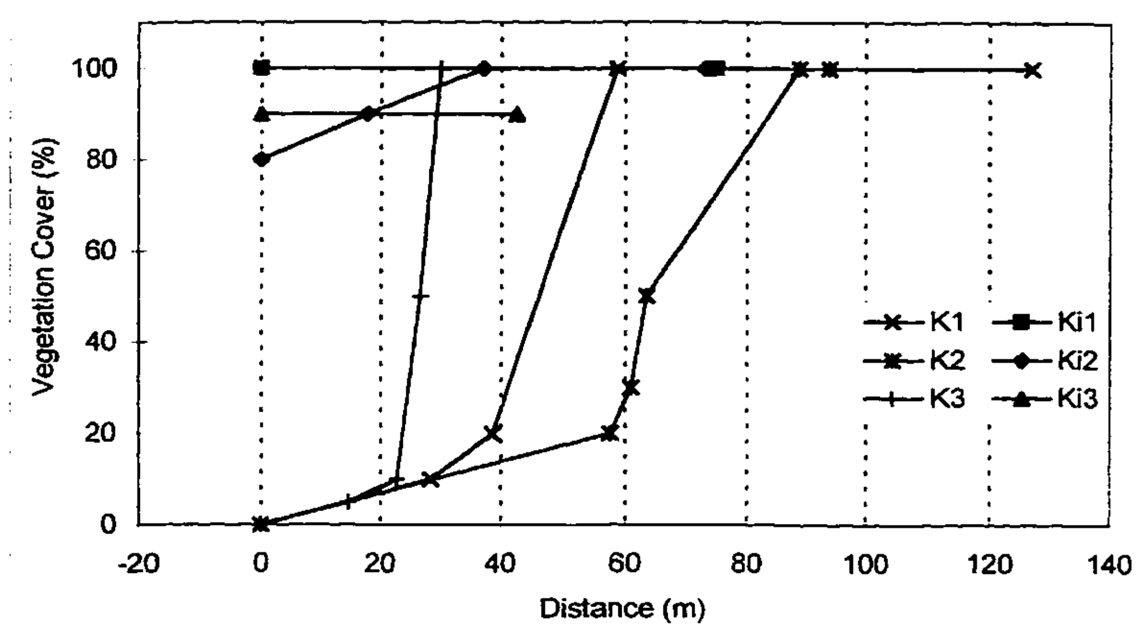


Figure 82. Vegetation cover (%) versus distance from the river along transects on three meander lobes upstream (K1, K2, K3) and downstream (Ki1, Ki2, Ki3) from the Libby Dam along the Kootenay River in 1996. The 0 distance is the position of the river's edge.

There was one transect line at Site 1 along the Upper Kootenay River which also had no seedling recruitment even though there was 17 m of open bar with 0 to 5% vegetation occurring. The non-vegetated zone was inundated during seed release in July, 1996 and 1997, resulting in the river's edge meeting the 100% vegetation cover zone. By the time the recruitment zone was exposed, seed release had ceased, resulting in no seedling establishment in this zone in either year of the study. This supports the pattern that vegetation cover to the river's edge will exclude seedling recruitment.

Cottonwoods Along the Fisher River

The Fisher River joins the Lower Kootenai River at the 'Big Bend', downstream of the Libby Dam at the former town site of Jennings. The Fisher River was studied as an adjacent control reach for the Lower Kootenai River study. The Fisher River is a higher gradient system than the Kootenay River, resulting in intense flash floods that do not occur on the Kootenay River. It is however, similar to the Lower Kootenai River in substrate composition, with the substrate surface of mainly large cobble with interstitial sand and some silt. The Fisher River is also a hydrologically gaining system with similar weather patterns as the Lower Kootenai River.

The Fisher River riparian zone was different from the Lower Kootenai River in that it had a full range of cottonwood size and thus, probably, age classes, arranged in similar patterns as found along the Upper Kootenay River with progressively larger trees moving away from the river (Figure 83). Both of

M – Mature black cottonwoods J – Juvenile black cottonwoods S – Cottonwood seedling recruitment zones

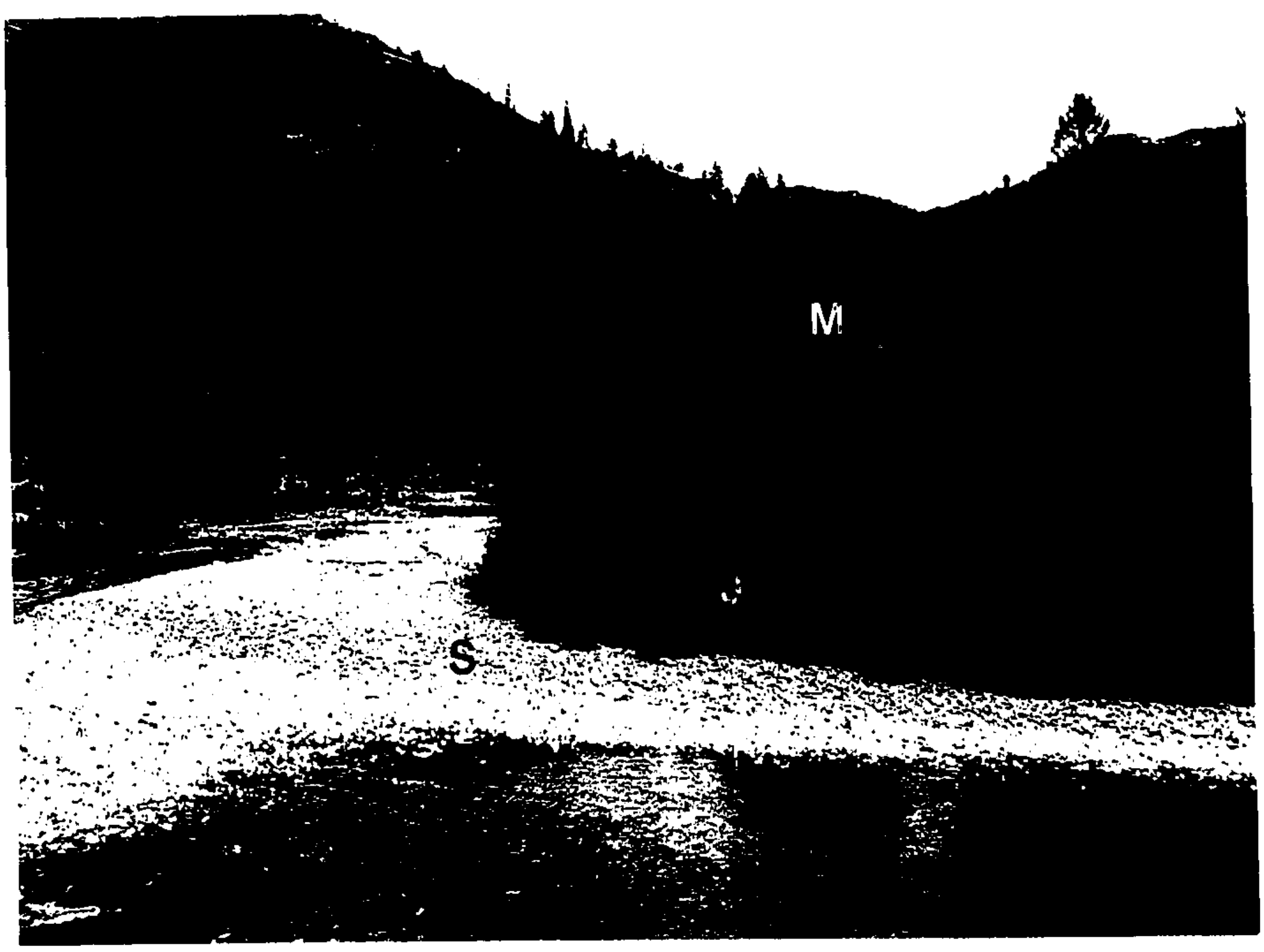


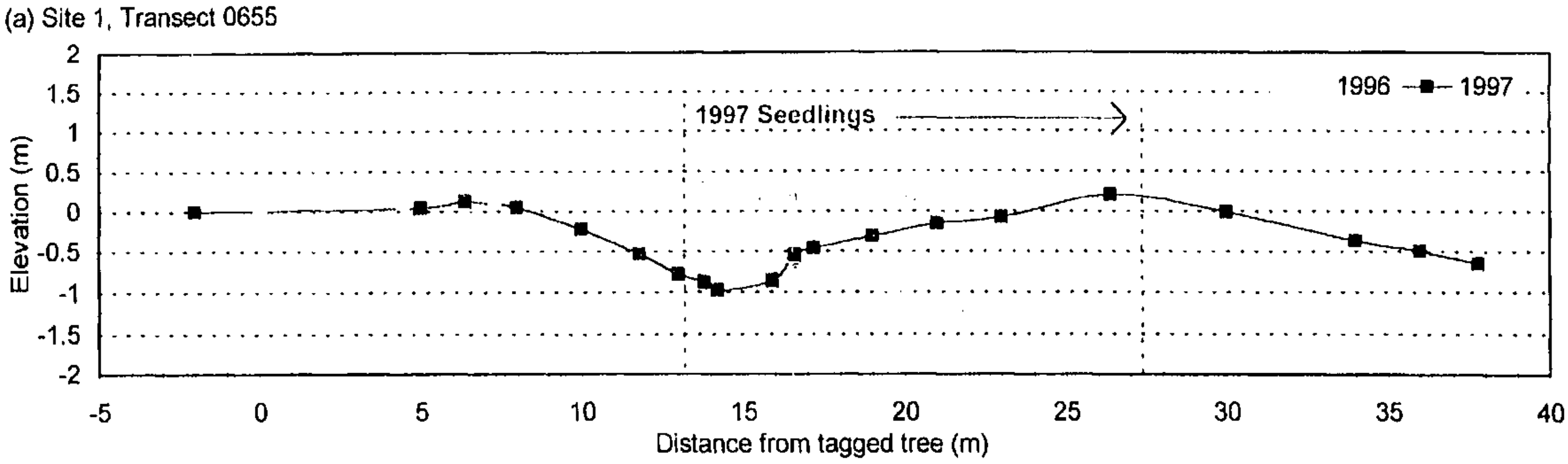
Figure 83 The black cottonwood population structure along the Fisher River upstream of Site 2 (48^0 19' N 115^0 18' W).

the meander lobes chosen for study sites had extensive initial seedling recruitment in 1996 and 1997 and this contrasted to the lack of recruitment along the Lower Kootenai River. The sites along the Fisher River experienced substantial amounts of deposition and scour which resulted in the loss of most of the 1996 seedlings in 1997, but which also left large recruitment zones (Figure 84). This geomorphic pattern also differs from the flow-attenuated adjacent Lower Kootenai sites that had little scour and deposition resulting in an absence of newly-produced, barren seedling recruitment zones. There was a significant difference between the change (scour and deposition) that occurred along the Fisher River compared to the Lower Kootenai River, there was a F-Value 70.775 and a P-value of $< .0001$ (appendix 2-275).

Because seedlings along the Fisher River were evaluated only once in 1996, no survival rates were determined. The densities were very similar in 1996 and in 1997 (160/m^2 in.1996, and 182/ m^2 in 1997 for Site 1, and 114/ m^2 in 1996 and 103/ m^2 in 1997 for Site 2, (F-Value .040, P-Value .8414, appendix 2-276). The cottonwood seedlings along the Fisher River did not experience a significant difference in survival rates between the two study sites as observed for the Upper Kootenay sites (F-Value .177, P-Value .6785, appendix 2-277). The 1997 seedling survival was 60% for Site 1 and 51 % for Site 2, values that were quite similar to those for the Upper Kootenay in 1997 (F-Value .625, P-Value .4321, appendix 2-278).

Along the Fisher River, the August 1996 seedling heights were not significantly different from 1997 seedling heights (13.6 mm in 1996 and 14.2 mm

(a) Site 1, Transect 0655



(b) Site 2, Transect 0658

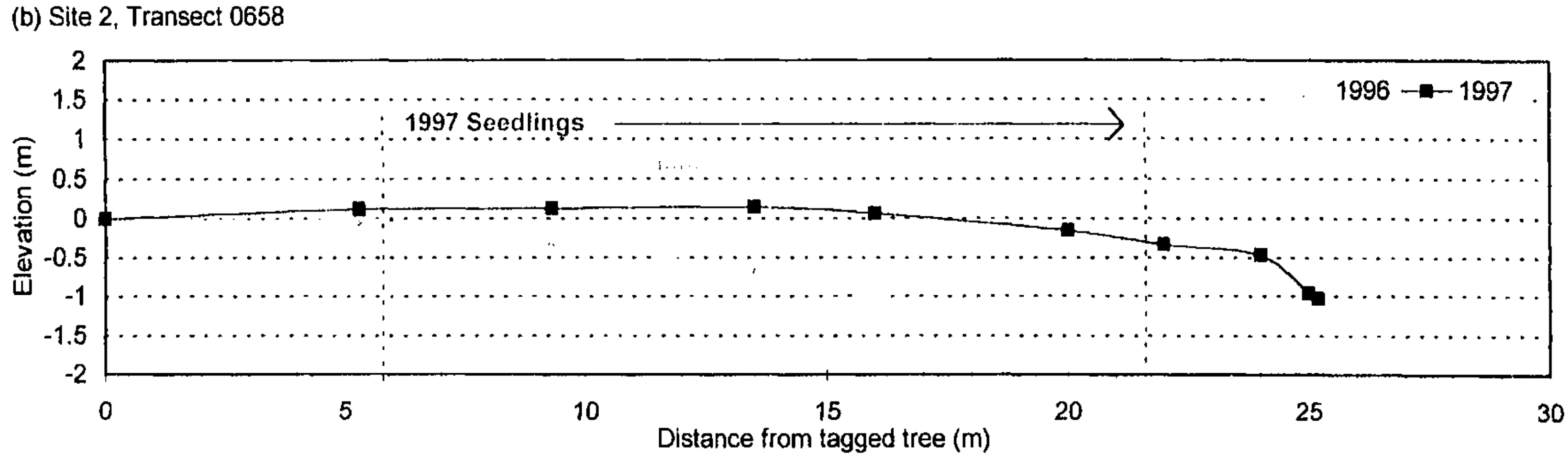


Figure 84. The Fisher River (a) Site 1, transects 0655 and (b) Site 2, 0658, at approximately 48^0 19' N 115^0 18' W, illustrating 1996 and 1997 seedling locations and 1996, 1997 cross-sectional elevations of these transect lines zeroed to base stage.

in 1997), although measurements were about 10 to 17 days earlier in 1997 (F-Value .026, P-Value .8721, appendix 2-279). However, there was a significant seedling height difference between the Fisher and the Upper Kootenay with F-Value 19.565, and P-Value < .0001 (appendix 2-280).

The Fisher River had similar weather patterns as the Lower Kootenai River and the Upper Kootenay River (Figure 85). As the three systems were hydrologically gaining, semi-arid systems, the effect of the Libby Dam on the Lower Kootenai was the principal influence on reducing seedling recruitment along establishment areas for the Lower Kootenai River.

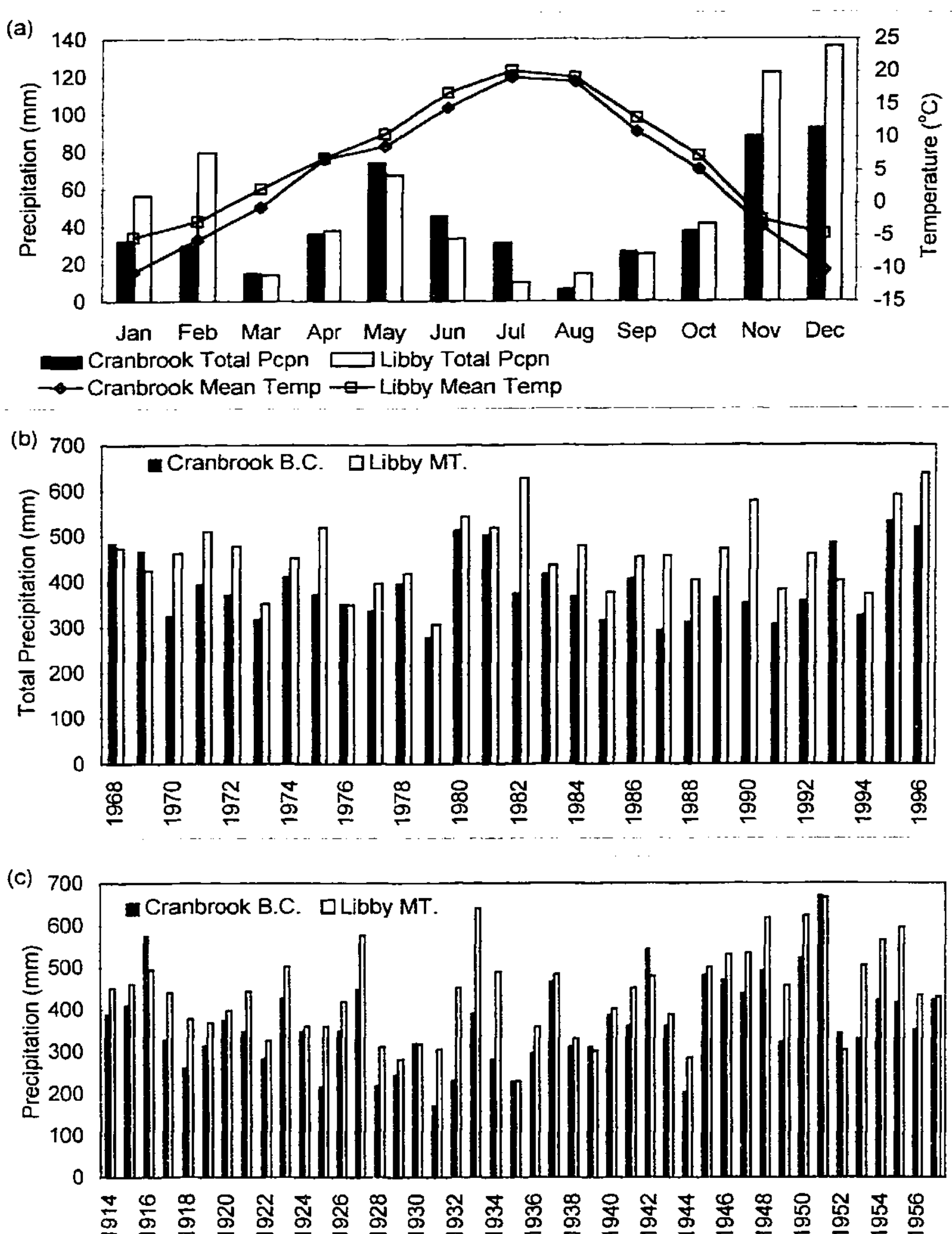


Figure 85. (a) The monthly mean temperature and precipitation for Cranbrook B.C., near the Upper Kootenay River and Libby MT., near the Lower Kootenai River, for 1996. (b & c) The annual precipitation for Cranbrook, obtained from Environment Canada, and Libby MT., obtained from U.S. Forest Service.

Conclusion

The operation of the Libby Dam attenuates the spring peak (flood) flows and releases maximal flows during the winter when power demands are greatest. This reverses the natural pattern of discharge in which winter flows are low and peak flows occur in late spring. This change in the flow pattern combined with other consequences of damming have resulted in geomorphological changes including a loss of dynamic channel meandering, the substantial reduction of suspended sediment load, transport and deposition, the loss of woody debris transport and deposition, and the encroachment of upland vegetation into the recruitment band of the riparian zone. These hydrologic, geomorphic, and vegetation changes have combined to exclude cottonwood seedling recruitment and this has resulted in an imbalance in the population structure of the riparian woodlands along the Lower Kootenai River.

While seedling recruitment has been deficient along the Lower Kootenai River following the commissioning of the Libby Dam, it has persisted along the free-flowing Upper Kootenay River and along the Fisher River which is adjacent to the study reach of the Lower Kootenai River. This indicates that the lack of cottonwood recruitment along the Lower Kootenai is not symptomatic of a general recruitment deficiency along the whole Kootenay River, nor reflective of regional conditions, such as climatic patterns, that impede cottonwood recruitment. Instead, the lack of seedling recruitment and the subsequent population imbalance along the Lower Kootenai River is very probably due to the occurrence, and particularly the pattern of operation, of the Libby Dam and Koocanusa Reservoir.

Limited clonal recruitment of cottonwoods has persisted along the Lower Kootenai River producing patches of juveniles originating from root suckers. However, even this recruitment mode is deficient along the Lower Kootenai River and limited to low elevation areas of meander lobes and limited fringes along mature groves. In contrast, recruitment through root suckers was more extensive along the Upper Kootenay and Fisher Rivers and resulted in mixtures of clonal saplings and new seedlings that combine to form bands of cottonwoods that parallel the stream and progress from young to mature trees with distance away from the stream channel. The understory structure was also deficient along the Lower Kootenai sites and thus other riparian plants including willows were also negatively impacted by the damming and artificial flow pattern.

The riparian cottonwoodlands provide the richest wildlife habitats in the Kootenay River Basin and healthy riparian ecosystems also contribute to healthy aquatic ecosystems, including fisheries. Thus, the continuing decline of the cottonwood forests along the Lower Kootenai River will have considerable environmental consequences and will lead to the progressive loss of wildlife habitat and many other indirect and generally undesirable consequences.

Chapter 4: Integration of results from the Elk and Kootenay rivers and restoration strategies for the Lower Kootenai River

The present study involved two overlapping investigations. The first study examined reproductive strategies of black cottonwoods and the influence of the extreme flood of 1995 of the Elk River on the cottonwoods and the geomorphology of the river valley. The second study investigated black cottonwood ecology along the Kootenay River and the effects of flood flow attenuation by the Libby Dam. These two studies have revealed aspects of black cottonwood reproductive ecology and its close association with river flooding. The studies should help to understand the Kootenay River riparian system and the influence of flow stabilization on the Lower Kootenai River.

The two investigations involved four adjacent study reaches. The Elk and Upper Kootenay rivers are located in the southeastern corner of British Columbia and the Fisher and the Lower Kootenai rivers are located in northwestern Montana. These four river reaches occur in the Rocky Mountain region along the west slope of the Rocky Mountains and in the Kootenay Sub-basin of the Columbia River Basin. Three of the study reaches: the Elk, the Upper Kootenay and the Fisher rivers, are (almost) free-flowing, while the Lower Kootenai River has been flow stabilized since 1973.

In addition to the geographic similarity of the four study reaches, they are also all black cottonwood-dominated with mixed woodlands along adjacent hillsides. The main similarities and differences are listed in Table 8 which recognizes that the four river systems are hydrologically gaining systems, receiving groundwater inflow from the forested hill and mountain sides along the rivers. This contrasts to the type of river of many previous studies where flow attenuation has resulted in loss of seedling recruitment. Those earlier studies involved hydrologically losing stream systems in which the riparian water table slopes downwards away from the river. The present study sought to determine if flow attenuation on a hydrologically gaining system would affect seedling recruitment as strongly as it does on hydrologically losing systems. The Lower Kootenai River has been strongly impacted by flow attenuation which has resulted in a lack of population replenishment and excluded seedling establishment during the two years of present study and apparently in the previous two decades.

For the present studies, the adjacent free-flowing streams were used as control reaches. The Elk River was paired with the Upper Kootenay River and the Fisher River was paired with the Lower Kootenai River. This allowed comparisons of geographically adjacent areas, and analyses of the flow-stabilized Lower Kootenai versus the free-flowing Upper Kootenay River and versus the adjacent free-flowing Fisher River.

The Elk River reach differed in several ways from the three other study reaches (Table 8). In particular, its climate is more humid due to higher precipitation and elevation (Figure 86). Thus, the Elk River cottonwood seedlings would receive more moisture from rain than the other reaches, and so these would be less dependent upon the riparian water table. This was apparently the case in 1996, when there was high seedling survival during the

Table 8. Comparison of the riparian environments along the Elk, Upper Kootenay, Fisher and Lower Kootenai rivers.

	ELK	UPPER KOOTENAY	FISHER	LOWER KOOTENAI
Hydrologically gaining	✓	✓	✓	✓
Semi-arid region		✓	✓	✓
Humid region predominates	✓			
Cobble substrate predominates	✓		✓	✓
Sand/silt substrate		✓		
High gradient	✓		✓	
Dammed				✓
Spring floods	✓	✓	✓	
Extensive active scour & deposition	✓	✓	✓	
Cottonwood recruitment sites	✓	✓	✓	
Mature black cottonwoods	✓	✓	✓	✓
Cottonwood seedlings	✓	✓	✓	
Woody debris deposition	✓	✓	✓	

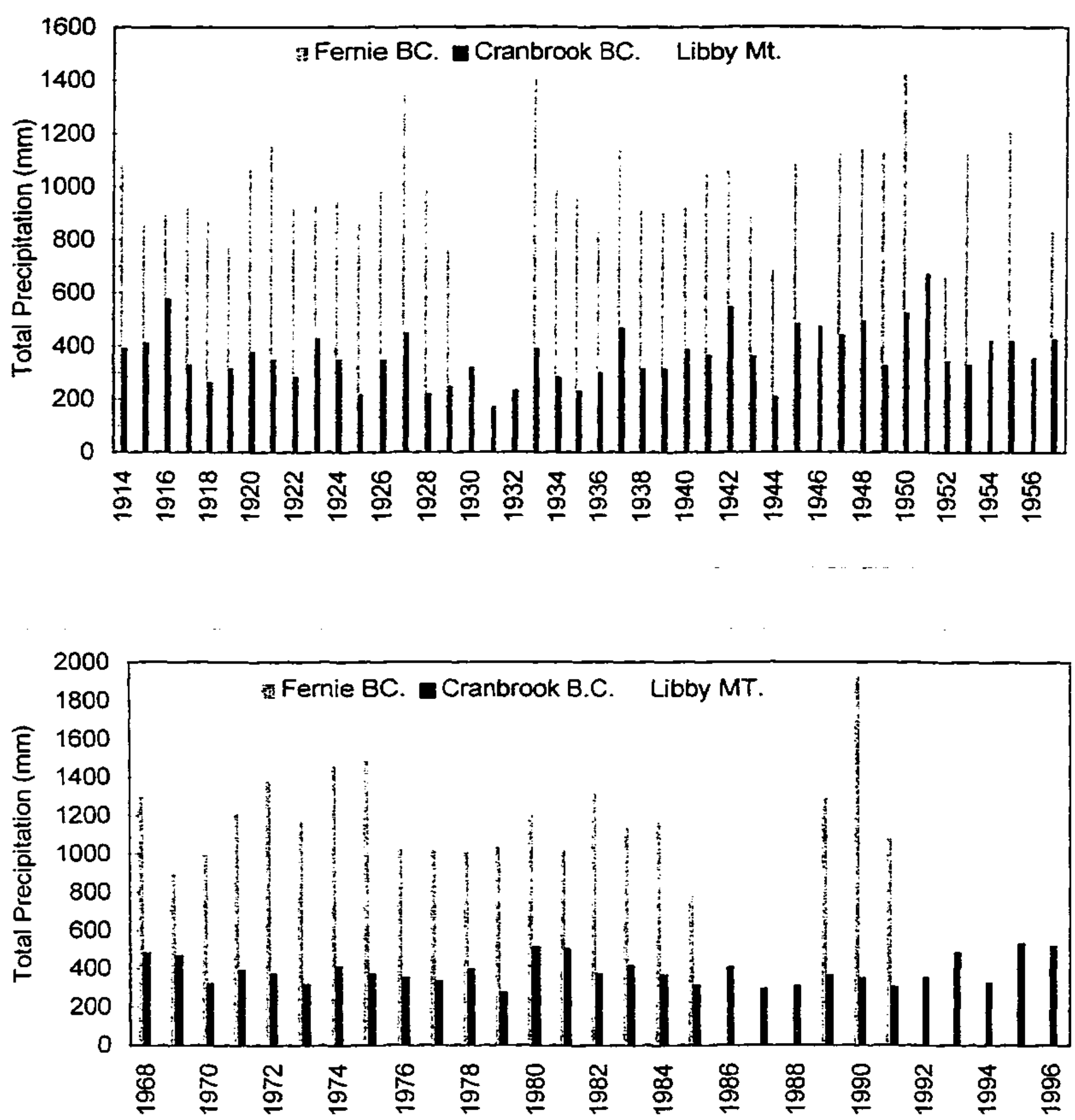


Figure 86. (a & b) The annual precipitation for Fernie, near the Elk River, Cranbrook, near the Upper Kootenay River B.C., and Libby, near the Lower Kootenai River MT. The Canadian records were obtained from Environment Canada, and the Libby, records are from U.S. Forest Service.

first summer. However, 1997 was a drier year than 1996, and this resulted in high cottonwood seedling mortality along the Elk River due to drought. This indicates that even in a humid, hydrologically gaining system, seedlings are still dependent on the riparian water table when sufficient precipitation is not received during the growing season.

Somewhat surprisingly, the drier, Upper Kootenay River system actually had less mortality due to drought stress in 1997. The differences in seedling survival rates were probably at least partly due to the substrate composition differences between the Elk and Kootenay rivers. The Upper Kootenay has a sand and silt substrate whereas the Elk has coarse cobble with interstitial sand and patches of surface sand. The deep sand and silt of the Kootenay acts as a capillary wick bringing moisture up to the roots of the seedlings while the Elk River cobble has a limited capillary fringe. This results in seedlings, established on a coarse substrate, being more dependent on the riparian water table if sufficient moisture is not received through precipitation. Even large patches of sand and silt over and between cobble did not prevent drought stress to seedlings along the Elk River. This demonstrates the importance of the capillary fringe for the success of cottonwood seedlings.

Due to the cobble substrate and capillary zone differences, river stage levels would be critical in the first year of seedling establishment along the Lower Kootenai River. The threat of mortality due to drought appears even to be high for older trees along the Lower Kootenai River, as some the mature trees were showing signs of drought stress including precocious senescence and crown die-back (Braatne et al. 1992, Weber 1995).

The Elk and Fisher rivers are both high gradient streams. Both have similar substrates consisting mainly of cobble with some sandy patches. The flood velocities on these two systems were sufficient to move large quantities of the coarse cobble. The resultant scour and subsequent deposition at meander lobes has produced more dynamic meandering than along the lower gradient, Upper Kootenay River. Along the fourth reach, the Lower Kootenai River has coarse cobble covered meander lobes and the stabilized, moderate flows have not been sufficient to produce enough scour and deposition. The three free flowing reaches had significant differences (F-Value 23.838, P-Value < .0001) in change from scour and deposition compared to the Lower Kootenai River (appendix 2-282). Without scour and deposition, seedling recruitment sites will not be created along the Lower Kootenai River.

Differences in substrate also affect the ability of vegetation to withstand scour. The flow velocities needed to scour away established vegetation on cobble are higher than flow velocities needed to scour vegetation on sand. The Elk, the Upper Kootenay, and the Fisher river systems experienced scour and deposition during both years of the study. Of these, the Elk and Fisher rivers experienced the most scour and deposition. However, some of their 1996 seedlings survived 1997 high flows as these were well anchored in the coarse cobble substrate.

The Upper Kootenay seedlings established in 1996 experienced less scour and deposition than those on the Elk and Fisher rivers but had minimal survival into 1997. This was probably primarily because seedlings along the Upper Kootenay River were poorly anchored on the mobile, sandy substrate. In contrast, the vegetation now established to the river's edge along the Lower Kootenai River is well anchored in cobble substrate. Since the Lower Kootenai River is also a lower gradient system, higher spring discharge releases from the Libby Dam may not be sufficient to cause the scour and deposition of the substrate or the scouring of the encroached vegetation. Consequently, a multiple-stepped process will be needed for cottonwood recruitment site rehabilitation.

Alternately, prolonged higher flows from the Libby Dam for a number of weeks may help to eliminate the less flood-tolerant grasses and other plants that have unnaturally encroached into the riparian zone (Rood and Bradley 1993). Established cottonwoods and willows are flood-tolerant and should not be affected by this periodic but temporary high water (Hosner 1958, Bradley et al 1991). Once the densities of encroaching vegetation have been reduced, a high pulse in early June (the average time for spring peak flows) may scour the remaining vegetation from the meander lobes creating recruitment sites for cottonwoods. Sufficient clearing of recruitment zones may require repeated flood treatments. Since mature cottonwood trees are still present, their seeds should find the newly created, barren and moist recruitment zones to germinate and become established if they are not dislodged by subsequent high flows.

An alternate method for recruitment site rehabilitation could involve the mechanical removal of vegetation that has encroached to the river's edge. Although the cost would be prohibitive to clear a large number of sites, there are very few meander lobes which are not utilized for human settlement and development. As these sites are rare, the survival of the cottonwoodlands in these areas is even more critical to the ecosystem. Mechanical removal of vegetation has produced encouraging results when combined with increased spring flows, along a stream where human settlement limits the feasibility of increased flows that would be needed to remove encroaching vegetation (Barinaga 1996). By first mechanically clearing the site of encroaching vegetation, the subsequent increased spring flood will reduce the encroachment of flood-intolerant species from establishing at the originally mechanically cleared sites. A study by Barinaga (1996) concentrated on fisheries restoration but the same strategy could also benefit the riparian plant community

Another restoration possibility might involve the planting of cottonwood whips, sapling stems that are harvested in the winter and plated into suitably moist substrate zones. Provided that sufficient genetic diversity is included, whip-planted cottonwoods might restore a cottonwood population faster than seedling recruitment. However, it would still be important to restore seedling recruitment so the system could more naturally replenish itself and to ensure genetic diversity and local adaptation.

The Koocanusa reservoir not only traps sediment but it also traps all woody debris. Consequently, the Lower Kootenai River lacks this debris which subsequently acts as localized sediment traps. Woody debris plays an important role in free-flowing systems by trapping sediment to create bars and raise their elevation through deposition. The elevated bars produce cottonwood recruitment sites which have some protection from scour during subsequent high flows. After the Lower Kootenai system has sediment and woody debris to the reservoir, the meander lobes have been scoured of the surface sand and silt and only coarse cobble remains. Some woody debris would help to trap the small amounts of sediment washed into the Lower Kootenai River by its tributaries and enable some favorable deposition along the river. The loss of woody debris also prevents the recruitment of cottonwoods by the rooting of branch fragments which are part of this debris left on meander lobes and other recruitment sites after high water. The planting of cottonwood whips could initially simulate this reproductive mechanism along the Lower Kootenai River.

New May through September flow releases from the Libby Dam were initiated after the white sturgeon were classified as an endangered species in 1992. The white sturgeon spawning is signaled by spring peak flows and typically corresponds to the same spring peak flows upon which the black cottonwoods dependent. The Libby Dam discharges have not produced natural flow patterns but instead, intermediate flows have been released for artificially longer durations over the growing season, with this management concentrating on benefiting only white sturgeon and not considering the ecosystem as a whole. Barinaga (1996) proposed a broader approach for bringing back failing fisheries. She theorized that by restoring the physical processes that shape a river's habitats, the biological processes will regenerate naturally. This approach proposes restoring more natural flows which would benefit not only a particular species of fish but the riparian habitats as well. The results from both of the investigations of the present study support this approach. Black cottonwoods would benefit from more naturally timed, increased flows with subsequent gradual draw-downs. The white sturgeon would probably respond favorably to this more natural flow pattern as well.

The higher and more natural spring and summer flows released from the Libby Dam since 1992 have helped to initiate root suckers close to mature black cottonwood trees. Although this method of reproduction does not contribute genetic diversity, it is helping to produce some juvenile saplings and contributes to the population structure. The higher flows also decrease drought stress experienced by some of the mature trees. The higher flows may prevent their loss, but cottonwood trees showing advanced stages of drought stress might not respond to these new higher flows (Braatne et al. 1992, Weber 1995).

In conclusion, the black cottonwoods of the Kootenay Valley rely on the dynamics of their system for continued replenishment. Flood attenuation and flow stabilization has led to declines in the age structure of the populations of cottonwood trees. It has also led to declines of other flood-tolerant riparian species including willow and red-osier dogwood in the Lower Kootenai system. Flood attenuation has permitted flood-intolerant vegetation encroachment to the river's edge eliminating cottonwood recruitment zones. In order to restore this system, more dynamic flows at appropriate time intervals need to be reestablished so recruitment zones are formed and seedlings recruitment is restored.

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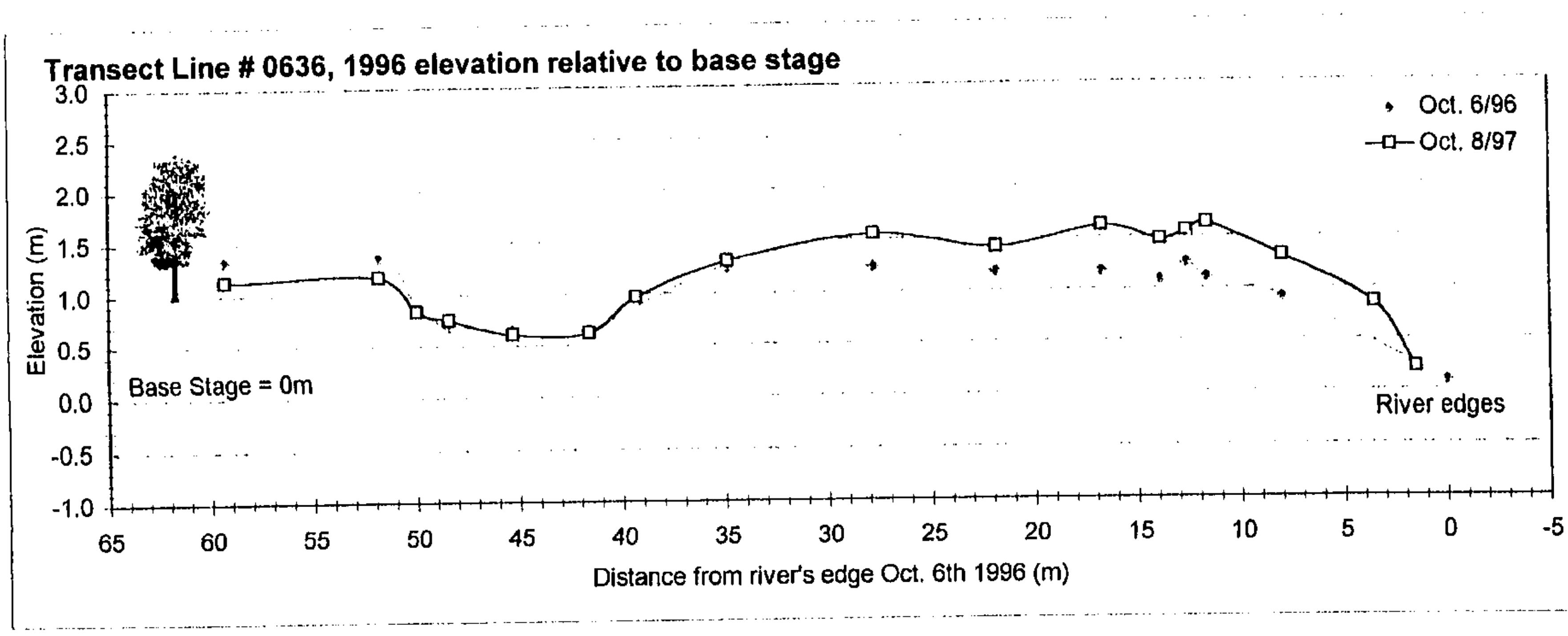
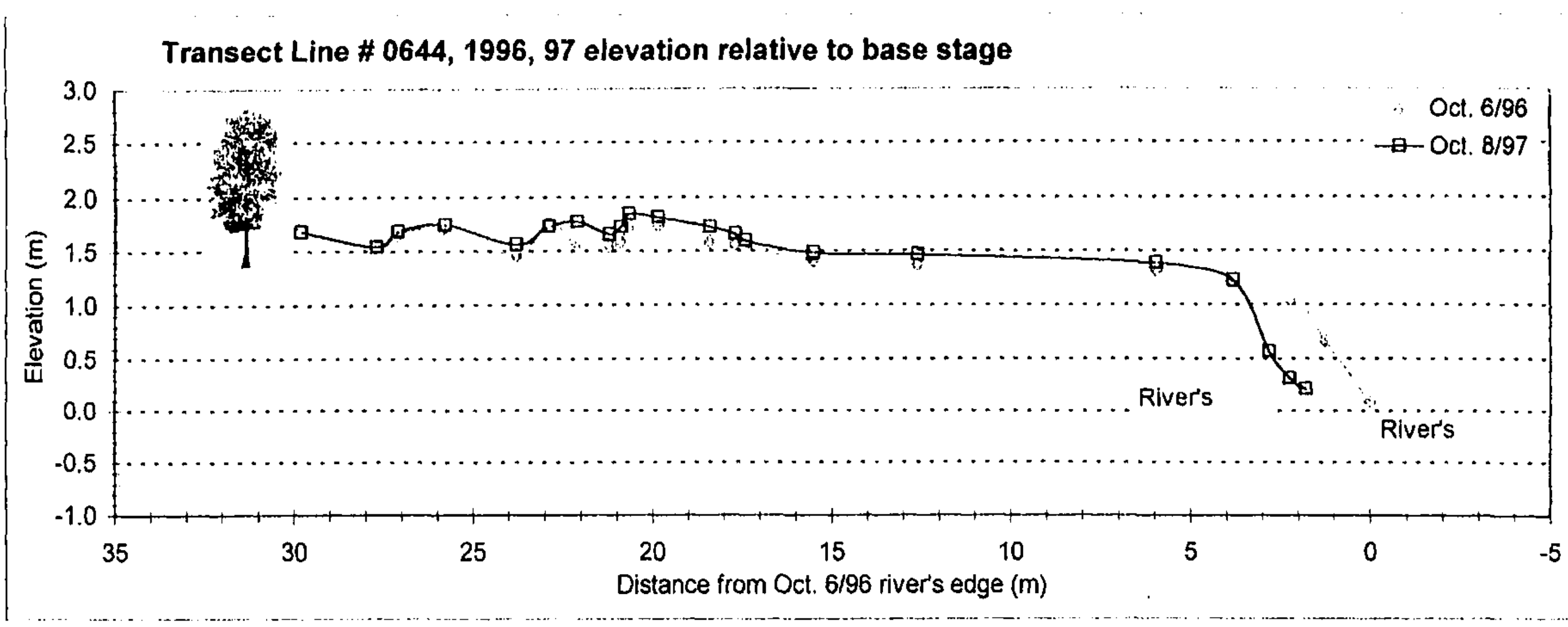
Appendix 1: Cross-Sectional Elevation Graphs

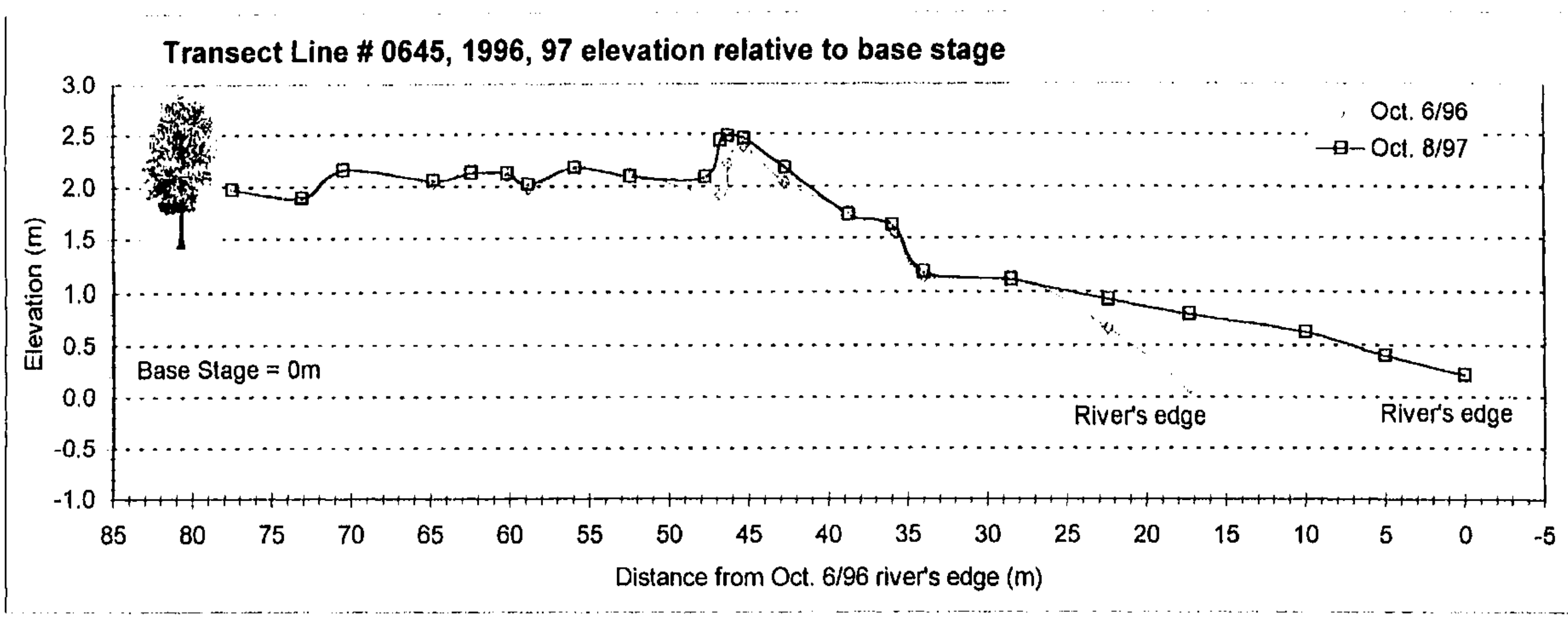
For each river reach

Elk River Site 1, elevation graphs for 1996 and 1997

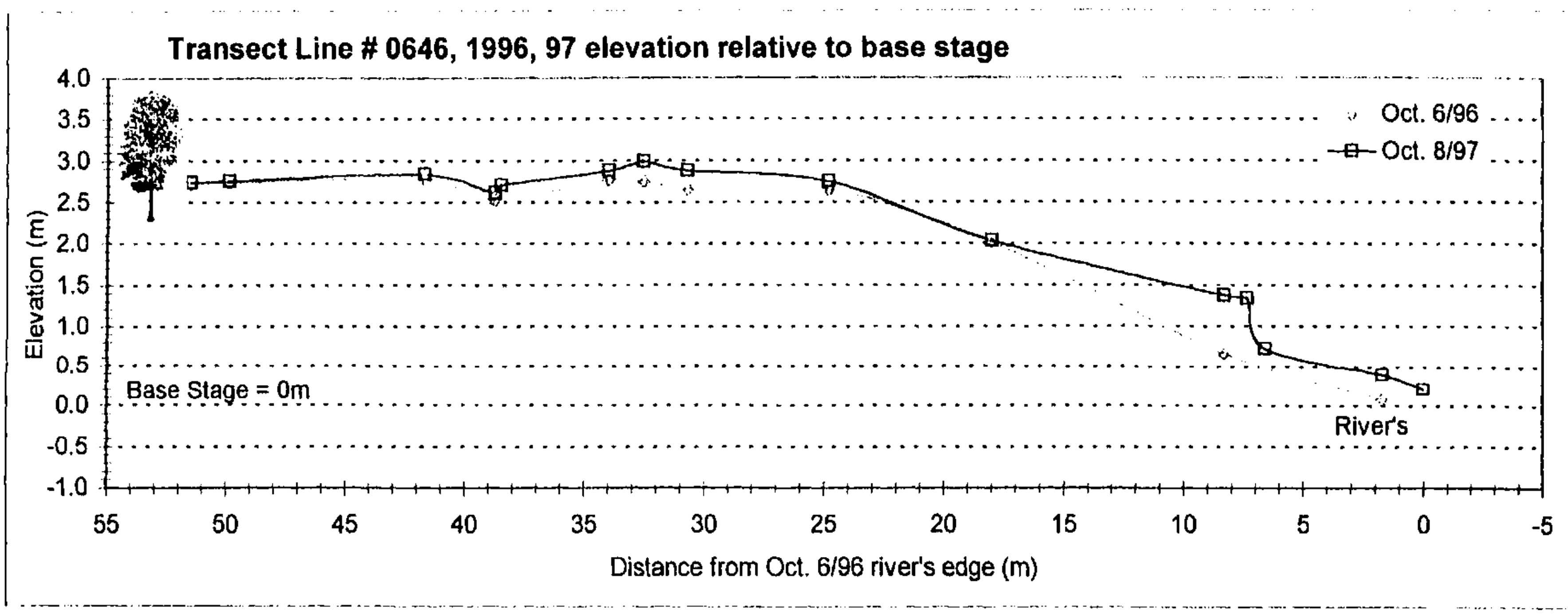

Transect Line # 0636, 1996 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base Stage = 0m
River edges
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from river's edge Oct. 6th 1996 (m)

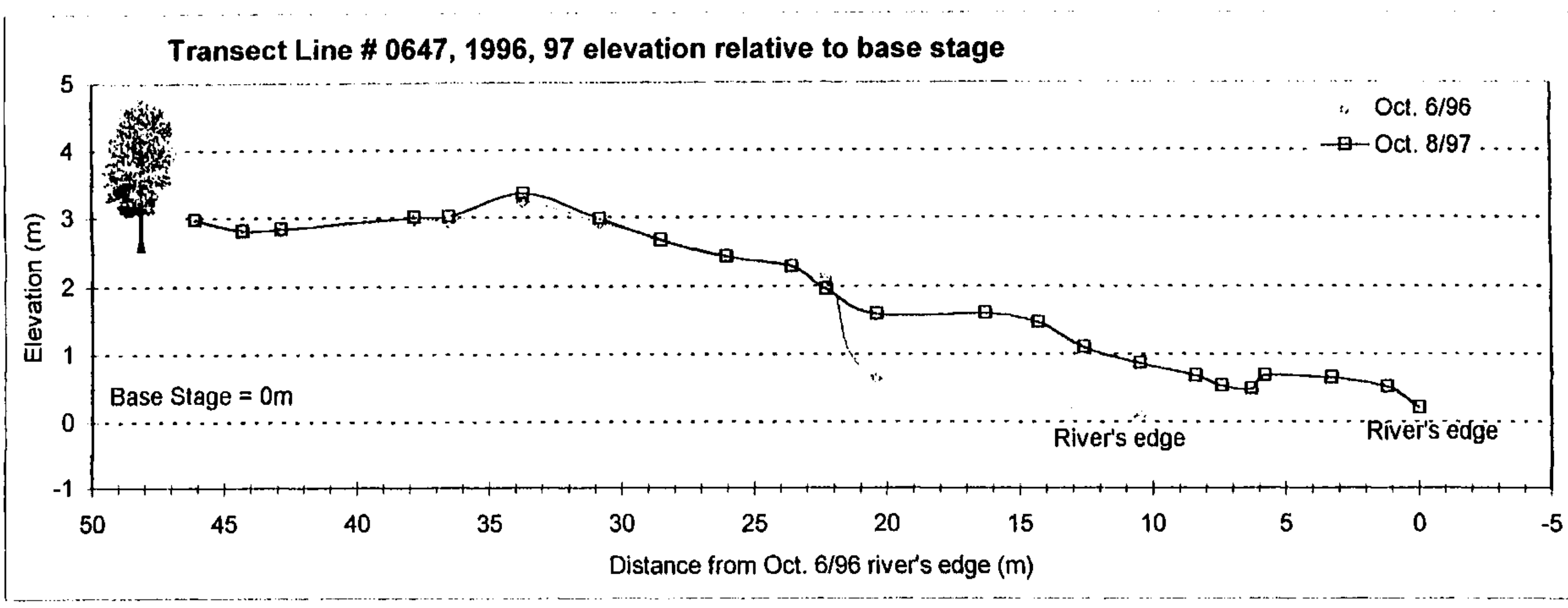


Transect Line # 0644, 1996, 97 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
35
30
25
20
15
10
5
0
-5
River's
River's
Distance from Oct. 6/96 river's edge (m)

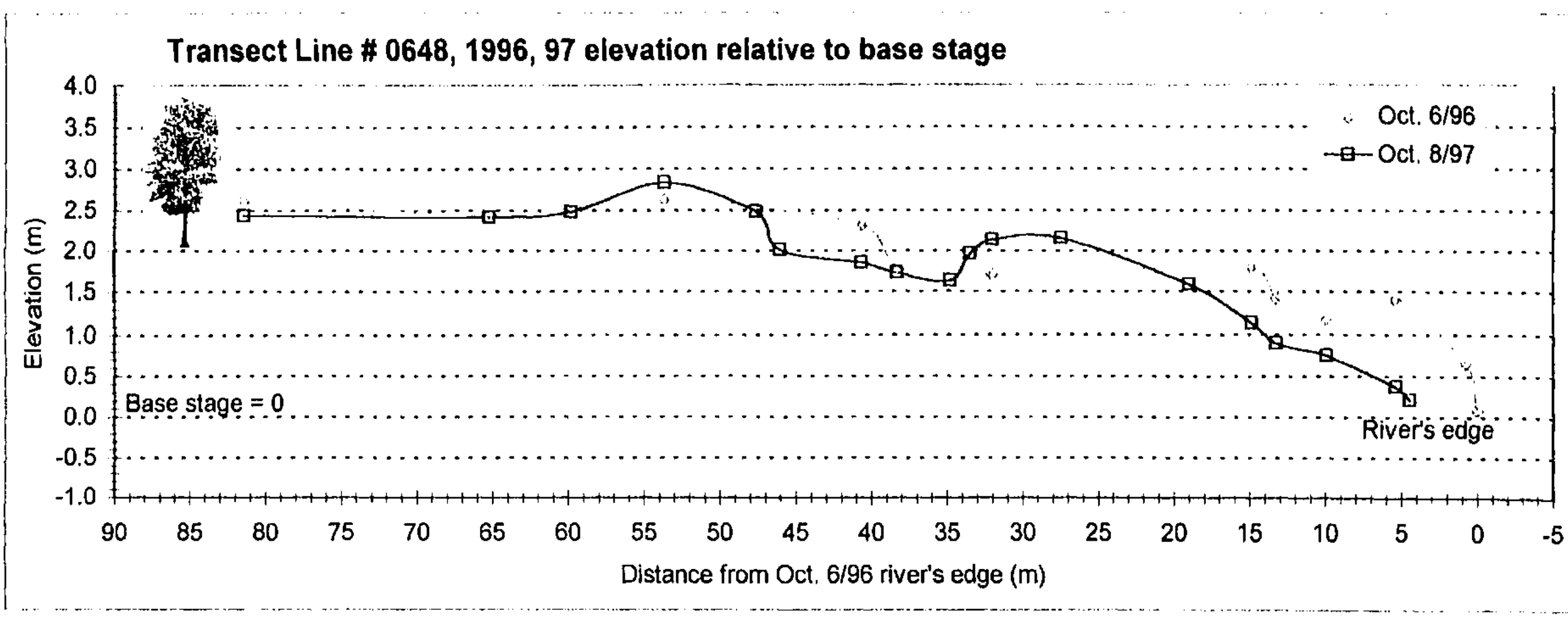


Transect Line # 0645, 1996, 97 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Elevation (m)
Base Stage = 0m
River's edge
River's edge
Distance from Oct. 6/96 river's edge (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5

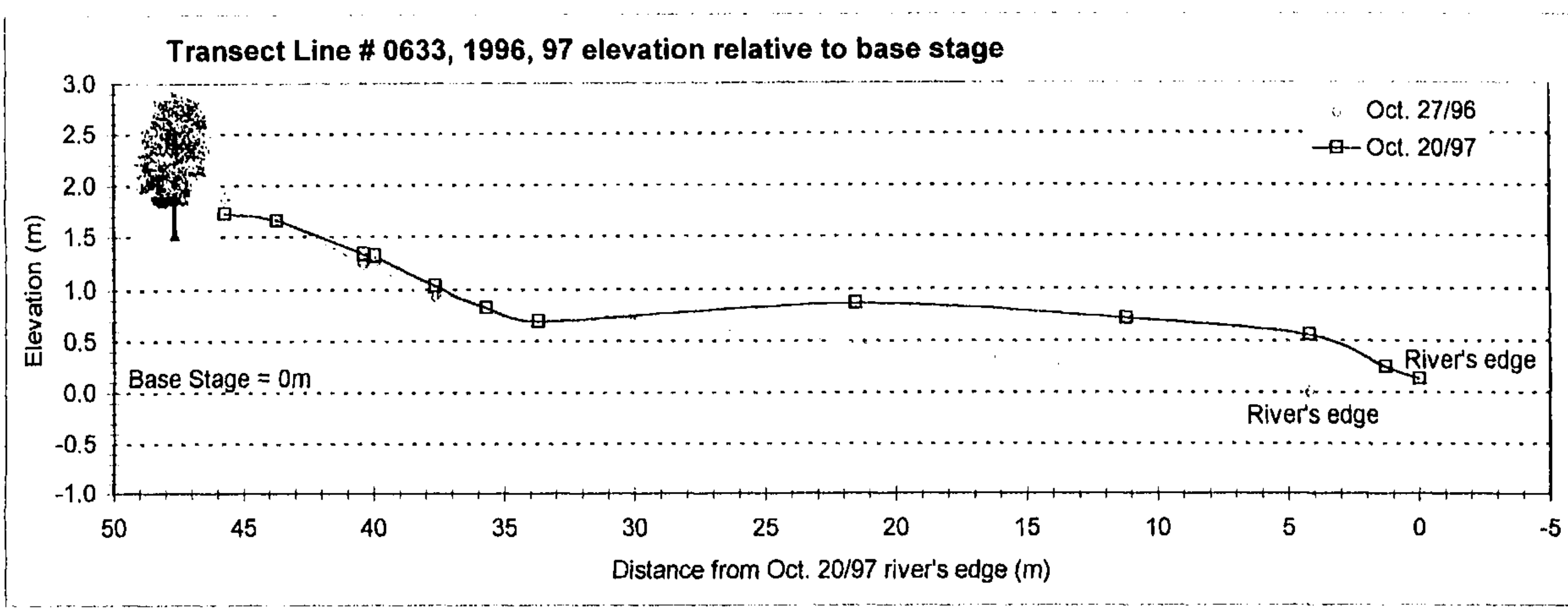

Transect Line # 0646, 1996, 97 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Base Stage = 0m
River's
Elevation (m)
Distance from Oct. 6/96 river's edge (m)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
55
50
45
40
35
30
25
20
15
10
5
0
-5



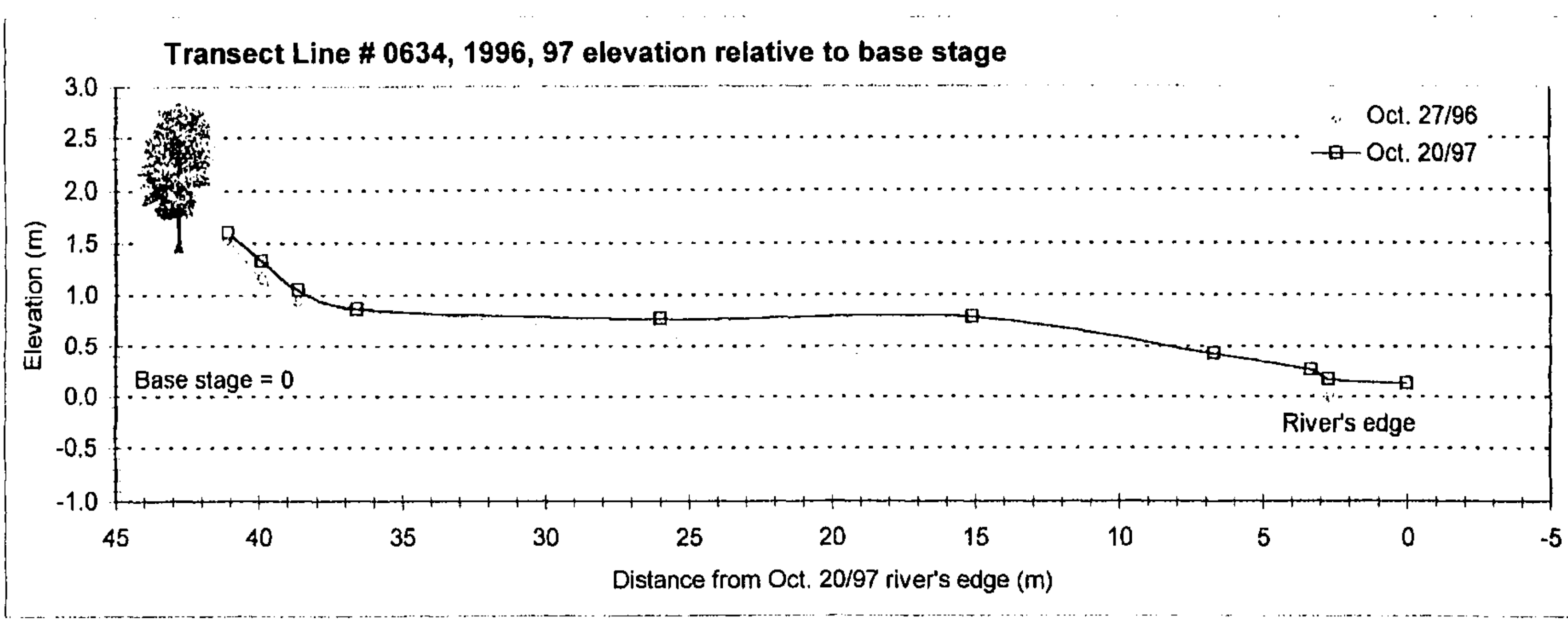
Transect Line # 0647, 1996, 97 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Elevation (m)
5
4
3
2
1
0
-1
Base Stage = 0m
River's edge
River's edge
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Oct. 6/96 river's edge (m)


Transect Line # 0648, 1996, 97 elevation relative to base stage
Oct. 6/96
Oct. 8/97
Elevation (m)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base stage = 0
River's edge
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Oct. 6/96 river's edge (m)

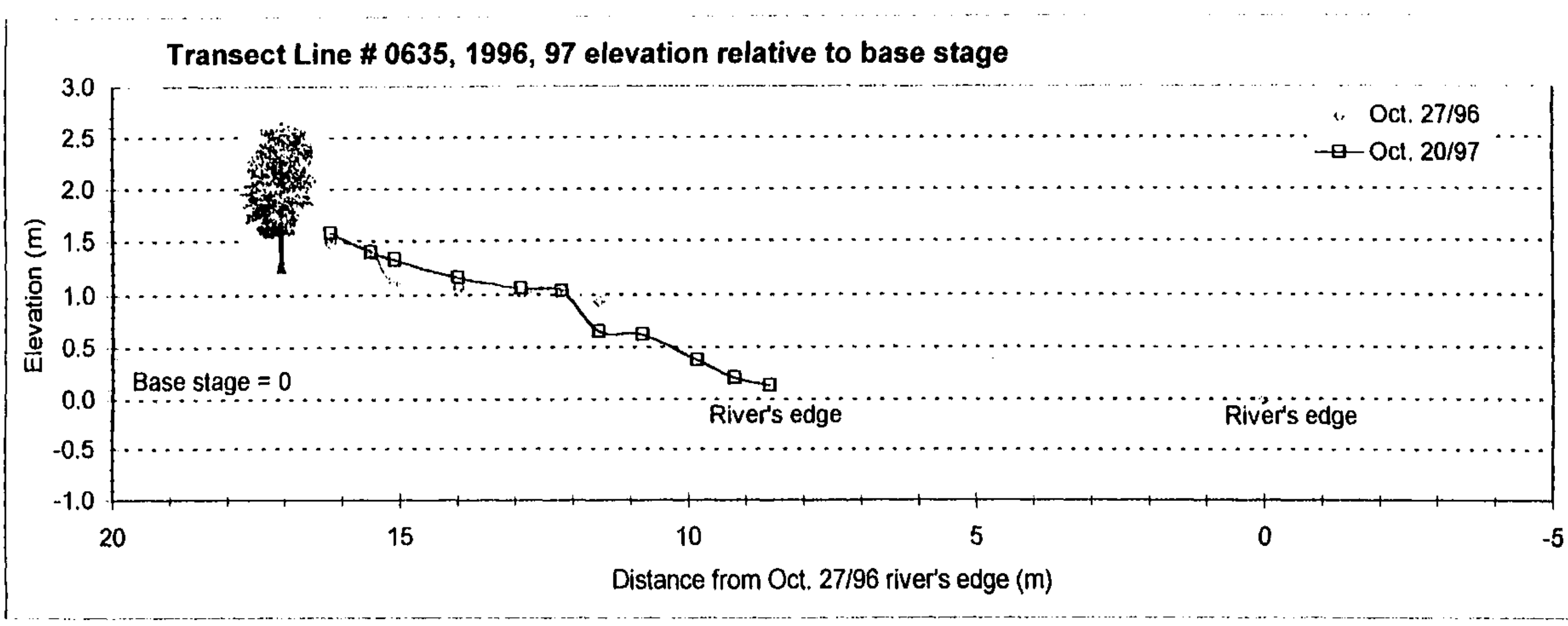
Elk River Site 2, elevation graphs for 1996 and 1997



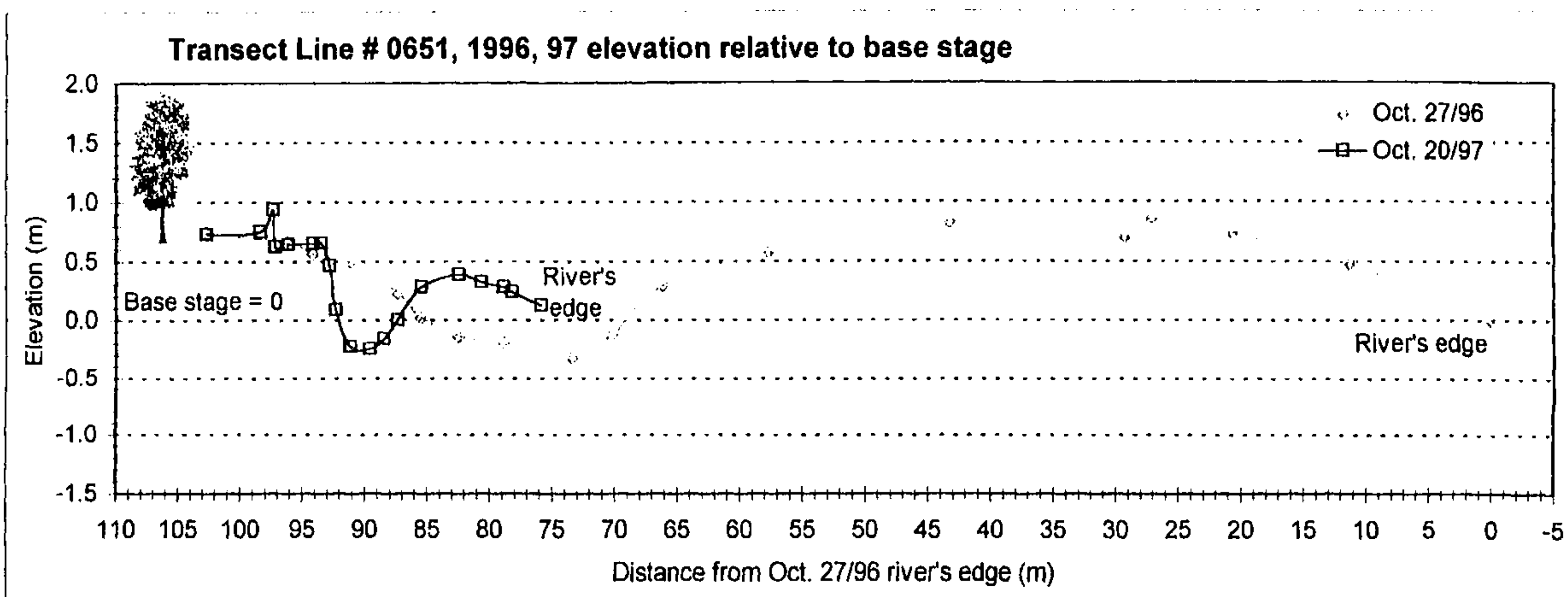
Transect Line # 0633, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base Stage = 0m
River's edge
River's edge
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Oct. 20/97 river's edge (m)



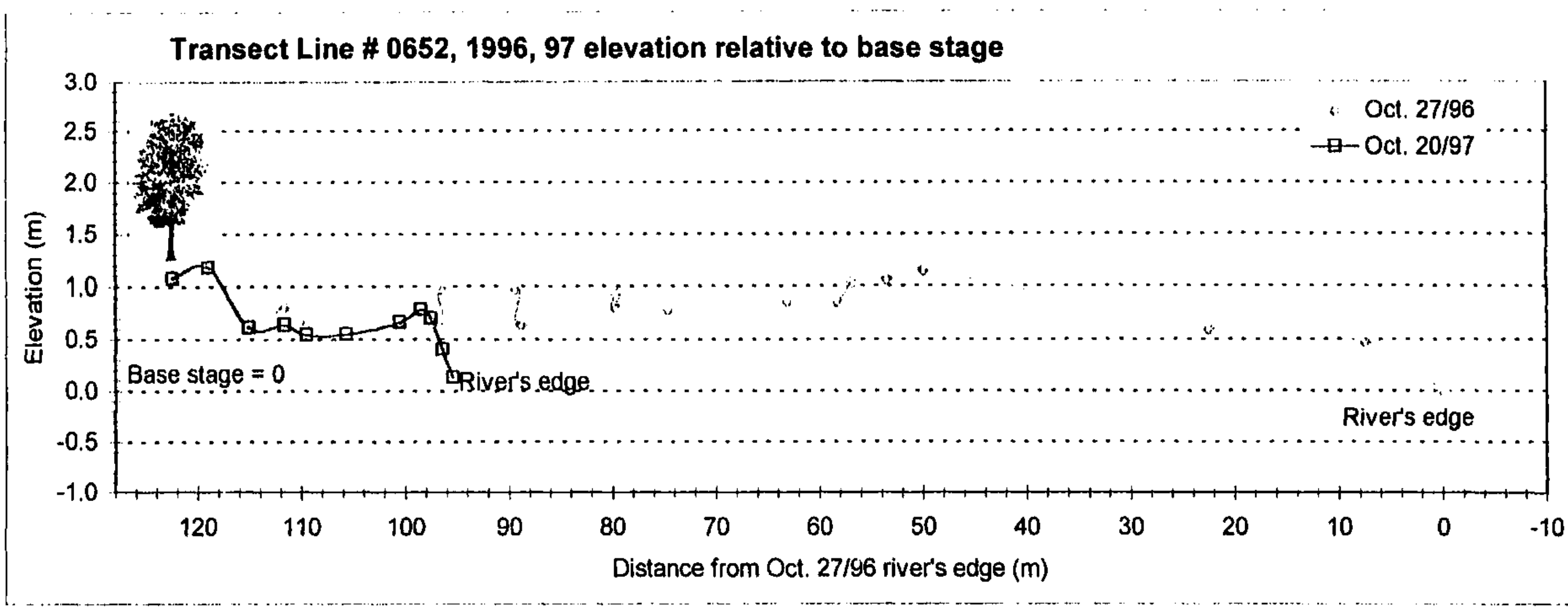
Transect Line # 0634, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base stage = 0
River's edge
45
40
35
30
25
20
15
10
5
0
-5
Distance from Oct. 20/97 river's edge (m)


Transect Line # 0635, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Elevation (m)
Base stage = 0
River's edge
River's edge
20
15
10
5
0
-5
Distance from Oct. 27/96 river's edge (m)

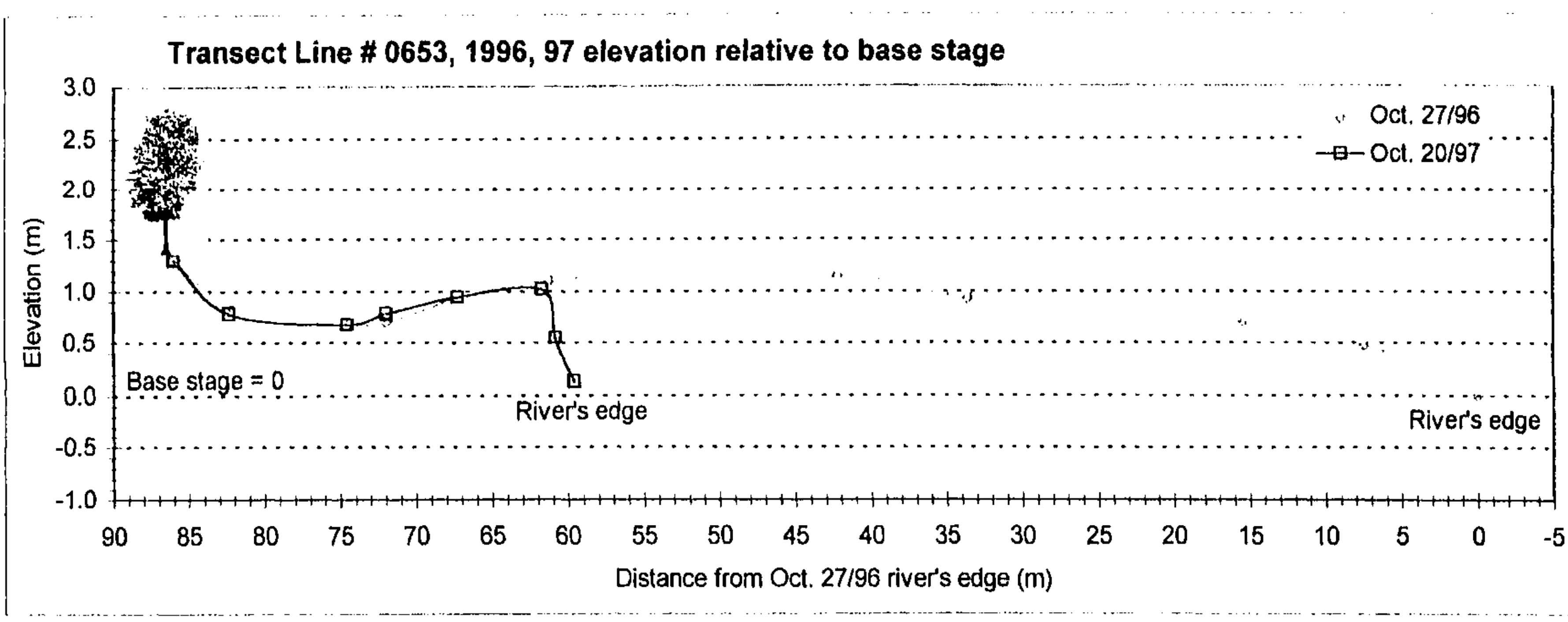
Elk River Site 3, elevation graphs for 1996 and 1997



Transect Line # 0651, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Elevation (m)
Base stage = 0
River's edge
River's edge
110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5
Distance from Oct. 27/96 river's edge (m)

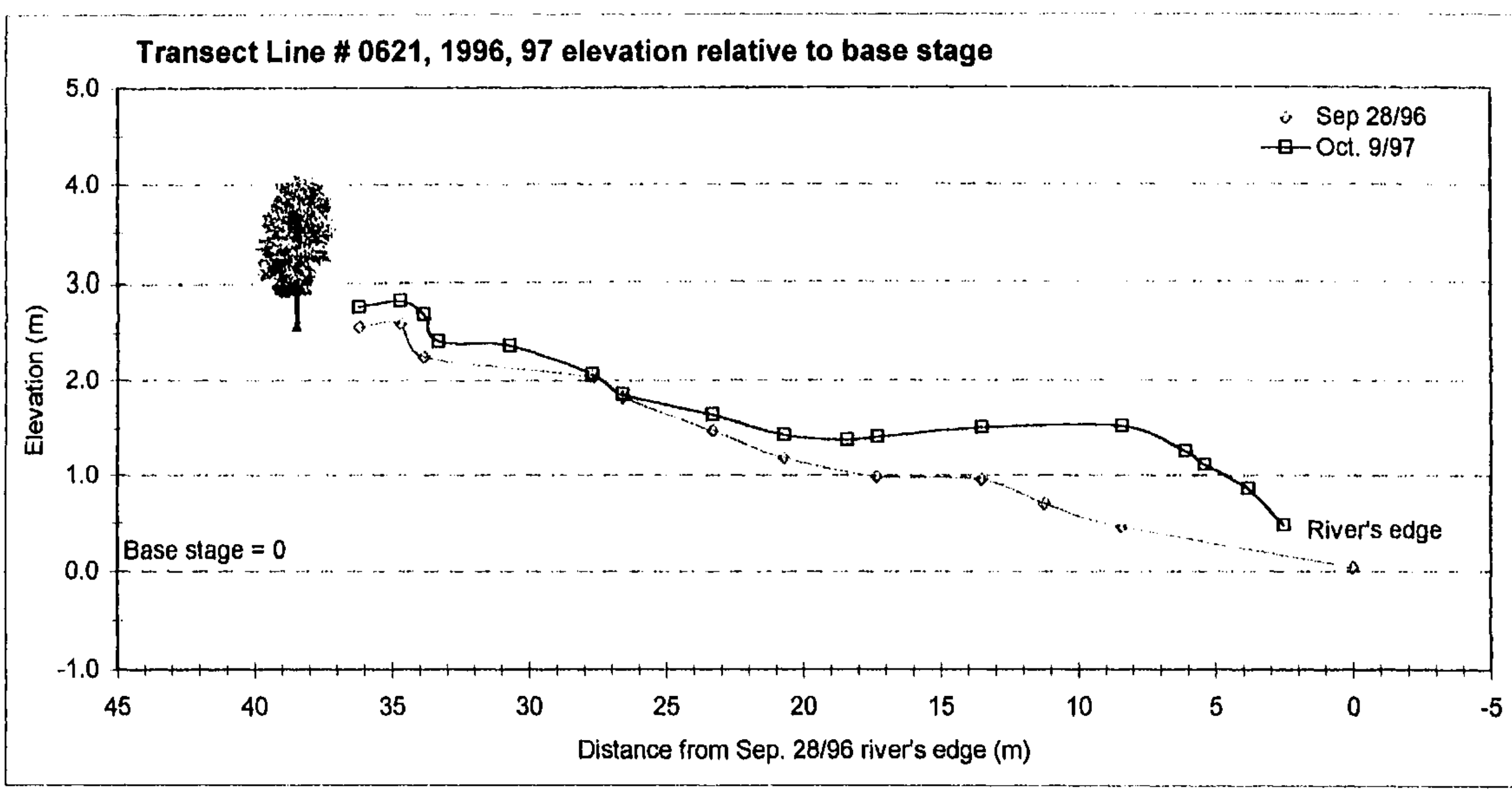


Transect Line # 0652, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base stage = 0
River's edge
River's edge
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
Distance from Oct. 27/96 river's edge (m)

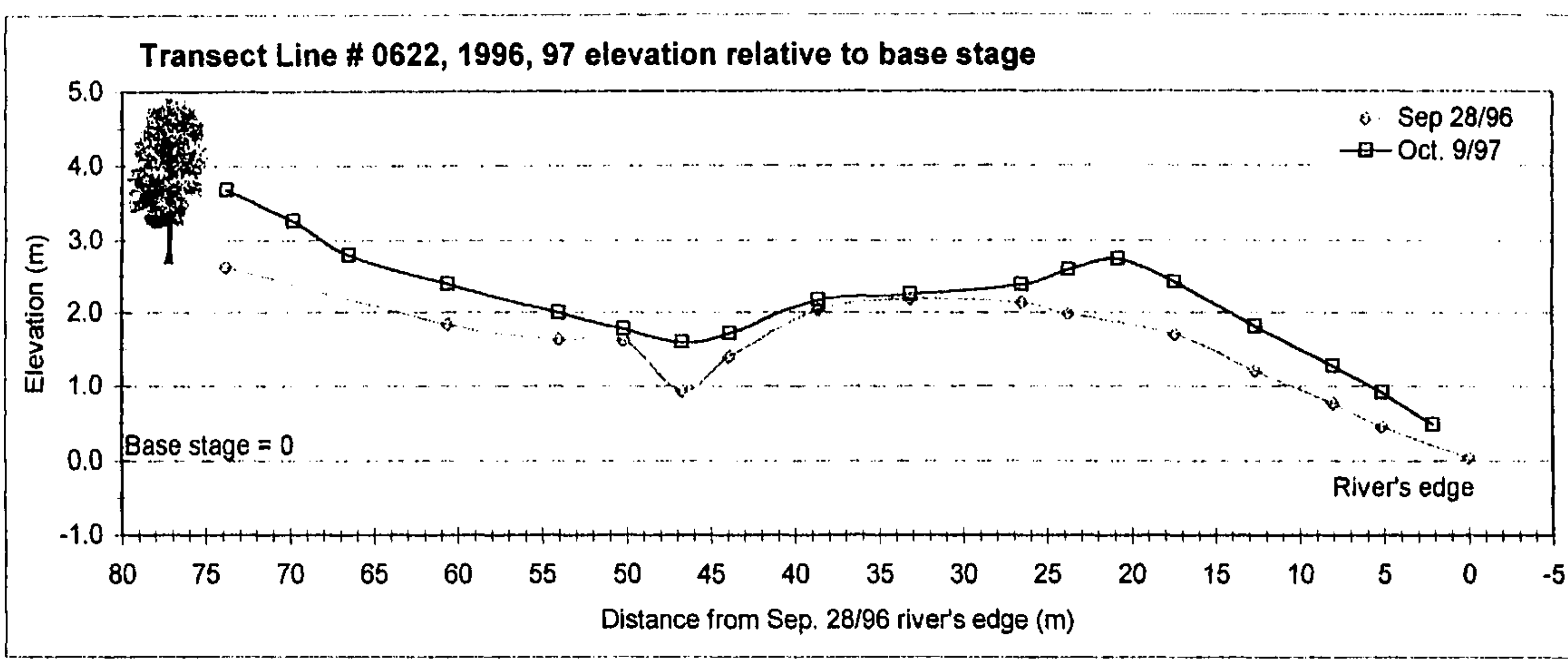


Transect Line # 0653, 1996, 97 elevation relative to base stage
Oct. 27/96
Oct. 20/97
Elevation (m)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base stage = 0
River's edge
River's edge
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Oct. 27/96 river's edge (m)

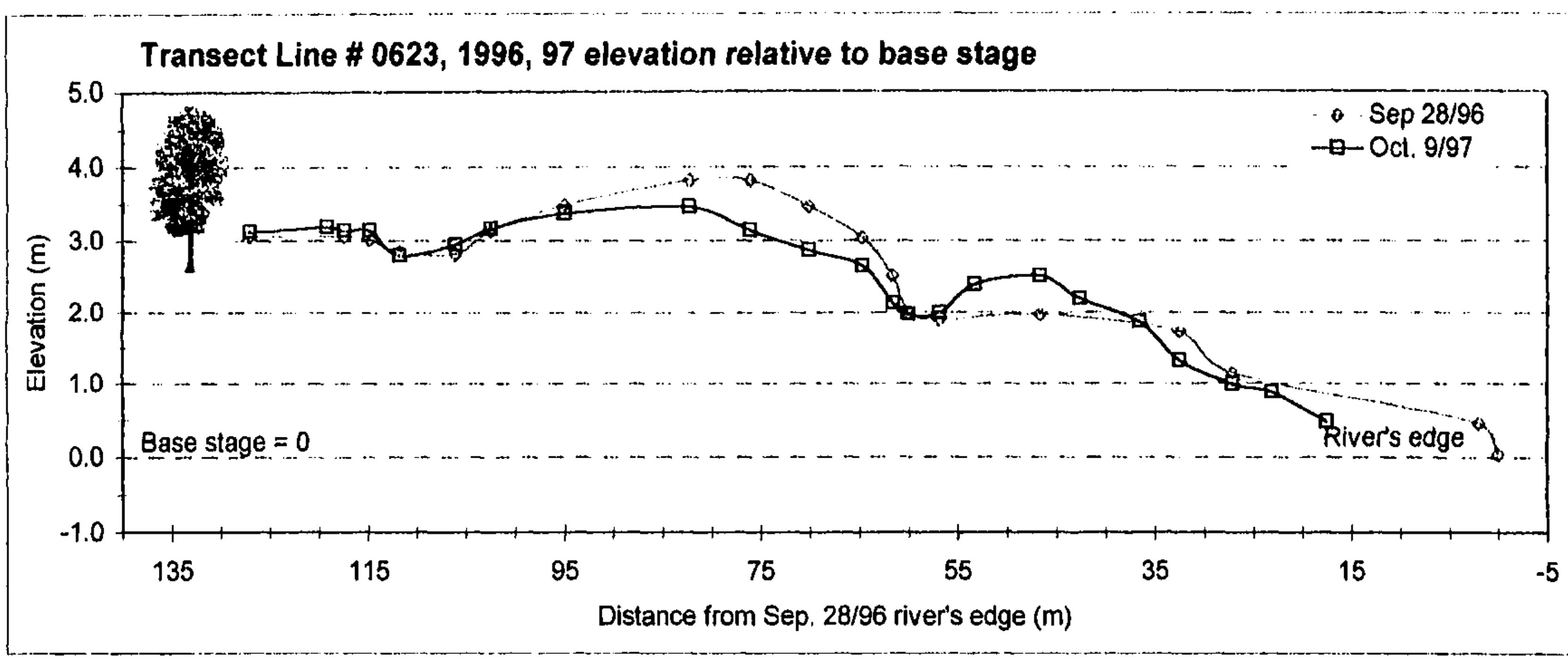
Upper Kootenay River Site 1, elevation graphs for 1996 and 1997



Transect Line # 0621, 1996, 97 elevation relative to base stage
Sep 28/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)

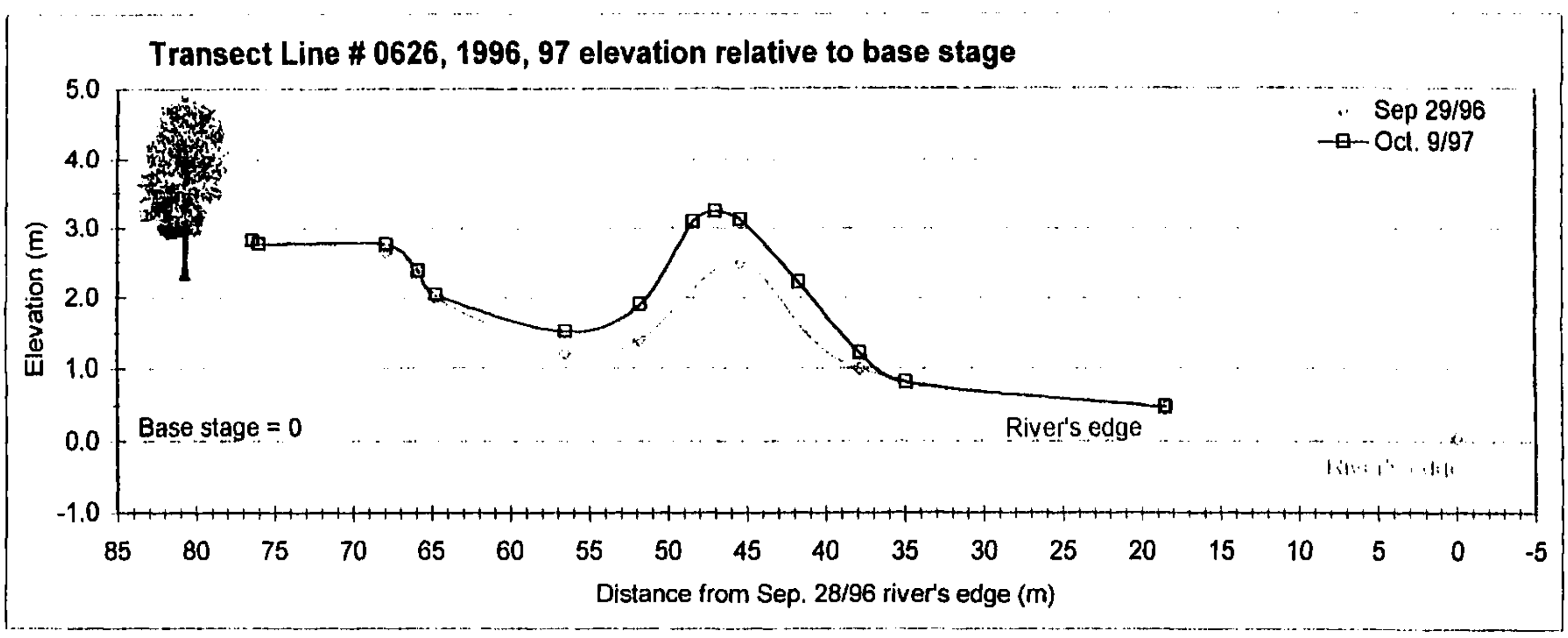


Transect Line # 0622, 1996, 97 elevation relative to base stage
Sep 28/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)

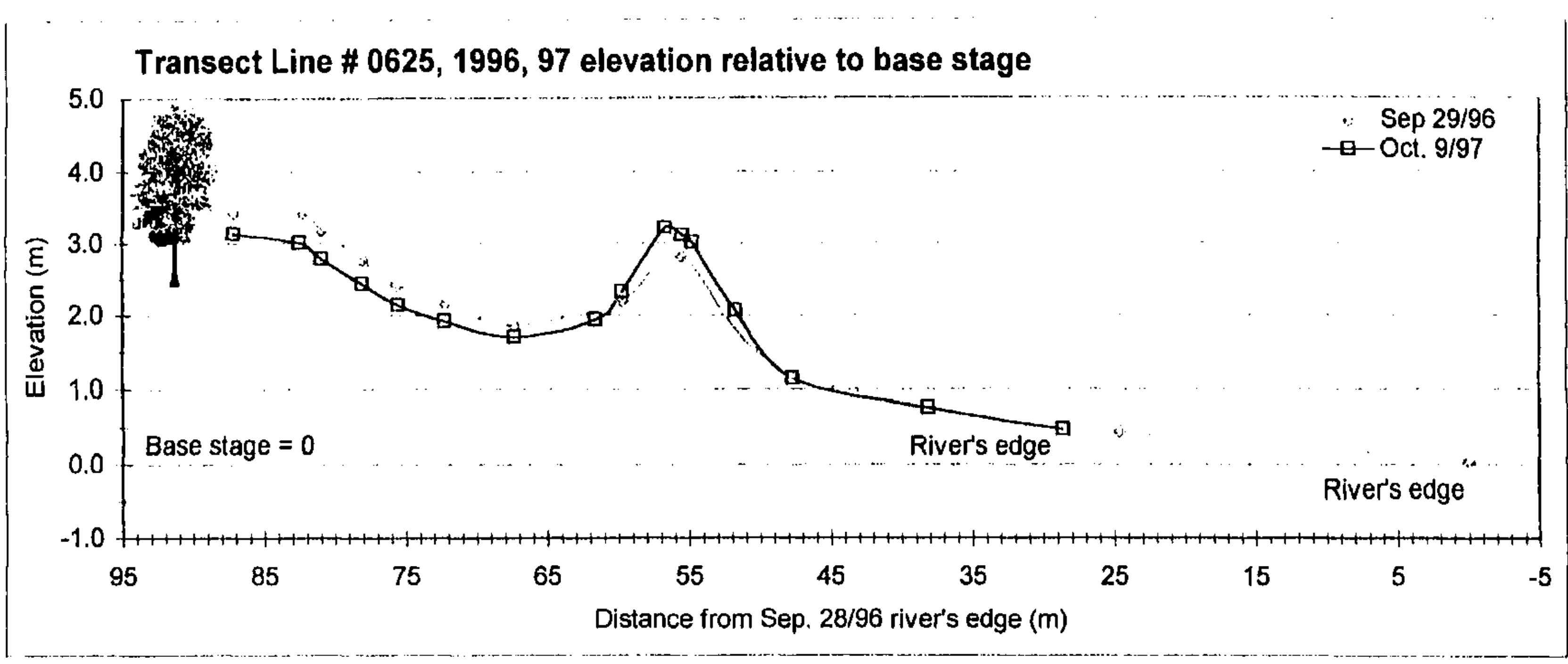


Transect Line # 0623, 1996, 97 elevation relative to base stage
Sep 28/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
135
115
95
75
55
35
15
-5
Distance from Sep. 28/96 river's edge (m)

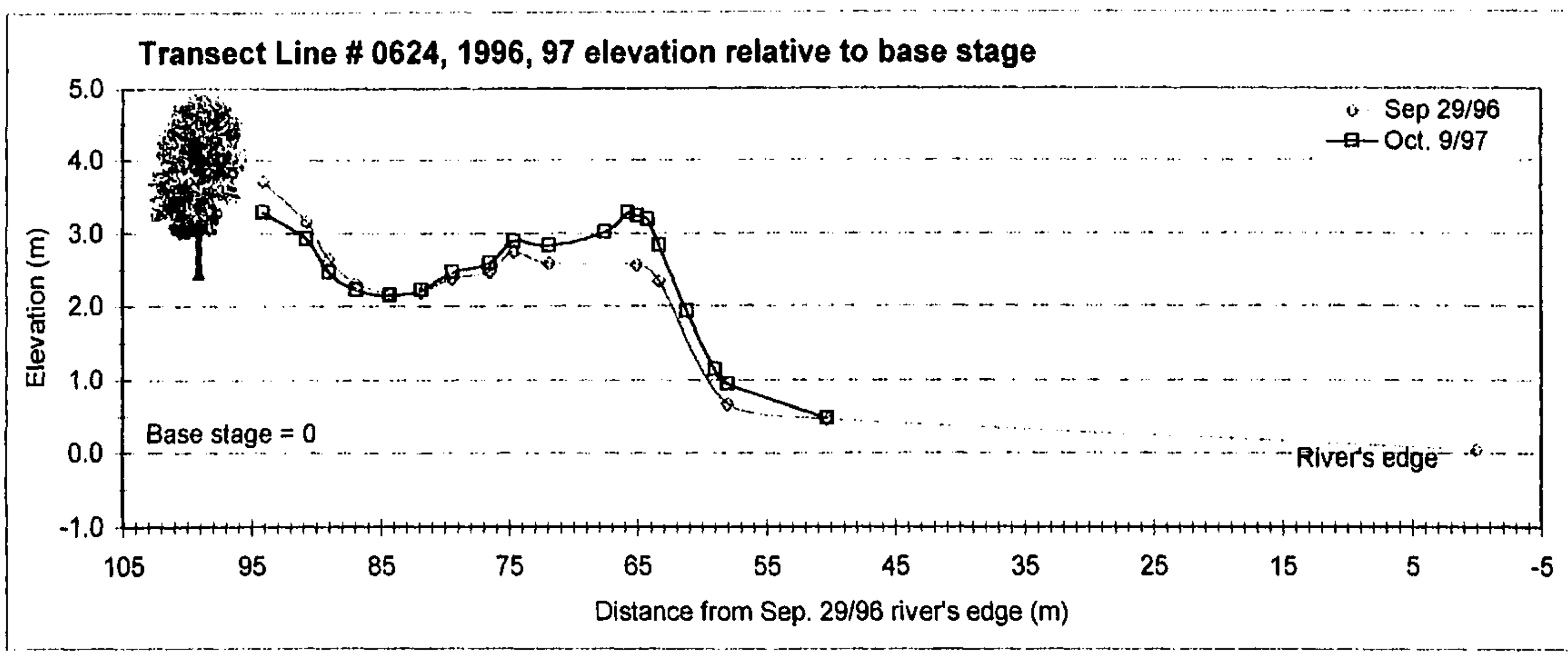
Upper Kootenay River Site 2, elevation graphs for 1996 and 1997



Transect Line # 0626, 1996, 97 elevation relative to base stage
Sep 29/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)

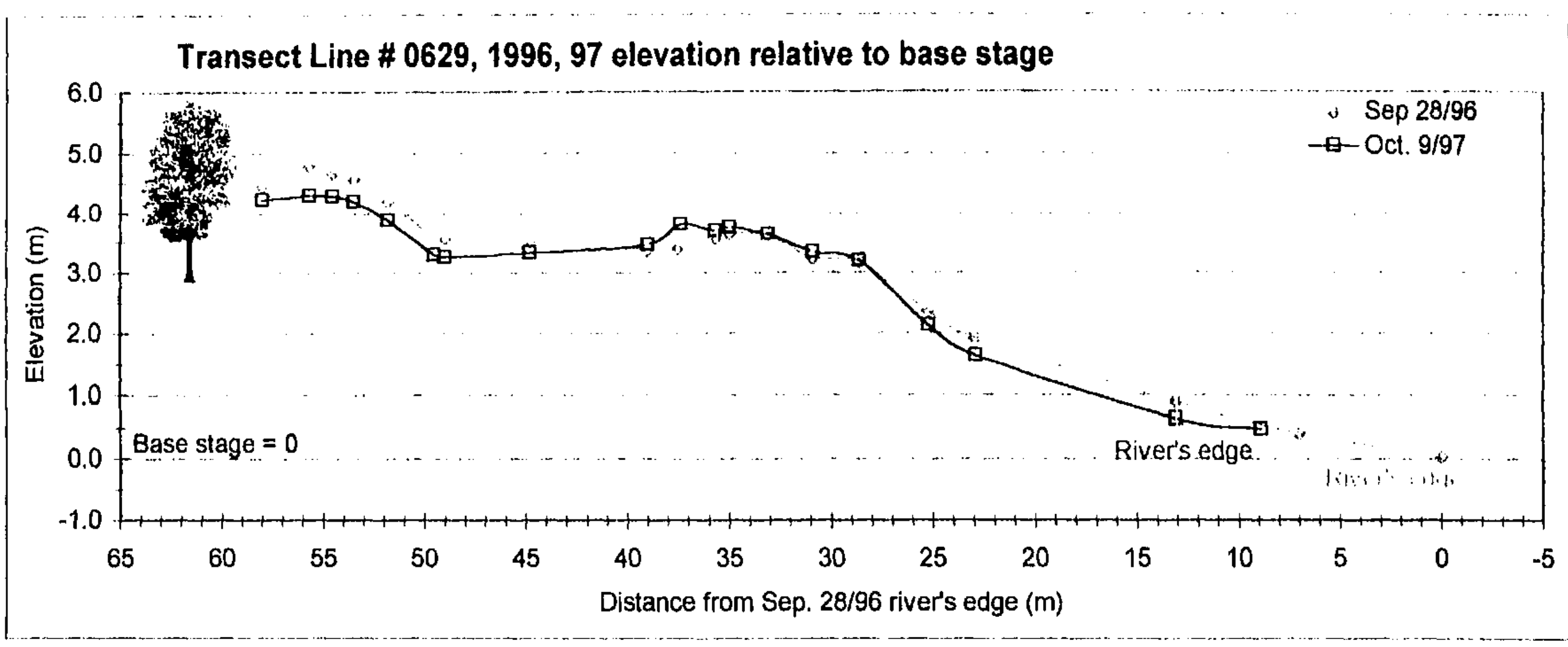


Transect Line # 0625, 1996, 97 elevation relative to base stage
Sep 29/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
River's edge
95
85
75
65
55
45
35
25
15
5
-5
Distance from Sep. 28/96 river's edge (m)

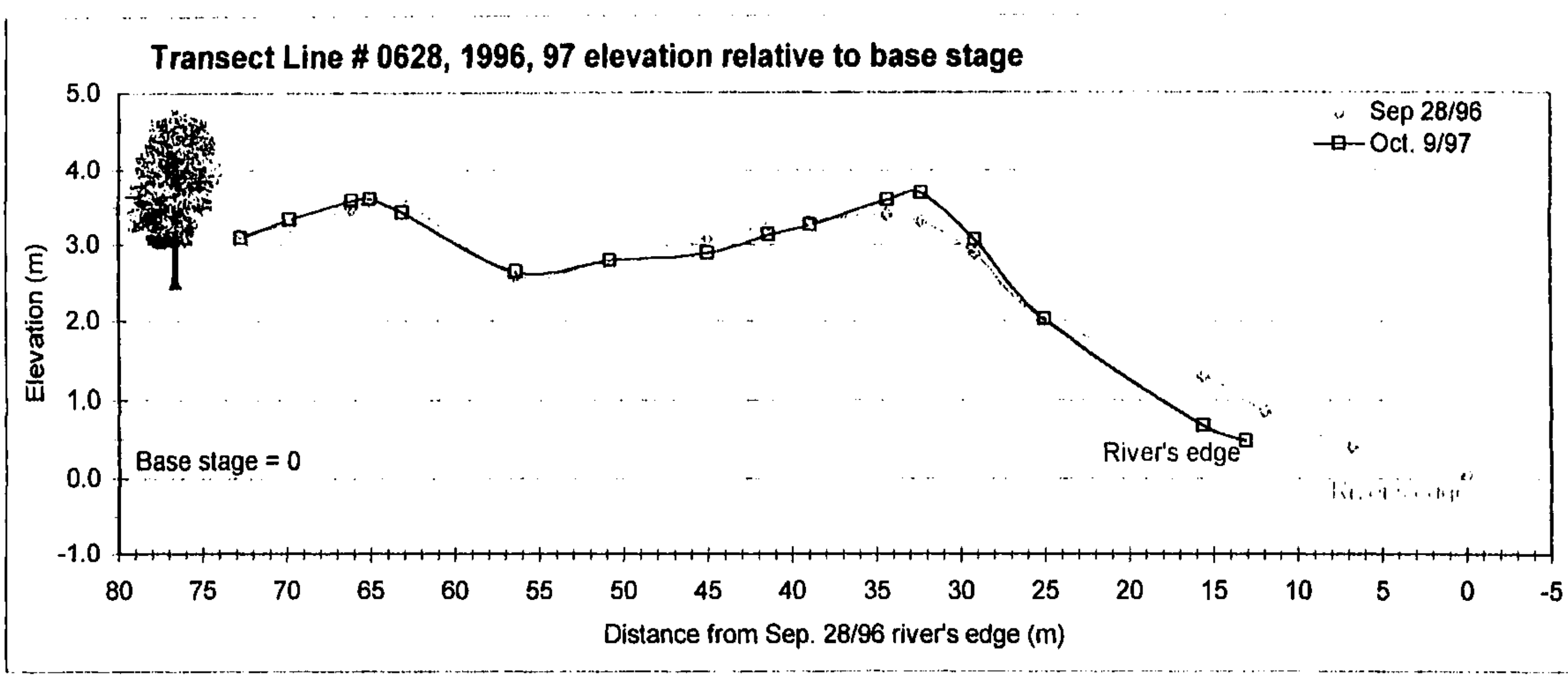


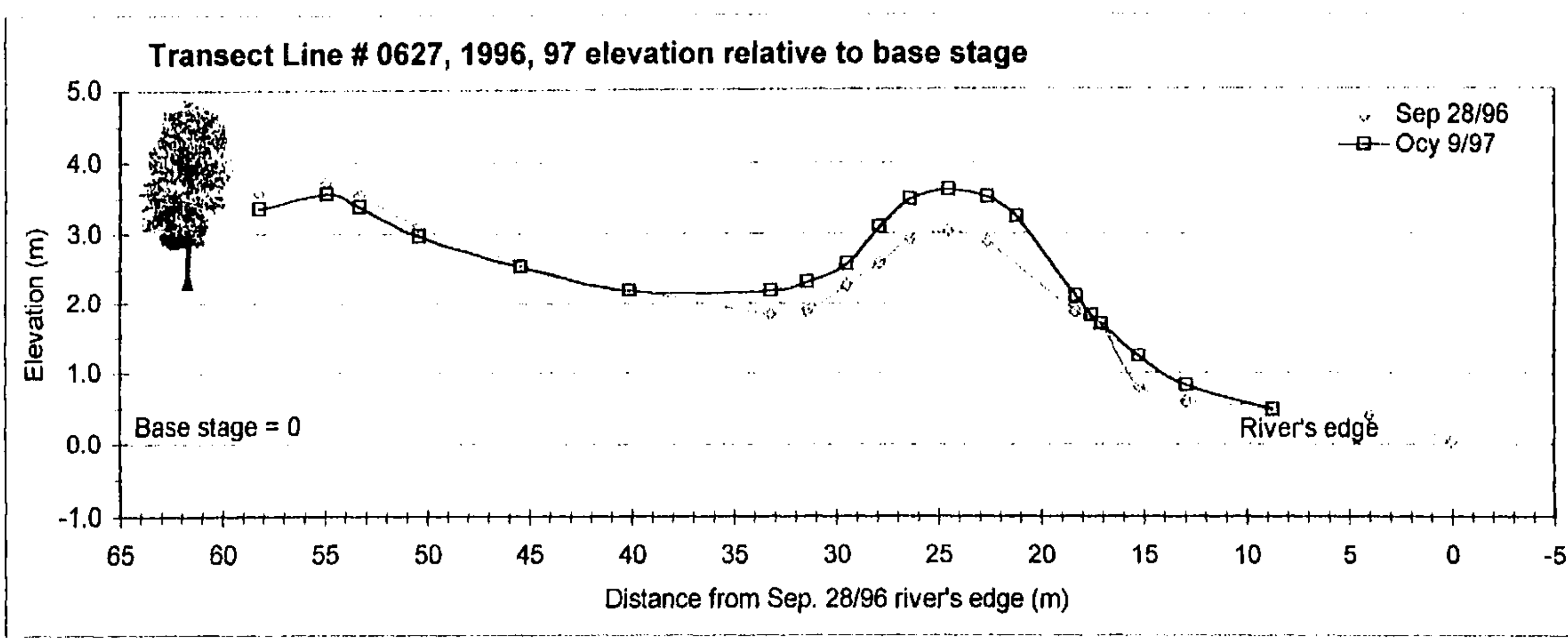
Transect Line # 0624, 1996, 97 elevation relative to base stage
Sep 29/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
105
95
85
75
65
55
45
35
25
15
5
-5
Distance from Sep. 29/96 river's edge (m)

Upper Kootenay River Site 3, elevation graphs for 1996 and 1997



Transect Line # 0629, 1996, 97 elevation relative to base stage
Sep 28/96
Oct. 9/97
Elevation (m)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)

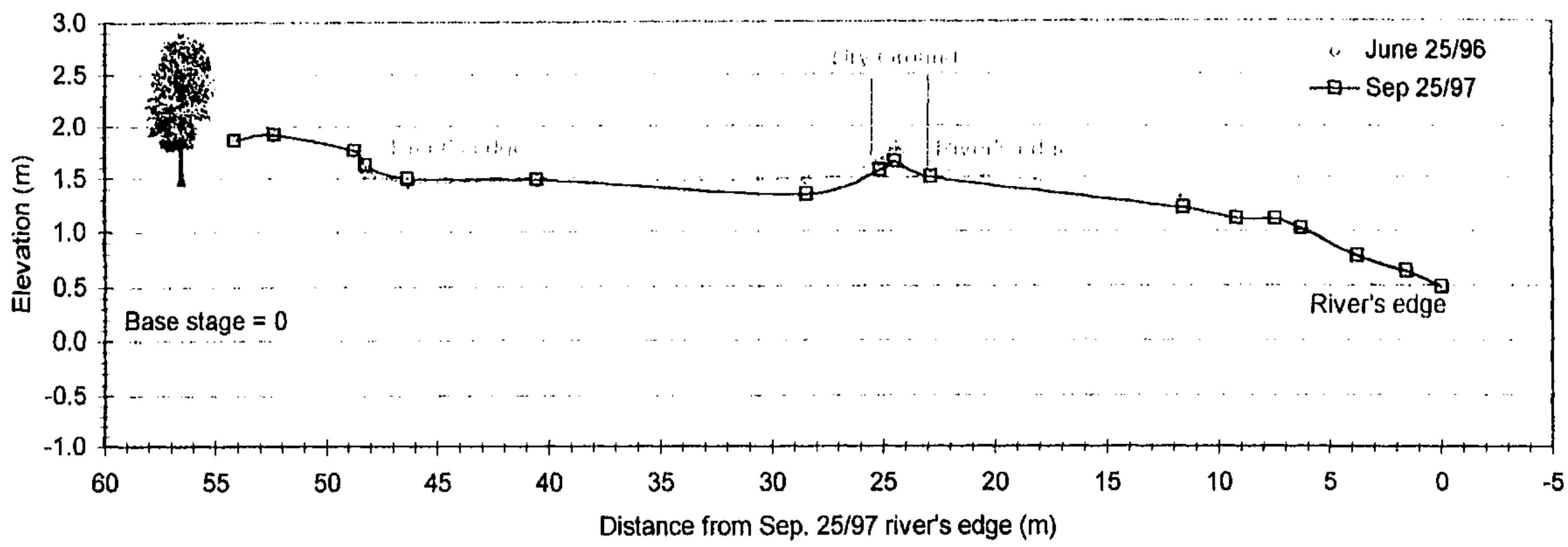

Transect Line # 0628, 1996, 97 elevation relative to base stage
Sep 28/96
Oct. 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)



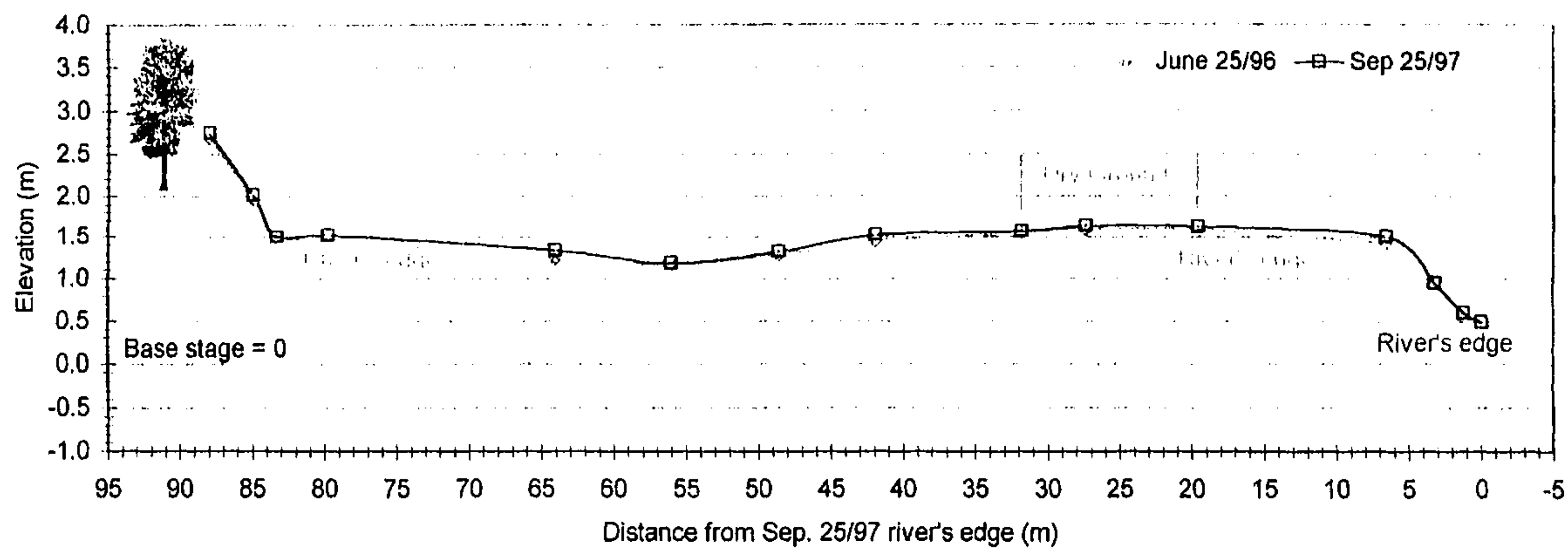
Transect Line # 0627, 1996, 97 elevation relative to base stage
Sep 28/96
Ocy 9/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 28/96 river's edge (m)

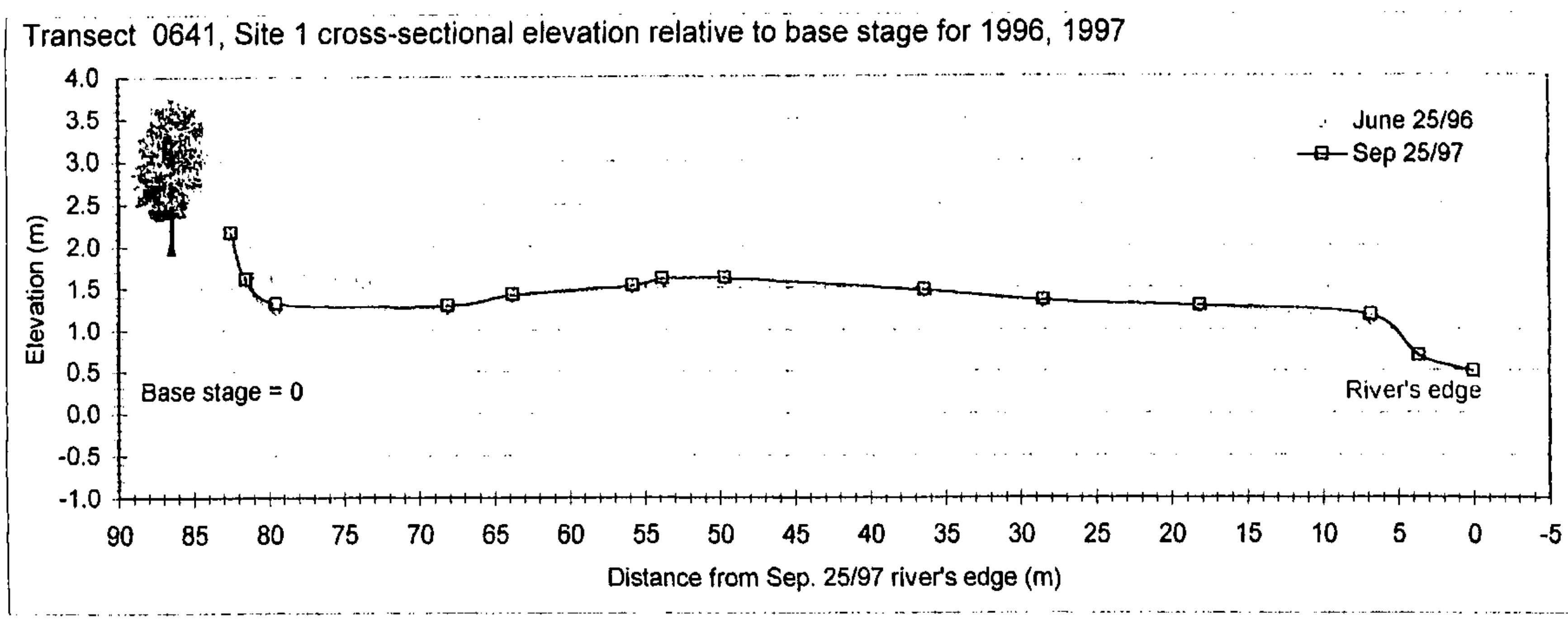
Lower Kootenai River Site 1, elevation graphs for 1996 and 1997

Transect 0643, Site 1, cross-sectional elevation relative to base stage for 1996 and 1997

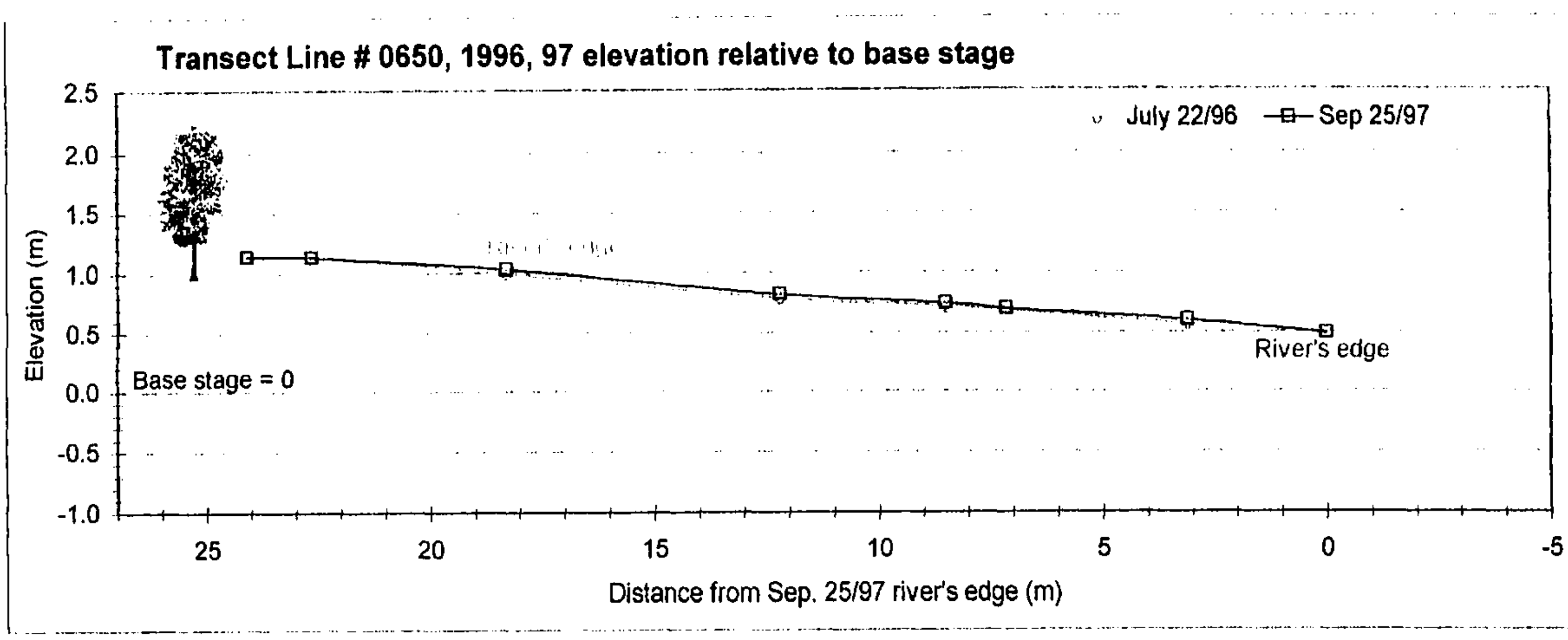


Transect 0642, Site 1, cross-sectional elevation relative to base stage for 1996 and 1997

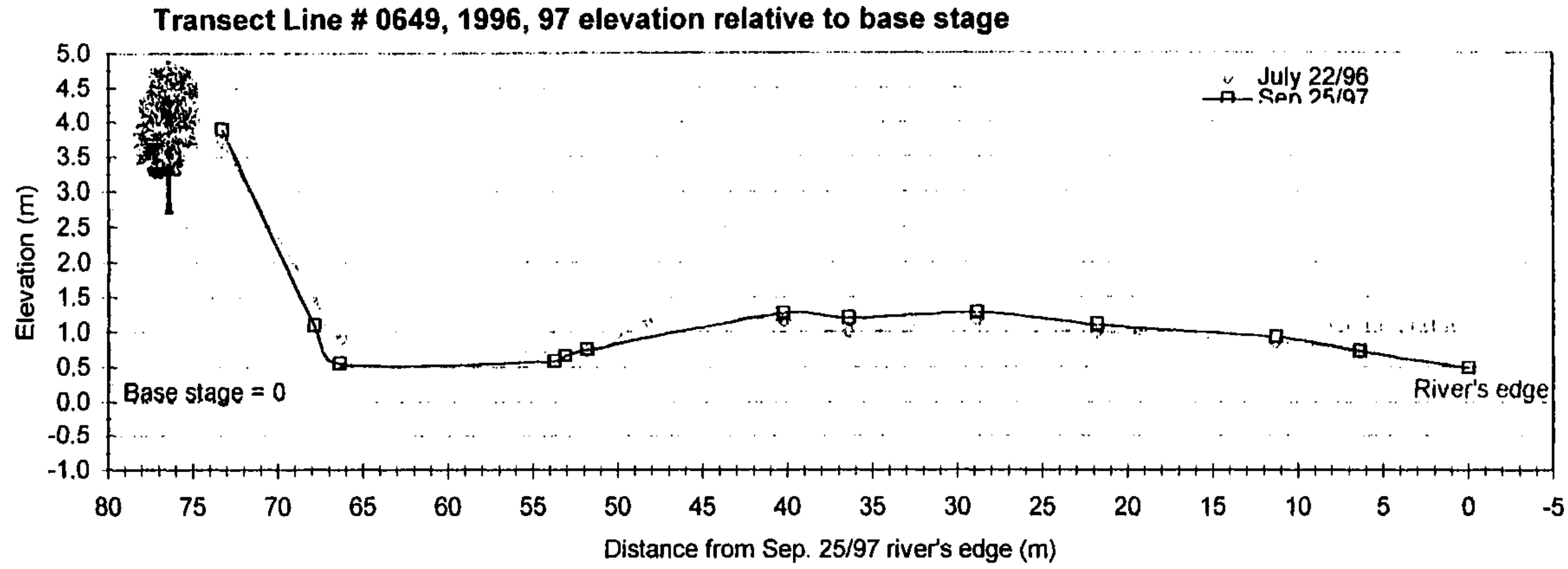



Transect 0641, Site 1 cross-sectional elevation relative to base stage for 1996, 1997
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Elevation (m)
June 25/96
Sep 25/97
Base stage = 0
River's edge
90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5
Distance from Sep. 25/97 river's edge (m)

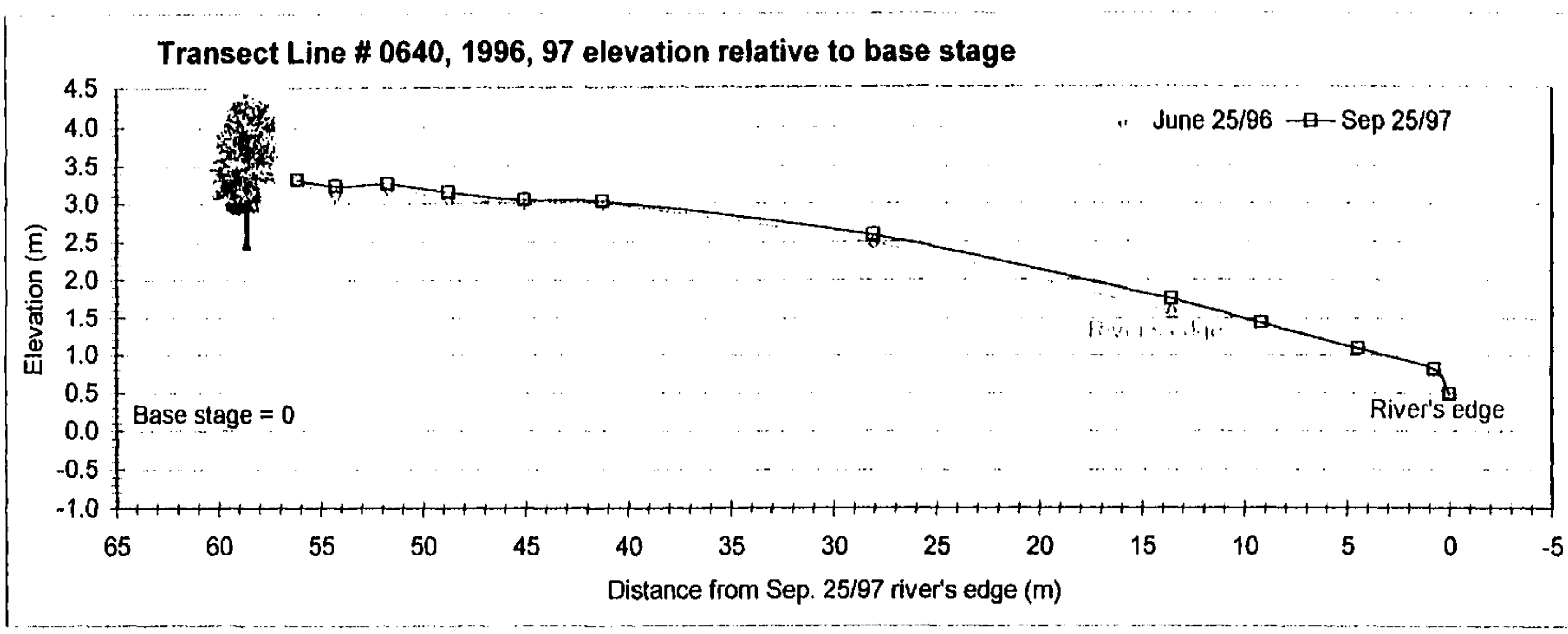
Lower Kootenai River Site 2, elevation graphs for 1996 and 1997


Transect Line # 0650, 1996, 97 elevation relative to base stage
July 22/96
Sep 25/97
River's edge
Base stage = 0
Elevation (m)
Distance from Sep. 25/97 river's edge (m)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
25
20
15
10
5
0
-5

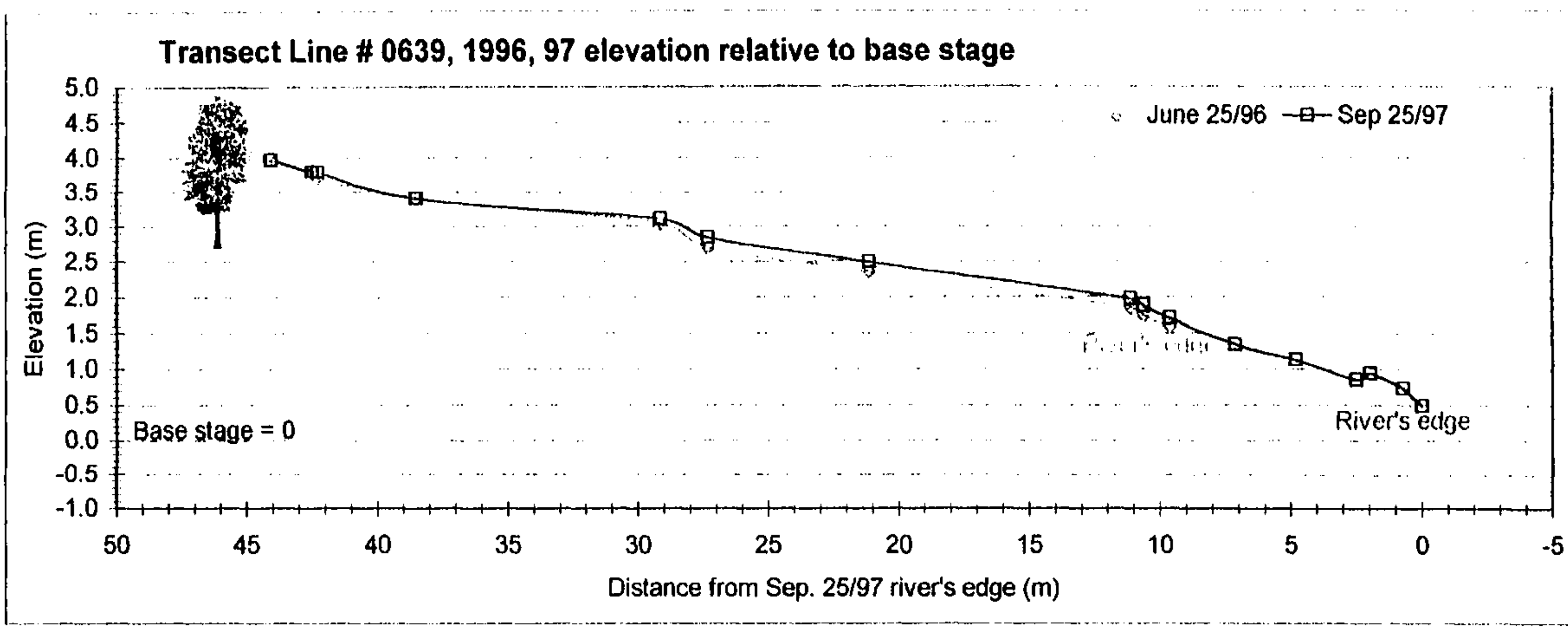
Transect Line # 0649, 1996, 97 elevation relative to base stage



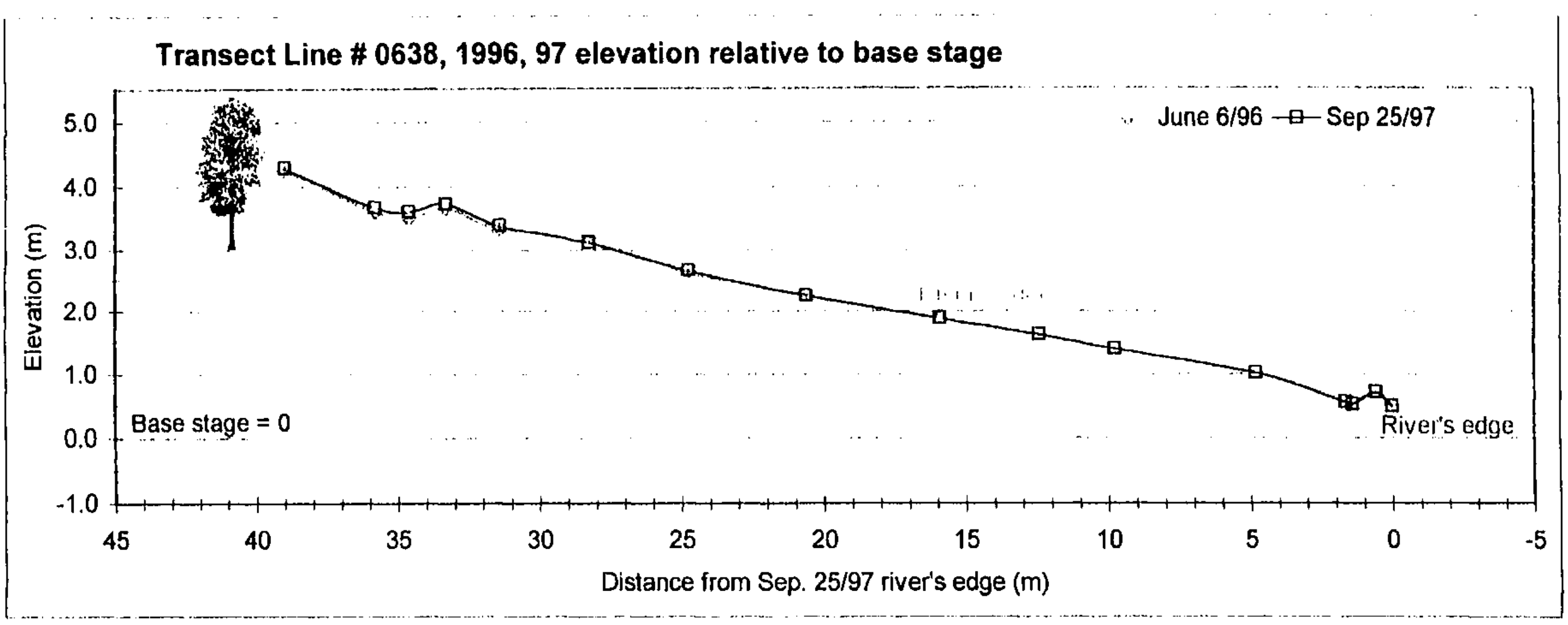
Lower Kootenai River Site 3, elevation graphs for 1996 and 1997



Transect Line # 0640, 1996, 97 elevation relative to base stage
June 25/96
Sep 25/97
Elevation (m)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Base stage = 0
River's edge
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 25/97 river's edge (m)

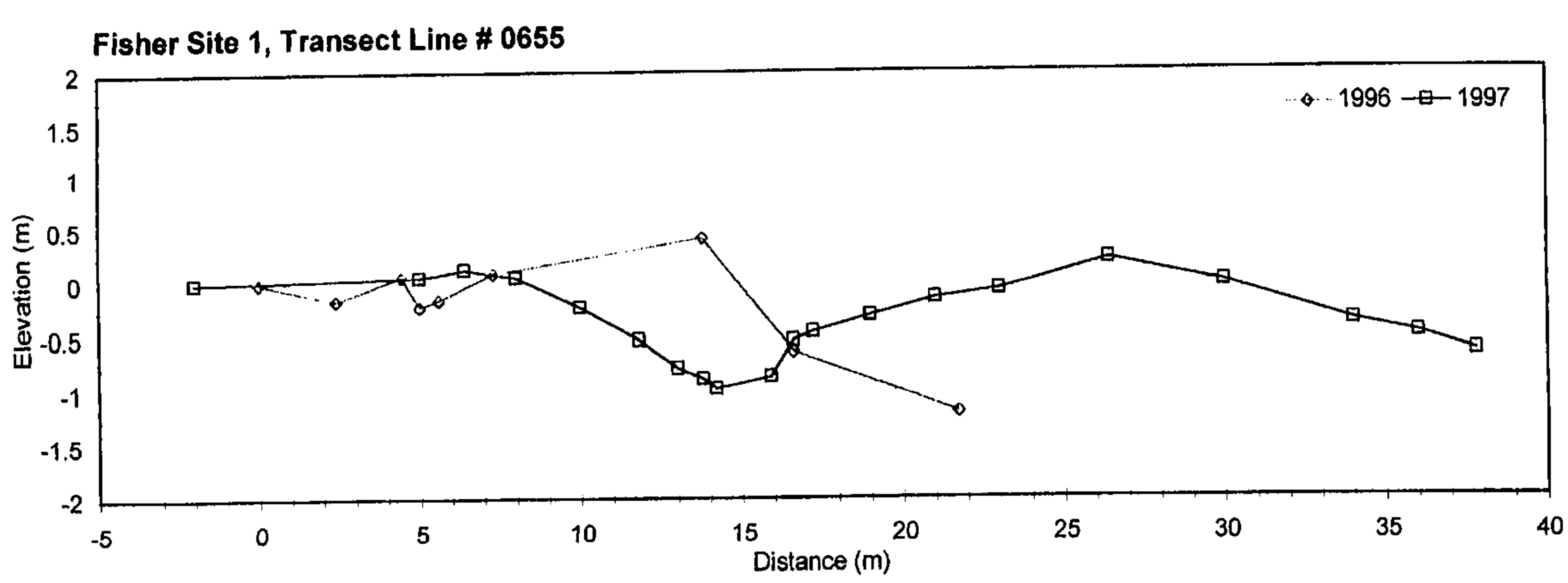


Transect Line # 0639, 1996, 97 elevation relative to base stage
June 25/96
Sep 25/97
Elevation (m)
Base stage = 0
River's edge
Distance from Sep. 25/97 river's edge (m)



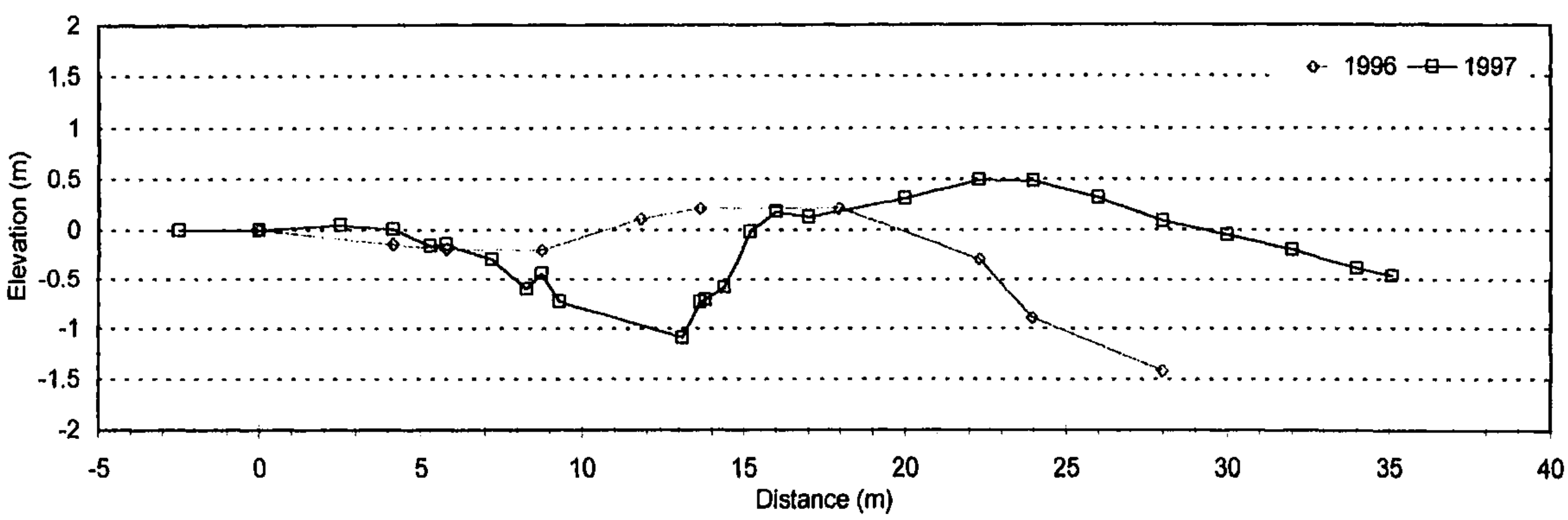
Transect Line # 0638, 1996, 97 elevation relative to base stage
June 6/96
Sep 25/97
Elevation (m)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Base stage = 0
River's edge
45
40
35
30
25
20
15
10
5
0
-5
Distance from Sep. 25/97 river's edge (m)

Fisher River Site 1, elevation graphs for 1996 and 1997

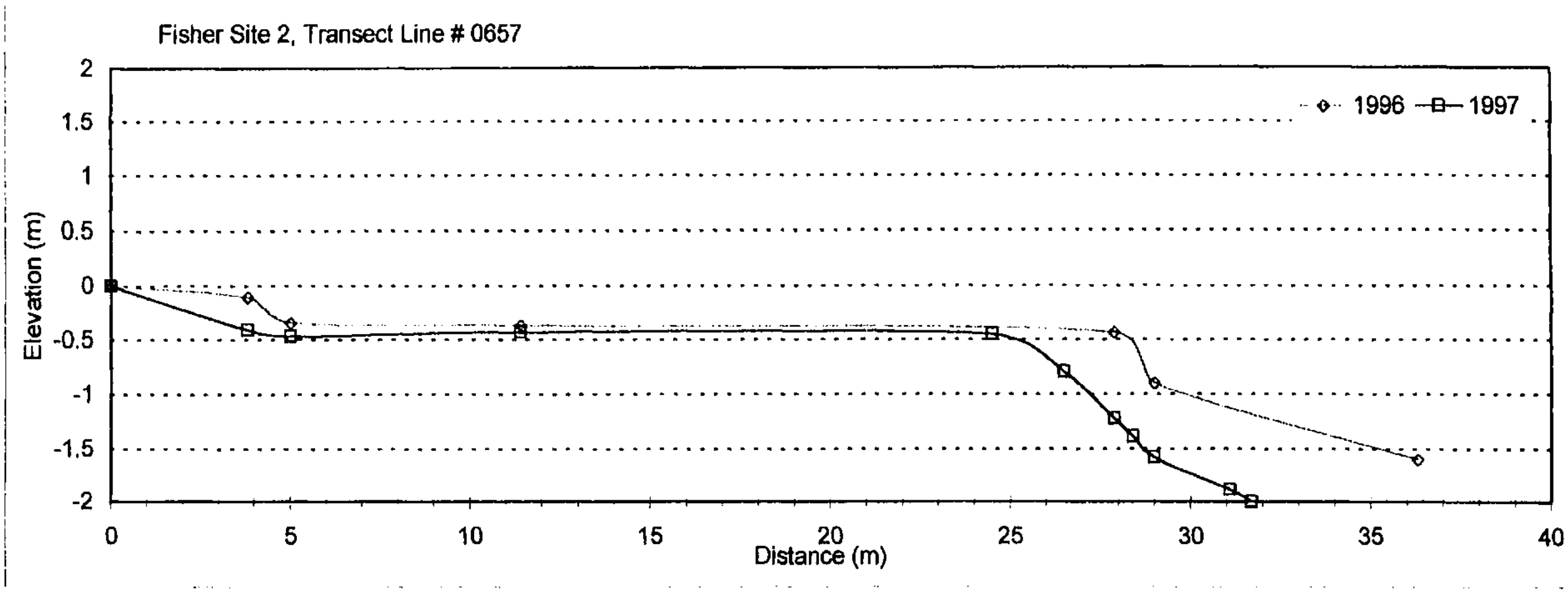


Fisher Site 1, Transect Line # 0655
1996
1997
Elevation (m)
Distance (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-5
0
5
10
15
20
25
30
35
40

Fisher Site 1, Transect Line # 0654

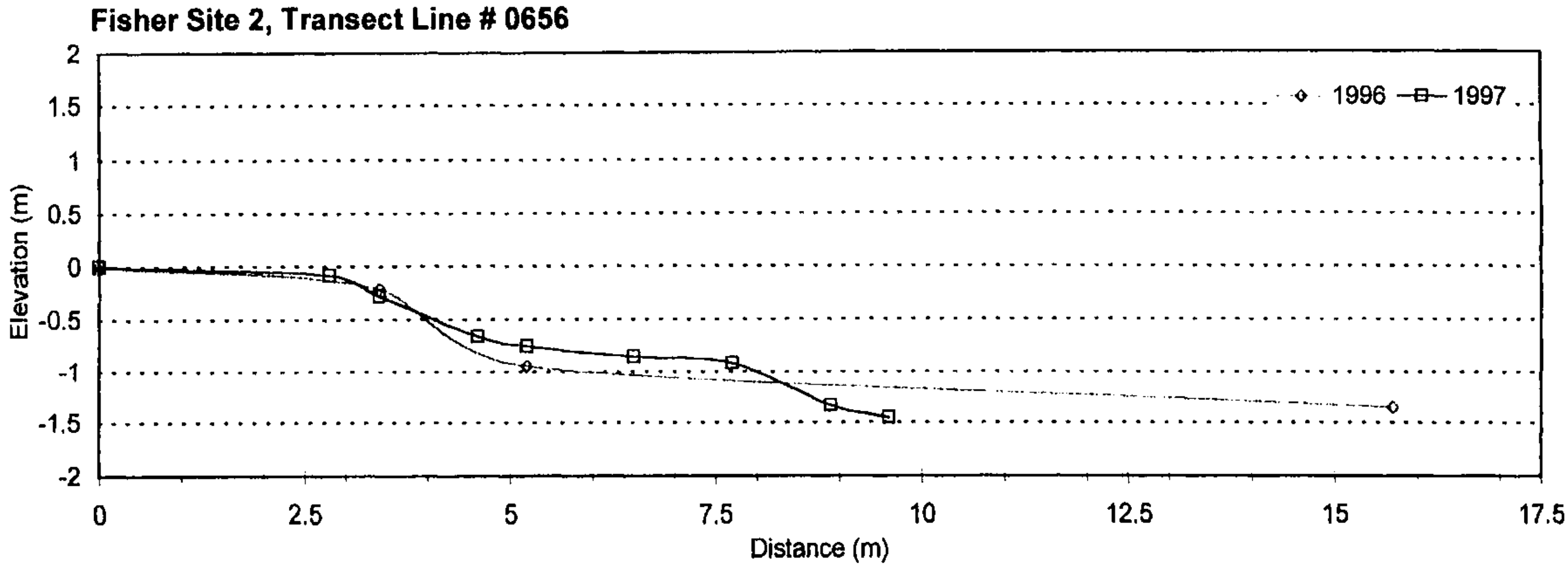


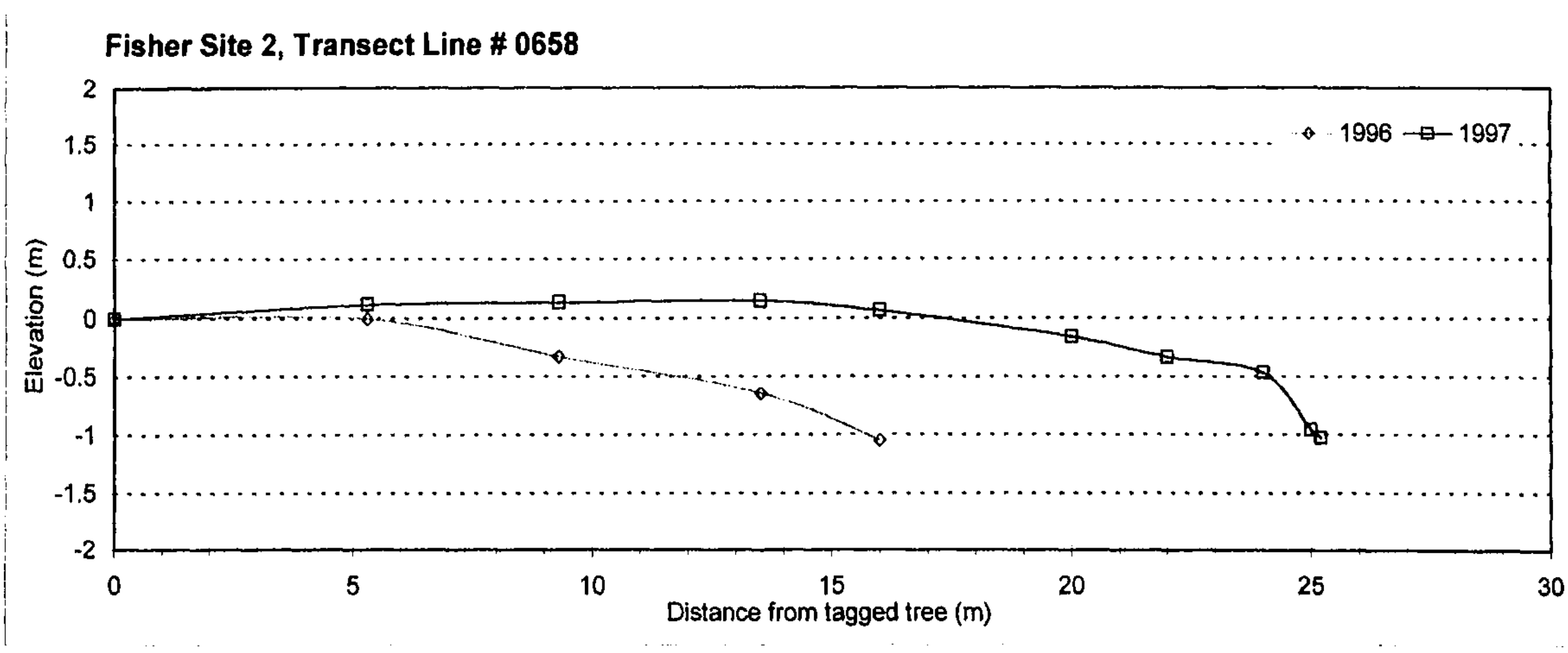
Fisher River Site 2, elevation graphs for 1996 and 1997



Fisher Site 2, Transect Line # 0657
1996
1997
Elevation (m)
Distance (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35
40

Fisher Site 2, Transect Line # 0656




Fisher Site 2, Transect Line # 0658
1996
1997
Elevation (m)
Distance from tagged tree (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30

Appendix 2: Statistical Analysis

Elk River Sites, height comparison for 1996 and 1997

ANOVA Table for Height

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	2435.068	2435.068	19.232	<.0001
Residual	172	21778.021	126.616		

Model II estimate of between component variance: 28.176
174 cases were omitted due to missing values.

Means Table for Height
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	108	16.149	11.792	1.135
1997	66	8.439	10.303	1.268

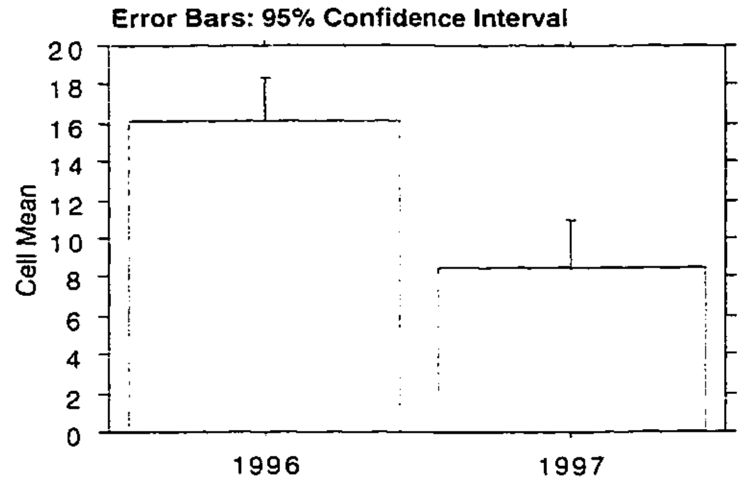
174 cases were omitted due to missing values.

Fisher's PLSD for Height
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	7.710	3.470	<.0001	S

174 cases were omitted due to missing values.

Interaction Bar Plot for Height
Effect: Year
Error Bars: 95% Confidence Interval



174 cases were omitted due to missing values.

Elk River Sites, Survival comparison for 1996 and 1997

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	162406.403	162406.403	18.264	<.0001
Residual	178	1582801.790	8892.145		

Model II estimate of between component variance: 1748.012
168 cases were omitted due to missing values.

Means Table for Survival
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	104	78.347	118.050	11.576
1997	76	17.531	44.334	5.085

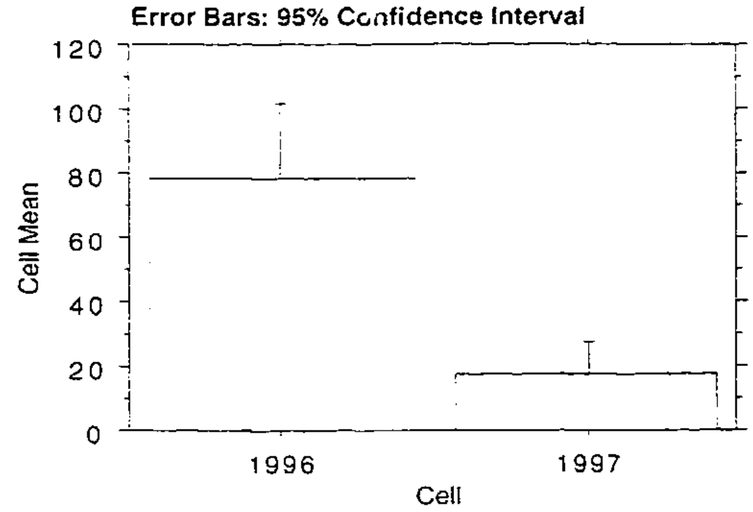
168 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	60.816	28.082	<.0001	S

168 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year
Error Bars: 95% Confidence Interval



168 cases were omitted due to missing values.

Elk River Sites, cobble versus fine substrate for 1996

ANOVA Table for Survival 96

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Substrate	1	1060.838	1060.838	.417	.5218
Residual	42	106751.016	2541.691		

Model II estimate of between component variance: •
12 cases were omitted due to missing values.

Means Table for Survival 96
Effect: Substrate

	Count	Mean	Std. Dev.	Std. Err.
C	18	64.787	47.135	11.110
F	26	54.800	52.529	10.302

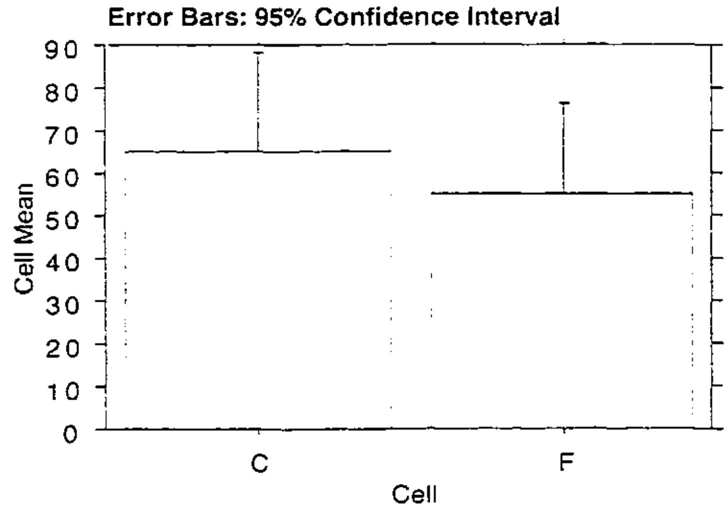
12 cases were omitted due to missing values.

Fisher's PLSD for Survival 96
Effect: Substrate
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
C, F	9.987	31.196	.5218

12 cases were omitted due to missing values.

Interaction Bar Plot for Survival 96
Effect: Substrate
Error Bars: 95% Confidence Interval



12 cases were omitted due to missing values.

Elk River Sites, cobble versus fine substrate for 1997

ANOVA Table for Survival 97

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Substrate	1	301.916	301.916	2.130	.1539
Residual	33	4677.059	141.729		

Model II estimate of between component variance: 11.98
21 cases were omitted due to missing values.

Means Table for Survival 97
Effect: Substrate

	Count	Mean	Std. Dev.	Std. Err.
C	9	0.000	0.000	0.000
F	26	6.720	13.678	2.682

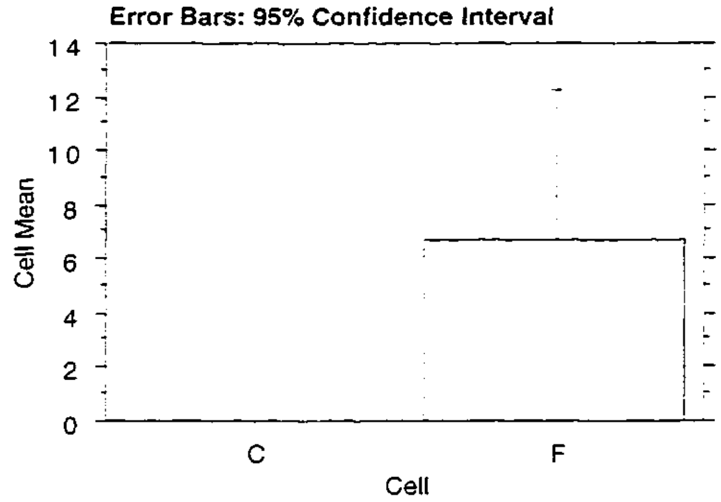
21 cases were omitted due to missing values.

Fisher's PLSD for Survival 97
Effect: Substrate
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
C, F	-6.720	9.367	.1539

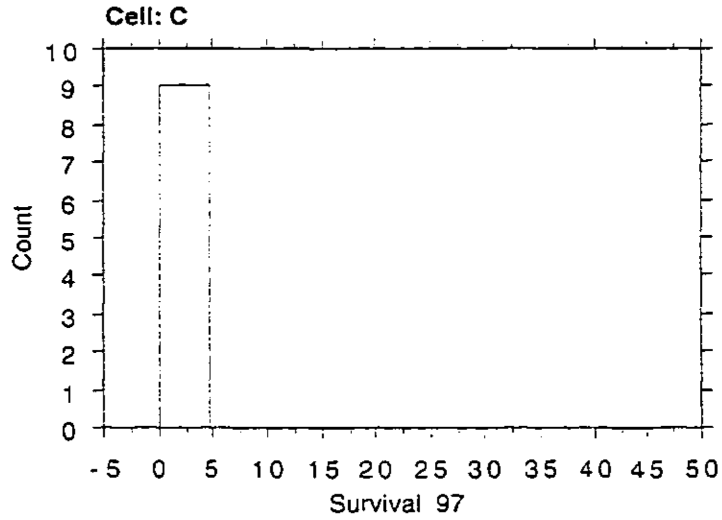
21 cases were omitted due to missing values.

Interaction Bar Plot for Survival 97
Effect: Substrate
Error Bars: 95% Confidence Interval

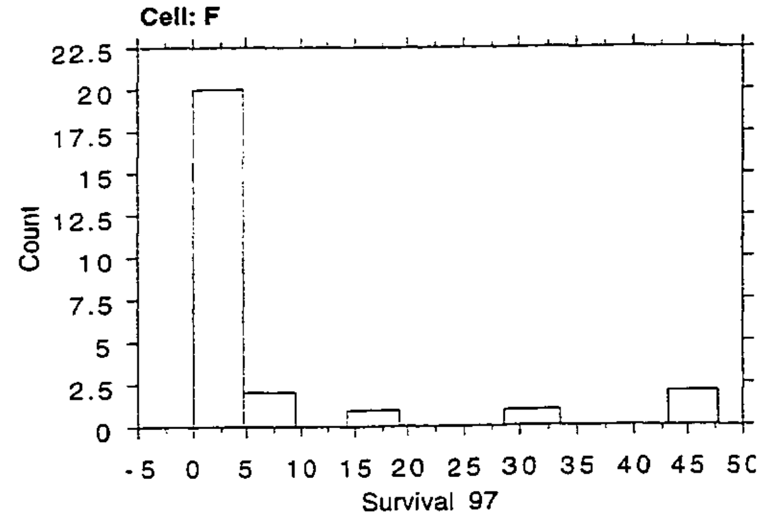


21 cases were omitted due to missing values.

Histogram
Split By: Substrate
Cell: C



Histogram
Split By: Substrate
Cell: F



Upper Kootenay versus Lower Kootenai for the amount of change (scour and deposition).

ANOVA Table for CHANGE
Row exclusion: ALLREACHELVSTATS

	DF	Sum of Squares	Mean Square	F-Value	P-Value
REACH	1	1.541	1.541	51.392	<.0001
SITE	2	.186	.093	3.099	.0474
REACH * SITE	2	.160	.080	2.668	.0720
Residual	192	5.756	.030		

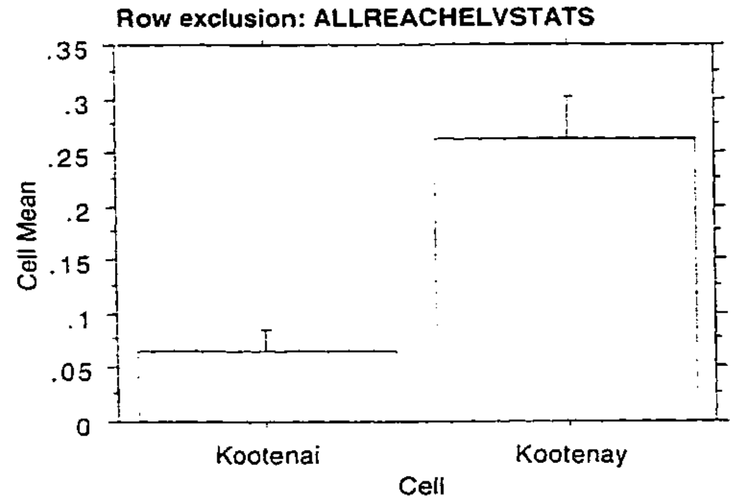
Means Table for CHANGE
Effect: REACH
Row exclusion: ALLREACHELVSTATS

	Count	Mean	Std. Dev.	Std. Err.
Kootenai	77	.067	.079	.009
Kootenay	121	.263	.218	.020

Fisher's PLSD for CHANGE
Effect: REACH
Significance Level: 5 %
Row exclusion: ALLREACHELVSTATS

	Mean Diff.	Crit. Diff	P-Value	
Kootenai, Kootenay	-.196	.050	<.0001	S

Interaction Bar Plot for CHANGE
Effect: REACH
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Means Table for CHANGE
Effect: SITE
Row exclusion: ALLREACHELVSTATS

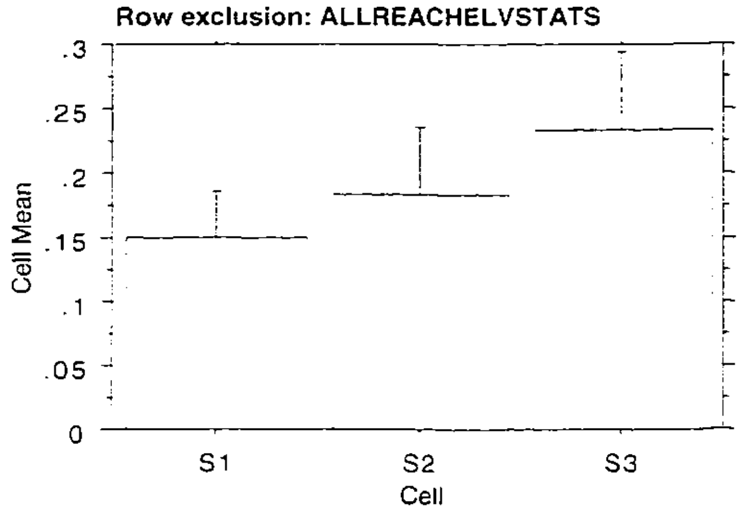
	Count	Mean	Std. Dev.	Std. Err.
S1	82	.150	.163	.018
S2	48	.184	.177	.026
S3	68	.233	.247	.030

Upper Kootenay versus Lower Kootenai for the amount of change (scour and deposition).

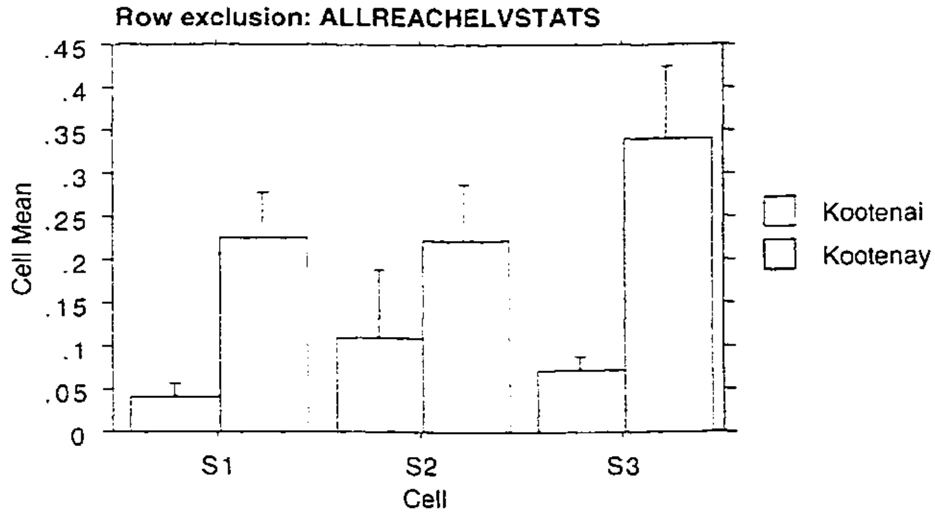
Means Table for CHANGE
Effect: REACH * SITE
Row exclusion: ALLREACHELVSTATS

	Count	Mean	Std. Dev.	Std. Err.
Kootenai, S1	34	.042	.040	.007
Kootenai, S2	16	.109	.147	.037
Kootenai, S3	27	.072	.040	.008
Kootenay, S1	48	.226	.175	.025
Kootenay, S2	32	.221	.181	.032
Kootenay, S3	41	.339	.269	.042

Interaction Bar Plot for CHANGE
Effect: SITE
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Interaction Bar Plot for CHANGE
Effect: REACH * SITE
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Upper Kootenay amount of change (scour and deposition) between transects.

ANOVA Table for CHANGE
Row exclusion: ALLREACHELVSTATS

	DF	Sum of Squares	Mean Square	F-Value	P-Value
TRANSECT	2	.031	.015	.319	.7277
Residual	118	5.667	.048		

Model II estimate of between component variance: •

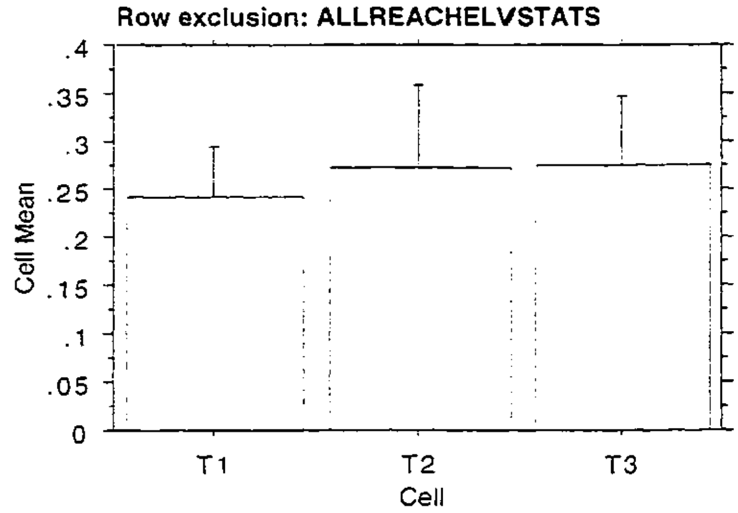
Means Table for CHANGE
Effect: TRANSECT
Row exclusion: ALLREACHELVSTATS

	Count	Mean	Std. Dev.	Std. Err.
T1	42	.241	.171	.026
T2	38	.273	.257	.042
T3	41	.276	.225	.035

Fisher's PLSD for CHANGE
Effect: TRANSECT
Significance Level: 5 %
Row exclusion: ALLREACHELVSTATS

	Mean Diff.	Crit. Diff	P-Value
T1, T2	-.032	.097	.5213
T1, T3	-.035	.095	.4697
T2, T3	-.003	.098	.9463

Interaction Bar Plot for CHANGE
Effect: TRANSECT
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Lower Kootenai amount of change (scour and deposition) between transects.

ANOVA Table for CHANGE
Row exclusion: ALLREACHELVSTATS

	DF	Sum of Squares	Mean Square	F-Value	P-Value
TRANSECT	2	.011	.006	.920	.4029
Residual	74	.459	.006		

Model II estimate of between component variance: •

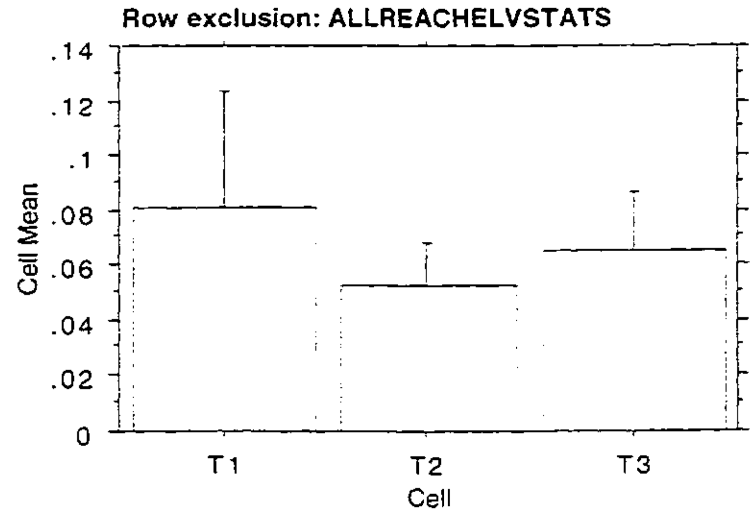
Means Table for CHANGE
Effect: TRANSECT
Row exclusion: ALLREACHELVSTATS

	Count	Mean	Std. Dev.	Std. Err.
T1	30	.080	.114	.021
T2	28	.052	.041	.008
T3	19	.065	.045	.010

Fisher's PLSD for CHANGE
Effect: TRANSECT
Significance Level: 5 %
Row exclusion: ALLREACHELVSTATS

	Mean Diff.	Crit. Diff	P-Value
T1, T2	.028	.041	.1796
T1, T3	.015	.046	.5166
T2, T3	-.013	.047	.5807

Interaction Bar Plot for CHANGE
Effect: TRANSECT
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Upper Kootenay Sites, height comparison for 1996 to 1997 seedlings

ANOVA Table for Height 96

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	23399.981	23399.981	26.767	<.0001
Residual	85	74306.968	874.200		

Model II estimate of between component variance: 518.451
67 cases were omitted due to missing values.

Means Table for Height 96
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	42	20.302	25.190	3.887
1997	45	53.122	33.129	4.939

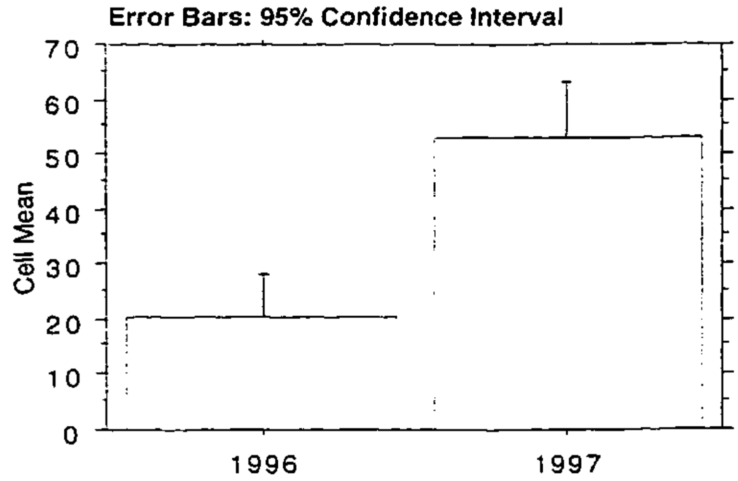
67 cases were omitted due to missing values.

Fisher's PLSD for Height 96
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	-32.820	12.613	<.0001	S

67 cases were omitted due to missing values.

Interaction Bar Plot for Height 96
Effect: Year
Error Bars: 95% Confidence Interval



67 cases were omitted due to missing values.

Upper Kootenay Sites, initial seedling densities for 1996 and 1997

ANOVA Table for Init. Den

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	3070878.877	3070878.877	57.823	<.0001
Residual	71	3770663.370	53107.935		

Model II estimate of between component variance: 83445.939
81 cases were omitted due to missing values.

Means Table for Init. Den
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	40	78.200	97.975	15.491
1997	33	490.303	325.783	56.711

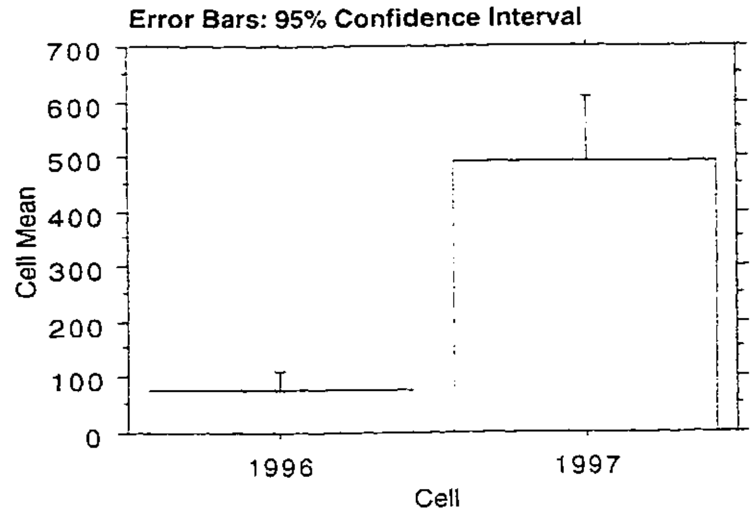
81 cases were omitted due to missing values.

Fisher's PLSD for Init. Den
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	-412.103	108.061	<.0001	S

81 cases were omitted due to missing values.

Interaction Bar Plot for Init. Den
Effect: Year
Error Bars: 95% Confidence Interval



81 cases were omitted due to missing values.

Upper Kootenay Sites, final (fall) seedling densities for 1996 and 1997

ANOVA Table for Final Den

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	479629.562	479629.562	23.656	<.0001
Residual	85	1723370.254	20274.944		

Model II estimate of between component variance: 10572.448
67 cases were omitted due to missing values.

Means Table for Final Den
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	42	33.190	54.975	8.483
1997	45	181.778	190.660	28.422

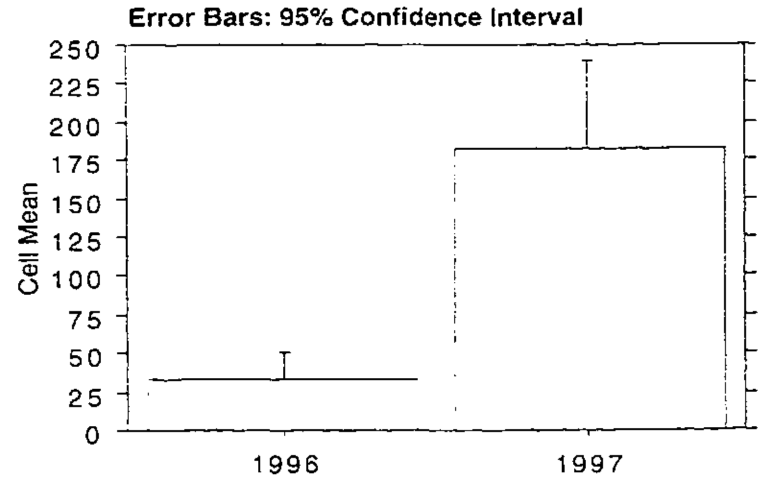
67 cases were omitted due to missing values.

Fisher's PLSD for Final Den
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	-148.587	60.741	<.0001	S

67 cases were omitted due to missing values.

Interaction Bar Plot for Final Den
Effect: Year
Error Bars: 95% Confidence Interval



67 cases were omitted due to missing values.

Upper Kootenay Sites, seedling survival for 1996 and 1997

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	81.983	81.983	.022	.8834
Residual	68	257361.219	3784.724		

Model II estimate of between component variance: •
84 cases were omitted due to missing values.

Means Table for Survival
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	39	47.799	69.565	11.139
1997	31	49.978	49.487	8.888

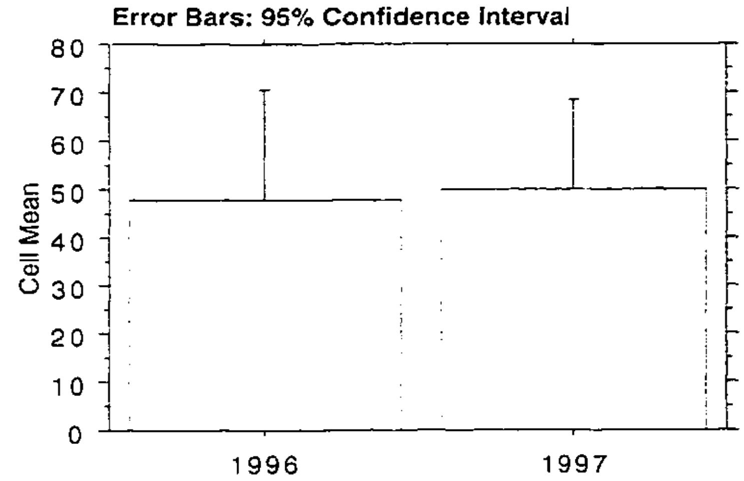
84 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
1996, 1997	-2.179	29.539	.8834

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year
Error Bars: 95% Confidence Interval



84 cases were omitted due to missing values.

Upper Kootenay Sites, seedling survival comparison for year (1996, 1997) and transect

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	634.956	634.956	.170	.6814
Transect	2	12920.719	6460.359	1.731	.1853
Year * Transect	2	5506.014	2753.007	.738	.4823
Residual	64	238856.689	3732.136		

84 cases were omitted due to missing values.

Means Table for Survival
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	39	47.799	69.565	11.139
1997	31	49.978	49.487	8.888

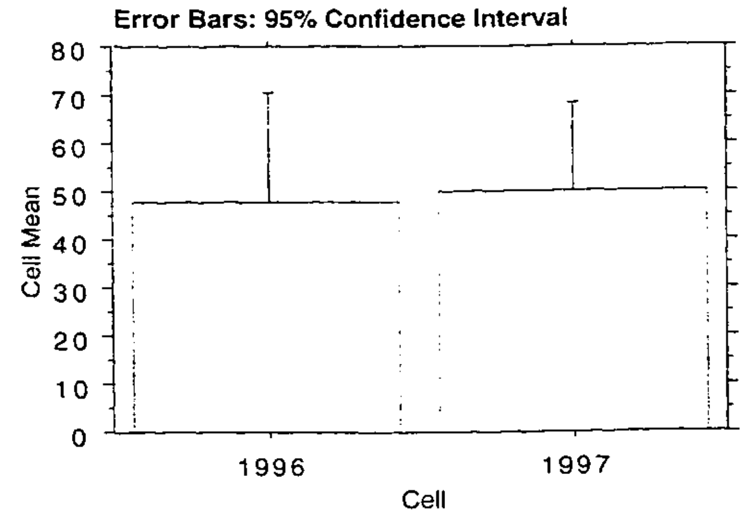
84 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
1996, 1997	-2.179	29.366	.8826

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year
Error Bars: 95% Confidence Interval



84 cases were omitted due to missing values.

Upper Kootenay Sites, seedling survival comparison for year (1996, 1997) and transect

Means Table for Survival
Effect: Transect

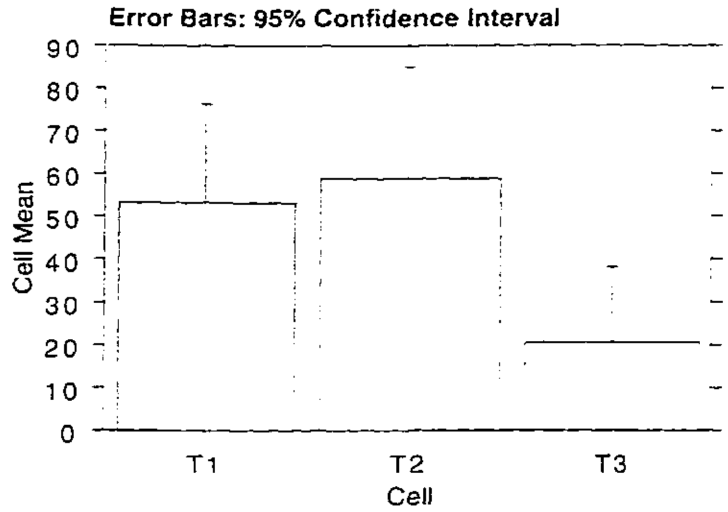
	Count	Mean	Std. Dev.	Std. Err.
T1	35	52.969	68.391	11.560
T2	22	58.631	59.913	12.774
T3	13	20.743	28.961	8.032

84 cases were omitted due to missing values.

Means Table for Survival
Effect: Year * Transect

	Count	Mean	Std. Dev.	Std. Err.
1996, T1	20	59.137	85.799	19.185
1996, T2	12	46.920	53.876	15.553
1996, T3	7	16.913	21.751	8.221
1997, T1	15	44.746	35.239	9.099
1997, T2	10	72.684	66.527	21.038
1997, T3	6	25.211	37.427	15.280

Interaction Bar Plot for Survival
Effect: Transect
Error Bars: 95% Confidence Interval



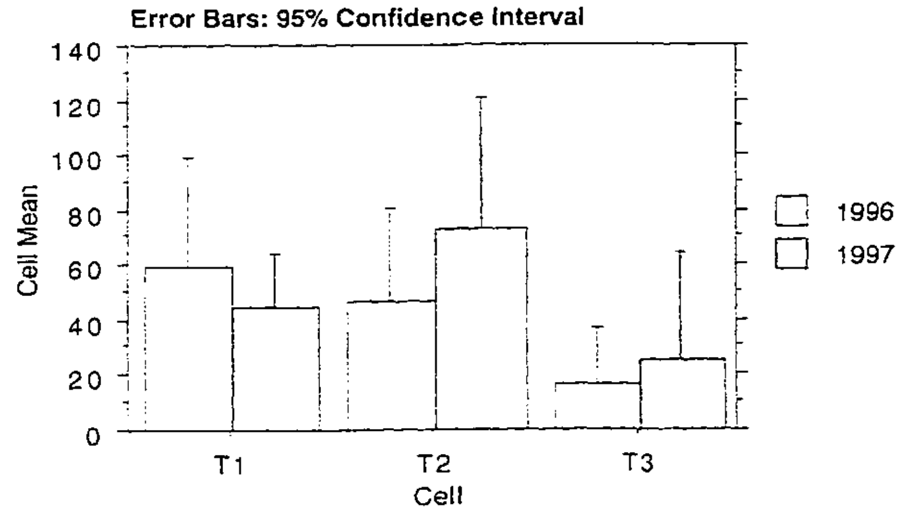
84 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Transect
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
T1, T2	-5.661	33.205	.7345
T1, T3	32.227	39.640	.1093
T2, T3	37.888	42.694	.0810

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year * Transect
Error Bars: 95% Confidence Interval



84 cases were omitted due to missing values.

Upper Kootenay Sites, seedling survival comparison for year (1996, 1997) and site

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	3.180	3.180	.001	.9757
Site	2	36586.440	18293.220	5.375	.0070
Year * Site	2	1546.826	773.413	.227	.7974
Residual	64	217808.625	3403.260		

84 cases were omitted due to missing values.

Means Table for Survival
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	39	47.799	69.565	11.139
1997	31	49.978	49.487	8.888

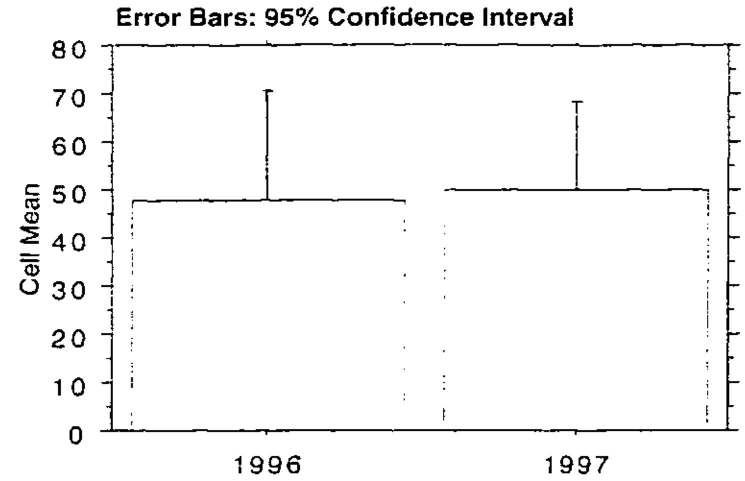
84 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
1996, 1997	-2.179	28.043	.8771

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year
Error Bars: 95% Confidence Interval



84 cases were omitted due to missing values.

Upper Kootenay Sites, seedling survival comparison for year and site.

Means Table for Survival
Effect: Year * Site

	Count	Mean	Std. Dev.	Std. Err.
1996, S3	16	21.528	36.111	9.028
1996, S2	11	64.934	89.165	26.884
1996, S1	12	67.120	77.505	22.374
1997, S3	12	19.107	23.218	6.702
1997, S2	12	77.585	59.249	17.104
1997, S1	7	55.572	36.795	13.907

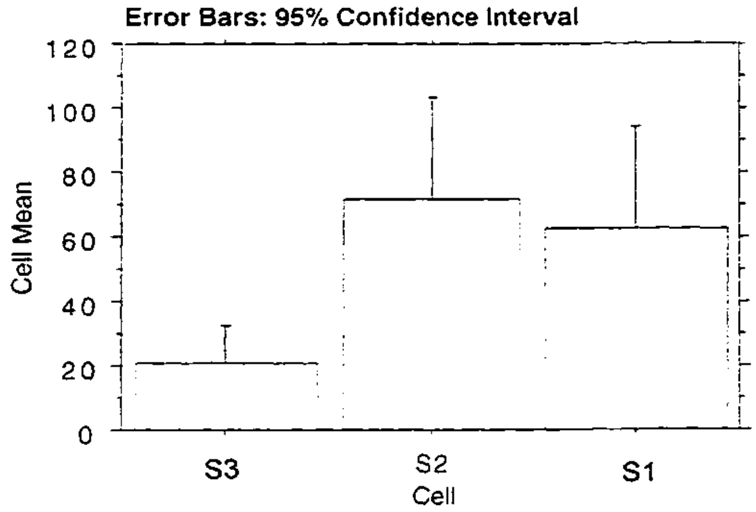
84 cases were omitted due to missing values.

Means Table for Survival
Effect: Site

	Count	Mean	Std. Dev.	Std. Err.
S3	28	20.490	30.750	5.811
S2	23	71.534	73.558	15.338
S1	19	62.865	64.459	14.788

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Site
Error Bars: 95% Confidence Interval



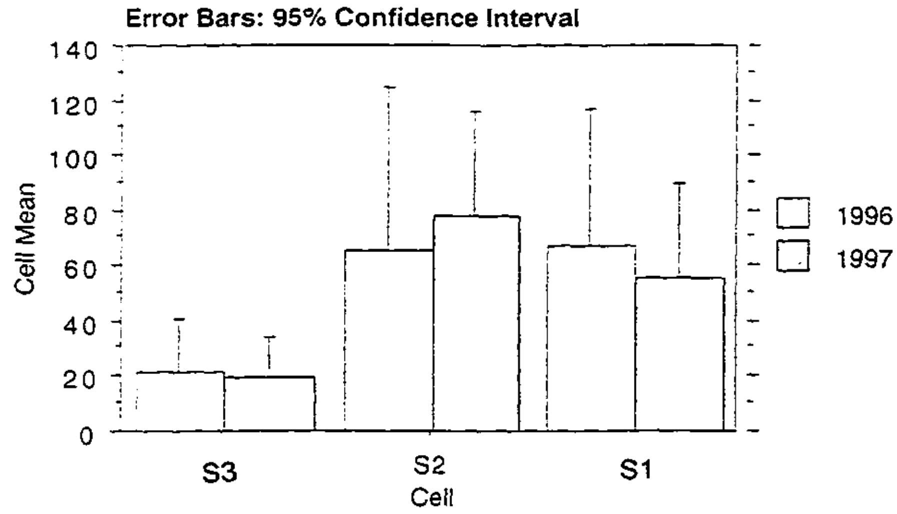
84 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Site
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
S3, S2	-51.044	32.796	.0028	S
S1, S3	-42.375	34.640	.0173	S
S2, S1	8.669	36.130	.6333	

84 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Year * Site
Error Bars: 95% Confidence Interval



84 cases were omitted due to missing values.

Fisher versus Lower Kootenai, amount of change (scour and deposition) that occurred

ANOVA Table for CHANGE
Row exclusion: ALLREACHELVSTATS

	DF	Sum of Squares	Mean Square	F-Value	P-Value
REACH	1	6.492	6.492	70.775	<.0001
Residual	129	11.833	.092		

Model II estimate of between component variance: .101

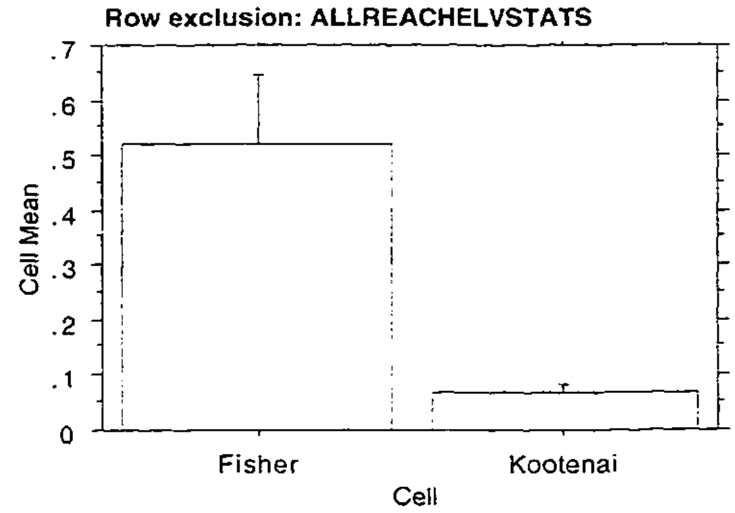
Means Table for CHANGE
Effect: REACH
Row exclusion: ALLREACHELVSTATS

	Count	Mean	Std. Dev.	Std. Err.
Fisher	54	.519	.463	.063
Kootenai	77	.067	.079	.009

Fisher's PLSD for CHANGE
Effect: REACH
Significance Level: 5 %
Row exclusion: ALLREACHELVSTATS

	Mean Diff.	Crit. Diff	P-Value	
Fisher, Kootenai	.452	.106	<.0001	S

Interaction Bar Plot for CHANGE
Effect: REACH
Error Bars: 95% Confidence Interval
Row exclusion: ALLREACHELVSTATS



Fisher Sites, initial seedling densities for 1996 and 1997 compared

ANOVA Table for Initial Den.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	860.306	860.306	.040	.8414
Residual	47	999021.326	21255.773		

Model II estimate of between component variance: •
33 cases were omitted due to missing values.

Means Table for Initial Den.
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	18	123.889	115.358	27.190
1997	31	132.581	160.499	28.826

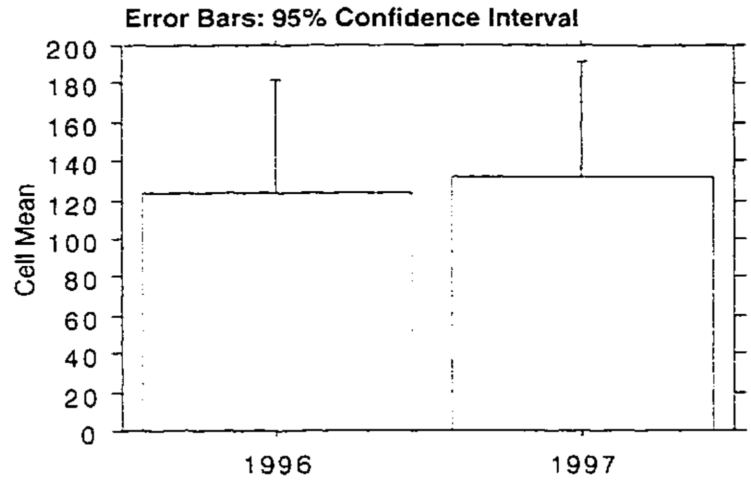
33 cases were omitted due to missing values.

Fisher's PLSD for Initial Den.
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
1996, 1997	-8.692	86.914	.8414

33 cases were omitted due to missing values.

Interaction Bar Plot for Initial Den.
Effect: Year
Error Bars: 95% Confidence Interval



33 cases were omitted due to missing values.

Fisher Sites, 1997 seedling survival, site comparison

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Site	1	766.016	766.016	.177	.6785
Residual	21	91036.000	4335.048		

Model II estimate of between component variance: •
59 cases were omitted due to missing values.

Means Table for Survival
Effect: Site

	Count	Mean	Std. Dev.	Std. Err.
S2	8	41.534	94.920	33.559
S1	15	53.651	44.696	11.540

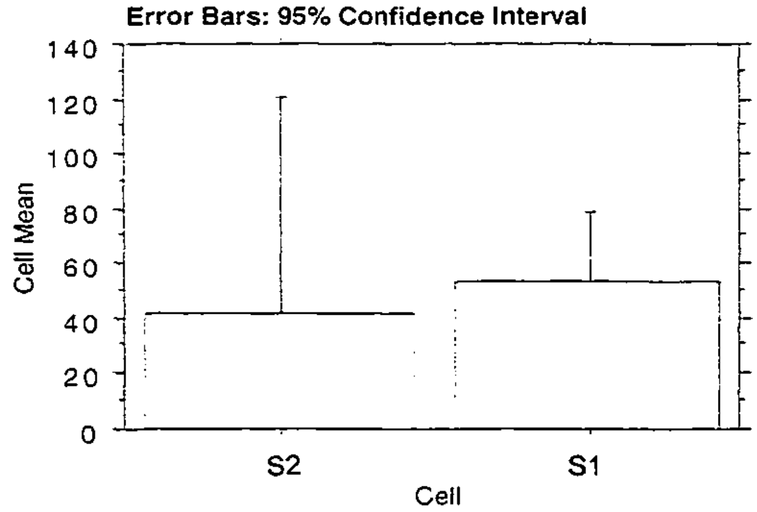
59 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Site
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
S1, S2	-12.117	59.945	.6785

59 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Site
Error Bars: 95% Confidence Interval



59 cases were omitted due to missing values.

Fisher versus Upper Kootenay, 1997 seedling survival comparison

ANOVA Table for Survival

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Reach	1	2358.290	2358.290	.625	.4321
Residual	62	233852.619	3771.816		

Model II estimate of between component variance: •
107 cases were omitted due to missing values.

Means Table for Survival
Effect: Reach

	Count	Mean	Std. Dev.	Std. Err.
Fisher	23	49.436	64.597	13.469
Kootenay	41	62.087	59.592	9.307

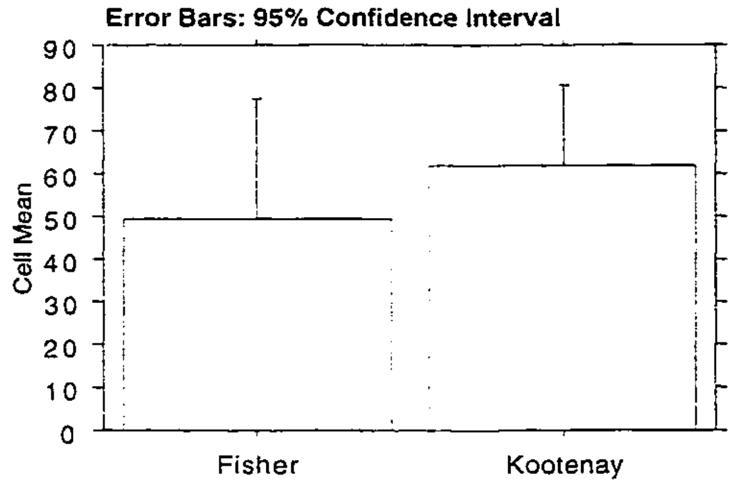
107 cases were omitted due to missing values.

Fisher's PLSD for Survival
Effect: Reach
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Fisher, Kootenay	-12.651	31.983	.4321

107 cases were omitted due to missing values.

Interaction Bar Plot for Survival
Effect: Reach
Error Bars: 95% Confidence Interval



107 cases were omitted due to missing values.

Fisher Sites, seedling height comparison for 1996 and 1997

ANOVA Table for Height

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Year	1	2.444	2.444	.026	.8721
Residual	47	4382.495	93.245		

Model II estimate of between component variance: •
33 cases were omitted due to missing values.

Means Table for Height
Effect: Year

	Count	Mean	Std. Dev.	Std. Err.
1996	18	15.156	5.424	1.278
1997	31	14.692	11.376	2.043

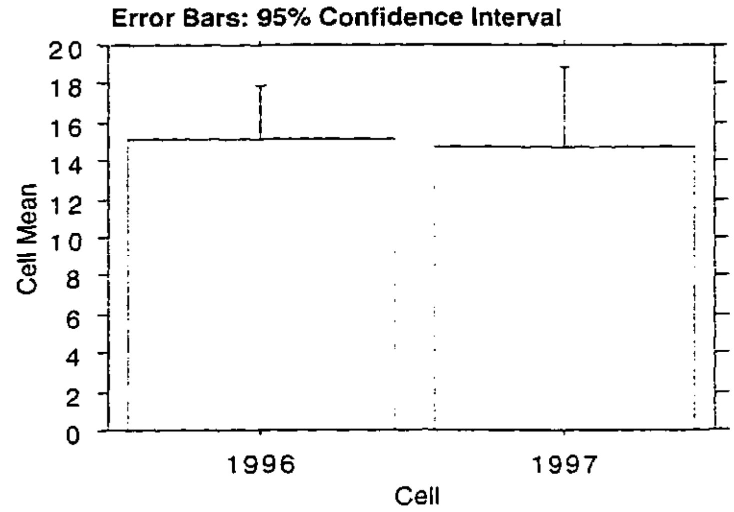
33 cases were omitted due to missing values.

Fisher's PLSD for Height
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
1996, 1997	.463	5.757	.8721

33 cases were omitted due to missing values.

Interaction Bar Plot for Height
Effect: Year
Error Bars: 95% Confidence Interval



33 cases were omitted due to missing values.

Fisher versus Upper Kootenay, seedling height comparison for 1996 and 1997

ANOVA Table for Height

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Reach	1	20662.006	20662.006	39.743	<.0001
Year	1	9711.283	9711.283	18.680	<.0001
Reach * Year	1	10171.544	10171.544	19.565	<.0001
Residual	100	51988.847	519.888		

67 cases were omitted due to missing values.

Means Table for Height
Effect: Reach

	Count	Mean	Std. Dev.	Std. Err.
Fisher	49	14.862	9.558	1.365
Kootenay	55	45.595	35.862	4.836

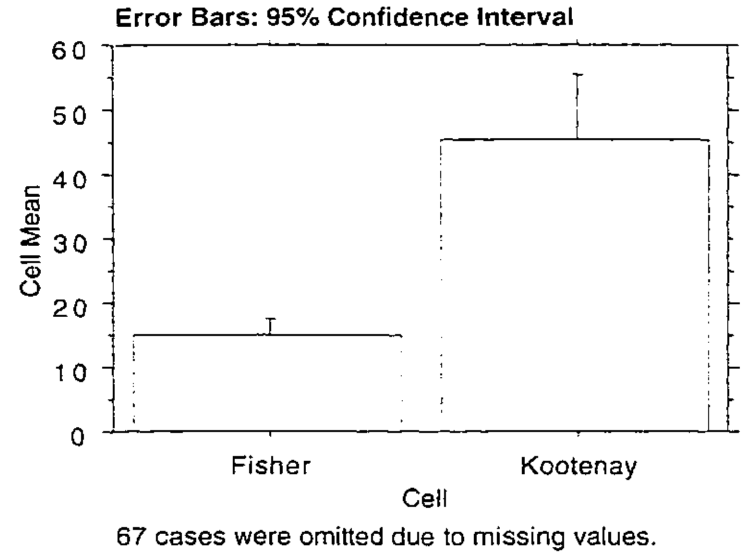
67 cases were omitted due to missing values.

Fisher's PLSD for Height
Effect: Reach
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
Fisher, Kootenay	-30.732	8.886	<.0001	S

67 cases were omitted due to missing values.

Interaction Bar Plot for Height
Effect: Reach
Error Bars: 95% Confidence Interval



67 cases were omitted due to missing values.

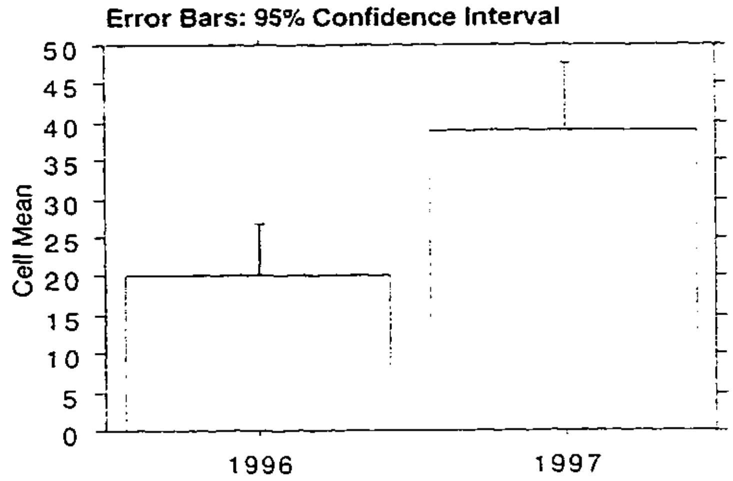
Fisher versus Upper Kootenay, seedling height comparison for 1996 and 1997

Means Table for Height
Effect: Reach * Year

	Count	Mean	Std. Dev.	Std. Err.
Fisher, 1996	18	15.156	5.424	1.278
Fisher, 1997	31	14.692	11.376	2.043
Kootenay, 1996	25	23.764	26.867	5.373
Kootenay, 1997	30	63.787	32.314	5.900

67 cases were omitted due to missing values.

Interaction Bar Plot for Height
Effect: Year
Error Bars: 95% Confidence Interval



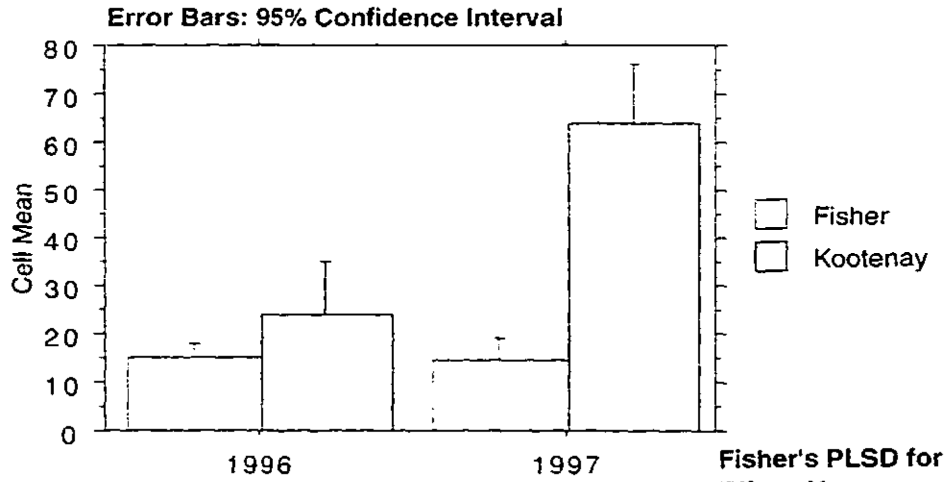
67 cases were omitted due to missing values.

Means Table for Height
Effect: Year

	Count	Mean	Std. D...	Std. Err.
1996	43	20.160	21.044	3.209
1997	61	38.837	34.378	4.402

67 cases were omitted due to missing values.

Interaction Bar Plot for Height
Effect: Reach * Year
Error Bars: 95% Confidence Interval



67 cases were omitted due to missing values.

Fisher's PLSD for Height
Effect: Year
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
1996, 1997	-18.677	9.008	<.0001	S

67 cases were omitted due to missing values.

The amount of change (scour and deposition) comparison of all four reaches

ANOVA Table for CHANGE

	DF	Sum of Squares	Mean Square	F-Value	P-Value
REACH	3	4.530	1.510	23.838	<.0001
TRANSECT	2	.233	.116	1.838	.1607
REACH * TRANSECT	6	.700	.117	1.841	.0906
Residual	327	20.716	.063		

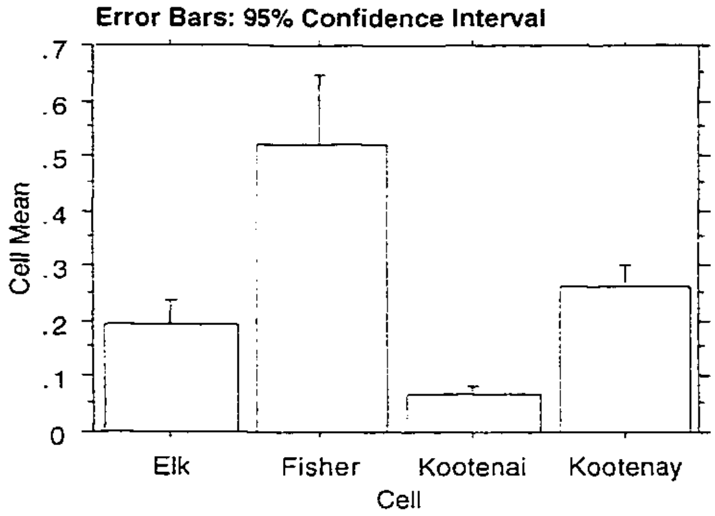
Means Table for CHANGE
Effect: REACH

	Count	Mean	Std. Dev.	Std. Err.
Elk	87	.194	.218	.023
Fisher	54	.519	.463	.063
Kootenai	77	.067	.079	.009
Kootenay	121	.263	.218	.020

Fisher's PLSD for CHANGE
Effect: REACH
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
Elk, Fisher	-.325	.086	<.0001	S
Elk, Kootenai	.128	.077	.0013	S
Elk, Kootenay	-.069	.070	.0523	
Fisher, Kootenai	.452	.088	<.0001	S
Fisher, Kootenay	.256	.081	<.0001	S
Kootenai, Kootenay	-.196	.072	<.0001	S

Interaction Bar Plot for CHANGE
Effect: REACH
Error Bars: 95% Confidence Interval



The amount of change (scour and deposition) comparison of all four reaches

Means Table for CHANGE
Effect: REACH * TRANSECT

	Count	Mean	Std. Dev.	Std. Err.
Elk, T1	28	.227	.199	.038
Elk, T2	30	.227	.261	.048
Elk, T3	29	.128	.174	.032
Fisher, T1	21	.388	.392	.086
Fisher, T2	28	.622	.501	.095
Fisher, T3	5	.491	.459	.205
Kootenai, T1	30	.080	.114	.021
Kootenai, T2	28	.052	.041	.008
Kootenai, T3	19	.065	.045	.010
Kootenay, T1	42	.241	.171	.026
Kootenay, T2	38	.273	.257	.042
Kootenay, T3	41	.276	.225	.035

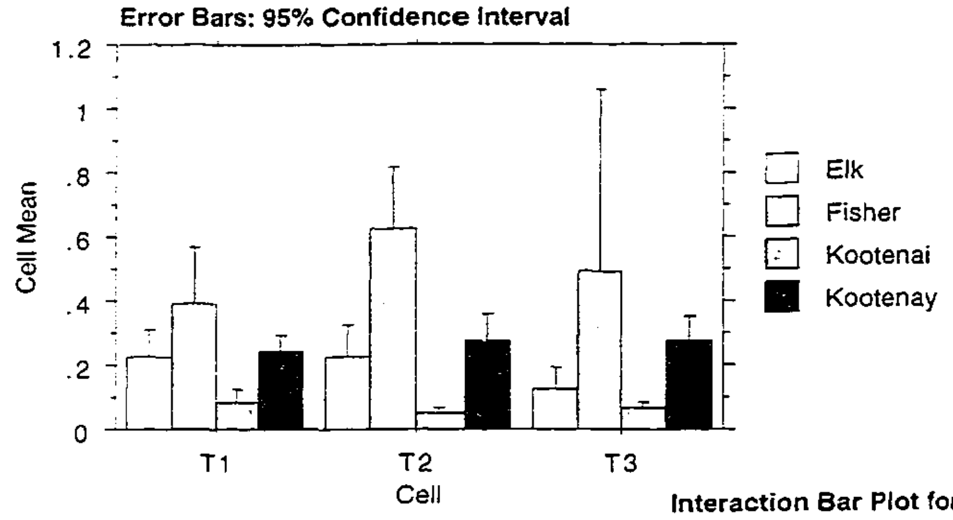
Means Table for CHANGE
Effect: TRANSECT

	Count	Mean	Std. Dev.	Std. Err.
T1	121	.224	.240	.022
T2	124	.291	.361	.032
T3	94	.199	.229	.024

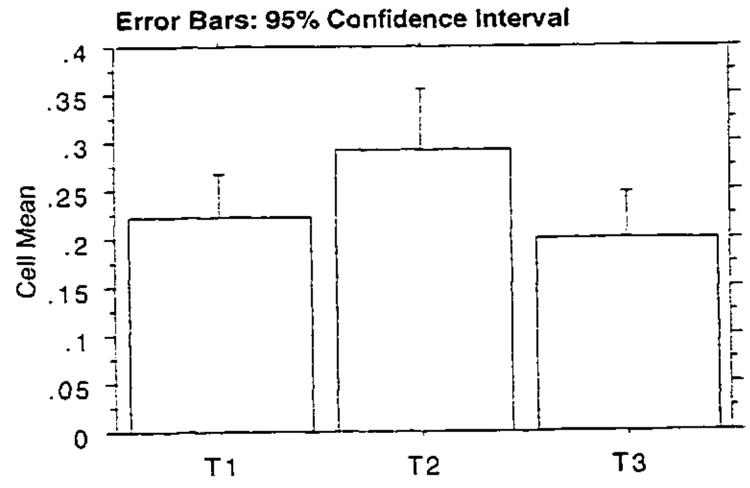
Fisher's PLSD for CHANGE
Effect: TRANSECT
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
T1, T2	-.067	.063	.0376	S
T1, T3	.024	.068	.4824	
T2, T3	.091	.068	.0083	S

Interaction Bar Plot for CHANGE
Effect: REACH * TRANSECT
Error Bars: 95% Confidence Interval



Interaction Bar Plot for CHANGE
Effect: TRANSECT
Error Bars: 95% Confidence Interval



Appendix 3: Clonal Leaf Morphology

and Substrate samples

A leaf off a cottonwood sapling displaying characteristics of clonal growth, this tree was 6 years old and the largest leaf from the tree would not fit on the page.

Soil samples from the rivers edge when it was not large cobble

Upper Kootenay River

Transect #	Sample	Particle size	Amount
K 1 0621	100g	< 0.6 mm	100 g
K1 0622	100g	< 0.6 mm	100 g
K1 0623	100g	< 0.6 mm	100 g
K2 0624	100g	< 0.6 mm	100 g
K2 0625	100g	< 0.6 mm	100 g
K2 0626	100g	< 0.6 mm	100 g
K3 0627	100g	< 0.6 mm	100 g
K3 0628	100g	< 0.6 mm	100 g
K3 0629	100g	< 0.6 mm	100 g

Elk River

Transect #	Sample	Particle size	Amount
E1a 0630	100 g	> 4.75 mm	24.99 g
		> 3.35 mm	1.67 g
		> 2.00 mm	1.85 g
		> 1.41 mm	1.00 g
		> 0.6 mm	5.03 g
		< 0.6 mm	65.02 g
E1a 0631	100 g	> 4.75 mm	13.61 g
		> 3.35 mm	7.12 g
		> 2.00 mm	9.7 g
		> 1.41 mm	6.8 g
		> 0.6 mm	7.39 g
		< 0.6 mm	155 g
E1 0636	100 g	< 0.6 mm	100 g
E1 0646	100 g	< 0.6 mm	100 g
E1 0647	100 g	< 0.6 mm	100 g
E1 0648	100 g	< 0.6 mm	100 g
E2 0635	100 g	> 1.41 mm	0.84 g
		> 0.6 mm	1.11 g
		< 0.6 mm	97.89 g

Fisher River

Transect #	Sample	Particle size	Amount
F1 0654	100 g	> 4.75 mm	61.69 g
		> 3.35 mm	9.09 g
		> 2.00 mm	8.34 g
		> 1.41 mm	3.66 g
		> 0.6 mm	4.78 g
		< 0.6 mm	12.34 g