STREAM RESTORATION AT DENALI NATIONAL PARK AND PRESERVE

Roseann V. Densmore and Kenneth F. Karle

U.S.G.S., Biological Research Division, 1011 East Tudor Rd., Anchorage, AK 99503, and National Park Service, P.O. Box 9, Denali National Park and Preserve, AK 99755.

ABSTRACT

Placer mining for gold has severely disturbed many riparian ecosystems in northern regions. We are conducting a long-term project to test methods to promote restoration of a placer-mined watershed in Denali National Park and Preserve. The project included hydrological restoration of the unstable and excessively confined stream with heavy equipment. We stabilized the floodplain with bioengineering techniques, including alder and willow brush bars anchored laterally to the channel and willow cuttings along the channel. A moderate flood near the end of construction showed that the brush bars provided substantial protection, but some bank erosion and changes in slope and sinuosity occurred. Subsequent refinements included greater sinuosity and channel depth, pool/riffle construction with stone weirs, and buried alder and willow brush projecting from the bank. The reconstructed stream and floodplain have remained stable for five years, but have not been re-tested by a another large flood. The willow/alder riparian plant community is naturally revegetating on the new floodplains, but vigorous willows which sprouted from branches in brush bars and banks still provide the erosion protection.

INTRODUCTION

Placer mining for gold has severely disturbed many riparian ecosystems in northern regions. Placer mining involves removing vegetation and topsoil, excavating gravel down to bedrock from the active floodplain, old terraces, and/or the active stream channel, and processing the gravel to remove the gold. Placer-mined streams in the Kantishna Hills region of Alaska's Denali National Park and Preserve have unstable or excessively confined streambeds and over-steep floodplains along many reaches. Piles of mine tailings have replaced much of the native streambed material. Some floodplain soil was stockpiled, but most was buried beneath tailings or washed downstream. Riparian vegetation is sparse or absent, and habitat value has been severely reduced.

With such a disturbed riparian ecosystem, recovery through natural processes is hindered. In channel reaches where the stream bed is incised and straightened, bed scouring continues to occur. During annual flooding, erosion of over-steep banks results in excessive sediment loading of the stream. This sediment load is then deposited in the channel downstream in areas of shallower gradient, resulting in additional problems such as cementing of substrates and clogging of benthic invertebrates. Incised stream channels also prevent flooding, thus interrupting the natural process of floodplain sediment deposition.

The National Park Service (NPS) is conducting long-term multi-disciplinary research on methods to promote riparian ecosystem recovery. The primary study site is abandoned placer claims on lower Glen Creek in the Kantishna Hills. Projects include studies of natural plant succession and revegetation methods on areas above the active floodplain, the role of mycorrhizae and other soil microflora, benthic invertebrate populations, water chemistry, and suspended sediment (Densmore, 1994; Karle et al., 1996; Landolt et al., 1992; Treu et al., 1996). This paper addresses our research on techniques to restore the active floodplain and stream channel which would (1) reduce erosion, (2) allow the stream to develop floodplains, sinuosity, and pools and riffles similar to premining conditions, and (3) minimize construction needs. We focus on bioengineering techniques for stabilization of reconstructed floodplains and streambanks.

STUDY AREA

The Glen Creek watershed study area is located in the Kantishna mining area, a group of rugged hills within Denali National Park and Preserve (Fig. 1). The watershed is 16.7 km^2, with elevations ranging from 648 m at the mouth to 1372 m near Spruce Peak. The Glen Creek watershed is in the continental climatic zone of interior Alaska, but the continental pattern is modified by cooler summers and higher precipitation because of the greater maritime influence and a higher elevation. July averages 12° C, while January averages -18° C. Precipitation averages 48 cm annually with 72% occurring from June through September.

The bedrock geology of the Glen Creek watershed is faulted and folded quartzite and hornblende schist of the Birch Creek formation. The study area on lower Glen Creek was covered in the middle Wisconsin with glacial ice from the Alaska Range, and gravel and rocks deposited by the glacier are mixed with bedrock material in the alluvial gravels.

The study area is at treeline, and trees are confined to favorable sites on alluvial terraces and south-facing slopes. Tall shrubs dominate riparian vegetation on the floodplain and younger terraces, and low shrubs and herbs form the tundra vegetation on colder, more exposed sites. The mining severely disturbed the vegetation on the study area, but the predisturbance vegetation can be inferred from remnants and adjacent less-disturbed watersheds. On these watersheds the floodplain is dominated by feltleaf willow (*Salix alaxensis*) (Viereck and Little, 1972) 3-4 m tall, mixed with varying amounts of American greenleaf alder (*Alnus crispa*) 1-2 m tall, and an understory that usually includes the low shrub cinquefoil (*Potentilla fruticosa*), bluejoint reedgrass (*Calamagrostis canadensis*) (Hulten, 1968), and dwarf fireweed (*Epilobium latifolium*). The floodplain is vegetated to the bankfull stream level; natural flood or ice events which remove vegetation and initiate primary riparian succession are infrequent. Higher areas have balsam poplar (*Populus balsamifera*) and younger white spruce (*Picea glauca*), and old terraces have open stands of white spruce with an understory of dwarf birch (*Betula glandulosa*) and diamondleaf willow (*Salix planifolia*).

The Glen Creek watershed was hand-mined from 1906 to 1941. The stream was diverted and dammed, and topsoil and fines were washed away, but the areal extent of disturbance was limited relative to later mining. In the 1970's, the study area on lower Glen Creek was extensively mined with the bulldozer/washplant method. In 1988, 9-15 years after mining had ceased, the study area was dominated by unstable gravel and rock spoil piles 3-8 m tall. Spoil piles differed in particle size distribution, depending on whether the excavated alluvial material had been processed and on the type or stage of processing, but most of the topsoil was gone.

Reclamation of the study area began in August 1988, when the area above the active floodplain was recontoured (Schramm, 1988). The recontouring redistributed spoil to reduce and stabilize slopes, but left the stream channel incised and unstable.

METHODS

Design parameters for channel and floodplain reconstruction are described elsewhere (Karle and Densmore, 1994a,b). We used a crawler-dozer, articulated front-loader, and dump truck to reconstruct a 425 m reach of Glen Creek (upper study area) in 1991, and a 925 m reach (lower study area) in 1992. The two study areas were separated by a relatively undisturbed reach in a narrow canyon. Most of the work involved recontouring raised tailings to a shallow sloping floodplain, leaving the existing channel undisturbed except for minor bank modifications. On the lower study area, a 110 m section of channel was repositioned from the valley wall to the center of the floodplain.

We predicted that serious damage could occur to the new floodplains if a major flood occurred before natural revegetation took hold. On undisturbed floodplains, vegetation anchors the substrate, decreases water velocity, catches organic debris, and promotes sediment deposition. We designed a brush bar to slow flood water velocity and encourage sediment deposition. The brush bars were bundles of cut alder, approximately 0.5 to 0.75 m in diameter and 4 to 5 m in length. Bars included one 4 to 5 m long feltleaf willow branch buried in the lower half of the bundle, and five feltleaf willow cuttings planted into the downstream side of the bundle. We used as little feltleaf willow as possible because few mature willows were left after mining, and we wanted to limit damage to the remaining habitat. Alder, on the other hand, was very abundant along old mining roads. The bundles were installed by first digging a trench into the floodplain perpendicular to the channel. Several manila rope lengths were placed across the open trench, the lower half of each bundle was set into the trench, and the trench was then backfilled, the top half of the bundle was added, and the ropes were tied around the bundle to anchor the bundle in place. We fertilized the brush bars with time-release Osmocote fertilizer (13-13-13 NPK) at a rate of 500 kg/ha. One-half of the fertilizer was spread in the bottom of the trench, and the other half was spread on the backfill. In 1991, we installed 26 brush bars on the upper study area. The bars were spaced two channel widths apart. For the 1992 project, we installed 30 brush bars on the lower study area, with the spacing at one channel width apart.

We also planted feltleaf willow cuttings and alder seedlings to anchor the substrate and catch organic debris. In 1991, on the upper study site, cuttings were planted on two newly-constructed floodplains, one protected by brush bars and one unprotected by brush bars. Each floodplain planting site was divided into three replicate blocks. Each block was divided into two plots. We collected feltleaf willow cuttings near the site and planted 25 seedlings in each plot in rows of five perpendicular to the stream in a 0.5 m wide band bordering the stream channel. In each replicate block, the upstream plot was fertilized with Osmocote 13-13-13 NPK at a rate of 500 kg/ha by spreading the fertilizer in the trench dug for each row of cuttings. In 1992, on the lower study area, we collected feltleaf willow cuttings near the site and planted 15 seedlings in each space between bars. Cuttings were planted in rows of five perpendicular to the stream in a 1.0 wide band bordering the stream channel. Each cutting was fertilized with one teaspoon of Osmocote (13-13-13).

A moderate flood occurred in the Glen Creek watershed just as the 1992 stream and floodplain work was completed. The effects of this flood provided important data which was used to refine the design and develop new techniques. We describe the flood effects in this section to provide sufficient background for our post-flood methods, but details of changes in channel and floodplain morphometry are presented in Karle and Densmore (1994a,b), and bioengineering results are expanded in the Results section. On the upper section, the flood eroded the floodplains which were not protected by brush bars. Brush bars provided substantial protection, but high water ran behind the brush bars, undercut the stream ends of some bars, washed out one bar, and cut a new channel between bars in a floodplain area with unconsolidated material. In the new channel section in the lower study area, the unarmored channel bed contributed to extensive erosion on the unprotected side of the channel. On the other side of the channel, water ran behind the first bars and undercut the stream ends of some bars, but most of the floodplain was protected. Overall, stream slope decreased and sinuosity increased.

To address these problems, we tested modifications and new techniques in 1994. These included construction on the upper study site of a point bar to create a meander with a deeper channel, reconstruction of eroded floodplains, and construction of a series of pools and rock weirs between the reconstructed floodplains. In the lower study area, we redesigned the channel structure with a deeper, narrow channel. A point bar and meander were also constructed. We deliberately bulldozed some soil and vegetation from adjacent areas with mature willow and alder into the new point bars and reconstructed floodplains. Design details are not included here but may be obtained from the author (Karle, unpublished data).

We addressed the problem of floodwater flowing around bars by extending the first four bars to reach a steep slope on the upper study area and to reach the second terrace on the lower study area. To protect the streambank itself, we buried willow and alder branches along 31 m of the bank of a reconstructed floodplain. We constructed the floodplain to a height just above the mid-season water level, placed branches 3-4 m long perpendicular to the stream with the ends projecting approximately 0.5 m from the bank, and bulldozed additional material over the branches. Branch density was 1-2 feltleaf willow and 2-3 alder branches/m of streambank. Feltleaf willows and one-half of the alders were buried with the branch tip projecting from the bank. The remaining alders were buried with the branch base projecting from the bank.

We evaluated bioengineering structures and plantings and natural revegetation on the upper study area in August 1995, and on lower study area in August 1996; on each site this was four growing seasons after the initial stream and floodplain reconstruction. We mapped the position of the brush bars in relation to the stream channel. We classified willow cuttings planted between bars as live, dead, or washed out, and measured the height of each willow plant. On the lower section, we counted the number of willows sprouting from the bars, and measured the height of each sprouted willow.

For the brush buried in the new floodplain, we mapped the location of each branch, recorded the species and whether the branch tip or base projected from the streambank, and the distance the branch projected from the bank. In 1995, we recorded the number of sprouts on each branch.

We established permanent plots for long-term monitoring on the reconstructed floodplains in 1993, and analyzed soil samples from these plots for texture and nutrients. We measured natural revegetation in these permanent plots by establishing line transects in the upper study area in 1995 and in the lower study area in 1996. On the upper study area, we established three 5 m line transects in each permanent plot, one transect perpendicular to the stream channel in the middle of the space between brush bars, one transect adjacent to the downstream side of a brush bar, and one transect on the upper slope of the floodplain above the brush bars. On the lower study area, we established four line transects in each permanent plot, one 6 m transect parallel to the stream between brush bars, two 4 m transects adjacent to the downstream sides of two brush bars, and one 5 m transect on the upper slope of the floodplain above the brush bars.

We measured cover in 1-cm increments along the line transects. Vascular plant cover was measured by species, and ground cover was measured as rock, soil, cryptogamic crust, moss, or litter. Cryptogamic crust is a mixture of algae and lichens growing on the soil surface. It appears as a blackish crust on the surface between stones on rocky sites and as spots or a continuous cover on areas with more soil. We measured species composition in a 0.5 x 5 m plot adjacent to one side of the transect on transects which were not next to a brush bar. On transects next to the brush bar, the line transect ran lengthwise down the center of the plot. All vascular plant taxa present in this plot were recorded. To measure woody plant density and growth, we subdivided the plot used to measure species composition into 0.5 x 0.5 m subplots. In each subplot, we measured the height of the tallest feltleaf willow seedling and the tallest alder seedling, and recorded the number of seedlings of all woody plant species.

RESULTS

Brush Bars

In the 1992 flood, most of the bank and floodplain erosion occurred on areas which were not protected by brush bars. For example, on the new channel section, serious erosion occurred on the unprotected west bank, as compared to minor erosion on the east side with the brush bars (Fig. 2). The first few bars on each reconstructed floodplain took the brunt of the flood. On the upper study area, the floodwater eroded the floodplain in front of and under the end of some of these bars, and bent the bar around the resulting corner. This configuration prevented further erosion and has remained stable, with the stream flow channeled against the front of the bar, and a pool formed on the downstream end of the bar. On the lower study area, the first bar washed out entirely and the second bar wrapped around. On the new channel section, the first bar remained in place and cobbles (to 20 cm) and gravel were deposited in front of and on top of the bar to a depth of 0.5 m.

Floodwater cut behind most of the brush bars in the upper study area. The main problem was not the formation of a high-water channel, but water flowing back into the channel in the areas between brush bars. This not only decreased deposition but eroded the existing floodplain material. On the lower study area, floodwater cut behind only the first few bars (Fig. 2). The remaining bars encouraged sediment deposition, as planned, with 5-10 cm of fines deposited between bars and large amounts of silt deposited within bars.

After four years, the manila ropes holding the brush bars had disintegrated, as planned. The willow branches and cuttings within the bars had sprouted and grown vigorously, and now held the bar together. Along the new stream channel in the lower study area, there were 4 ± 0.3 (mean ± SE) willow plants sprouting per bar from 25 bars. Most plants from brush bar sprouts were 0.5-1.5 m tall, with a mean height of 90 ± 5.1.

Willow Cuttings

The willow cuttings planted along the stream bank provided little or no erosion protection during the 1992 flood. At the time of the flood, the cuttings on the upper study area had grown for one year and the cuttings on the lower study area had just been planted. On the upper study area, all the cuttings planted on a floodplain which was not protected by brush bars were washed out, while only 14% of the willows planted between brush bars on both sites were washed out.

Four years after planting, overall survival of cuttings which were not washed out was 80% (Fig. 3). On the upper study site, the fertilization treatment had no effect on survival, but fertilized cuttings were twice as tall as unfertilized cuttings (Fig. 3).

Natural Revegetation

Natural revegetation of the reconstructed floodplains was relatively slow on both study areas, with the exception of islands of vigorous growth around brush bars. After four years, vascular plant cover on the floodplain above the brush bars was 10% on the upper study site and only 2% on the lower study site, with similar cover levels for nonvascular plants (Fig 4). Almost all of the nonvascular plant cover on the study areas was cryptogamic crust, a thin blackish layer on the soil surface composed primarily of two nitrogen-fixers, the cyanobacteria *Microcoleus vaginatus* and the soil lichen *Collema tenax* (J. Belnap, personal communication). On the lower study site, vascular and nonvascular plant cover between bars was higher than on the floodplain above the bars. On both sites, the highest cover and most vigorous vegetation was adjacent to the brush bars (Fig. 4).

The woody plants colonizing the reconstructed floodplains included feltleaf willow, other willow species, alder, balsam poplar, and white spruce. The density of all woody taxa, measured as seedlings/m^2 (mean ± SE), was 23 ± 3.7 on the floodplain above the brush bars, 23 ± 2.4 between brush bars, and 38 ± 4.7 adjacent to brush bars. Seedling density was similar in all areas of the lower study area (31 ± 5.4 on the floodplain above the brush bars, 33 ± 7.4 between brush bars, and 30 ± 3.4 seedlings/m^2 adjacent to brush bars).

All floodplain areas of both study sites were well stocked with feltleaf willow, the dominant riparian species (Fig. 5). However, only seedlings adjacent to brush bars were growing rapidly (Fig. 6). Seedlings on the remainder of the floodplain were growing relatively slowly (measured seedlings were three or four years old) (Fig. 5). Stocking of alder was relatively high on all areas of the upper site (Fig. 5). On the lower site, alder stocking was high only adjacent to the brush bars, and there were very few alder seedlings on the floodplain above the brush bars.

Post-Flood Experiments

On the lower study area, the new meander constructed with deeper channels and a new point bar has remained stable, but the new meander on the upper study area increased in length, eroding the cut bank. The rock weirs partially maintained the pool and riffle sequence, but the pools partially filled with gravel. On the reconstructed floodplain where we buried willow and alder branches which projected from the streambank, 93% of the willow branches had sprouted by 1995. By the end of the 1997 growing season, we observed that these willow sprouts had grown vigorously and the streambank appeared to be fully vegetated.

DISCUSSION

The moderate 1992 flood demonstrated that the brush bars protected unvegetated floodplains. In fact, the brush bars stabilized the channel so effectively that we were concerned that they prevented needed channel adjustments in some spots. After four years, the ropes had decayed, and the bars were held together by vigorous feltleaf willow plants which had sprouted from the willow branches planted in the bars. In addition, the 1992 flood filled the brush bars with silt, and vegetation established within the bars. The growth of vegetation within and adjacent to the bars was stimulated by the time-release fertilizer placed in the bars, and also by nitrogen from decomposition of the alder leaves on the branches buried under silt.

The brush bars on the upstream end of floodplains were too short to prevent erosion from the floodwater cutting behind bars. We extended the bars to reach higher terraces or slopes adjacent to the floodplain, and willows in these extensions have also grown vigorously. The rock weirs on the upper study area have successfully directed water flow toward the center of the channel and away from the erodible streambank. However, the weirs have not been able to maintain the desired pool/riffle sequence, and the constructed pools have mostly filled with gravel. The streambank protection design with buried alder and willow branches projecting from the streambank successfully revegetated the streambank with feltleaf willow. The post-1992 flood design modifications, including the modified channel design, extended brush bars, rock weirs, and streambank plantings have tested only by annual high water levels, but have not been subjected to another large flood.

The 1992 flood eroded both freshly planted feltleaf willow cuttings and cuttings which had been growing for one year. After four years, the willows from fertilized cuttings were vigorous and provided a band of vegetation along the streambank. Our experiments showed that the time-release fertilizer was essential on low-nutrient placer mine tailings, as the unfertilized cuttings were stunted and not vigorous. A temporary lack of mycorrhizae contributed to the need for fertilizer. Laursen (unpublished data) investigated mycorrhizal development on planted feltleaf willow cuttings on our study site. He found that development of mycorrhizal associations was delayed on cutting roots for one to two growing seasons. We strongly recommend using time-release fertilizer in subarctic riparian areas. In previous work, we found that almost all of the nitrogen from regular fertilizer leached rapidly from the root zone and into the water table, and had little effect on the planted cuttings (Densmore et al., 1987; Neiland et al., 1981). Fertilizer release in the time-release fertilizer we use is temperature-dependent, meaning that in the subarctic climate of our study area fertilizer release is usually spread over more than one growing season.

Our design relied on natural revegetation for restoration of riparian revegetation on the reconstructed floodplains. After four years, all floodplain areas had been colonized by the dominant riparian species. The species composition was similar to successional communities on nearby unmined streams (Densmore, 1994). However, the growth rate of feltleaf willows was optimal only adjacent to brush bars. The growth rate of willows was slow on the upper part of the floodplain above the brush bars, particularly on the lower study area. In previous work in this study area, we have found that low levels of nitrogen in the mine tailings were a major factor limiting growth of feltleaf willow and other species. Feltleaf willow seedling growth was better between bars because of fertilizer on cuttings, silt deposition, and perhaps because seedlings were closer to water table.

On the lower site, very few alder seedlings established on the floodplain above the brush bars. The alder seed source was adequate, so we attribute the lack of alders to the lack of adequate fines and nutrients in the mine tailings used to construct this floodplain. We found in other work on this site that coarse, well-drained, nutrient-poor substrates limit alder seedling establishment, but not the growth of established plants (Densmore, 1994).

We predict that all areas of the reconstructed floodplains on the upper study site, and the streamside areas with brush bars on the lower study site will naturally revegetate to riparian tall shrub communities. Because of the slow growth of feltleaf willow and the absence of alder, we speculate that the upper part of the reconstructed floodplains on the lower study area may eventually regenerate to a sparsely vegetated subalpine community rather than to tall riparian shrub. In view of the slow growth of natural revegetation, our temporary floodplain stabilization techniques, particularly the brush bars, still provide most of the floodplain protection.

ACKNOWLEDGEMENTS

This work was supported by funding and logistical support from the National Park Service, with special assistance from A. R. Carter and P. Spencer, and by the U. S. Geological Survey, Alaska Biological Research Center. J. Van Horn, M. Pope, M. Emers, M. and A. Vander Meer, J. Forbes, T. Ledwidth, and L. Sansone provided field assistance.

LITERATURE CITED

Densmore, R. V. 1994. Succession on regraded placer mine spoil in Alaska, U.S.A., in relation to initial site characteristics. Arctic and Alpine Research. 26: 354-363.

Densmore, R. V., B. J. Neiland, J. C. Zasada, and M. A. Masters. 1987. Planting willow for moose habitat restoration on the North Slope of Alaska, U.S.A. Arctic and Alpine Research 19:539-543.

Hulten, E. 1968. Flora of Alaska and Neighboring Territories. Stanford University Press, Stanford, California.

Karle, K. F. and R. V. Densmore. 1994a. Stream and floodplain restoration in Glen Creek, Denali National Park and Preserve. United States Department of Interior, National Park Service. Technical Report NPS/NRWRD/NRTR-94/17.

Karle, K. F. and R. V. Densmore. 1994b. Stream and floodplain restoration in a riparian ecosystem disturbed by placer mining. Ecological Engineering 3:121-133.

Karle, K. F., P. J. Edwards, and E. Major. 1996. Streambed disturbances during and after restoration of Glen Creek, Denali National Park and Preserve, Alaska. Proceedings , American Water Resources Association Annual Symposium-Watershed Restoration Management: physical, chemical, and biological considerations. Syracuse, NY.

Landolt, J. C., S. L. Stephenson, G. A. Laursen, R. V. Densmore. 1992. Distribution patterns of cellular slime molds in the Kantishna, Denali National Park and Preserve, Alaska. Arctic and Alpine Research. 24:244-248.

Neiland, B. J., J. C. Zasada, R. Densmore, M. A. Masters, and N. Moore. 1981. Investigations of techniques for large-scale reintroduction of willows in arctic Alaska. Technical research report, University of Alaska-Fairbanks Agricultural and Forestry Experiment Station. 448 p.

Schramm, D. 1988. Environmental assessment, Glen Creek reclamation project, Denali National Park and Preserve. United States Department of Interior, National Park Service, Alaska Regional Office, Anchorage.

Treu, R., G. A. Laursen, S. L. Stephenson, R. V. Densmore, J. C. Landolt. 1996. Vascular plant-fungal symbioses (mycorrhizae) from Denali National Park and Preserve. Mycorrhiza. 6:21-29.

Viereck, L. A. and E. L. Little. 1972. Alaska trees and shrubs. United States Department of Agriculture, Forest Service. Agricultural handbook No. 410.

Fig. 1. Location of the study area.

Fig. 2. Map of the new stream channel section in the lower study area, showing brush bars, the location of east streambank before and after 1992 flood, the estimated location before and after 1992 flood of the section of the west streambank between surveyed cross-sections, and the new brush bar extensions and new point bar constructed after the 1992 flood.

Fig. 3. Survival and growth of planted feltleaf willow cuttings after four years, with and without time-release fertilizer on the upper study area, and with time-release fertilizer on the lower study area.

Fig. 4. Vascular and nonvascular plant cover after four years on the reconstructed floodplains above the brush bars, between the brush bars, and adjacent to the brush bars on upper and lower study areas.

Fig. 5. Natural revegetation of feltleaf willow and alder after four years on the reconstructed floodplains above the brush bars, between the brush bars, and adjacent to the brush bars. Stocking levels were measured as the percentage of 0.25 m^2 plots with at least one seedling.

Fig. 6. Growth of feltleaf willow seedlings after four years on the reconstructed floodplains above the brush bars, between the brush bars, and adjacent to the brush bars.

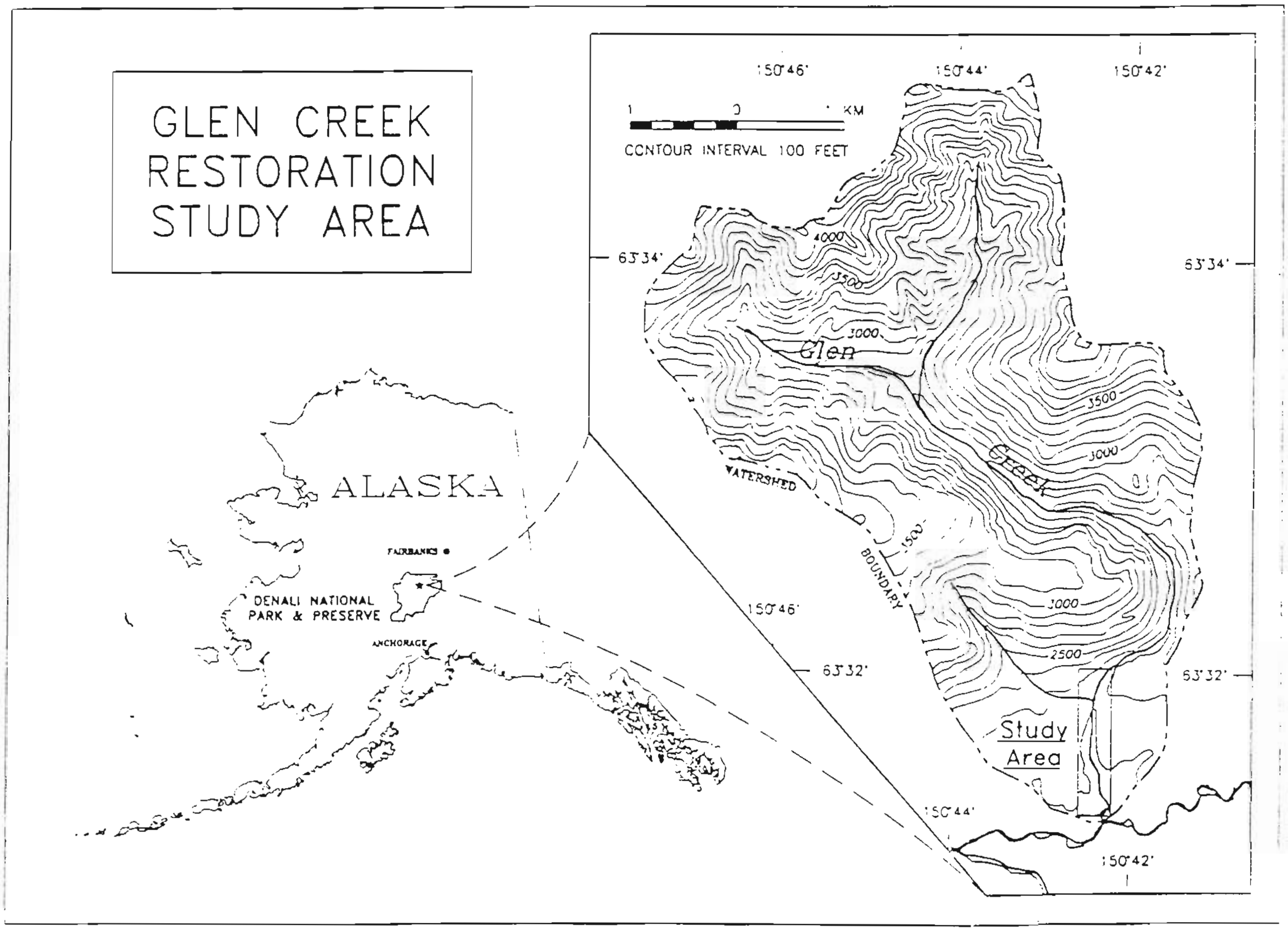


FIGURE 1. Map showing location of study area.

Fig 2

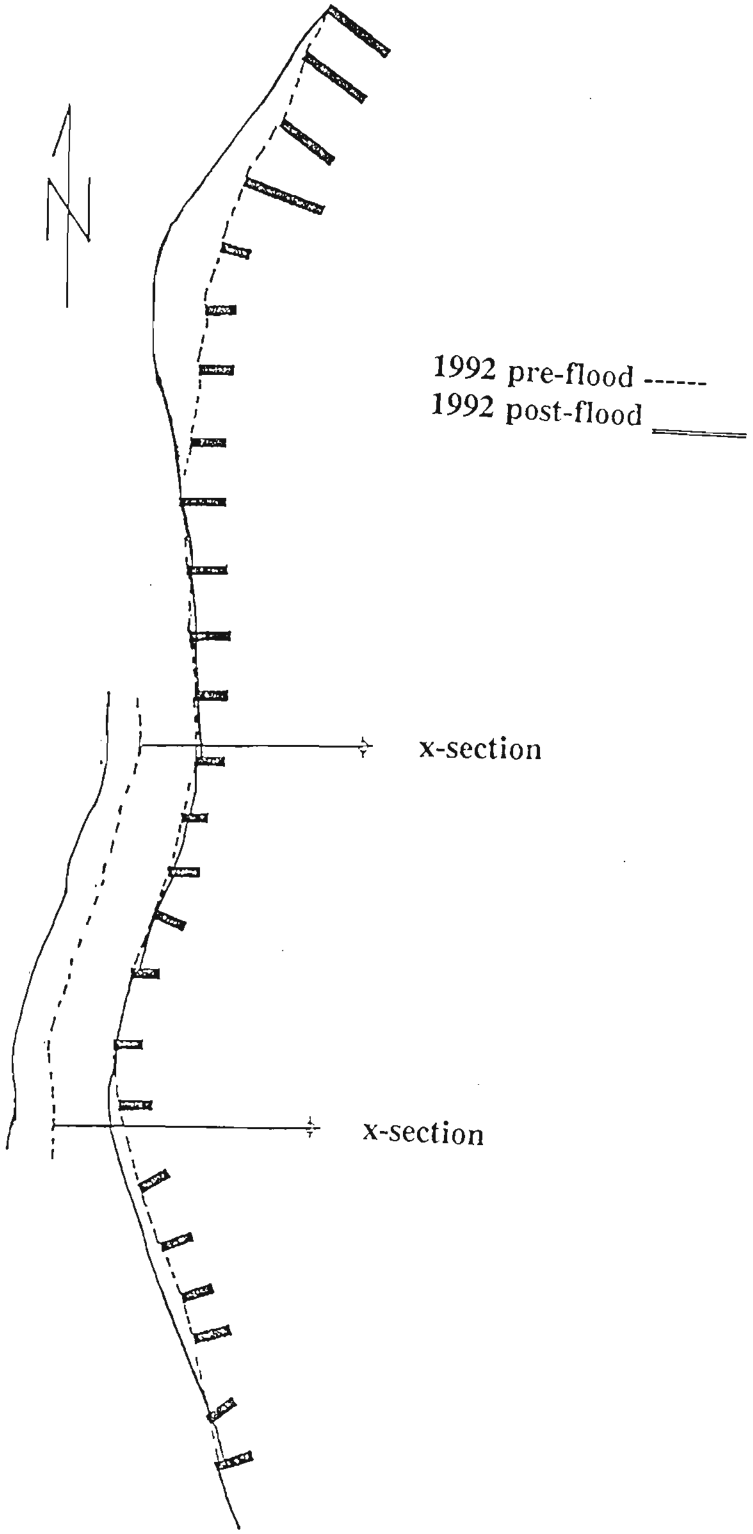


Fig 3

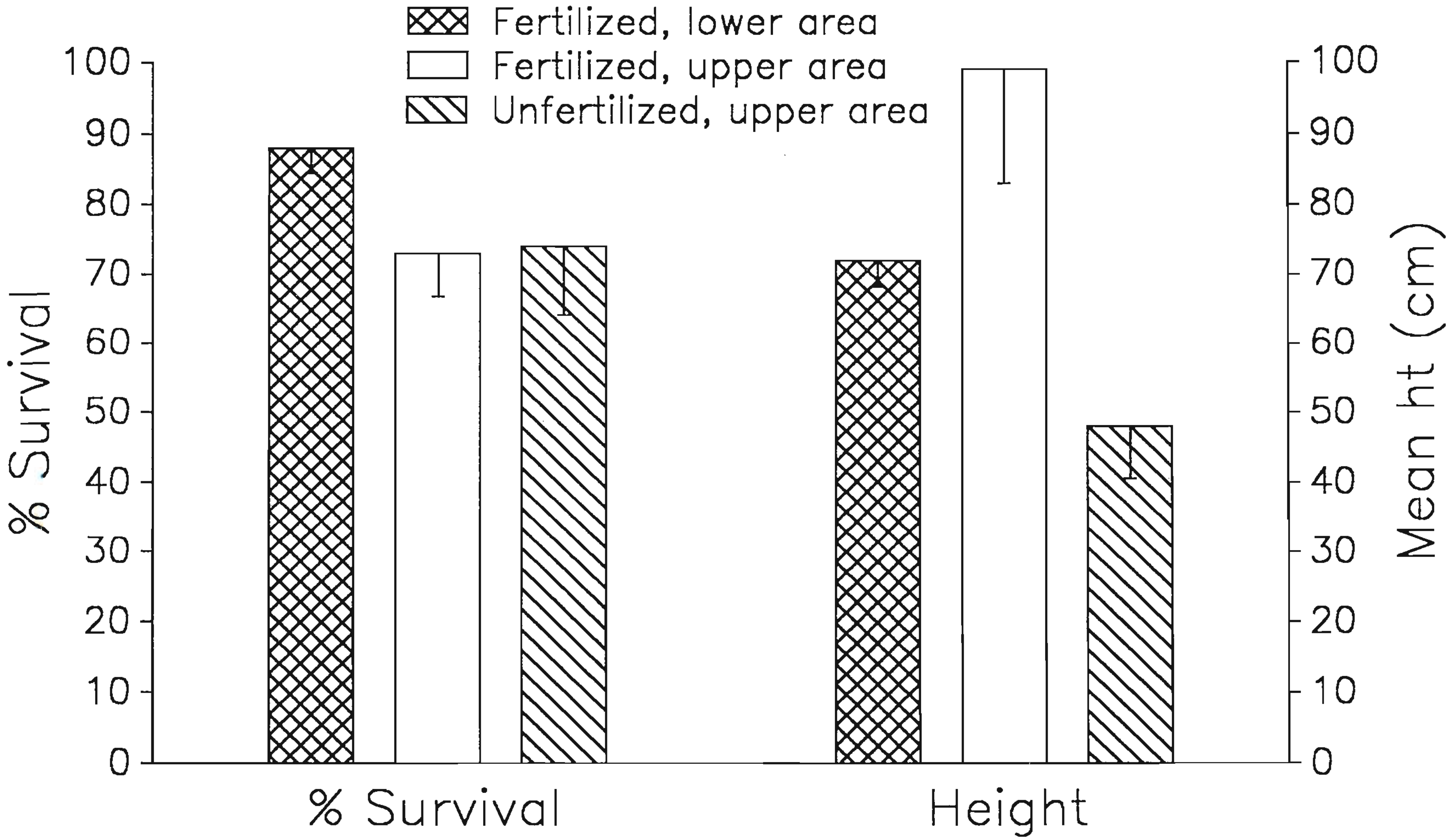
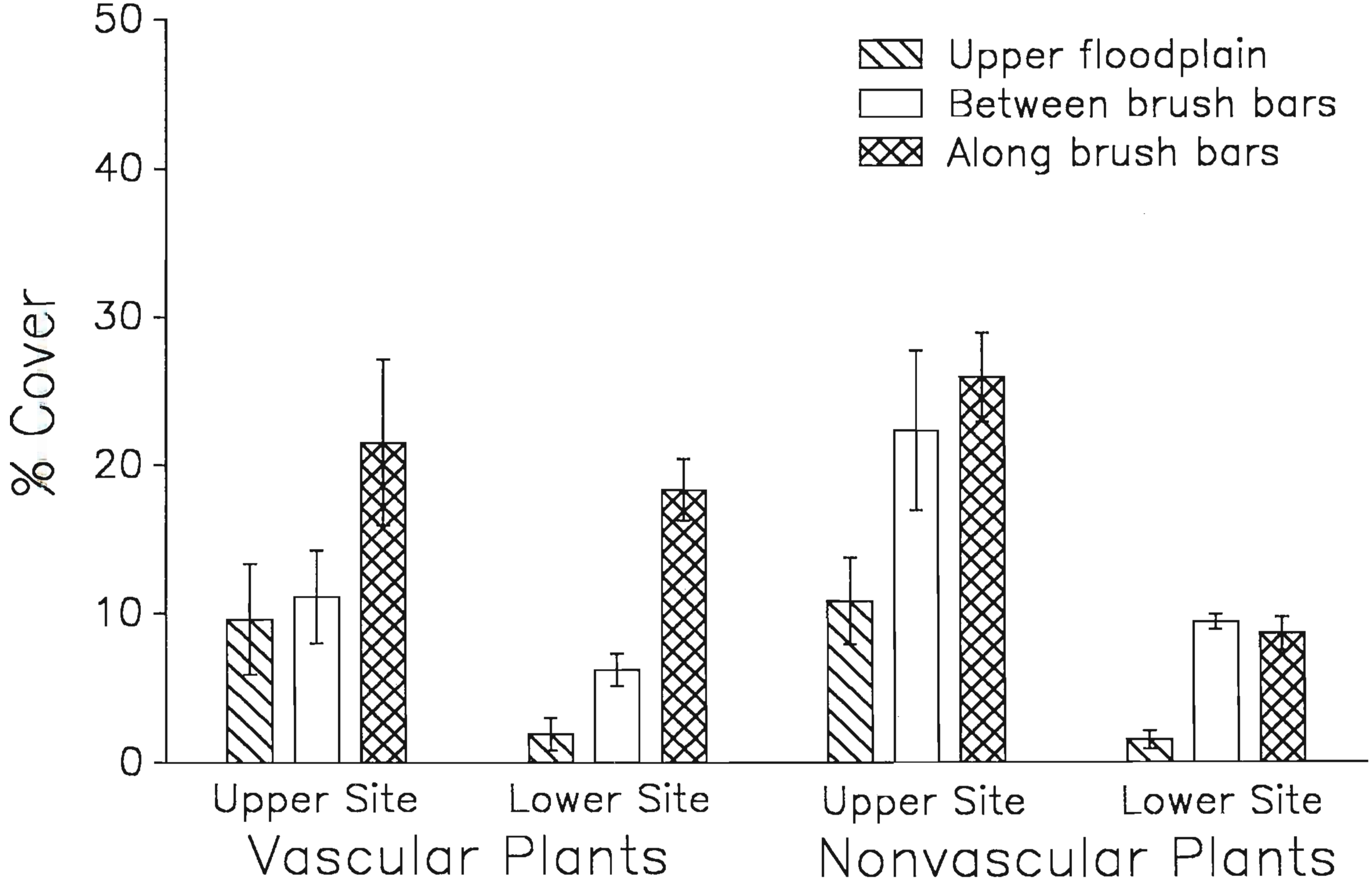
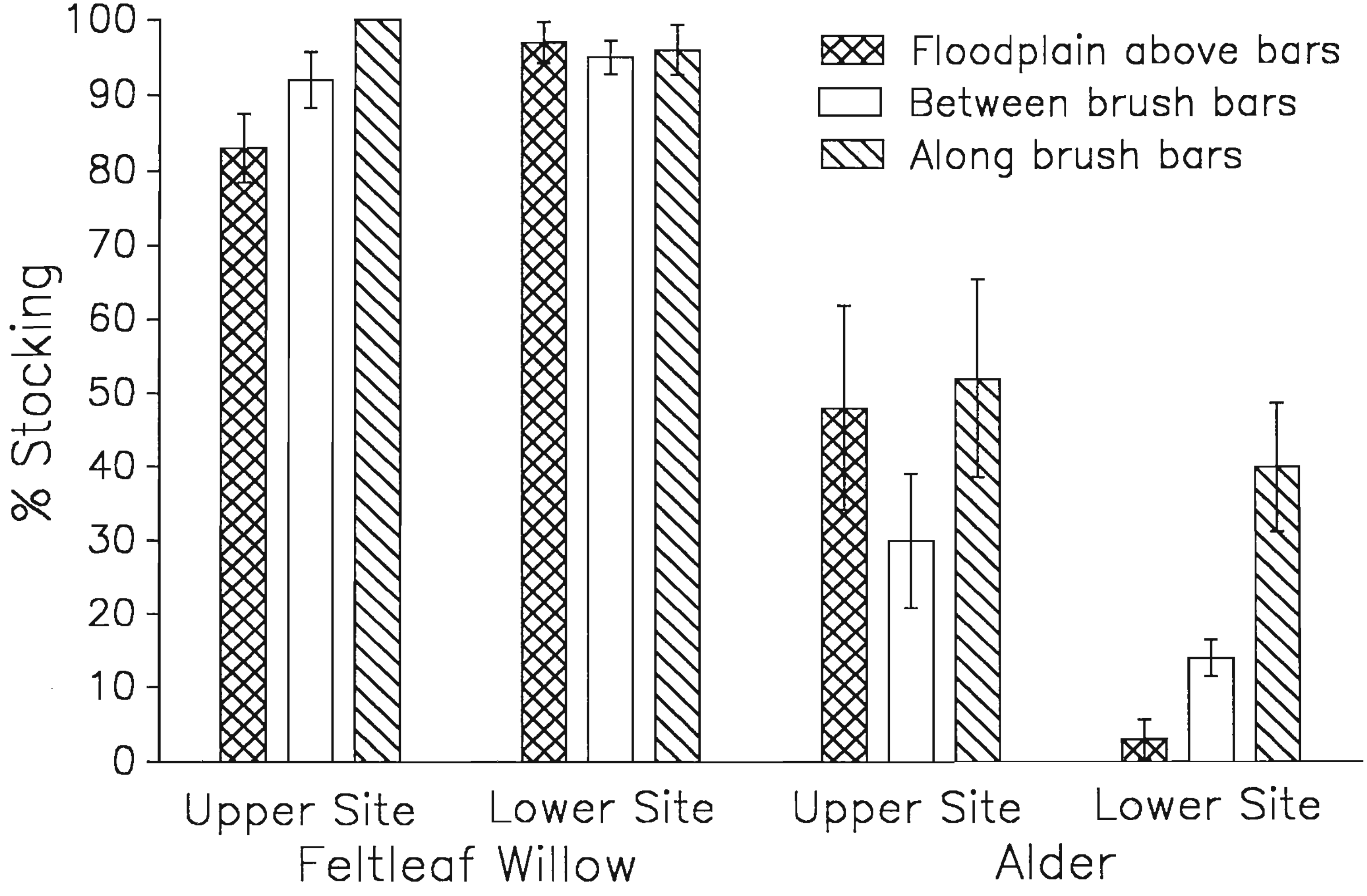

Fertilized, lower area
Fertilized, upper area
Unfertilized, upper area
% Survival
0
10
20
30
40
50
60
70
80
90
100
Mean ht (cm)
0
10
20
30
40
50
60
70
80
90
100
% Survival
Height

Fig 4


50
40
30
20
10
0
% Cover
Upper floodplain
Between brush bars
Along brush bars
Upper Site
Lower Site
Vascular Plants
Upper Site
Lower Site
Nonvascular Plants



100
90
80
70
60
50
40
30
20
10
0
% Stocking
Floodplain above bars
Between brush bars
Along brush bars
Upper Site
Lower Site
Feltleaf Willow
Upper Site
Lower Site
Alder