HENRETTA CREEK AND LAKE – A DECADE OF RECLAMATION MONITIORING

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ABSTRACT

This paper presents the vegetation restoration results of a 10 year monitoring project along the reclaimed Henretta Channel and Lake at Teck Coal's Fording River Operations in southeastern British Columbia. Vegetation monitoring utilized permanent vegetation plots and photo points to assess vegetation restoration success. Heavy metal uptake by vegetation utilized by wildlife was also analyzed for four species: *Salix bebbiana*, *Populus trichocarpa*, *Medicago sativa*, and *Festuca* spp. Results in 2010 indicated that vegetation was at early- to mid-seral stages on average and showed good growth, vigour, diversity, and natural regeneration since initial seeding and planting. The heavy metal analysis of vegetation tissue found no significant difference between the study site and the control site (no mine influence). A qualitative Proper Functioning Condition (PFC) analysis indicated lotic and lentic areas were functioning properly and showing steady improvement over time. Past aquatic habitat monitoring of water quality and benthic assemblages indicated a healthy aquatic system supporting a self-sustaining Westslope cutthroat trout population. Monitoring and PFC analysis allowed for a critical assessment of the restoration success. Findings will help inform various aspects of all future reclamation activities while recommendations specific to stream restoration projects include channel design and integration of rip-rapped banks.

KEY WORDS: riparian, Proper Functioning Condition, heavy metals.

INTRODUCTION

From 2000 to 2010 Teck Coal Limited (Teck), Fording River Operations (FRO) completed an annual fish and fish habitat monitoring program within the Henretta Creek Valley, focusing on the Henretta Creek Reclaimed Channel and Henretta Lake. The major restoration and construction phases of Henretta Lake and the Henretta Creek Reclaimed Channel were completed in 1998 and 1999. Riparian vegetation re-establishment monitoring occurred during this time as well. Surveys were completed for the final year of the riparian re-establishment monitoring program in Lower Henretta Creek as well as Proper Functioning Condition (PFC) of the lentic and lotic constructed habitat and heavy metal uptake by vegetation utilized by ungulates. Proper functioning condition is a qualitative method for assessing the condition of riparian-wetland areas. The assessment considers hydrology, vegetation, erosion/deposition (soils), and fish-related channel morphology attributes and processes (Prichard et al., 1998). The PFC is a state of resiliency that will allow riparian-wetland areas to hold together during high-flow events (5 to 20 year events) with a high degree of reliability while contributing to fish habitat health. Reconstruction of functioning habitat has general guidelines but site specific conditions always add new knowledge to the body of science. As such, Henretta Channel and Lake provides a unique opportunity to assess construction and monitoring design, as well as an assessment of reclamation as a functioning habitat.

The Henretta Creek Reclaimed Channel is located near the mouth of Henretta Creek in the upper Fording River drainage on the FRO mine site, approximately 35 km northeast of Elkford, BC (Figure 1). The riparian vegetation surveys occurred along Henretta Lake and Henretta Creek Reclaimed Channel (Reaches 2, 3, and 4) (Figure 1). The main objectives were to evaluate the success of the riparian zone restoration along the recreated Henretta Channel, assess PFC of the lotic (Reaches 2 and 4) and lentic (Reach 3) reaches and determine heavy metal and selenium uptake by vegetation utilized by wildlife species.

METHODOLOGY

Vegetation Monitoring

Six permanent plots (50 m^2 area) were established in 2002 for vegetation monitoring. Two plots were established along Reach 2 and four plots along Reach 4 (Figure 1). Plots were established in areas considered representative of bank condition within the riparian zone at the time of establishment. Vegetation monitoring in 2002 consisted of density counts for planted trees and shrubs. Vegetation plots in 2010 consisted of percentage of canopy-cover for all species utilizing a modified Daubenmire (1959) system (addition of trace class), density and utilization. Percent cover was added together for all three layers when layers occurred resulting in the possibility of greater than 100% cover within plots. Species richness and diversity were analysed using standard measures. Vegetation richness was defined as the number of species recorded within plots. Species diversity (H) was calculated using the formula:

$$H = \sum_{i=1}^{S} \pi \times \log \pi$$

- where S is the number of plant species; and,
- Pi is the proportion of the total plant species belonging to the i^{th} species (Brewer, 1979).

Hence, diversity increases with richness (number of species), and with evenness, where evenness is the spread among species. For example, a site with an even number of each species would have greater diversity (H approaches one) than a site dominated by one species (H approaches zero) but the same number of species as the first example. Resulting numbers ranged from zero to one with numbers closest to one representing higher diversity.

Photo Point Monitoring

Permanent photo points were established in Year 1 of post-construction monitoring (2000) using GPS points and orange steel spikes pounded into the ground for future location. Photos were taken in 2000, 2002, 2006, and 2010. Photo comparison illustrates changes in vegetation cover where no vegetation plots occurred and during years when no vegetation monitoring was conducted.

Wildlife utilization of plants was recorded within vegetation plots. Utilization was divided into four classes; light (1-35%), moderate (36-65%), heavy (66-80%), and extreme (>80%) browsing. Wildlife utilization data was used to select appropriate plant species to collect vegetation tissue for heavy metal analysis while in the field.

PFC surveys utilized the Technical References 1737-15, and 1737-16 procedures (Prichard et al. 1998; 2003) for Henretta Channel and Lake (lotic and lentic respectively) assessments. Assessment followed their methodology and utilized their field data sheets.

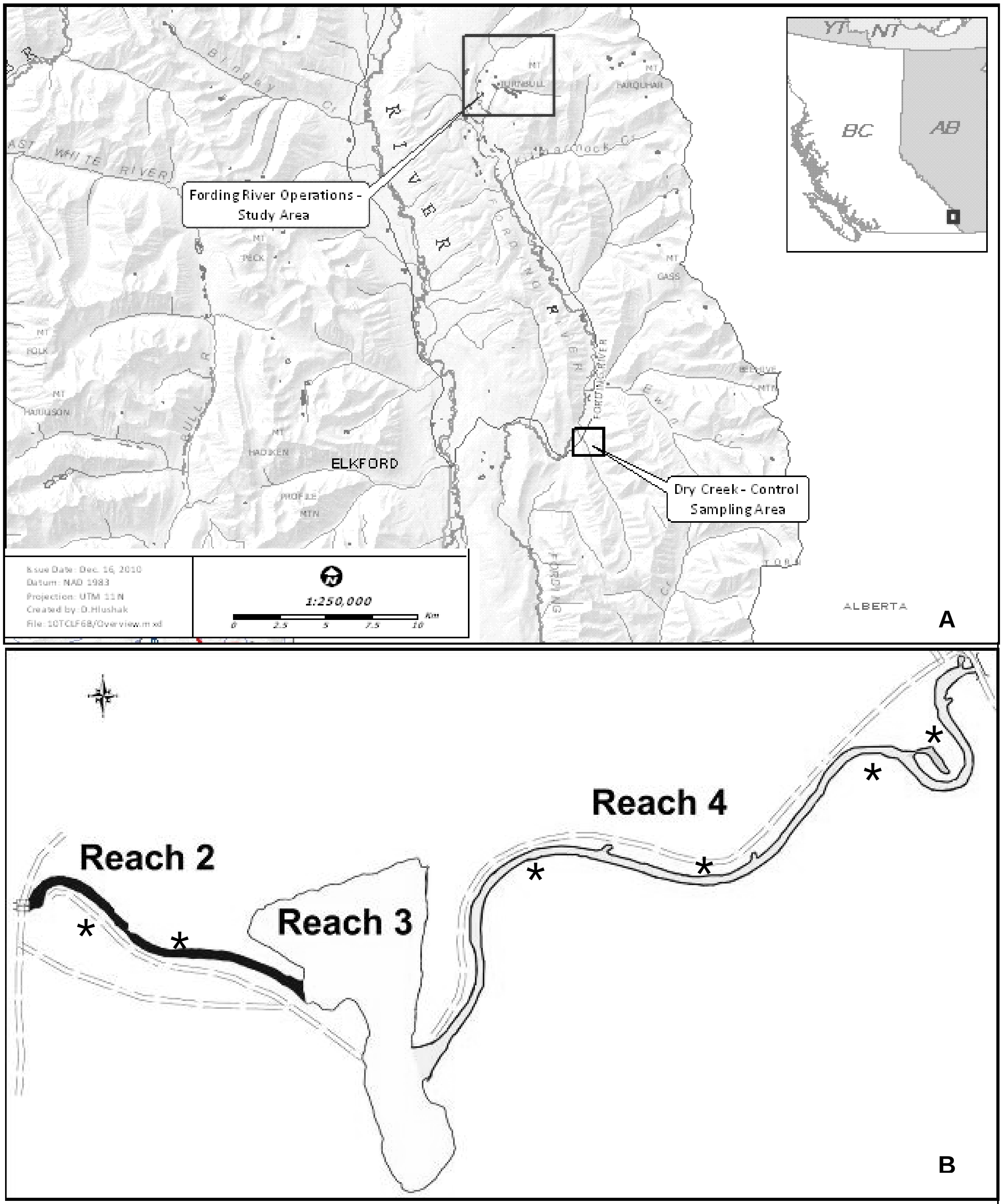

Figure 1: Site location (A) and schematic (B) design of reach classification. Reaches 2 and 4 are Henretta Reclaimed Channels and Reach 3 is Henretta Lake, vegetation plot locations marked with *.

Heavy metal sampling of vegetation utilized by wildlife was included in the final site assessment since "wildlife habitat" was the end land use designated in the reclamation plan at the time monitoring occurred. Sixteen plant tissue sampling points were pre-field selected, consisting of the approximate center of each point bar for the lotic reaches (or two points evenly spaced for large point bars). This resulted in four sampling points for Reach 2 and seven points for Reach 4. Five sampling points for Reach 3 were evenly spaced around the lake excluding the north end which is adjacent to active mining and not reclaimed yet. The four species collected were selected from the overall observation of the dominant species utilized by wildlife while in the field. These were; black cottonwood (*Populus trichocarpa*), Bebb's willow (*Salix bebbiana*), fescue (*Festuca spp*), and alfalfa (*Medicago sativa*). This resulted in thirty two samples with a total of 7 cottonwood, 8 Bebb's willow, 9 fescue, and 8 alfalfa samples for the study area. Two different dominant species samples were taken at each sampling point. Not all sampling points had all four species present, resulting in the slight imbalance in the number for each species sampled.

Dry Creek (approximately 20 km south) was selected as the control reach for metal uptake analysis. Dry Creek is within a similar geographical area but is not within an active mining area or influenced by mining activity (Figure 1). Because Golder Associates Ltd (Golder) had already collected and processed plant tissue for heavy metal from Dry Creek for a previous study in 2009, data was shared for this project. However, only two of the species selected in 2010; willow and fescue were available through Golder. Therefore two samples each of black cottonwood and alfalfa were collected along Dry Creek.

A total of 36 plant tissue samples (4 from the control reach and 32 from the study area) were sent to Maxxam Analytics in Burnaby, British Columbia for metal analysis, including selenium concentration. The lab analyzed samples for 31 heavy metals using Inductively Coupled Plasma – Mass Spectrometry (ICPMS) with elements detected by atomic spectroscopy. Analysis for the Henretta site focused mainly on comparison of concentration levels for samples taken at the study area to concentration levels of the control samples from Dry Creek. Only riparian vegetation along the lotic and lentic reaches was sampled so Dry Creek riparian vegetation was the control for both lotic and lentic reaches.

RESULTS

Riparian Vegetation Monitoring

The vegetation cover recorded in Reach 2 averaged 117% (95% confidence interval of 79.4 – 314.4) and Reach 4 averaged 165.6% (95% confidence interval 98.6 – 235.1). The percentage of vegetation cover within plots can be greater than 100% because of the layers (tree, shrub, forbs, and grasses) of vegetation (Figure 2).

The results from the vegetation plots for all vegetation types combined are illustrated in Figure 2. Reach 2 was dominated by Bebb's willow at 52% cover, cottonwood just under 16%; forbs accounted for 21% (alfalfa (75%)), and grass was 11 % (fescue (59%)) of the area. Forb cover at Reach 4 was dominant at 36% cover, followed by grass at 35%, trees at 18%, and shrubs at 11%.

Species Diversity and Richness

Species diversity of all species is higher than each of the vegetation classes except for Reach 2, Plot 1 where willow dominated the plot thereby reducing species diversity (Figure 3A). Species diversity index was only similar for grasses (Figure 3A). Reach 2 species diversity index was significantly lower than

Reach 4 (P = 0.023 STDEV = 0.1197) for all vegetation types. Species diversity indices for all species and for each vegetation group were highly variable between plots (Figure 3A). There was a statistically significant difference in Reach 2 between Plots 1 and 2 with a P = 0.00005 (STDEV = 0.0177) for all species combined. Diversity index for all species combined in Reach 4 was high (0.76) compared to Reach 2 (0.51). For grass vegetation types diversity was moderate (0.38) and similar to Reach 2 (0.39). Forb diversity was lower for Reach 4 (0.21) compared to Reach 2 (0.45) and shrub/tree diversity was higher for Reach 4 (0.23) compared to Reach 2 (0.16) with the shrub/tree vegetation type having the lowest diversity when averaged across reaches.

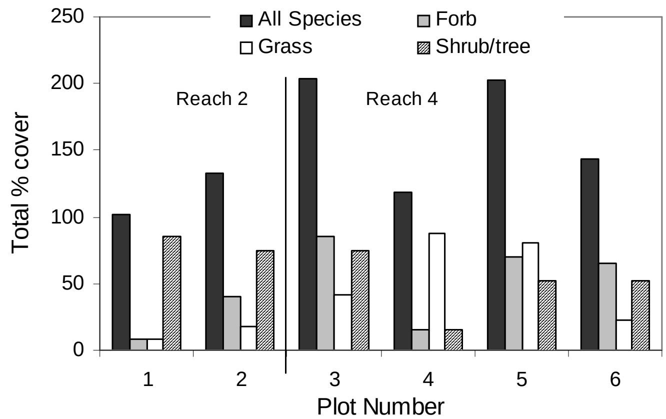

Figure 2. Graph of all vegetation cover percentages within each plot and all species combined.

Species richness (number of species) was not significantly different between vegetation groups, reaches or plots (Figure 3B). The shrub/tree combined vegetation type had the lowest richness (2 trees and 2 species of willow). Reach 2 species richness (16 species total) was similar to Reach 4 (22 species total) (Figure 3B).

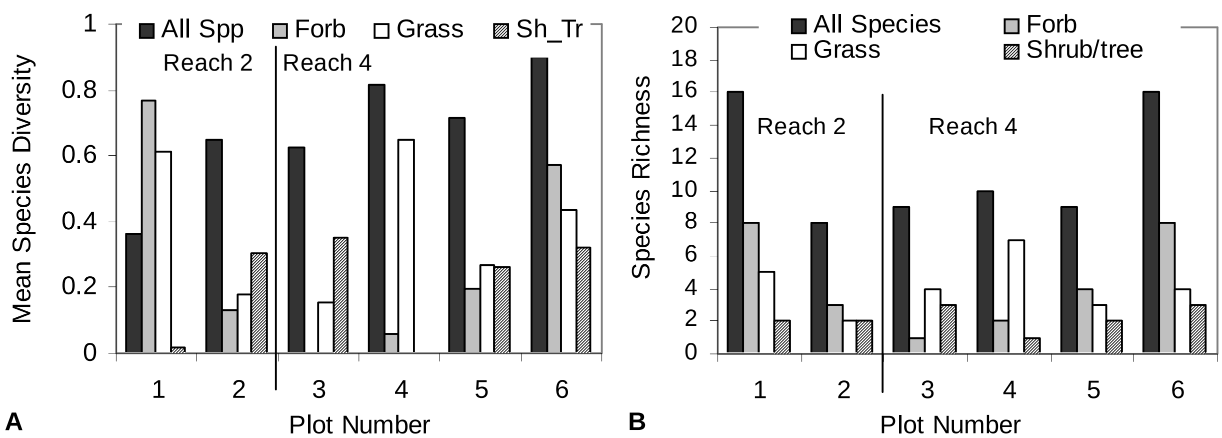

Figure 3. Mean species diversity for all plots in Reaches 2 and 4 (A). All Spp = all species combined, Sh_Tr = shrubs and trees combined. Graph B is species richness by plot for vegetation types and all species combined within each reach.

As expected, plant heights increased from 2002 to 2010; however heavy browse of cottonwood in particular, impacted the overall mean growth. Combining all woody species, the mean height for Reaches

2 and 4 increased significantly using a 2-tailed T-Test (P=0.005, t= 3.24, df 17, and P=0.016 t=2.57, df 27 respectively) from 2002 to 2010 within established plots.

Proper Functioning Condition for Lotic and Lentic Areas

Reach 2 was rated as **Functioning—at Risk** in accordance with its capability and potential, which is limited by the confined channel form due to construction of the channel through bedrock. Most of Reach 2 was at the early-seral stage with some very small areas at the start of mid-seral stage and some areas still mainly bare ground. Functional condition showed an upward trend indicating it should continue to improve with time achieving proper functioning condition as vegetation cover improves. The north shore of the reach is adjacent to mining activity so assessment did not go beyond the planted area. The confined channel was acknowledged as outside the control of the manager and as such did not impact the rating.

Reach 3, Henretta Lake, was rated as **PFC** in accordance with its capability and potential. Reach 3 was limited by the north shore bank, which has not been restored as it was still adjacent to active mining operations. Reach 3 displayed an upward trend in function condition from early-seral to mid-seral stage for the majority (75%) of the shoreline and the hydric meadow island complex. The very steep high bank at the north end was still bare ground, which has not been reclaimed yet. Therefore, the condition was not included in the assessment but it was recorded as a potential area that could put the condition at risk.

Reach 4 accounts for 70% of the constructed channel area and was rated as **PFC** in accordance with its capability and potential. Reach 4 was limited by the constructed channel form and the extensive use of rip-rap to waters edge, along 33% of bank reach area. Most of the riparian zone was at early- to mid-seral stage. Four of the five constructed fish alcoves were at mid-seral stage, while some sections of the bank were still bare ground. The constructed fish alcoves functioned as floodplains with no or limited fish access ten years later. Rip-rapped areas had no to very limited vegetation establishment. Proper functioning condition analysis revealed an upward trend indicating function should continue to improve with time.

Henretta Creek reclaimed channel was assessed as **PFC** for Reach 2 and Reach 4 combined in accordance with its capability and potential. Because Reach 4 was 70% of the total reclaimed channel more weight was given to it for the overall assessment.

Heavy Metal and Selenium Uptake by Plant Tissue

Concentrations of heavy metal varied among the plant species. Mean levels of copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) were higher than the levels from the control reach (Dry Creek) for all species combined but not significantly. However, only Zn was slightly higher than the normal concentrations found in vegetation (20-150 mg/kg), with black cottonwood and willow both above normal concentrations of Zn. However, levels of Zn were well below the maximum tolerable levels for livestock (NCR 1980). No significant differences were found in metal concentration levels among species between reaches 2, 3, and 4. All metal concentrations were compared (ANOVA) between reaches with the control; Cu was the only metal that was significantly different (P = 0.005) between reaches. The Cu levels for Reaches 2, 3, and 4 were not above normal concentrations found for these species of vegetation.

Mean metal concentrations by species were compared between reaches and the control (Figure 4). Alfalfa (Med sat on graph) had the highest total concentrations for all reaches. However, there were no significant differences between species within the reaches. Reach 4 had the least amount of variation between concentration levels for black cottonwood (Pop tri), willow (Sal beb), and fescue (Fes spp).

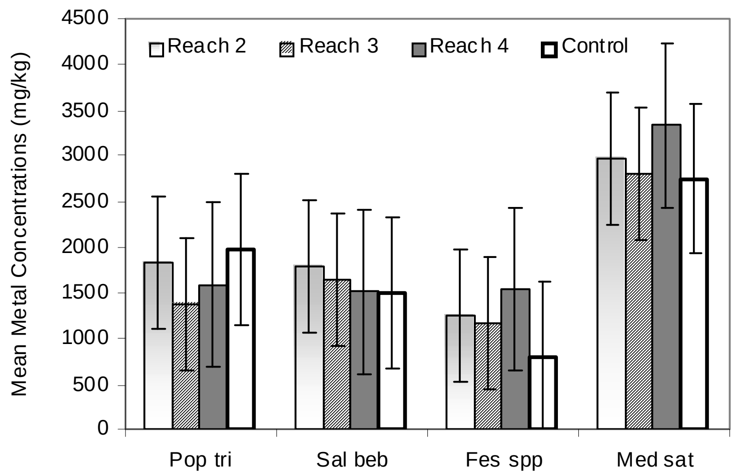

Figure 4. Mean total metal concentrations per reach (± SD) grouped by species.

Selenium (Se) levels for vegetation along Henretta Creek and lake (Henretta Reach 3) had a mean value of 2.07 mg/kg (±0.65 SD) while Dry Creek samples had a mean of 1.55 mg/kg (±1.55 SD). However, Henretta Reach had 32 samples (Pop tri, Sal beb, Fes spp, and Med sat) while Dry Creek had 8 samples of the 4 species resulting in too small of a sample size for the high variability of the data. Alfalfa had the highest concentrations of Se for both Henretta and Dry Creek reaches The range for Se in alfalfa in Henretta Reach samples was 1.33 to 4.04 (8 samples) and the range found in Dry Creek samples was 3.06 and 4.44 mg/kg (2 samples). Selenium levels for the study area and the control area were at the low end of the scale for normal concentrations found in plants of the same genus and/or species.

DISCUSSION

Plot data indicated that Reach 2 was dominated by shrubs (52% willow) with woody vegetation (willow, cottonwood, and spruce) accounting for 68% of the vegetation ground cover, while forbs and grasses covered 32%. However, due to the small sample size representing Reach 2, vegetation population results had very low precision (large range in confidence level and SD). The two permanent vegetation plots occurred along sections of bank dominated by shrubs, while field observation indicated Reach 2 vegetation was dominated by forbs (alfalfa dominant) and grass (fescue dominant) cover (Figure 5A). Additionally, low vegetation density and a high percentage of bare ground were also common along banks in sections of Reach 2 not captured in plot data. Bank slopes with low relief had good vegetation cover while steep banks had low vegetation cover and a high percentage of bare ground. Vegetation retention and expansion is facilitated by gentle slopes as observed in Reach 2.

Reach 4 had four plots, which increased precision slightly. Plot data indicated Reach 4 was dominated by grass and forbs (71% of cover) and had lower increases in tree and shrub heights compared to 2002 data. This contrasted sharply with field observations that Reach 4 had higher woody vegetation cover along banks and along the top edge of banks compared to Reach 2. The woody vegetation was also taller than was generally noted along Reach 2. None of the plots occurred along the banks of the five fish alcoves, which had high densities of woody vegetation, or along sections of bank that had high woody vegetation densities (Figure 5B). Reach 4 was dominated by woody vegetation, which was supported by photo monitoring showing steady improvement since 2006 in most areas.

Figure 5. Reach 2 looking west (downstream) of vegetation Plot 2 (A). Reach 4 looking downstream (B).

Species richness was similar for both reaches and was high for a system with only ten years of growth since channel construction. Species diversity was also high for a relatively young channel, although Reach 2 was not as diverse as Reach 4 because of areas dominated by one species. Reach 2 occurred in an area where bedrock restricted the potential width of the constructed channel and steep slope gradients limited plant establishment. Where steep banks occurred in Reach 4 a similar pattern of reduced plant cover and increased bare ground was observed.

The contrast between data results from non-random plot locations and very small sample size illustrates the inherent problems with certain sampling designs set up to monitor site restoration over time. The photo point comparison helped to illustrate vegetation progress through time, but does not capture species diversity and richness or actual cover.

Proper Functioning Condition

Reach 2 was assessed in 2010 as “**Functioning – at risk**” with an upward trend. Photo comparison of the changes between the 2000 photos (newly constructed) through to the 2010 showed that Reach 2 is in an upward trend and is functioning physically. Monitoring and site assessment in 2010 found that woody vegetation one metre or greater in height covered approximately 20% of the banks (north and south sides combined). The remaining 80% of the cover was grass and forbs and/or stunted or browsed shrubs less than 50 cm in height (Figure 5A).

This contrasted sharply with Reach 4 at **PFC**, which had substantial growth and increased density of woody vegetation that covered longer sections of both the north and south side banks (Figure 5B). However, the Reach 2 channel is underlain by a bedrock base which may be limiting the vegetation potential. Even with this limitation there was a diverse age-class distribution and composition of riparian vegetation. The reach is in balance with the water and sediment being supplied by the watershed as there was no excessive erosion or deposition occurring. The riparian vegetation was providing a food source of invertebrates and sustaining healthy fish populations and water quality. Yet the area was assessed as still at-risk because soil and vegetation attributes made it susceptible to degradation. Systems rated as **Functional – at risk** with an upward trend can move quickly to **PFC** in relatively short time frames. Past assessments have shown systems moving from at-risk to proper function condition in as little as 5 months for Texas Creek in Colorado (Prichard et al., 1998).

Reach 3, Henretta Lake, was rated as **PFC,** the hydrology category was very positive; with riparian wetland area saturated at or near the surface or inundated in relatively frequent events. Fluctuations of water levels were not excessive and the riparian area had achieved potential extent in some areas and enlarging in others. Water quality is sufficient to support riparian-wetland plants, natural surface and subsurface flow patterns were not altered by disturbance, and there was no headcut affecting the outflow of the lake. The north end of the lake that has not been reclaimed yet and was not included in the PFC assessment has the potential, though not a significant risk, of causing degradation to riparian-wetland and hydrology if a major bank failure were to occur.

The vegetation assessment was also very positive with the vigour of the riparian-wetland plants being the only concern. Approximately 65% of the riparian vegetation was rated as high vigour, while approximately 35% of the area was rated low because of low vigour and sparse vegetation cover in places. Vegetation with high vigour occurred at the south end of the lake and included the hydric meadow islands and adjacent banks with woody vegetation established (Figure 6C). The areas with poor vigour occurred along the east shore north of the confluence of Reach 4, where most of the woody vegetation was only 30 to 40 cm tall when present and at, and north of, the confluence of Reach 2 and Reach 3 (outlet of Henretta Lake and start of Reach 2) (Figure 6A & B). There are a number of possible causes of the poor vigour and stunted growth noted in these two areas: 1) compacted soils (old access roads); 2) reduced fertility compared to other areas; or 3) an imbalance in soil pH could be inhibiting plant uptake of nutrients and may be causing adverse reactions between traces of heavy metal and the plants' ability for translocation of nutrients (Adriano 1986). Further analysis of soil in these areas would be required in order to assess the impact of soil parameters on plant vigour. There were no erosion/deposition problems and banks were stable even where vegetation was sparse and the north end.

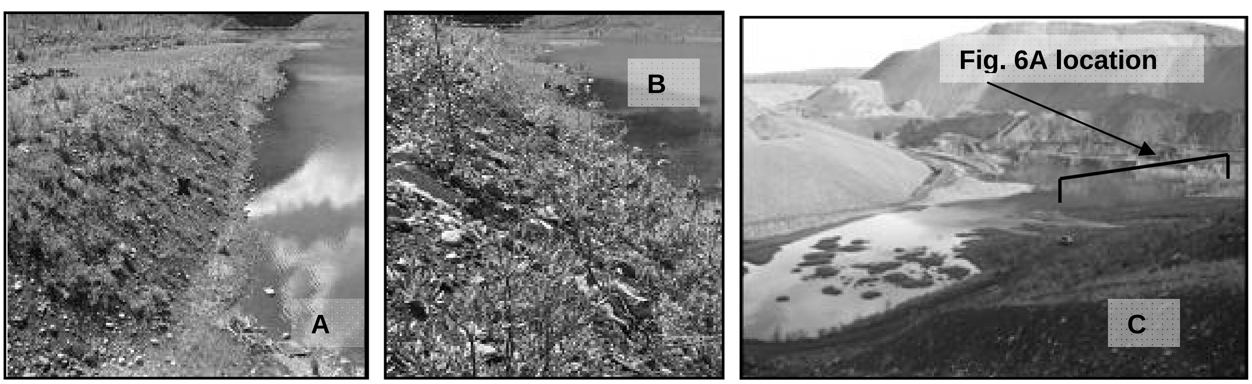

Figure 6. The east bank of Henretta Lake shows the woody vegetation with low vigour and stunted growth looking south (A). The X marks the approximate location that Figure B, a close-up starts at, also looking south. Figure C is Henretta Lake looking north.

Reach 4 was assessed at **PFC,** although it was limited by the constructed channel form and the extensive use of rip-rap to the water's edge in areas (36% of the north bank and 30% of the south bank) where a channel liner was required. Rip-rap stabilizes banks and was the priority purpose as the constructed sections of lined channel required this level of protection. However, rip-rap reduces channel functionality and limits the shading potential of riparian zone vegetation by eliminating shrub and tree establishment next to the water's edge in these areas. The five fish alcoves functioned similar to floodplains and the wider sections of the constructed channel provided the potential for floodplain formation and natural channel sinuosity to evolve, which was occurring in places.

As noted for Reach 2, Reach 4 floodplain (terrace) above bankfull heights was not inundated during frequent events (5 to 20 year events). There were small floodplains developing within the bankfull channel that were starting to function as floodplains during frequent events. Some bars were still in the forming process and had the potential to offer new sites in the future. The fish alcoves were also functioning as floodplains for frequent events within the bankfull channel but offered no to limited access for juvenile fish (Figure 7). While no cottonwood or willow seedling establishment was noted in 2010, root suckering and past seedling establishment supplied diversity in age range for cottonwood and willow species. Engelmann spruce was establishing by seed, with vigorous growth occurring for seedlings as well as the older planted stock.

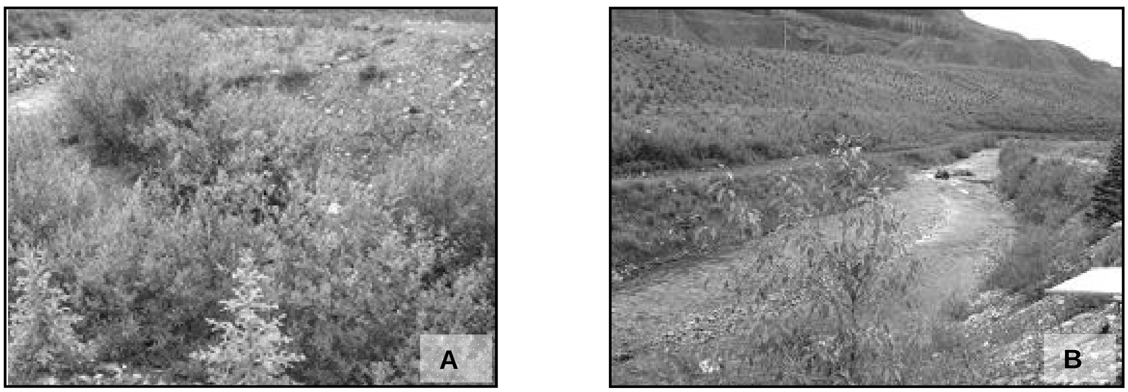

Figure 7. Reach 4 looking down from the top of bank at a fish alcove (A) and a developing floodplain within the constructed channel (B).

Reach 4 also scored well for erosion/deposition with the only negative point being the limited lateral stream movement associated with natural sinuosity. This did not impact the assessment rating as Reach 4 was functioning at the potential restricted by the constructed channel width and design. Even with this limitation there was evidence that some natural sinuosity was establishing with the development of small point bars and mid-channel bars (Figure 7).

Fish related functioning condition was assessed at 'moderately well' for Reach 4. Despite the 68% bare ground due to rip-rap and some bare spots on overly steep banks, many areas had well established, vigorously growing, woody vegetation, providing overhead cover for fish.

The PFC assessment also used the past fish monitoring work to assess water quality, benthic and fish usage. All three reaches have good water quality and support healthy benthic communities and self-sustaining Westslope cutthroat trout population. This contributed to the positive assessment ratings for the three reaches.

Heavy Metal Concentrations

There were no significant differences found for vegetation trace metal levels between the three reaches that comprised Henretta Reclaimed Channel (Henretta Reach). Only copper (Cu) levels were significantly different between the control (Dry Creek) samples and Henretta Reach. Cu levels recorded for the study site vegetation were within normal levels range found in plants and well below maximum tolerable levels for livestock (NRC 1980).

Selenium levels were similar between the control and Henretta Reach and both had levels much lower (<5 mg/kg) than the normal concentration found in plants (<25 mg/kg). Since levels were similar between the control and the reclaimed reaches no identifiable impact to wildlife from browsing vegetation is likely to occur from selenium or any of the other heavy metal concentrations found in the plant material tested.

CONCLUSION

Riparian vegetation on average has been increasing in size, vigour, cover, and diversity since the initial seeding and planting of Henretta Creek and Henretta Lake. Black cottonwood and willow growth and density were higher for Reach 4, which represents over 70 % of the lotic riparian area. Species richness was high for lotic reaches with high diversity for Reach 4 and moderate for Reach 2 reflecting lower single species dominating sampling plots. Considering the short time of 10 years since initial construction, vegetation has been greatly advanced by seeding and planting compared to a system left to regenerate with no active reclamation.

Proper Functioning Condition assessment of Henretta Creek and Henretta Lake found that the lotic and lentic sections were in **PFC** in accordance with their capability and potential within the restraints of the constructed channel design and materials. The lotic and lentic areas had sections that could benefit from additional work, but Reaches 2, 3 and 4 have an increasing trend of vegetation improvement with self-sustaining vegetation and channel stability.

Heavy metal analysis found no significant differences between the study site and the control (Dry Creek) vegetation for all elements tested except copper (Cu). However, Cu levels recorded for the study site vegetation were within normal levels found in plants and well below maximum tolerable levels for livestock. Selenium levels were not significantly different between the study area and the control reach.

Photo-point monitoring showed a continuing increase in vegetation growth and density for the majority of the lotic and lentic riparian vegetation from 2000 to 2010.

FUTURE CONSIDERATIONS

Vegetation Monitoring

Future monitoring methodology for new projects should be changed from a small sample size of predetermined locations based on vegetation occurring at the time of establishment to a systematic sampling along permanently established transect lines or permanent random plot selection with the number of plots sufficient to be representative of the area being monitored. One option is to use 100 m long transect lines with systematic sampling every x metres along the transect line. Multiple pairs of transect lines should be considered per reach, depending on the linear length of the channel, in order to capture a representative pool of plots for the site. Either sampling design should have sufficient plots to ensure a high confidence level for statistical analysis.

Data for percent cover for all vegetation as well as density and heights of woody vegetation should be collected at the initial sampling after planting is completed and during the monitoring process. This would provide comparison analysis to assess vegetation growth and expansion or areas that need additional work before monitoring is completed.

Proper Functioning Condition

At the time of channel construction, a wider channel with floodplains (2-year flood return interval elevations) should be planned within the sinuous channel. The channel should be wide enough in multiple locations for a natural floodplain turnover rate to develop, allowing natural meandering so the channel is able to reach a natural equilibrium within the floodplain. Even when site limitations restrict the width of the constructed channel, incorporation of a narrow floodplain in places where appropriate conditions exist would contribute to reaching a proper functioning condition.

When there is a need for rip-rap banks, narrow floodplains could be constructed, where possible, between the rip-rap bank and the channel, allowing shrub and tree establishment (or planted) next to the channel for improved shading and fish cover.

When there is sufficient area available, 3:1 slopes which retain vegetation and support natural regeneration, are recommended. Constructed banks should not be steeper than 3:1 when possible to reduce the potential for erosion and increase vegetation recruitment potential.

Heavy Metal Concentrations

Selenium and all heavy metal concentrations in soil are important factors in uptake by plants. Heavy metals in general are also influenced by soil properties such as pH, texture, organic matter content, cation exchange capacity and interactions among these elements (Jung, 2008). Total metal concentrations in soil and soil pH are the main factors controlling heavy metal contents in plants (Adriano, 1986). Soil testing of these parameters should be included in the monitoring protocols along with vegetation tissue sampling for heavy metal levels so areas of potential concern can be more accurately analyzed. A larger sample size from the control reach is also recommended to increase confidence levels in analysis.

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