Columbia River Project Water Use Plan

Kinbasket and Arrow Reservoirs Revegetation Management Plan

Implementation Year 6

Reference: CLBMON-12

Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

Study Period: 2017

Okanagan Nation Alliance, Westbank, BC
and
LGL Limited environmental Research Associates, Sidney, BC

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KINBASKET AND ARROW LAKES RESERVOIRS

Monitoring Program No. CLBMON-12

Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis




Implementation Year 6 – 2017

Final Report

Prepared for

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Burnaby, BC

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Cover photos

From left to right: Kellogg's sedge (*Carex lenticularis* ssp. *lipocarpa*) plugs, Edgewood; dead cottonwood (*Populus balsamifera* ssp. *trichocarpa*) stakes, Edgewood; live cottonwood stakes, Edgewood; cottonwood seedlings, 12 Mile. All photos © Michael T. Miller, LGL Limited.

EXECUTIVE SUMMARY

The Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis (CLBMON-12) is a Water Licence Requirement project initiated in 2008 to assess the effectiveness of revegetation treatments applied to the reservoir drawdown zone between 2009 and 2011 under the CLBWORKS-2 program.

The primary objectives of this study are: (i) to assess the short-term effectiveness of the revegetation program at expanding the quality (as measured by diversity, distribution and vigour) and quantity (as measured by cover, abundance and biomass) of vegetation in the drawdown zone within the 434 to 440 m ASL elevation band; and (ii) to assess whether revegetation establishment is facilitated by the implementation of the Water Use Plan operating regime (2007-2017), including soft constraints.[1]

Prior to 2017, data collection entailed resampling vegetation composition and cover within previously established and monitored long-term plots stratified by region, elevation band, and treatment type (Miller *et al*. 2016). For 2017, we expanded the scope of sampling to include an array of CLBWORKS-2 treatment areas (mapped polygons) not previously covered under the CLBMON-12 monitoring scheme. At each new polygon, as well as at polygons already containing permanent plots, we established from one to seven (depending on polygon size and habitat heterogeneity) new "survivorship" plots. The plots were situated semi-randomly within representative revegetation areas. At each survivorship plot, we recorded the numbers of surviving individuals associated with each CLBWORKS-2 revegetation treatment. These totals were subsequently used to generate survival rate estimates for specific species, sites, and planting methods (e.g., seedlings versus live stakes) based on the reported initial planting densities provided by the CLBWORKS-2 annual reports and associated databases

Our overall conclusions are consistent with those reached following previous study years (Enns and Overholt 2013a, Miller *et al.* 2016): revegetation efforts to date have achieved mixed success. A portion of the stock (primarily Kellogg's sedge, Columbia sedge, and black cottonwood) planted between 2009 and 2011 has survived and taken root and, in limited areas, is growing vigorously. An estimated 76 per cent of treated polygons, representing about 82 ha of drawdown zone habitat, support at least some surviving transplants. The plantings in these areas may now be providing some ancillary ecological services such as increased erosion control, browse for waterfowl, and perching habitat for birds. For about one quarter of the treated areas (approximately 26 ha), survival of plantings has been minimal to non-existent.

Multivariate analyses identified site, vegetation community type (VCT), and rooting zone soil texture as potentially important predictors of transplant establishment success and long-term survivorship. Elevation within the drawdown zone (which may be regarded as a proxy for operating conditions since low elevations are inundated earlier, for longer periods, and to greater depth than high elevations) was a less informative predictor of revegetation performance.

[1] Soft Constraints are operational targets developed by the Columbia Water Use Planning Consultative Committee (WUP CC) for the benefit of various interests (vegetation, wildlife, fish, culture and heritage, recreation, erosion, and power generation). Each target identifies the ideal/preferred reservoir operations (water level over the year) for a specific interest. While the reservoir was not operated to target specific soft constraints, the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2017, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 47% of the time.

In several areas, survival of plantings has been minimal or has failed. Failures can probably be ascribed to a combination of environmental factors including prolonged inundation, infertile or unstable substrates, wave action and erosion/deposition, soil moisture deficits, ATV traffic and other forms of human disturbance, and herbivory. In areas where revegetated plants have taken hold, a lack of new recruits indicates that ecological filters preventing natural succession have not been adequately addressed and suggests that revegetated populations may not be self-sustaining over the long term. These areas may require additional physical works (i.e., site alterations such as tilling, diking, windrows, mounding) or repeat planting entries to maintain the presence of vegetation over time.

At the community level, treatments have resulted in some local increases in species cover and richness, both via infill planting of graminoids (primarily sedges) and shrubs (primarily black cottonwood) in previously vegetated habitats, and through the introduction of these taxa into otherwise unvegetated microsites. Surviving sedge plugs (primarily those of Kellogg's sedge and Columbia sedge) have contributed sporadically to the ground cover at various locations, while in areas such as 12 Mile (Revelstoke Reach) and Lower Inonoaklin (Arrow Lakes), planted cottonwood stakes have successfully taken root and now form small leafy stands several metres in height. Soil textures on favourable microsites ranged from loamy to sandy to fragmental and were usually well-drained.

Despite a statistically significant increase in shrub cover between treated and untreated sites for certain habitat types such as PA (redtop upland), the overall contributions from revegetation have not led to statistically significant changes in terms of species composition, richness, or diversity. This could be because not enough time has elapsed since treatments were applied for successional effects to manifest themselves (particularly in the case of developing cottonwood stands). Nevertheless, it is becoming evident that for many barren regions of the drawdown zone, additional physical modifications aimed at ameliorating site conditions will likely have to be applied in concert with repeated planting interventions if lasting community changes are to be achieved.

The status of CLBMON-12 after Year 6 (2017) with respect to the study management questions (MQs) is summarized in table form below. Commencing in 2015, MQs dealing exclusively with existing vegetation (as opposed to revegetation effectiveness) have been primarily addressed through the associated study CLBMON-33. Supporting documentation pertaining to existing vegetation can be found in Miller *et al*. (2015; 2018). The status of this second set of MQs after Year 6 has also been updated and summarized in the table below, following the summaries for revegetation MQs.

KEYWORDS: Arrow Lakes Reservoir; soft constraints operating regime; vegetation community; revegetation; diversity; biomass; Kellogg's sedge; black cottonwood; effectiveness monitoring; drawdown zone; reservoir elevation.

<table>
<tr><th colspan="2">Revegetated Areas</th></tr>
<tr><th>Management Question (MQ)</th><th>Summary of Key Results</th></tr>
<tr><td>MQ1. What is the quality and quantity of vegetation in revegetated areas between elevations 434 m to 440 m compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?</td><td>
<u>Summary Findings</u>
As of 2017, there was a notable increase in shrub cover in treated compared to untreated controls. The difference was statistically significant for sites within the PA (redtop upland) vegetation community type. Otherwise, there were no statistically significant differences in vegetation quantity or quantity between treated and untreated areas.
<u>Sources of Uncertainty/ Limitations</u>
The recency of revegetation treatments (6 to 8 years) relative to plant generation times and community succession processes limits our ability to comment definitively on their long-term efficacy. For example, we do not yet know if the current generation of transplanted sedges and cottonwoods will recruit replacements and become self-sustaining stands over time. Similarly, it is unclear yet if, over time, planted vegetation will have a facilitating effect on other vegetation (e.g. whether young developing cottonwood stands, once their canopies become more fully developed, will help shade out highly competitive stands of reed canarygrass).
Hypothesis testing around this MQ assumed that the initial, pre-treatment vegetation was similar in the case of both treated and control sites. However, Enns and Overholt (2013) noted that early vegetation measurements were sometimes higher in control versus treatment plots due to planting being applied to very poor areas up to their boundaries, and adjacent controls having slightly better growing conditions. To the extent that treated sites were starting from a position of relative disadvantage compared to controls, this could have biased our results toward an underestimation of revegetation effectiveness.
Hypothesis testing also required that a random sampling design be employed during monitoring. However, the outcome of this approach was that some areas with relatively good revegetation performance were (through random chance) not monitored over the entire course of the study.
<u>Comments</u>
A longer time series of data is required to address this question fully.
One of the assumptions implicit in this MQ is that nurse species (such as cottonwood) can modify abiotic conditions (e.g. light availability, nutrient content) and over time create new ecological niches suitable for the gradual spontaneous recolonization of desired species. This may be a valid assumption (Bourgeois et al. 2016); however, research indicates that shade-adapted species often do not readily colonize naturally within the first decade or two of restoration and may need to be planted later in succession after the forest canopy has developed (McLaine et al. 2011).
Studies also show that the decrease in light availability after tree planting is a major driver for the recolonization of herbaceous species (McLaine et al. 2011; Harris et al. 2012). For riparian systems restored using tree plantings in Quebec, understory species composition did not begin to show a significant response until ~13 years after planting, which was when canopy cover began to increase substantially (Bourgeois et al. 2016). Once canopy cover passed a threshold of ~40%, plant succession started and led to the re-establishment of forest communities 17 years after planting. Likewise, Hasselquist et al. (2015) similarily report that timelines for achieving species richness objectives in restored riparian reaches should be extended to 25 years or longer.
Therefore, to capture long-term successional trajectories and to better determine if revegetated areas of ALR are indeed self-sustaining, it is recommended that further, targeted assessments (focusing on high survival areas only) be undertaken at 5-year intervals (e.g. in 2024 and 2029) for a total of 20 years of monitoring.
In the case of black cottonwood plantings, other rationales for suggesting this extended time frame include:
</td></tr>
</table>

Revegetated Areas

Management Question (MQ)	Summary of Key Results
	(i) Riparian cottonwood generally reaches flowering age between 8 and 10 years (Zasada and Phipps 1990); the Arrow Lake Reservoir plantings are thus just entering reproductive maturity and would not have had time to begin recruiting new seedlings into the population. (ii) In 2017, it was observed that planted cottonwood stakes had begun to spread within some treated, high-elevation beach habitats via horizontal, clonal root suckering. Some suckers have produced shoots up to 1-m tall, suggesting that planted stands could begin to produce shaded microsites and nesting habitat within the next 10 years through vegetative pathways alone, an important operational finding that can only be confirmed through subsequent monitoring. In the case of sedge plantings, our rationale for considering this extended time frame is: The lifespan of planted Kellogg's and Columbia sedge plantings is unknown, but the limited data available on *Carex* demography (e.g., Borkowska 2014) indicate that plugs should only be expected to survive *in situ* for a few more years. At some treated sites, planted plugs show evidence of being fertile (i.e. they have begun generating seed). However, to date there is no strong evidence that plugs have begun to replace themselves *in situ* (either via germination or through clonal spread). Hence, we are unable to confirm yet if the planting program is likely to result in sustainable vegetation growth with respect to graminoid species, as per the 2007 Order for Columbia River Projects.
MQ2. What are species-specific survival rates under current operating conditions (i.e. what are the tolerances of revegetated plant communities to inundation timing, frequency, duration and depth)?	**<u>Summary Findings</u>** 2017 assessments of planting survivorship considered eight revegetation species employed in the CLBWORKS-2 program: five sedge and sedge-like species (Kellogg's sedge, Columbia sedge, water sedge, woolgrass, and small-fruited bulrush) along with three woody shrub/tree taxa (black cottonwood, red-osier dogwood, and willow spp.). Survivorship rates of both graminoid and shrub seedlings and shrub live stakes have varied highly depending on substrate and site, with rates ranging from 0 (in many locations) to 100 per cent. **<u>Sources of Uncertainty/ Limitations</u>** Survivorship was estimated indirectly based on the number of visible live plantings at each sample plot and the reported stocking rates for each species or treatment type. In numerous instances, planted vegetation could not be distinguished with certainty from natural vegetation. Thus, estimates are approximate.
MQ3. What environmental conditions, including the current operating regime (i.e. timing, frequency, duration and depth of inundation), may limit or improve the restoration and expansion of vegetation communities in the drawdown zone?	**<u>Summary Findings</u>** Revegetation performance appears to be correlated to a range of environmental factors including inundation, infertile or unstable substrates, wave action and erosion, sedimentation, and soil moisture deficits. All aspects of the operating regime have the potential to limit or improve the restoration and expansion of vegetation communities. Timing of inundation determines the ability of restored vegetation to set roots, grow, and reproduce within the annual cycle. Frequency of inundation can affect establishment rates, especially of woody species at upper elevations. Duration and depth of inundation determine the levels of anoxia that plants must endure and the degree of seasonal exposure to wave action, erosion, sedimentation, and woody debris. **<u>Sources of Uncertainty/ Limitations</u>** Insufficient treatment replications (both spatially and temporally) limit our ability to directly correlate revegetation effectiveness with different operational components (i.e., timing, frequency, duration and depth of inundation), and to separate these effects from other, non-operational effects. **<u>Comments</u>**

Revegetated Areas	
Management Question (MQ)	**Summary of Key Results**
	Physical works projects aimed at establishing vegetation in the Arrow Lake Reservoir drawdown zone should strive to ensure that adequate experimental replication (including spatial and temporal replication) is incorporated as an intrinsic component of any future revegetation prescriptions.
MQ4. What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-2, at increasing the quality and quantity of vegetation in the drawdown zone?	**<u>Summary Findings</u>** Of the various sedge and sedge-like (graminoid) species that were transplanted into the drawdown zone (Kellogg's sedge, Columbia sedge, water sedge, woolgrass, and small-fruited bulrush), only Kellogg's sedge and Columbia sedge succeeded in establishing with any consistency at multiple sites. The proportion of sampled treatment polygons where these two species showed at least some establishment success six to eight years post-planting was relatively high (68.4 and 56.5 per cent, respectively). Black cottonwood stakes and seedlings also showed relatively high establishment frequency, with at least some surviving transplants recorded in 52.3 and 77.8 per cent of sampled polygons, respectively. Surviving sedge plugs (primarily those of Kellogg's sedge and Columbia sedge) have contributed sporadically to the ground cover at various locations, while in some areas such as 12 Mile and Lower Inonoaklin, planted cottonwood stakes have successfully taken root and now form small leafy stands several metres in height. However, none of the treatments has yet shown to be effective at increasing the quality and quantity of associated vegetation. This may be because not enough time has elapsed since planting for beneficial effects to become evident. **<u>Comments</u>** A longer time series of data is required to address this question completely (see comments to MQ1, above). To capture the longer-term successional trajectories and better determine the quality and quantity of the successfully revegetated areas, it is recommended that further sampling and mapping (of successful areas only) be undertaken at 5-year intervals (e.g. in 2024 and 2029) up to 2029 (for a total of 20 years of monitoring).
MQ5. Does implementation of the revegetation program result in greater benefits (e.g., larger vegetated areas, more productive vegetation) than those that could be achieved through natural colonization alone?	**<u>Summary Findings</u>** The program has shown modest benefits beyond what would occur through natural colonization, primarily relating to the increase in sedge densities at various locations and the establishment of young cottonwood trees at some mid and high elevation sites. There has been relatively little success in getting herbaceous vegetation to establish on barren sites, and much of the gains there appear transitory (due to a lack of ongoing recruitment). **<u>Sources of Uncertainty/ Limitations</u>** This MQ is closely related to MQ1, above. Most of limitations identified in relation to MQ1 also apply to this MQ. **<u>Comments</u>** A longer time series of data is required to address this question completely (see comments to MQ1, above). To capture the longer-term successional trajectories and better determine the quality and quantity of the successfully revegetated areas, it is recommended that further sampling and mapping (of successful areas only) be undertaken at 5-year intervals (e.g. in 2024 and 2029) up to 2029 (for a total of 20 years of monitoring).

Revegetated Areas

Management Question (MQ)	Summary of Key Results
MQ6. Is there an opportunity to modify operations to more effectively maintain revegetated communities at the landscape and site level in the future?	**<u>Summary Findings</u>** In theory, opportunities exist for modifying operations to help restoration goals, but this idea has not been adequately tested. Soft constraints were operational targets. The reservoir was not operated to target specific soft constraints, although the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2017, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 46% of the time. Experience with the revegetation program to date suggests that operations will be most effective at maintaining revegetated communities to the extent they are employed to limit not just the depth but also the duration of inundation during the summer and early fall growing season. **<u>Sources of Uncertainty/ Limitations</u>** As noted above (MQ 3), insufficient replication of alternative operational regimes, and of the 2008-2011 revegetation treatments across elevation bands, habitat types, and years, precludes testing of hypotheses around revegetation efficacy as it relates to operational (reservoir-related) and non-operational (environmental) factors.

Existing Vegetation

Management Question (MQ)	Summary of Key Results
MQ1. What is the species composition (i.e., distribution, diversity, and vigour) of existing vegetation communities (as identified by Enns et al. 2007) in relation to elevation in the drawdown zone?	**<u>Summary Findings</u>** Enns *et al*. (2007 and subsequent reports) identified 16 riparian vegetation community types (VCTs) based on a combination of similar topography, soils, and vegetation features. This classification was later modified by Miller *et al*. (2018) to include 21 distinct types. VCTs with relatively high species richness include PE-Sedge, Reed-rill, PC-sedge, and Redtop upland; less speciose VCTs include PC-reed canarygrass and Sandy beach. PC-reed canarygrass is also amongst the VCTs with the lowest diversity, reflecting its cover dominance by a single species (reed canarygrass). VCTs with moderate to high diversity include Gravelly beach, PE-sedge, Reed-rill, PE-foxtail, PC-sedge, and Redtop upland. Certain VCTs tend to associate closely with specific elevation bands (e.g., PE-foxtail and Sandy beach with low elevation bands, Cottonwood riparian, Shrub riparian, and Redtop upland with upper elevation bands), while other VCTs (e.g., Gravelly beach, PC-reed canarygrass, and Reed-rill) span a range of elevations (Miller *et al*. 2018). Therefore, compositional gradients related to elevation are best analyzed at the species level. Approximately 230 vascular plant species (excluding aquatics) have been recorded in the drawdown zone to date. Of these, the most ubiquitous are reed canarygrass, Kellogg's sedge, common horsetail, Canada bluegrass, and Columbia sedge, which together account for 35 per cent of all species records between 2010 and 2016. Kellogg's sedge is the most ubiquitous species at low elevation, followed by reed canarygrass, little meadow-foxtail, common horsetail, and Columbia sedge. Together, these species account for 42 per cent of species records at low elevation. Mid- and high-elevation sites support many of the same common species as low-elevation sites but have higher frequencies of perennial grasses and woody shrubs. Reed canarygrass is the most frequent species at mid elevation, followed by Kellogg's sedge, common horsetail, and Canada bluegrass. Common shrubs are black cottonwood and Sitka willow. Reed canarygrass is also the most ubiquitous species in the upper (non-forested) elevation bands, followed by black cottonwood and common horsetail. There is a slight (statistically insignificant)

Existing Vegetation	
Management Question (MQ)	**Summary of Key Results**
	increase in species richness and diversity as one moves from lower to higher elevations in the drawdown zone, but these variables appear to be more closely tied to substrate, soil moisture, and exposure than to elevation *per se* (Miller *et al.* 2018). Vigour overall has not shown any strong trends in relation to elevation (Enns and Overholt 2013a). **Sources of Uncertainty/ Limitations** • Only the 43 study areas selected for sampling in 2007 by BCH have been formally assessed, meaning some vegetation types may be under-sampled. • Wetland communities have yet to be completely described for the ALR. • Potential inaccuracies in the DEM (digital elevation model) could affect the interpretation of results as they relate to elevation.
MQ2. What is the cover, abundance and biomass of existing vegetation communities (as identified by Enns et al. 2007) in relation to elevation in the drawdown zone?	**Summary Findings** High plant covers are associated with VCTs such as Reed-rill, PC-reed canarygrass, PC-sedge, and shrub riparian. VCTs typically supporting low covers include Gravelly beach, Sandy beach, PE-foxtail, PC-foxtail, and Redtop upland. In terms of plant guilds (functional groups), the vegetation structure of the drawdown zone is dominated at low elevations by graminoids (grasses and sedges), by grasses at mid elevations, and by grasses, shrubs, and trees at upper elevations (Miller *et al.* 2018). Plant cover generally increases with elevation, but it can also be highly patchy and dependent on substrate, soil moisture, exposure, and latitude. For example, sites receiving minimal July inundation were more likely to be associated with high relative shrub cover than sites with more regular July inundation, which were more strongly correlated with high relative herb high cover. High reed canarygrass cover was associated with latitudes north of Nakusp, moist to wet sites, and elevations < 437.5 m. Sitka willow showed similar habitat relationships except that, for this species, higher cover was associated with elevations > 437.5 m. The weedy species annual knawel, hare's-foot clover, and meadow barley were associated with dry conditions on southerly sites at elevations > 436.5 m. Cover of Kellogg's sedge and thread rush was correlated with southerly latitudes, low elevations (< 435.5 m), and uneven topography (Miller *et al.* 2018). These relationships will be more fully catalogued under CLBMON-35 (program in progress). Vegetation heights consistently increase with increasing elevation. When shrubs and trees are excluded, plant biomass is highest at mid elevation in the reservoir due to the high cover of the very dense and heavy reed canarygrass patches. When shrubs are included in the biomass estimates, the highest overall biomass is at 438-440 m in the shrub and riparian forest communities where plants are taller, more completely developed, and more abundant (Enns and Overholt 2013a). **Sources of Uncertainty/ Limitations** See comments under MQ1.
MQ3. How does the current operating regime affect the within-community quality and quantity (i.e., species cover, abundance, biomass, diversity and distribution within existing communities) of existing vegetation?	**Summary Findings** As noted above, operation of the reservoir has resulted in identifiable vegetation zonation patterns within the drawdown zone between 434 m and 440 m that are correlated to varying degree with elevation, reservoir operations, and topo-edaphic features. To the best of our knowledge, the current operating regime has succeeded in maintaining these basic zonation patterns over time. Sites that undergo prolonged inundation (>100 days) tend to have lower vegetation cover, height, biomass, and abundance than sites with a longer exposure period (Enns and Overholt 2013a). However, coarse-textured soils with poor water-holding capacity at high elevation can also show reductions in these traits, presumably due to drought stress. Some species and communities likely benefit from seasonal inundation,

Existing Vegetation	
Management Question (MQ)	**Summary of Key Results**
	though not from scouring or from wave action on exposed high energy sites. In the fall of 2015, after an unusually low summer reservoir maximum of 435.5 m, vegetation growing above the summer flood line was more vigorous and appeared, in general, to benefit from the yearlong release from inundation. However, at some sedge-dominated sites a band of greener, lusher foliage was observed just below the flood line and several species were undergoing a late-season flowering pulse or were dispersing seed. The increase in available soil moisture following brief inundation likely allowed some species to extend their growing season into the fall, suggesting that in some cases the short-term benefits of brief inundation may exceed or at least equal those accruing from non-inundation (Miller et al. 2016). With the exception of the Beach (BE) VCT, where diversity may have increased, and the PC-reed canarygrass VCT, where diversity may have decreased, there were few notable directional changes in diversity between 2010 and 2016, implying that the composition of VCTs has remained relatively stable over time (Miller *et al*. 2018). However, there have been small but statistically significant declines in overall per cent plant cover at all elevations, and in the cover of some plant guilds (forbs, sedges and sedge allies, pteridophytes), between 2010 and 2016. Per cent cover of grasses has not changed, while that of shrubs may have increased slightly. At mid elevation, forb cover appears to have decreased relative to cover of graminoids, pteridophytes, and shrubs. At low elevation, the proportional cover of grasses versus that of sedges and sedge-like plants has fluctuated over time. Whereas the two groups had similar coverage on average in 2013, grasses were more than twice as abundant (on average) as sedges and their allies in 2016. Since 2012, the reservoir has experienced an incremental increase in seasonal growing degree days (GDDs) at low elevation that appears to coincide with the declining trend in the covers of forbs, sedges, and pteridophytes over the same period. At mid elevation, where total cumulative GDDs declined from 2010 until the middle of the monitoring period before increasing again, cover of grasses has tended to follow a slightly divergent pattern, with highest average covers recorded in 2012 and lower covers thereafter. The implication is that, with the probable exception of shrubs, decreases in late summer inundation do not necessarily translate into an increase in plant density or abundance at the local scale. **<u>Sources of Uncertainty/ Limitations</u>** • Lack of a formal study (experimental) control, which is necessary to separate operational effects from other environmental effects (e.g., annual climatic variation). • Lack of historical baseline information on the conditions that pertained prior to introduction of soft constraints. • The duration of this monitoring program may not have been long enough to fully assess the long-term effects of the current operating regime on the structure and composition of existing vegetation communities. **<u>Comments</u>** Soft constraints were operational targets. The reservoir was not operated to target specific soft constraints; however, the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2016, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 48% of the time. The variable annual reservoir operations that have prevailed since the start of the study in 2007, in combination with the biannual sampling regime, limit our ability to test specific hypotheses around impacts stemming from alterations to the frequency, timing, depth, and duration of inundation.
MQ4. Is there a shift in community structure (e.g., species dominance) or a potential loss of existing vegetated communities that	**<u>Summary Findings</u>** Temporal, localized fluctuations in cover (Enns and Overholt 2013a; Miller *et al.* 2015; 2018), together with a pattern of directional declines observed between 2010 and 2016 for some plant groups such as forbs and sedges, and increases for some groups such as shrubs, raises reasonable doubts about the effectiveness of the current operating regime in maintaining the vegetation status quo at the site level. The

Existing Vegetation	
Management Question (MQ)	**Summary of Key Results**
is attributable to environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation)?	drawdown zone supports a vegetation assemblage that is adapted to, and may even depend on, a variable regime of seasonal flooding as part of annual moisture requirements. Thus, we can expect to see directional changes in vegetation cover and composition in response to any consistent, directional changes in the timing, depth, frequency, and duration of inundation. For example, recent monitoring suggests that successive years of above-average summer exposure could lead to a more shrub-dominated system supporting lower overall covers of herbaceous groups such as forbs and sedges. While there is currently no compelling evidence to indicate that the Water Use Plan operating regime is failing to maintain overall vegetation structure and composition of existing vegetation communities in the drawdown zone, existing vegetation will likely only be maintained in its present state if the historical pattern of variability in hydroperiod is maintained (Miller *et al*. 2018). **Sources of Uncertainty/ Limitations** The duration of this monitoring program may not have been long enough to fully assess the long-term effects of the current operating regime on the structure and composition of existing vegetation communities.
MQ5. What are the species-specific survival rates under soft constraints operating regime (i.e., what are the tolerances of existing plant species to inundation)?	**Summary Findings** Enns and Enns (2012) reviewed the flood tolerances of a range of common, dominant drawdown zone species. Mortality of weedy annuals, seedlings, and herbaceous perennials was common after extended inundation, but replacements also took place. Invasions from upslope occurred, were lost, and recurred. Willows declined in Revelstoke Reach at mid elevations as a result of populations expanding into these sites and subsequently being inundated for longer than their usual tolerance would allow. Black cottonwood is also largely restricted to upper elevations of the drawdown zone where inundation duration is reduced. Horsetails, along with well-established tussocks of sedges (e.g., Kellogg's sedge, Columbia sedge) and other graminoids (e.g., little meadow-foxtail, thread rush, Canada bluegrass, reed canarygrass) are highly robust to episodes of deep and prolonged inundation, but are vulnerable to erosive forces, wave action, and sediment deposition on exposed aspects (Enns and Overholt 2013a, Miller *et al*. 2018). **Sources of Uncertainty/ Limitations** The original study design (Enns et al. 2007) did not include a replicated, controlled approach for directly estimating species-specific mortality, or for distinguishing inundation impacts on survivorship from other environmental impacts (e.g., herbivory, drought). Thus, species-specific survivorship rates, as these relate to inundation, can only be inferred indirectly based on observed changes in plant composition over time within repeat monitoring plots. The potential for prolonged (> 1 year) time lags in plant responses to changing hydroregimes also limits our ability test hypotheses around operational impacts on plant survival. This MQ will be more thoroughly addressed under CLBMON-35 (program in progress) for a select group of key species. **Comments** Soft constraints were operational targets. The reservoir was not operated to target specific soft constraints; however, the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2016, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 48% of the time.
MQ6. What recommendations can be made to more effectively maintain existing vegetation at the site level in the future?	**Summary Findings** The drawdown zone of Arrow Lakes Reservoir supports a vegetation assemblage that is adapted to, and may even depend on, a variable regime of seasonal flooding as part of annual moisture requirements. The best way to ensure that the soft constraints operating regime continues to maintain the existing vegetation status quo is to maintain a similar level of variability in hydroperiod to that which has prevailed historically.

Existing Vegetation	
Management Question (MQ)	**Summary of Key Results**
	if the objective is to enhance existing vegetation types, our models suggest that both cover and structural diversity at all elevations can be maximized in the following way: (i) by delaying inundation for as long as possible in the spring (preferably until after June), to allow time for germination, establishment, and the completion of reproductive cycles; (ii) by allowing for sufficient June/July inundation at low and mid elevations (434-438 m ASL) to reduce summer drought stress for inundation-adapted species; and (iii) by minimizing (but not eliminating) the depth and duration of inundation at high elevations (>438 m ASL), to maintain herbaceous cover while facilitating woody shrub establishment and growth. **Sources of Uncertainty/ Limitations** The variable annual reservoir operations that have prevailed since the start of the study in 2007, in combination with the biannual sampling regime, limit our ability to predict specific impacts stemming from alterations to the frequency, timing, depth, and duration of inundation. At present we can only offer hypotheses, based on the best available data, around the potential long-term outcomes of different hydroperiod scenarios. **Comments** It may be possible to implement physical works (PW) to either protect or create habitats in the drawdown zone, which could lead to the maintenance of vegetation communities. For example, in Kinbasket Reservoir, elevated mounds and windrows have been constructed at some sites to increase topographic heterogeneity. PW at some sites (e.g., Burton Creek) are currently under consideration. These efforts are localized, small-scale projects that will not result in widespread benefits to drawdown zone vegetation.

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Control plot – long-term monitoring plot in a non-revegetated area of the drawdown zone that serves as a statistical control for a corresponding **treated plot** (see below). Control plots and their paired treated plots share a similar elevation, topography, substrate, and **vegetation community type** (see below).

Diversity – a measure of the species diversity within a sample of study plots that incorporates both species richness (see below) and species evenness (the relative abundance of species within the sample).

Elevation band – for monitoring purposes, the drawdown zone between 434 and 440 m is stratified into three separate elevation bands: 434-436 m ASL, 436-438 m ASL, and 438-440 m ASL.

Landscape unit – one of two general geographic regions of the Arrow Lakes Reservoir; Revelstoke Reach (northern section) and Lower Arrow Lakes (southern section).

Plot – primary sampling unit for obtaining field data within each treated, control, and existing vegetation area. Plots are permanently located for long-term monitoring and have a dimension of 10-m x 5-m (50-m^2).

Richness – the number of vascular plant species present in a sample of study plots.

Stake polygon – additional temporary plot for assessing live stake survival densities over a larger area than that provided by the long-term plots. Stake polygons are rectangular and usually located adjacent to existing plots, with dimensions determined by the extent of the treated area and by terrain features, typically ranging in size from 200 m^2 to 1,500 m^2. No additional stake polygons were sampled in 2017.

Site – one of 43 designated monitoring sites in the Arrow Lakes Reservoir selected by BC Hydro for which aerial photos have been acquired biennially beginning in 2007, and for which base mapping was created by delineating polygons on aerial photographic mosaics.

Survivorship plot – additional, temporary 50-m^2 sample plots established within a selection of CLBWORKS-2 treatment polygons in 2017 for enumerating live densities of surviving planted species. 1-7 plots were situated semi-randomly within representative treated areas, depending on polygon size and habitat heterogeneity.

Treated plot – long-term monitoring plot in an area of the drawdown zone that was revegetated using one of the revegetation prescriptions developed for CLBWORKS-2.

Treatment polygon – Revegetation prescription areas in the drawdown zone mapped and treated under CLBWORKS-2. A given treatment polygon could consist of multiple treatment areas, with each area receiving a different treatment or combination of treatments, sometimes with multiple entries occurring over successive years.

Vegetation community type (VCT) – a general classification for vegetation communities identified in the drawdown zone of the Arrow Lakes Reservoir, consisting of habitats that share similar vegetation, substrates, and topography. The 21 currently recognized VCTs (Miller et al. 2018) are described in Section 4.1.

1.0 INTRODUCTION

Reservoirs managed for hydro-electric power production typically experience extreme fluctuations in water levels, with associated drawdown zones measuring vertically in the tens of metres (Abrahams 2006; Lu *et al*. 2010). These drawdown zones (defined as the exposed part of the shoreline below the top water line) are generally challenging environments for most plant species; alternating cycles of flooding and exposure produce repeated cycles of disturbance, colonization (during low water levels), and recession (during high water levels). The extreme magnitude of water fluctuations can lead to long-term declines in plant species richness, a loss of rare plant associations, and invasions by exotic species (Hill *et al*. 1998; Yang *et al*. 2012). Steep and unstable banks, long fetches with associated wave action that reduces the substrate's organic matter and prevents plant growth, low levels of soil nutrients, accumulations of large woody debris with associated scouring, and high rates of erosion and sediment deposition provide additional challenges to vegetation establishment in the drawdown zones reservoirs (Johnson 2002; Abrahams 2006; Yang *et al*. 2012).

Arrow Lakes Reservoir, in southeastern British Columbia, is 232 km long and holds a licensed volume of 7.1 million-acre feet (MAF; BC Hydro 2005). Water level elevations are managed under a regime that permits a normal annual reservoir minimum of 419.9 m above sea level (ASL) and a normal reservoir maximum of 440.1 m ASL—a difference of 20.2 m. The large variations in water levels result in only sparse vegetation cover throughout much of the drawdown zone, which in turn impacts ecosystem functions, wildlife values, and aesthetics. These cumulative impacts on reservoir shoreline vegetation communities had not been addressed until BC Hydro entered into the planning process for the Columbia River Water Use Plan (WUP) in 2001. During this planning process, the WUP Consultative Committee (WUP CC) recognized the value of vegetation in improving aesthetic quality, controlling dust storms, protecting cultural heritage sites from erosion and human access, and enhancing littoral productivity and wildlife habitat (BC Hydro 2005).

In lieu of operational changes such as maintaining lower reservoir elevations, the WUP CC recommended that a revegetation program be undertaken in Arrow Lakes Reservoir (BC Hydro 2005). The first phase of the revegetation program (CLBWORKS-2: Mid-Columbia and Arrow Lakes Reservoir Revegetation) was conducted in the reservoir over four years from 2008 to 2011 between the locations of Revelstoke and Renata, B.C. The revegetation approach included planting of graminoid plugs (e.g., Kellogg's sedge, Columbia sedge, water sedge, and woolgrass) as well as shrub seedlings and live stakes (black cottonwood, willow, and red-osier dogwood) at prescribed areas of the drawdown zone between 434 m and 440 m ASL. In some cases, treatments were repeated over successive years to facilitate the growth of vegetative cover in areas thought to have good potential to become self-sustaining. A total of 108 hectares were planted over this period, encompassing approximately 17 sites and 155 treatment polygons (Keefer *et al*. 2008; 2009; Keefer Ecological Services 2010; 2011).

The decision of the WUP CC to support a revegetation program for the reservoir was predicated on the assumption that the soft constraints operating regime (inundation cycles) would be effective in maintaining current levels of vegetation, and that revegetation activities would be a more cost-effective means of remediating and expanding vegetation cover for ecological and social benefits than imposing hard constraints on the operation of the reservoir (BC Hydro 2005). Soft constraints are operational targets developed by the WUP CC for the benefit of various interests (vegetation, wildlife, fish, culture and heritage, recreation, erosion, and power generation). Each target identifies the ideal/preferred reservoir operations (water level over the year) for a specific interest. The degree to which an individual objective is met varies by water year and the requirements of competing objectives. The soft constraint targets identified for vegetation (BC Hydro 2005) were to:

- Maintain lower reservoir water levels during the vegetation growing season to preserve current levels of vegetation, with priority given to maintaining existing vegetation at and above 434 m (1424 ft) elevation.
- Maintain lower reservoir levels during the late growing season if vegetation is showing signs of stress as a result of inundation during the early growing season (May to July).

To verify the assumption that soft constraints are effective at maintaining drawdown zone vegetation, and to evaluate how effectively revegetation efforts are meeting the multiple objectives set by the WUP CC, the Committee recommended several effectiveness monitoring programs, including the following two vegetation monitoring programs:

- CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources
- CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

CLBMON-33 is a 10-year program to assess the impacts of the soft constraints operating regime on existing vegetation in the drawdown zone of Arrow Lakes Reservoir. The primary objective of this project, which was initiated in 2007, is to monitor landscape level changes in the spatial extent, structure, and composition of vegetation communities within the 434-440 m ASL elevation band of the drawdown zone, and to assess if any observed changes are attributable to the soft constraints operating regime. Results of this program will help determine whether changes to the reservoir's operating regime may be required to maintain or enhance existing shoreline vegetation and the ecosystems it supports.

CLBMON-12 is a 10-year program to evaluate planting survivorship and the effectiveness of various revegetation treatments in Arrow Lakes Reservoir at increasing the quantity and quality of self-sustaining vegetation within the drawdown zone. CLBMON-12 is designed to span the period from 2008 to 2017 and to occur in alternating years from 2009 onward. Work completed during the first five implementations (2008, 2009, 2011, 2013, and 2015) is described in Gibeau and Enns (2008), Enns *et al*. (2009), Enns and Enns (2012), Enns and Overholt (2013a), and Miller *et al.* (2016). Here, we report results at the project's 10-year mark (2017), equating to the sixth implementation year.

2.0 PROGRAM OBJECTIVES AND MANAGEMENT QUESTIONS

Revegetated Areas

The primary objective of CLBMON-12 is to assess the short-term effectiveness of the revegetation program at expanding the quality (as measured by diversity, distribution and vigour) and quantity (as measured by cover, abundance and biomass) of vegetation in the drawdown zone for ecological and social benefits (BC Hydro 2005). The specific management questions (MQs) for this monitoring program address whether the continued implementation of the soft constraints allows for the establishment and expansion of vegetation at the site level through a revegetation program in the drawdown zone of Arrow Lakes Reservoir (BC Hydro 2008):

MQ1: What is the quality and quantity of vegetation in revegetated areas between elevations 434 m to 440 m compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?

MQ2: What are species-specific survival rates under current operating conditions (i.e. what are the tolerances of revegetated plant communities to inundation timing, frequency, duration and depth)?

MQ3: What environmental conditions, including the current operating regime (i.e. timing, frequency, duration and depth of inundation), may limit or improve the restoration and expansion of vegetation communities in the drawdown zone?

MQ4: What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-2, at increasing the quality and quantity of vegetation in the drawdown zone?

MQ5: Does implementation of the revegetation program result in greater benefits (e.g., larger vegetated areas, more productive vegetation) than those that could be achieved through natural colonization alone?

MQ6: Is there an opportunity to modify operations to more effectively maintain revegetated communities at the landscape and site level in the future?

Existing Vegetation

Initially, this monitoring program also assessed the intra-community response of existing vegetation communities to the Water Use Planning operating regime at the local (site) level (Enns *et al*. 2007). The following management questions were framed for existing vegetation communities (BC Hydro 2008):

MQ1: What is the species composition (i.e., distribution, diversity, and vigour) of existing vegetation communities (as identified by Enns et al. 2007) in relation to elevation in the drawdown zone?

MQ2: What is the cover, abundance and biomass of existing vegetation communities (as identified by Enns et al. 2007) in relation to elevation in the drawdown zone?

MQ3: How does the current operating regime affect the within-community quality and quantity (i.e., species cover, abundance, biomass, diversity and distribution within existing communities) of existing vegetation?

MQ4: Is there a shift in community structure (e.g., species dominance) or a potential loss of existing vegetated communities that is attributable to environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation)?

MQ5: What are species-specific survival rates under soft constraints operating regime (i.e., what are the tolerances of existing plant species to inundation)?

MQ6: What recommendations can be made to more effectively maintain existing vegetation at the site level in the future?

Commencing in 2015, MQs dealing exclusively with existing vegetation (as opposed to revegetation effectiveness) have been primarily addressed through the associated study CLBMON-33, following the recommendations of Enns and Overholt (2013a) and Okanagan Nation Alliance and LGL Limited (2014). However, the status of these MQs after Year 6 (2017) is summarized at the end of this report, along with the status of revegetation MQs (Section 7.0).

2.1 Management Hypotheses

Monitoring for the CLBMON-12 project is intended to test the following null hypothesis and associated sub-hypotheses related to revegetation effectiveness:

H_{01}: Revegetation treatments between elevation 434m and 440m support continued natural recolonization of the drawdown zone.

H_{01A}: There is no significant difference in vegetation establishment (based on species distribution, diversity, vigour, biomass and abundance) at control versus treatment locations.

H_{01B}: There is no significant difference in the cover of vegetation in control versus treatment locations.

H_{01C}: There is no significant difference in the cover of vegetation communities and vegetation establishment (based on species distribution, diversity, vigour, biomass and abundance) arising from different revegetation prescriptions.

H_{02}: Reservoir operating conditions have no significant effect on vegetation establishment in revegetated areas between elevation 434m and 440m.

H_{02A}: Vegetation establishment (based on species cover, distribution, diversity, vigour, biomass and abundance) is not significantly affected by the timing of inundation at control and treatment sites.

H_{02B}: Vegetation establishment (based on species cover, distribution, diversity, vigour, biomass and abundance) is not significantly affected by the frequency of inundation at control and treatment sites.

H_{02C}: Vegetation establishment (based on species cover, distribution, diversity, vigour, biomass and abundance) is not significantly affected by the duration of inundation at control and treatment sites.

H_{02D}: Vegetation establishment (based on species cover, distribution, diversity, vigour, biomass and abundance) is not significantly affected by the depth of inundation at control and treatment sites.

3.0 STUDY AREA

Arrow Lakes Reservoir is situated on the Columbia River between Revelstoke and Castlegar, BC (Figure 3-1). The reservoir is ~230 km long and was formed in 1968 by the completion of Hugh Keenleyside Dam, 8 km west of Castlegar. The reservoir includes three main sections: Lower and Upper Arrow Lakes in the south, and Revelstoke Reach in the north. It has a north-south orientation and lies between the Monashee Mountains in the west and the Selkirk Mountains in the east. Two Biogeoclimatic zones occur within the study area: the Interior Cedar Hemlock (ICH) and the Interior Douglas-fir (IDF). Further details on study area climate, physiography, and geology are provided in Enns et al. (2007).

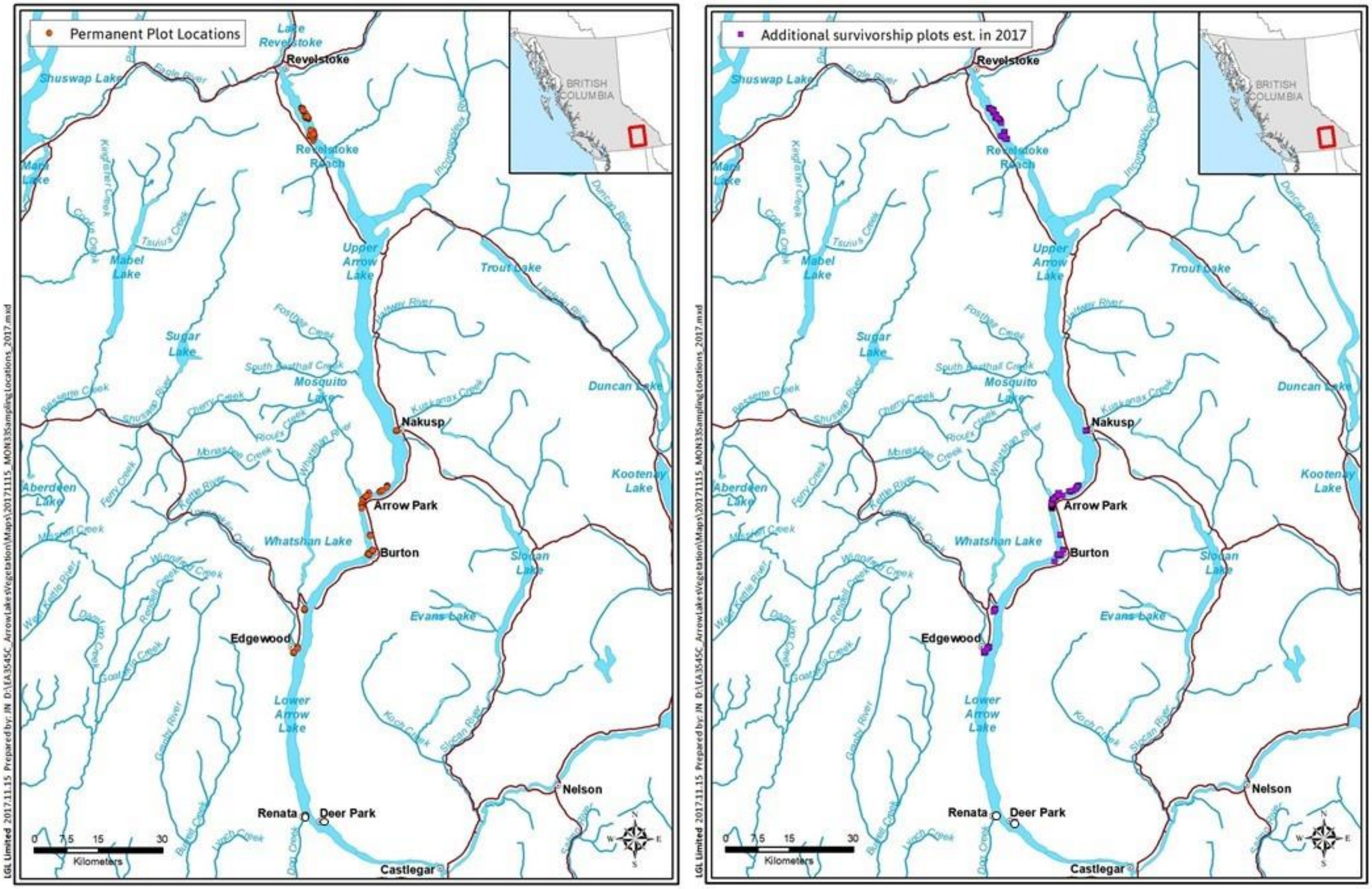


Figure 3-1: Location of 2017 sample areas in the drawdown zone of the Arrow Lakes Reservoir between Revelstoke and Castlegar, B.C. Left map shows permanent monitoring plots (orange dots), established in previous implementation years; right map shows additional new “survivorship” plots (purple squares) established in 2017

4.0 METHODS

4.1 Study Design

In previous study years, vegetation covers and biomass were sampled within permanent monitoring plots (Gibeau and Enns, 2008; Miller *et al.* 2016) and the following specific questions were addressed:

1. Has the revegetation program been effective, to date, at expanding the quality (as measured by diversity and composition) and quantity (as measured by cover and biomass) of vegetation in the drawdown zone for ecological and social benefits?
2. To what extent is revegetation effectiveness influenced by soft constraint reservoir operations (i.e., hydroperiod)?

The 2017 study design followed the same general approach of previous years, but with a greater emphasis given this year to obtaining species-specific survival rates for planted plugs and live stakes, and identifying the ecological and/or operational filters that might be inhibiting or enhancing survivorship of transplants.

Thus, in addition to revisiting previously-established monitoring plots, we expanded the scope of sampling to include an array of CLBWORKS-2 treatment areas (mapped polygons) not previously covered under the CLBMON-12 monitoring scheme (Figure 3-1). At each new polygon, as well as at polygons already containing permanent plots, we established from 1 to 7 (depending on polygon size and habitat heterogeneity) new "survivorship" plots. The plots were situated semi-randomly within representative revegetation areas. At each survivorship plot, we recorded the numbers of surviving individuals associated with each CLBWORKS-2 revegetation treatment. These totals were subsequently used to generate survival rate estimates for specific species, sites, and planting methods (e.g., seedlings versus live stakes) based on the reported initial planting densities provided by the CLBWORKS-2 annual reports and associated databases (Keefer *et al*. 2008; 2009; Keefer Ecological Services 2010; 2011).

A year-by-year summary of the CLBWORKS-2 planting program is provided in Appendix 10.1. Treated sites were within one of 43 designated study areas selected by BC Hydro for long-term vegetation monitoring (Enns *et al*. 2007). Sampling was stratified geographically between the two major landscape units, Revelstoke Reach and Lower Arrow Lakes. A total of 107 treatment polygons were monitored on both sides of the reservoir between Edgewood in the south and McKay Creek, just south of Revelstoke The specific reservoir locations visited in 2017 were (from south to north): Edgewood (north and south), Lower Inonoaklin, Burton (north and south), Fairhurst Creek, East Arrow Park, North Arrow Park, Nakusp, 12 Mile, 9 Mile, 8 Mile, and McKay Creek (Figure 3-1).

At the selected polygons, 129 10-m x 5-m (50-m2) field plots with a long-term sampling history (i.e., established in 2011 or earlier) were resampled. Of these, 75 plots were located in treatment sites and 54 served as non-treated control plots. The treated and control plots were a subset of those previously monitored by Enns and Overholt (2013a and previous), stratified by treatment type, vegetation community type (VCT), and elevation. In addition, a total of 153 10-m x 5-m (50-m^2) survivorship plots were established and sampled.

The 2017 study employed the community classification system developed by Enns *et al.* (2007, 2010) and subsequently modified by Miller *et al.* (2018; Table 4-1). Detailed descriptions of the various community types (both original and modified) are provided in Appendix 10.2.

Table 4-1: Vegetation community types (VCTs) of Arrow Lakes Reservoir. Original names (from Enns *et al.* 2010) are shown along with recently introduced revisions to the classification (in bold). Not all VCTs (e.g., BB, SF, SS) are typically vegetated.

Original VCT code	Original name	New name (in bold)	Typical elevation
BB	Boulders, steep	Boulders, steep	all
BE	Sandy beach	Sandy beach	low
BG	Gravelly beach	Gravelly beach	mid to low
CL	Saskatoon–cliffs and rock	Saskatoon–cliffs and rock	high
CR	Cottonwood riparian	Cottonwood riparian	high
		Shrub riparian	high
IN	Industrial/ residential/recreational	Industrial/ residential/recreational	all
LO	Log zone	Log zone	high
PA	Redtop upland	Redtop upland	high
		PC–Willow	mid
PC	Reed Canarygrass mesic	**PC–Reed canarygrass**	mid
		PC–Foxtail/horsetail	low
		PC–Sedge	mid to low
PE	Horsetail lowland	**PE–Foxtail**	low
		PE–Sedge	low
PO	Pond	Pond	mid
RR	Reed–rill	Reed–rill	all
RS	Willow stream entry	Willow stream entry	Mid to high
SF	Failing slope	Failing slope	mid to low
SS	Steep sand	Steep sand	mid to low
WR	River entry	River entry	all

4.2 Reservoir Operations

Historical daily water levels during 2004–2016, measured at the Fauquier elevation gauge, were used to examine patterns of seasonal water level heights in the reservoir across years and to determine the proportion of time each 1-m elevation band was above water during each month of April–September of each year. For each elevation band and year, a monthly inundation depth was calculated by taking the average of the daily inundation depths. Exposure time was calculated by determining the total number of days each month that the elevation band was above the recorded daily water level, and dividing this total by the number of days for that month.

4.3 Field Sampling

Field sampling sessions were timed to correspond generally with sampling in previous study years. Vegetation sampling occurred during two field sessions: 17–27 May and 2–7 June, when the reservoir elevation was between 433.1 and 436.9 m ASL. A crew of four workers participated in the field sampling sessions. Site access was via truck and walk-ins. Predetermined sample points were located in the field using a hand held GPS receiver (Garmin GPSMap 60CSx).

4.3.1 Treated and Control Plots

Vegetation was sampled within 10 m x 5 m (50 m^2) plots established around each predetermined plot centre (using the supplied UTM coordinates). Plots were assessed for plant species composition/cover and selected topo-edaphic characteristics. Based on this assessment, a vegetation community type (VCT) was assigned. Plot data were entered onto a field data form (Appendix 10.3) following a modified version of the standards in B.C. Ministry of Forests and Range and B.C. Ministry of Environment (2010).

Per cent cover, measured as the percentage of the ground surface covered when the crowns are projected vertically, was visually estimated and rounded as follows: traces = 0.1%; <1% rounded to 0.5%; 1-10% rounded to nearest 1%; 11-30% rounded to nearest 5%; 31-100% rounded to nearest 10%. Percent covers were considered additive due to overlapping crowns and final tallies for species and layers could exceed 100% cover.

Planting survivorship was assessed by tallying the number of live plugs and/or stakes of each planted species. The overall vigour of each planted species was also recorded, following the vigour categories presented in Table 4-2.

Live plant numbers were later converted to density/Ha using the known sample dimensions. We then compared these values to the initial average stocking densities previously reported for various treatment types (Keefer Ecological Services Ltd. 2011) to derive an indirect estimate of survivorship.

As noted by Enns *et al*. (2012), CLBWORKS-2 treatments dating back to 2011 and earlier could not always be distinguished from natural vegetation, given that seedlings were often interplanted with existing vegetation and that transplants had no tags, pins, or other markings. If the plants were found in relatively uniform rows or in a grid-like pattern of planted plugs, the area was assumed to have been treated. However, in some cases it was not possible to tell definitively if a microsite mapped as treated had in fact been planted. Where the planting history was ambiguous, or in plots where non-planted individuals co-occurred with planted individuals, natural plants might be inadvertently included in the counts of transplants, potentially resulting in an overestimate of planted survivorship in some areas.

Shallow soil pits (to 30 cm) were dug near the centre of each sample plot to assess soil texture, a potentially important variable in revegetation success. Soil textures were categorized as either fragmental, sandy, loamy, silty, or clayey depending on the particle size distribution within the mineral portion of the rooting zone. Rooting zone soil particle size was further categorized based on the soil classification system in Section 2-10 of B.C. Ministry of Environment, Lands and Parks and B.C. Ministry of Forests (1998). The different rooting zone particle size classes are shown in Table 4-2. Other biotic and abiotic attributes recorded at each sample location are listed in Table 4-2. Information on slope aspect was subsequently used to compute "heatload," which is aspect weighted by solar exposure and latitude (McCune and Keon 2002). The 2014 digital elevation model (DEM) supplied by BC Hydro was used to determine plot elevations.

Table 4-2: Attributes collected for plot samples using field data form.

Attribute	Unit / Category
Date	
Surveyor(s)	
Site	Site names follow those used in the CLBWORKS-2 reports, with some minor modifications (e.g. "Drimmie Creek" replaced by "12 Mile")
Plot number	Established plot names used for permanent monitoring plots ("treated" and "control"); new names assigned to "survivorship" plots based on CLBWORKS-2 polygon no.
Waypoint and UTM coordinates	Easting and northing (for newly established sample points)
Plot type	Treated, control, survivorship
Vegetation community type (VCT)	See Table 4-1 for VCT categories
Treatment type	Sedge plugs, cottonwood seedlings, cottonwood stakes, willow stakes, dogwood stakes
Photo numbers	Photos taken from centre of plot facing north, east, south, west; also vertically looking down
Structural stage	Sparse/pioneer, herb, low shrub, tall shrub, pole/sapling, young forest, mature forest, old forest
Aspect (heat load)	Degrees, used to estimate heat load. Heat load = $(1-\cos(\theta-45))/2$, where θ = aspect.
Slope	Degrees
Soil moisture regime	Very xeric, xeric, subxeric, submesic, mesic, subhygric, hygric, subhydric, hydric
Primary water source	Precipitation, surface seep, stream sub-irrigation, stream surface flooding
General surface topography	Concave, convex, straight
Microtopography	Smooth, channeled, gullied, mounded, tussocked
Surface substrate	Per cent rock, mineral soil, organics, wood, water
Rooting zone texture/particle size	Sandy (skeletal), coarse-loamy (skeletal), fine-loamy (skeletal), coarse-silty, fine-silty, silty-skeletal, fine-clayey, very-fine-clayey, clayey-skeletal
Scouring, erosion, or deposition	Qualitative evidence of scouring, erosion, or deposition – yes or no
Site disturbance	Qualitative evidence of non-operational site disturbance (ATV, wildlife, etc.) – yes or no
Vegetation cover	Per cent cover, by species and layer (trees, shrubs, herbs, moss)
Planting survival	No. live planted plugs or stakes (revegetation areas only)
Vigour of surviving plants	Categorical code: 0 (dead), 1 (poor), 2 (fair), 3 (good), 4 (excellent)

4.3.2 Survivorship plots

The same information as described above for treated and control plots was recorded for survivorship plots, with the exception of per cent cover data.

4.4 Statistical Analyses

The variation in general descriptors (cover, richness and diversity) between control and treated plots was assessed with a series of boxplots and unbalanced two-ways analyses of variance (ANOVAs). Cover was computed by adding up all vegetation within the herb layer and the shrub layer, separately, while richness and diversity were computed for vegetation from all layers. Richness and diversity (Shannon's index, Legendre and Legendre 1998) were computed only with taxa identified to species (i.e. individuals identified to genus only were included in the cover totals but not in richness or diversity) in order to avoid over-estimating richness or diversity. Boxplots (Massart et al. 2005) were used to display trends in cover of herb, cover of shrub, overall richness, and overall diversity between control and treated plots and among elevation bands (low: 434-436 mASL, mid: 436-438 mASL, and high: 438-440 mASL) and vegetation community types (VCTs). In order to avoid misrepresenting cases with small sample size, boxplots were used for cases when enough data points were available (i.e. six or more data points); in case where fewer data points were available, boxes were omitted, and all single data points were represented with filled circles in the figure. ANOVAs were tested with 9,999 permutations.

Species compositions of control and treated plots were compared using similarity coefficients and principal coordinate analysis (PCoA) and Kendall W analysis of concordance (Legendre 2005). Two asymmetrical coefficients (D14 and D17-euclidian distance) were used to compute similarity among sites based on species composition (Legendre and Legendre 1998). The two coefficients differ in their treatments of abundant and rare species; D14 gives the same weight to abundant and rare species in determining similarity among plots, while differences for abundant species contribute more than differences for rare species to the similarity among sites for D17 (Legendre and Legendre 1998). In addition, multivariate regression trees (MRT; Dea'th and Fabricius 2002), including computation of indicator species, were constructed to explore relationships between species composition and environmental characteristics. Both the Kendall W analysis of concordance and the MRT were performed with species that appeared in at least three plots (to remove extremely rare occurrences). Variables included in the MRT were plot type (control or treated), elevation band (low, mid, high), vegetation community type (VCT), and site (location). The MRT approach is detailed further in Appendix 10.4.

Planting survivorship rates were compared among species, elevation bands, treatment types, sites, and vegetation communities using boxplots (described above). Graminoid seedlings, shrub seedlings and live-stakes treatments were considered separately. Univariate regression trees (URT; Appendix 10.5) were used to explore the influence of various topo-edaphic variables on revegetation survivorship. Environmental variables considered were: elevation band, site, treatment type, VCT, slope, and rooting particle size class.

A classification tree was constructed similarly, but in this case with a binary dependent variable (yes/no) to indicate the presence of at least some survivorship vs. zero survivorship (rather than per cent survivorship). The trees were pruned to maximize variation explained by the pseudo-R^2 (given that the goal of the analysis was descriptive, not predictive), while aiming for a compromise between deviance explained and parsimony (i.e., the trees were not necessarily the most parsimonious but were pruned to remove the extra branches after the main drop in deviance). Trees were run using package "tree" in the R language.

Vigour of the planted vegetation in each plot was rated on a semi-quantitative sliding scale ranging from 0 (dead) to 4 (excellent). Frequencies of plots showing each category of vigour were compared across sites, VCTs, and elevation bands using chi-square tests. Chi-square tests were conducted as in Miller et al. (2015), with the addition of the computation of Freeman-Tukey deviates when tests were significant (Legendre and Legendre 1998). The Freeman-Tukey deviates were computed for each cell of the contingency table and used to assess which frequencies were statistically different than expected based on the hypothesis that plots of all vigour would be randomly distributed. They are computed using the following formula: $O^{1/2} + (O+1)^{1/2} - (4*E+1)^{1/2}$ where

> O = observed frequencies of plots and E = expected frequencies under Ho , with the expectation being that O and E are independent (frequencies are equal).

Freeman-Tukey deviates were compared to a criterion corresponding to $(\upsilon^* \chi^2_{[1,\alpha]})$/ number of cells$)^{1/2}$, where υ stands for the degrees of freedom (corresponding to (number of rows -1) (number of columns -1)), χ^2 for the Chi-square statistic, and α to the significance level, set at 0.05 unless otherwise specified. To control for the effect of several simultaneous tests of significance, a Bonferroni correction was applied to the criterion (Legendre and Legendre 1998). Hence, α was divided by the number of simultaneous tests carried out (corresponding to the total number of cells to which the posthoc tests are performed), and the criterion was adjusted for the new α. Therefore, the corrected criterion becomes $(\upsilon^* \chi^2_{[1,\alpha/no.cells]})$/ number of cells$)^{1/2}$. If the absolute value of the Freeman-Tukey deviate was higher than the criterion in a given cell, it was concluded that the observed values were statistically different than the expected values (Legendre and Legendre 1998). For example, it would mean that the frequency of plots of excellent vigour was statistically higher than expected at high elevation.

To assess further if habitat similarities and dissimilarities among the various treated sites were helping drive observed differences in revegetation success (survivorship), we computed a distance matrix of environmental variables associated with the sample plots and represented the distances with PCoA diagrams, with survivorship results overlaid. Variables included were elevation band, VCT, vegetation structural stage, general topography, microtopography, soil moisture, rooting zone texture, and slope. Ordinations were first computed using all sample plots (i.e., all treatment types combined), then separately for Kellogg's sedge and black cottonwood treatment types.

5.0 RESULTS

5.1 Reservoir Operations and GDDs

Water levels in Arrow Lakes Reservoir between 2009 and 2017 (Figure 5-1) show considerable variability in elevation across years. However, water levels typically rise quickly from approximately the beginning of May each year, and peak during mid-late July before gradually subsiding throughout the remainder of the summer and fall. The 10 to 90 percentile range indicates daily differences in water levels of up to ~8 m across years. The reservoir exceeded the normal operating maximum during July 2012. Water levels during 2015 and 2016, but particularly during 2015, were low compared to years prior. In 2015, water levels peaked on 13 June at 435.48 m, remaining at or above 435.4 m for a total of six days before receding. In 2017, water levels peaked on 29 July at 439.5 m, remaining at or above 438 m for a total of 27 days before receding (Figure 5-1).

The proportion of time each 1-m elevation band between 434 and 440 m was above water during each month from May to September is shown in Table 5-1, for the years 2006-2016. In most years, exposure time began to decrease in June each year with most of the lowest six elevation bands (434-439 m) completely inundated in July. Receding water levels after this time result in increased exposure time during August and again in September. In 2015, in contrast, all but the lowest elevations (434-435 m) were fully exposed for the entire growing season (Table 5-1).

Effective growing degree days (GDDs) indicate the number of accumulated heat units available for plant growth each month, once time underwater has been accounted for (Table 5-2). GDDs during April and May are consistent across most elevation bands each year, since reservoir water levels are typically below 434 m during these periods. Effects of inundation on GDDs at the lower elevations become apparent during late May (e.g., 2008, 2010, 2013, 2016) and June, with effects becoming pronounced across most elevations by July. Nevertheless, the combination of variable monthly temperatures combined with a variable hydroperiod results in considerable variability in cumulative monthly GDDs per 1-m elevation band across years. For example, July GDDs were notably higher in 2015 and 2016 than in previous years, especially as compared to 2012, whereas 2008 and 2011 both had relatively low August GDDs. June GDDs were higher at low elevations, but reduced at upper elevations, in 2009 compared to 2015, a reflection of the earlier onset of inundation, but warmer June temperatures, that prevailed in 2015. In 2016, April GDDs were substantially higher than at any time in the previous decade, due solely to the unusually warm spring temperatures that year (Table 5-2).

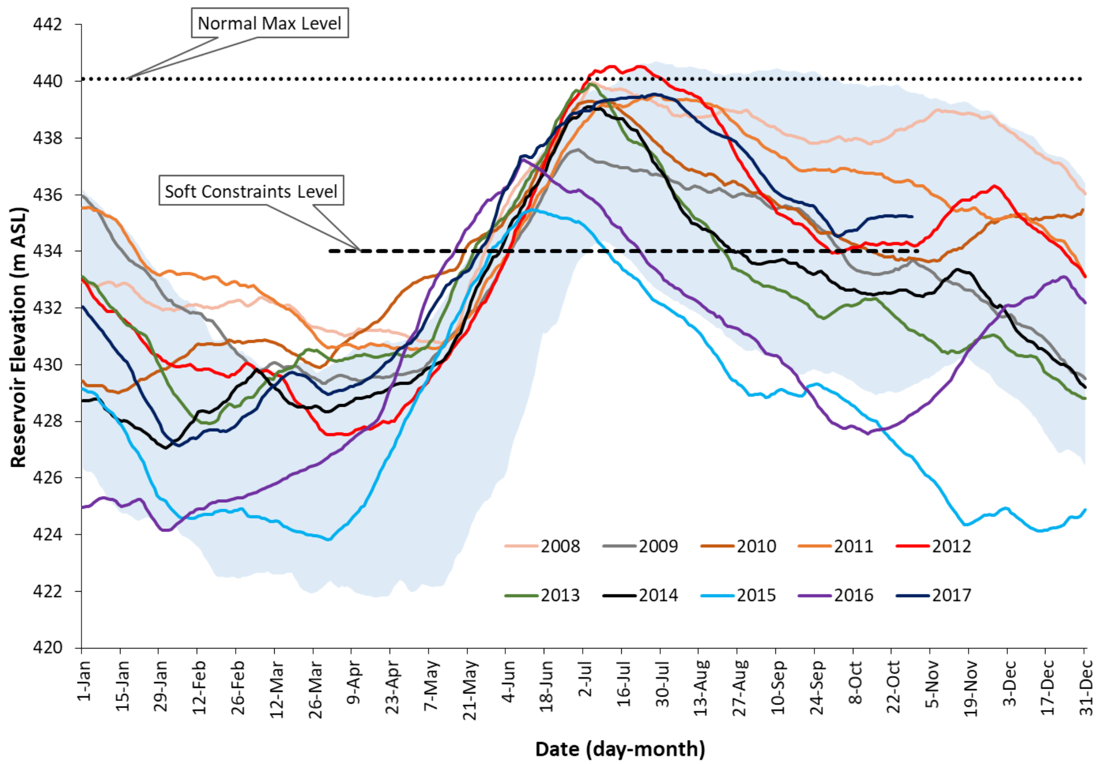


Figure 5-1: **Daily water levels in Arrow Lakes Reservoir shown by year for 2008–2017.** Water level data for 2017 were available to 29 October only at the time of this report. Shaded area illustrates the range of the daily 10th and 90th percentile of water levels across all years. Normal Max Level: normal maximum operating level of the reservoir (440.1 m ASL). Soft Constraints Level: maximum reservoir level targeted under soft constraints for vegetation for the period April 1 to Oct. 31. Target was met 47 per cent of the time between 2008 and 2017.

Table 5-1: Proportion of monthly days that each 1-m elevation band from 434–440 m ASL in Arrow Lakes Reservoir was above water for the months of April to September, 2006–2016. Cells are colour-coded by proportion: red: < 0.1 or ~0-3 days; yellow: 0.1–0.9 or ~3-27 days; green: > 0.9 or ~27-31 days.

		Year										
Month	**Elevation (m ASL)**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
April	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	438	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	437	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	436	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	435	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	434	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	438	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	437	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	436	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
	435	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68
	434	0.97	0.94	0.87	1.00	0.61	1.00	1.00	0.71	1.00	0.90	0.45
June	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	0.83	1.00	0.97	1.00	0.93	1.00	0.83	0.80	1.00	1.00	1.00
	438	0.57	0.67	0.73	1.00	0.73	0.90	0.70	0.63	0.77	1.00	1.00
	437	0.43	0.37	0.40	0.73	0.53	0.70	0.57	0.47	0.60	1.00	0.80
	436	0.27	0.20	0.17	0.57	0.33	0.50	0.43	0.27	0.40	1.00	0.00
	435	0.13	0.10	0.00	0.37	0.07	0.30	0.27	0.00	0.17	0.23	0.00
	434	0.00	0.00	0.00	0.13	0.00	0.13	0.13	0.00	0.03	0.00	0.00
July	440	1.00	1.00	1.00	1.00	1.00	1.00	0.10	1.00	1.00	1.00	1.00
	439	0.03	1.00	0.00	1.00	0.55	0.16	0.00	0.61	0.77	1.00	1.00
	438	0.00	0.10	0.00	1.00	0.16	0.00	0.00	0.45	0.29	1.00	1.00
	437	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.03	0.10	1.00	1.00
	436	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.97
	435	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.65
	434	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.32
August	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	0.94	1.00	1.00	0.32	0.45	1.00	1.00	1.00	1.00
	438	0.58	1.00	0.00	1.00	1.00	0.00	0.26	1.00	1.00	1.00	1.00
	437	0.32	0.61	0.00	1.00	0.81	0.00	0.10	1.00	1.00	1.00	1.00
	436	0.16	0.23	0.00	0.19	0.00	0.00	0.00	0.90	0.90	1.00	1.00
	435	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.68	1.00	1.00
	434	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.23	1.00	1.00
September	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	438	1.00	1.00	0.40	1.00	1.00	0.97	1.00	1.00	1.00	1.00	1.00
	437	1.00	1.00	0.00	1.00	1.00	0.47	1.00	1.00	1.00	1.00	1.00
	436	1.00	1.00	0.00	1.00	0.87	0.00	0.87	1.00	1.00	1.00	1.00
	435	0.97	0.90	0.00	0.23	0.27	0.00	0.47	1.00	1.00	1.00	1.00
	434	0.67	0.50	0.00	0.00	0.00	0.00	0.03	1.00	1.00	1.00	1.00

Table 5-2: Available monthly GDDs during each year (2006-2016) within each 1-m elevation band from 434–440 m ASL in Arrow Lakes Reservoir. The total calculated GDDs for an elevation band based on daily mean temperatures for each month were weighted by the proportion of time the elevation band was above water that month. For visual reference, cells are arbitrarily colour-coded to reflect relative GDD accumulation: red: 0 GDDs; yellow: > 0 ≤ 150 GDDs; green: > 150 GDDs.

		Year										
Month	Elevation (m ASL)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
April	440	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	439	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	438	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	437	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	436	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	435	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
	434	74.85	50.00	23.95	47.60	79.40	21.90	45.70	43.75	39.35	61.35	128.80
May	440	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	175.45
	439	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	175.45
	438	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	175.45
	437	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	175.45
	436	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	169.79
	435	162.65	172.75	150.85	146.85	130.90	139.60	137.85	170.85	137.60	202.00	118.85
	434	157.40	161.60	131.39	146.85	80.23	139.60	137.85	121.25	137.60	182.45	79.24
June	440	230.70	194.80	190.30	236.80	195.00	177.55	142.70	179.30	204.25	283.05	205.70
	439	192.25	194.80	183.96	236.80	182.00	177.55	118.92	143.44	204.25	283.05	205.70
	438	130.73	129.87	139.55	236.80	143.00	159.80	99.89	113.56	156.59	283.05	205.70
	437	99.97	71.43	76.12	173.65	104.00	124.29	80.86	83.67	122.55	283.05	164.56
	436	61.52	38.96	31.72	134.19	65.00	88.78	61.84	47.81	81.70	283.05	0.00
	435	30.76	19.48	0.00	86.83	13.00	53.27	38.05	0.00	34.04	66.05	0.00
	434	0.00	0.00	0.00	31.57	0.00	23.67	19.03	0.00	6.81	0.00	0.00
July	440	343.55	360.40	267.40	352.55	292.25	220.80	26.73	329.05	330.90	323.15	257.35
	439	11.08	360.40	0.00	352.55	160.27	35.61	0.00	201.68	256.18	323.15	257.35
	438	0.00	34.88	0.00	352.55	47.14	0.00	0.00	148.60	96.07	323.15	257.35
	437	0.00	0.00	0.00	204.71	0.00	0.00	0.00	10.61	32.02	323.15	257.35
	436	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	323.15	249.05
	435	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	323.15	166.03
	434	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	229.33	83.02
August	440	258.05	248.70	234.50	307.60	259.70	254.60	281.15	287.30	297.70	253.40	282.05
	439	258.05	248.70	219.37	307.60	259.70	82.13	126.97	287.30	297.70	253.40	282.05
	438	149.84	248.70	0.00	307.60	259.70	0.00	72.55	287.30	297.70	253.40	282.05
	437	83.24	152.43	0.00	307.60	209.44	0.00	27.21	287.30	297.70	253.40	282.05
	436	41.62	56.16	0.00	59.54	0.00	0.00	0.00	259.50	268.89	253.40	282.05
	435	0.00	0.00	0.00	0.00	0.00	0.00	0.00	157.55	201.67	253.40	282.05
	434	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.68	67.22	253.40	282.05
September	440	172.00	141.35	115.25	174.40	111.25	170.20	172.70	162.50	147.90	100.15	120.45
	439	172.00	141.35	115.25	174.40	111.25	170.20	172.70	162.50	147.90	100.15	120.45
	438	172.00	141.35	46.10	174.40	111.25	164.53	172.70	162.50	147.90	100.15	120.45
	437	172.00	141.35	0.00	174.40	111.25	79.43	172.70	162.50	147.90	100.15	120.45
	436	172.00	141.35	0.00	174.40	96.42	0.00	149.67	162.50	147.90	100.15	120.45
	435	166.27	127.22	0.00	40.69	29.67	0.00	80.59	162.50	147.90	100.15	120.45
	434	114.67	70.68	0.00	0.00	0.00	0.00	5.76	162.50	147.90	100.15	120.45

5.2 Community Responses to Planting Treatments

5.2.1 Cover

A total of 102 species of herbs (grasses and forbs), and 12 species of shrub (including shrub forms of trees such as black cottonwood), were recorded in sample plots in the Arrow Lake Reservoir drawdown zone in 2017.

Per cent cover of herbs (Figure 5-2) differed significantly among elevation bands ($F=9.8$, $p=0.002$), while differences between treated and control plots were not statistically significant ($p>0.1$). Interactions were also non-significant.

Herb cover also did not differ significantly between treated and control plots when compared across different VCTs (all $p>0.1$; Figure 5-3).

Per cent cover of shrubs (Figure 5-4) differed significantly between treated and control plots ($F=3.3$, $p=0.036$), as well as among elevation bands ($F=7.5$, $p=0.0055$). Interactions were non-significant. Generally, plots planted with shrubs at mid and high elevations showed increased shrub cover six to eight years post-treatment compared to plots that were left untreated. This effect was due almost entirely to black cottonwood treatments, as plantings of all other shrub species had low survivorship (Section 5.3, below). Median shrub per cent cover in treated plots was ~1 per cent, but ranged as high as 20 per cent in some plots (Figure 5-4).

When stratified by VCT (Figure 5-5), shrub covers differed significantly between treated and control plots in PA (redtop upland) habitats ($F=6.4$, $p=0.016$) but not in other VCTs ($p>1$). In PA habitats, plots treated with shrub stakes or seedlings had a median shrub cover of ~4 per cent (ranging up to 15 per cent), compared to a median of <1 per cent (with highs of ~2 per cent) for control plots.

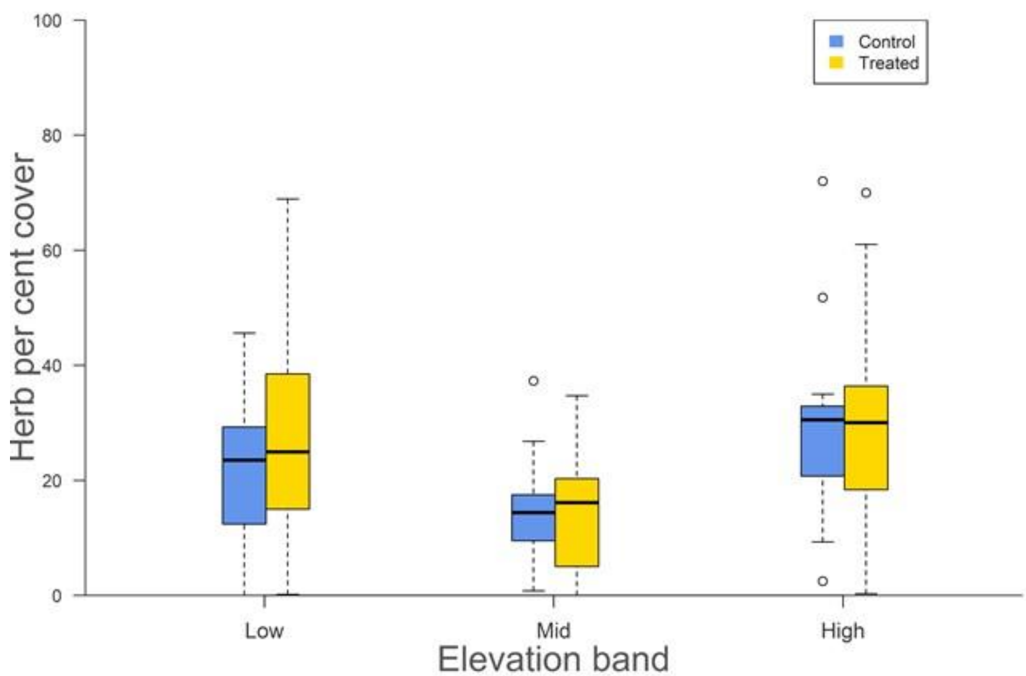


Figure 5-2: Variation in total per cent cover of herbs in control and treated plots across the three monitored elevation bands in Arrow Lakes Reservoir. Low = 434-436 m ASL; Mid = 436-438 m ASL; High = 438-440 m ASL.

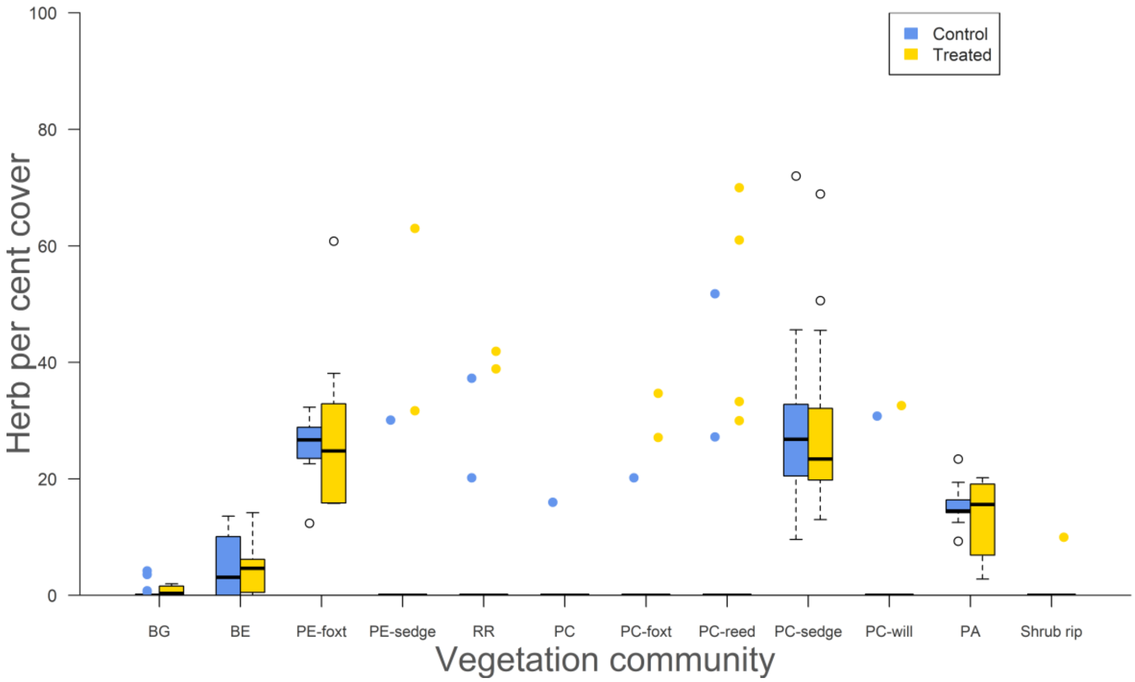


Figure 5-3: Variation in total per cent cover of herbs in control and treated plots across different vegetation community types (VCTs) in Arrow Lakes Reservoir. ANOVA tests were applied to PE-Foxtail, PC-Sedge, PA, BG, and BE. Other VCTs not tested due to a lack of replicates or large numbers of plots with no herbs present. VCTs with <6 data points are represented by colored filled dots. Low = 434-436 m ASL; Mid = 436-438 m ASL; High = 438-440 m ASL. See Table 4-1 for vegetation community types.

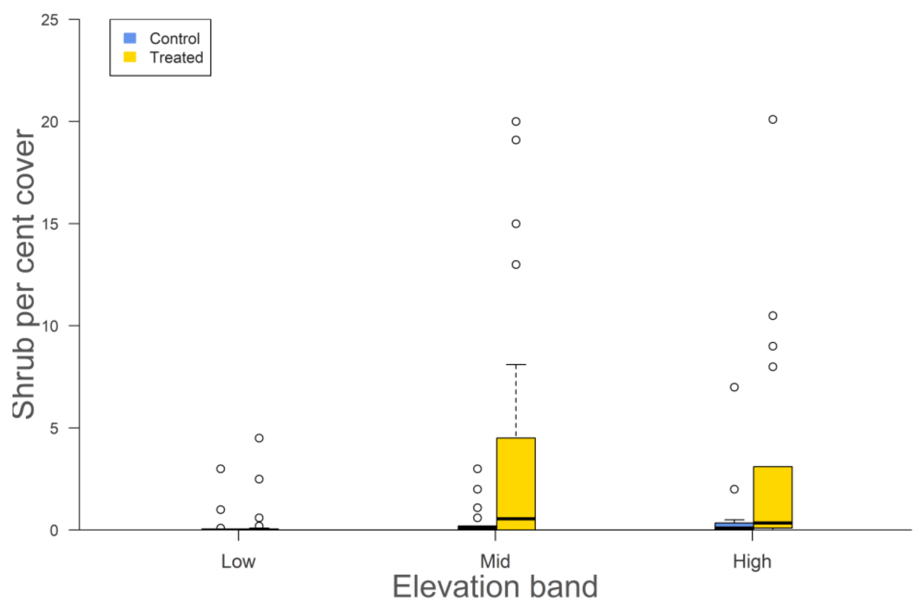


Figure 5-4: Variation in total per cent cover of shrubs in control and treated plots across the three monitored elevation bands in Arrow Lakes Reservoir. Low = 434-436 m ASL; Mid = 436-438 m ASL; High = 438-440 m ASL.

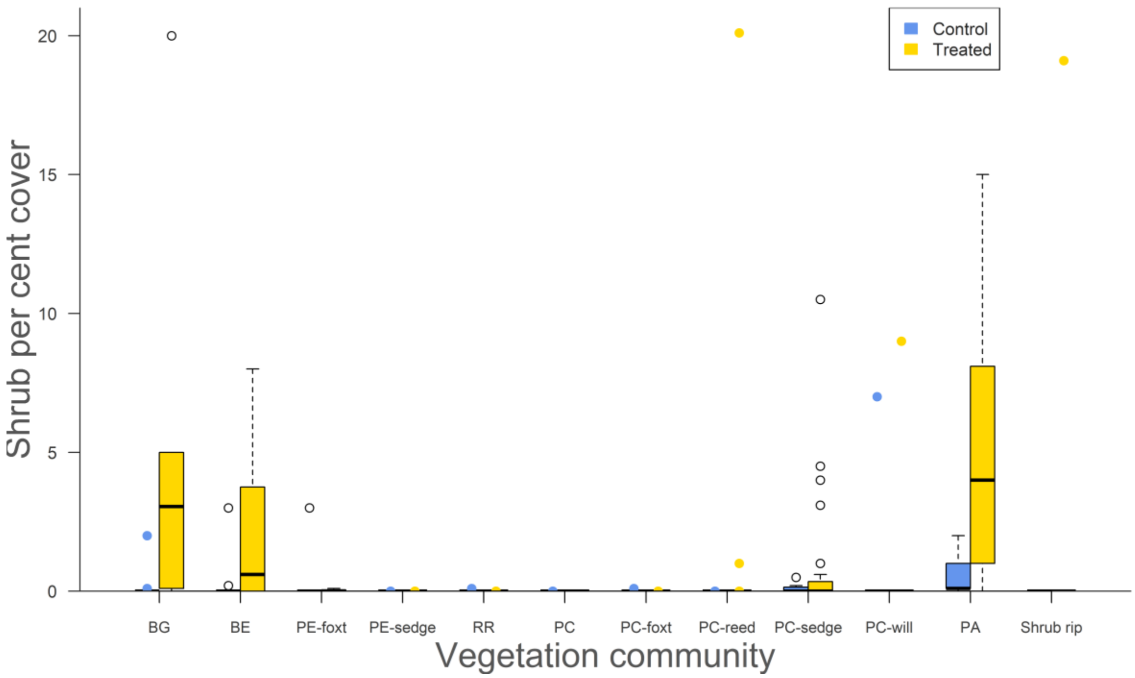


Figure 5-5: Variation in total per cent cover of shrubs in control and treated plots across different vegetation community types (VCTs) in Arrow Lakes Reservoir in 2017. ANOVA tests were applied to PE-Foxtail, PC-Sedge, PA, BG, and BE. Other VCTs not tested due to a lack of replicates or large numbers of plots with no herbs present. VCTs with <6 data points are represented by colored filled dots. See Table 4-1 for VCT definitions.

5.2.2 Richness

Revegetation treatments did not have a strong effect on species richness in sample plots. Median richness in treated plots was slightly higher in low and high elevation plots, and slightly lower in mid elevation plots, relative to controls (Figure 5-6). However, differences were not statistically significant (p>0.1).

Among community types (Figure 5-7), treated plots in the BE (sandy beach), PE-Foxtail, and PC-Sedge VCTs appeared to have somewhat higher species richness than non-treated plots, but the differences were, again, not significant (p>0.1).

The apparent slight trend toward higher richness in these treated habitats may be due in part to the introduction of sedge species (via planting of plugs) into communities where these species were not successfully establishing on their own (e.g., sparsely vegetated beach areas). It is possible that the presence of treatment species is acting in some areas to facilitate colonization by other species, leading to an increase in richness over time, although minor differences more likely reflect natural variation between treatment and control plots (Enns *et al.* 2009).

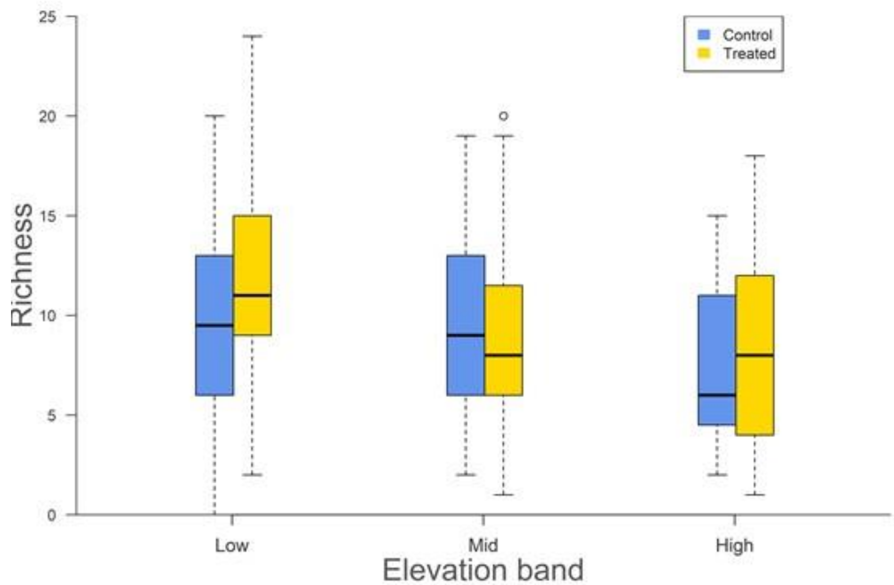


Figure 5-6: Variation in species richness (number of species) in control and treated plots across the three monitored elevation bands in Arrow Lakes Reservoir in 2017. Tested with 2-way unbalanced ANOVA with 9999 permutations. Low = 434-436 m ASL; Mid = 436-438 m ASL; High = 438-440 m ASL.

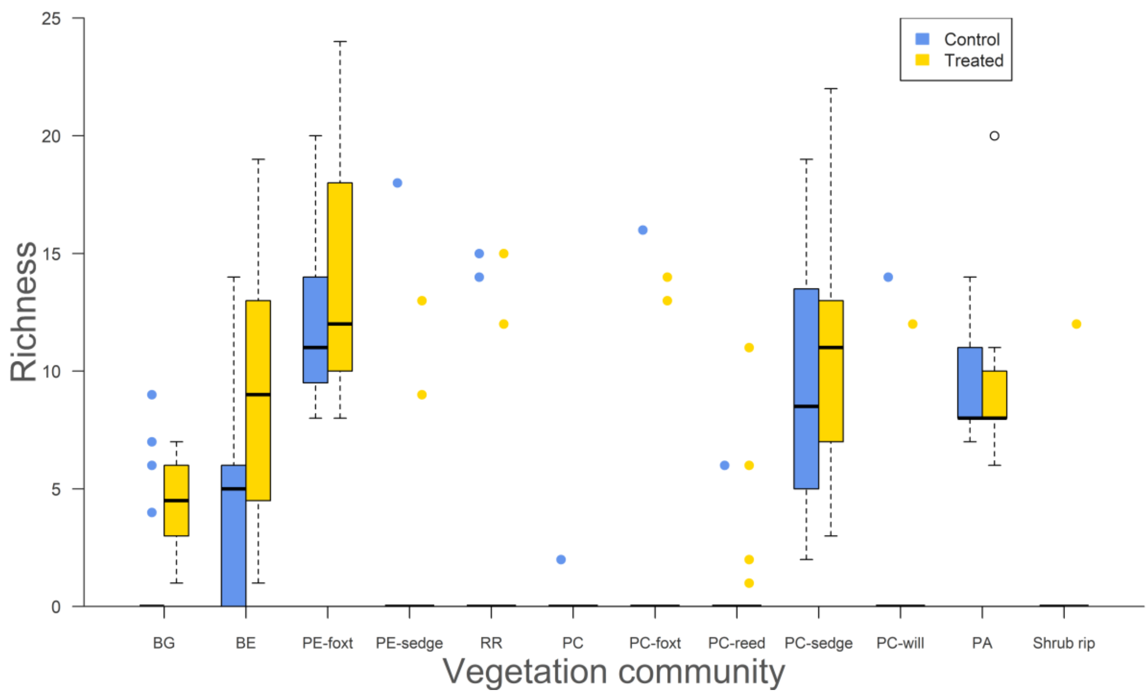


Figure 5-7: Variation in species richness (number of species) in treated and control plots across different vegetation community types (VCTs) in Arrow Lakes Reservoir in 2017. Tested with 2-way unbalanced ANOVA with 9999 permutations. See Table 4-1 for VCT definitions.

5.2.3 Diversity

To date, revegetation treatments appear to have had a modest effect on the overall plant diversity (Shannon's index) of monitored plots (Figure 5-8). As with richness, median diversity in treated plots was slightly higher in low and high elevation plots relative to controls, although differences were not significant (p>0.1).

Among community types, however (Figure 5-9), diversity in treated plots was marginally significantly higher for the PC-Sedge VCT (F=4.2, p=0.049), and was close to being significantly different for both the PA (F=3.6, p=0.07) and BE (F=3.3, p=0.09) VCTs.

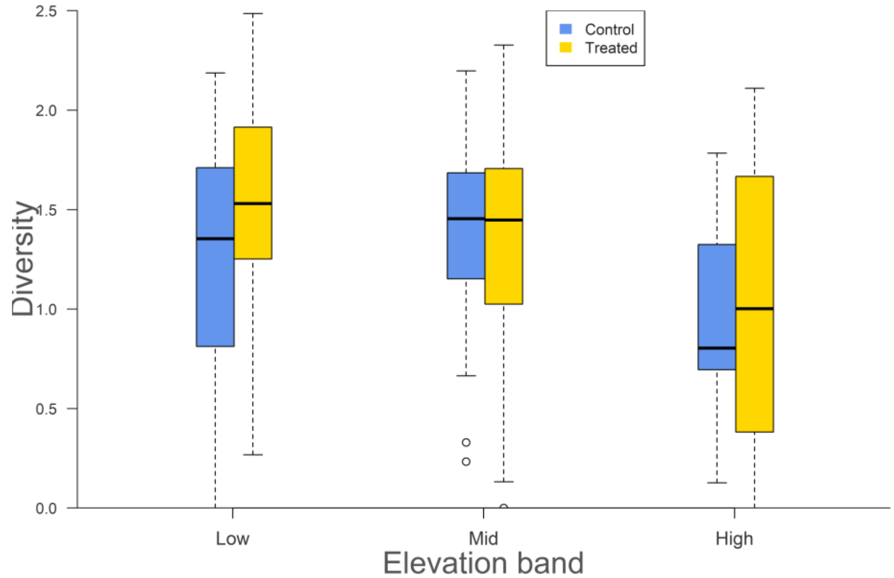


Figure 5-8: Variation in species diversity (H') in control and treated plots across the three monitored elevation bands in Arrow Lakes Reservoir in 2017. Tested with 2-way unbalanced ANOVA with 9999 permutations. Low = 434-436 m ASL; Mid = 436-438 m ASL; High = 438-440 m ASL.

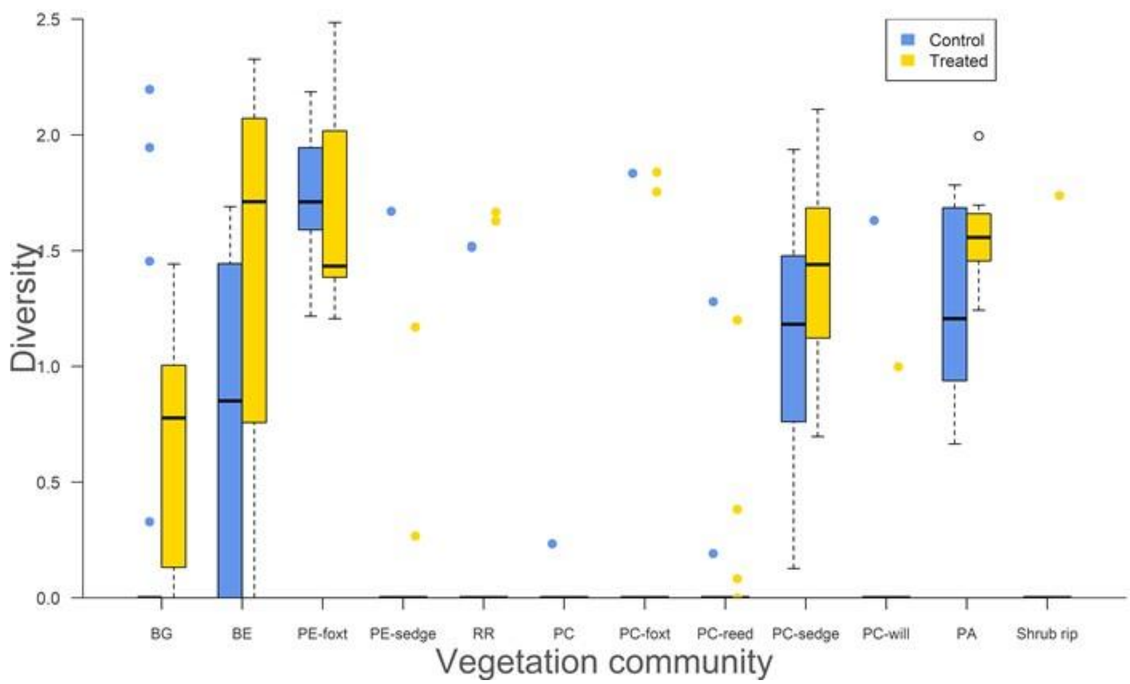


Figure 5-9: Variation in species diversity (H') in treated and control plots across different vegetation community types (VCTs) in Arrow Lakes Reservoir in 2017. Tested with 2-way unbalanced ANOVA with 9999 permutations. See Table 4-1 for VCT definitions.

5.2.4 Composition

We used principal coordinate analysis (PCoA) diagrams to assess how treated and control plots cluster in ordination space in terms of species composition and environmental variables. Two similarity coefficients, one giving the same weight to abundant and rare species (Figure 5-10) and one giving greater weight to abundant species (Figure 5-11), were used. The two resulting diagrams do not suggest a strong distinction between control and treated plots based on species composition, although some treated, mid elevation plots in 9 Mile, Edgewood, Lower Inonoaklin, 12 Mile and McKay Creek appear to cluster together at the bottom (Figure 5-10) or right (Figure 5-11) of the ordinations. These plots were all located in BG or BE communities.

Elevation and site appear to be a stronger driver of similarity among plots than the presence of treatments. For example, control and treated plots at high elevation in several Revelstoke Reach sites cluster together on the right of the diagram, while several low and mid elevation sites at Burton cluster at the top left corner (Figure 5-10). The results were similar when more weight was given to abundant than rare species in the computation of similarities, except for increased clustering of control and treated plots at low elevation in Fairhurst Creek (Figure 5-11).

The similar species compositions of treated and control plots is reflected in the results of a K-Means partitioning analysis, which suggest that elevation, rather than treatment, was the main driver in segregating species (Table 5-3).

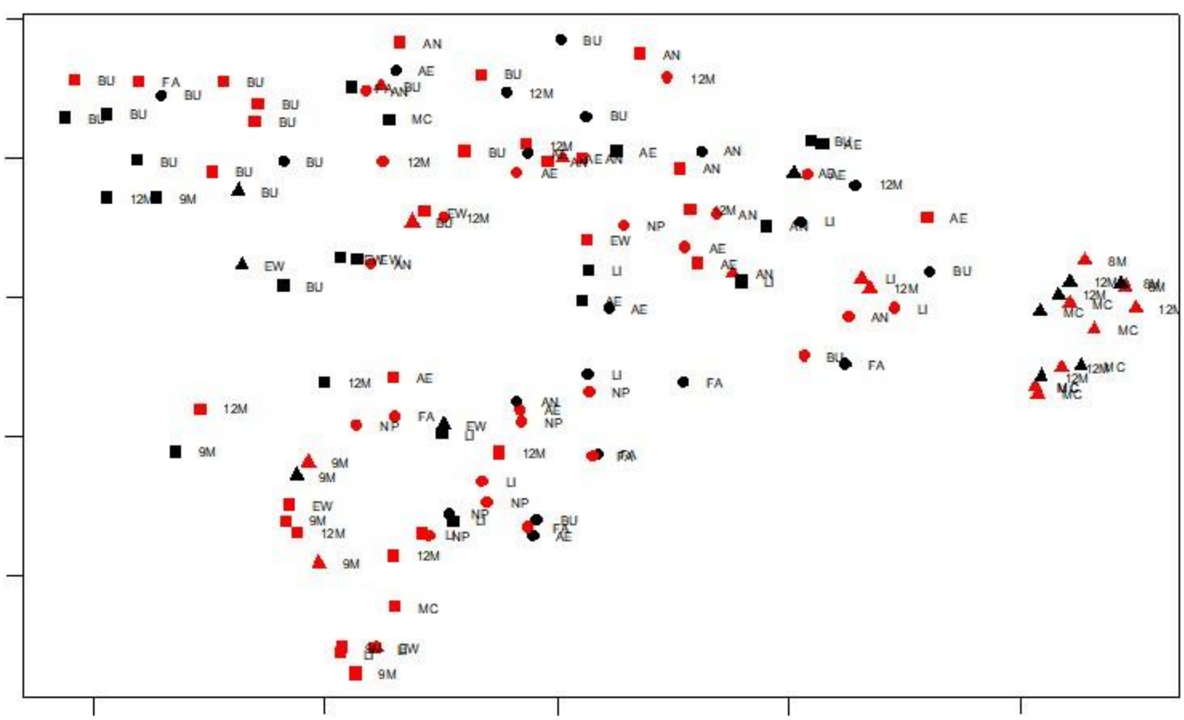


Figure 5-10: PCoA diagram showing the similarity among control and treated plots based on their species composition (D14 coefficient). Axis 1 explains 16% of the variation in similarities, and axis 2, 15%. Black = control plots; red = treated plots; o = low elevation; □ = mid elevation; Δ = high elevation; BU = Burton, LI = Lower Inonoaklin, MC = McKay Creek, NP

= Nakusp, 12M = 12 Mile, 9M = 9 Mile, 8M = 8 Mile, AN = Arrow Park North, AE = Arrow Park East, EW = Edgewood, FA = Fairhurst.

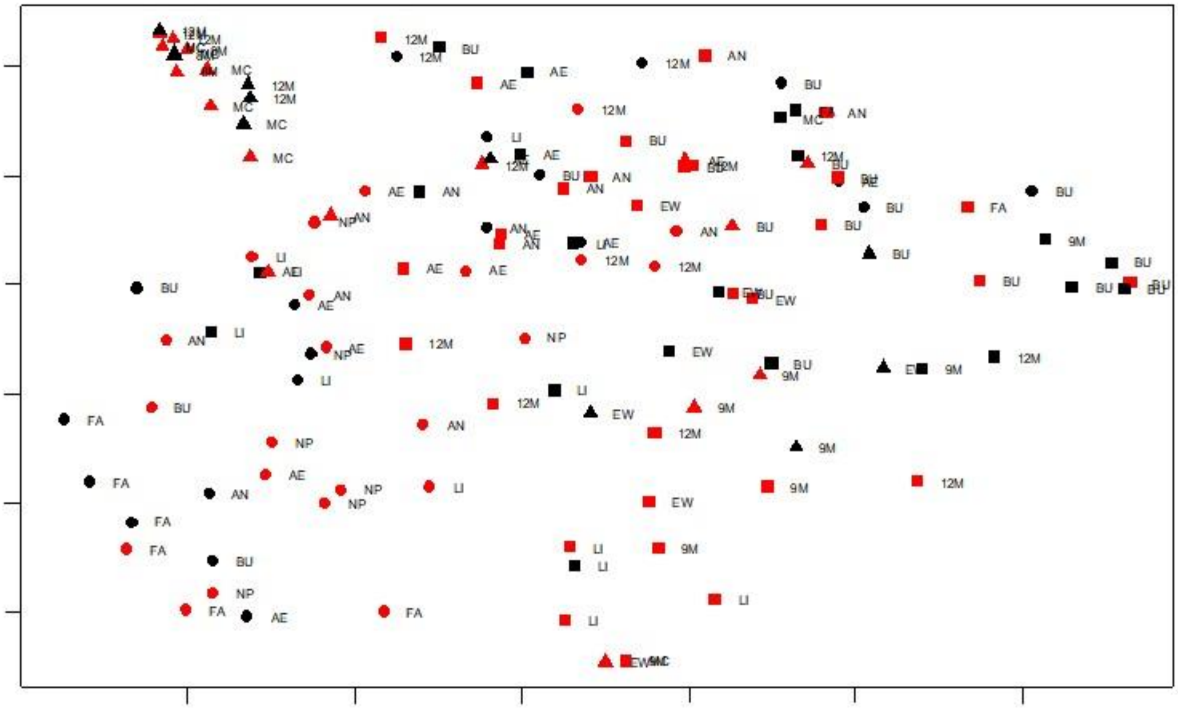


Figure 5-11: PCoA diagram showing the similarity among control and treated plots based on their species composition (D17 coefficient and Hellinger distance). Axis 1 explains 17% of the variation in similarities, and axis 2, 16%. Blue= control plots; yellow= treated plots; o = low elevation; □ = mid elevation; Δ = high elevation; BU = Burton, LI = Lower Inonoaklin, MC = McKay Creek, NP = Nakusp, 12M = 12 Mile, 9M = 9 Mile, 8M = 8 Mile, AN = Arrow Park North, AE = Arrow Park East, EW = Edgewood, FA = Fairhurst.

Table 5-3: List of concordant species as detected by the Kendall W analysis per group, and the characteristics that are associated with each group. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ (no * means $p < 0.1$). See Appendix 10.7 for expanded species names.

Group	Characteristic	Species code
1	Low elevation	AGROSTO**, ALOPAEQ***, CARDPEN*, CARELEN***, CERANUT***, CONYCAN*, EPILCIL*, ERIGPHI*, JUNCFIL**, JUNCTEN**, MATRDIS***, MONTLIN***, MYOSLAX**, PLAGSCO**, POA ANN***, POTENOR***, RORICUR***, RORIPAL***, RUMETRI**, SCIRATR, SPERRUB, VEROPER***
2	High elevation	CAREAPE**, CERAFON**, HIERPIL***, LEUCVUL**, POA PRA***, RUMEACO***, SALISIT*

Finally, we looked at factors influencing species composition using a multivariate regression tree (MRT). Results suggest that community type and location were the primary predictors of species composition (Figure 5-12). However, a split in species composition between control and treated plots was observed for BE (sandy beach), BG (gravelly beach), PA (redtop upland), and Shrub riparian VCTs (Figure 5-12, Appendix 10.6). Interestingly, the two most planted species (Kellogg's sedge at low elevation, and black cottonwood at mid and high elevations) were the only significant indicator species for treated plots of these VCTs at several sites (Appendix 10.6). While such a result could be expected following intensive planting treatments, it may also speak to a lack of effectiveness on the part of treatments (as of yet) to facilitate establishment of other species not favoured by control conditions—species that might contribute to the compositional "uniqueness" of treated plots over time. Consistent with the results of similarity analyses represented by the PCoA ordinations (Figure 5-10, Figure 5-11), the Burton and Fairhurst sites appear to possess distinct community composition elements that distinguish them from other sites (Figure 5-12).

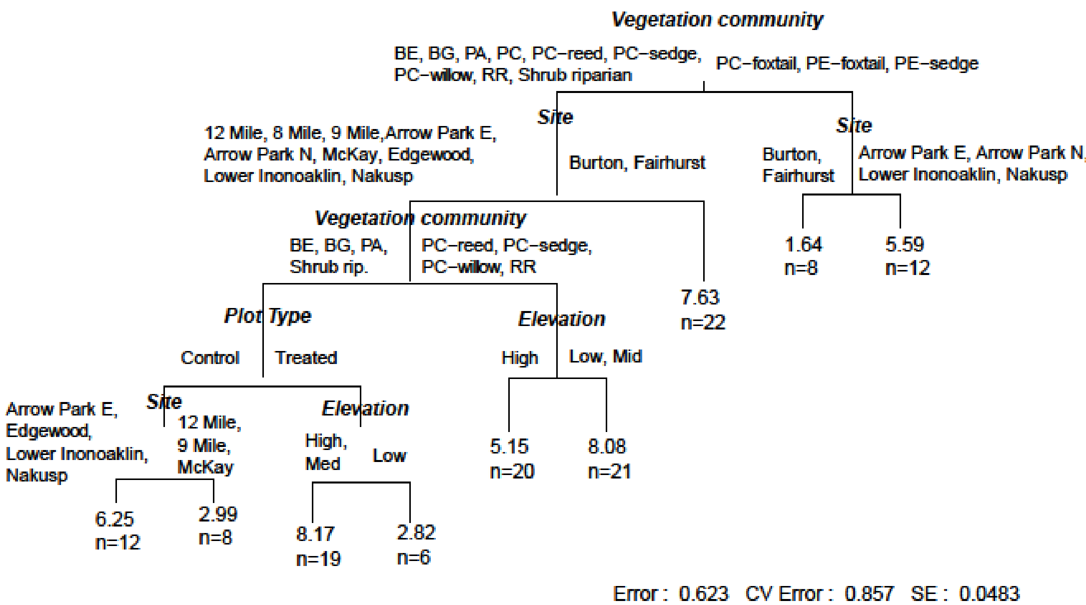


Figure 5-12: Multivariate regression tree (MRT) showing the partition of plots based on species cover (species present in >3 plots), VCTs, sites, treatment (treated/control), and elevation band. Numbers at the terminal leaves are the relative error and number of plots per group. The total variance explained by the tree is 38%.

5.3 Revegetation Survivorship and Vigour

5.3.1 Survivorship

Assessments of planting survivorship in 2017 considered eight revegetation species employed in the CLBWORKS-2 program: five sedge and sedge-like species (Kellogg's sedge, Columbia sedge, water sedge, woolgrass, and small-fruited bulrush) along with three woody shrub/tree taxa (black cottonwood, red-osier dogwood, and willow spp.; Table 5-4). Of the planted graminoids, Kellogg's sedge (aka lenticular sedge; *Carex lenticularis* var. *lipocarpa*) had the highest establishment frequency across sampled treatment polygons (68.4%), followed by Columbia sedge (56.5%). The three obligate wetland species (water sedge, woolgrass, and small-fruited bulrush) all had low overall establishment frequencies. Among woody species, black cottonwood stakes and seedlings were relatively likely to show some establishment success (52.3% and 77.8%

of polygons sampled, respectively), while most treatments involving red-osier dogwood and willows were unsuccessful (Table 5-4).

Table 5-4: Treatment types assessed for survivorship in permanent monitoring plots, as well as in new "survivorship" plots established in 2017 (Figure 3-1). Shown are the number of sampled CLBWORKS-2 polygons corresponding to each treatment, and the per cent of sampled polygons where at least some survivorship was recorded.

Treatment	Total polygons sampled	No. polygons with some establishment	No. polygons with zero establishment	Per cent (%) polygons with some survivorship
Kellogg's sedge seedlings	57	39	18	68.4
Columbia sedge seedlings	46	26	20	56.5
water sedge seedlings	24	2	22	8.3
woolgrass seedlings	17	3	14	17.6
small-fruited bulrush seedlings	6	1	5	16.7
black cottonwood stakes	44	23	21	52.3
black cottonwood seedlings	9	7	2	77.8
red-osier dogwood seedlings/stakes	11	1	10	9.1
willow seedlings/stakes	18	1	17	5.6

Graminoid seedlings: At the site level, survivorship rates of graminoid seedlings have been highly variable (Figure 5-13). Estimated survivorship within sample plots (treatment and survivorship plots combined) ranged from 0 (in many locations) to 100 per cent. As reflected by boxplot interquartile ranges, survivorship was consistently >0 for the low elevation band at 12 Mile, Nakusp, and Arrow Park North, and for the mid elevation band at 12 Mile, Burton, Arrow Park East, and Lower Inonoaklin. However, instances of notable survivorship were recorded for all three elevation bands at several additional sites such as 8 Mile, McKay Creek, 9 Mile, Arrow Park East, Fairhurst Creek, and Edgewood (Figure 5-13).

Note that estimates of 100 per cent survivorship do not seem biologically reasonable (considering the challenging environment involved and the timeframe of six to eight years post-planting), and most likely are not. Rather, these (and other similarly high) estimates may be artifacts of the challenges we encountered in reliably differentiating transplanted material from non-planted, "natural" vegetation during the course of field sampling. The ambiguity tended to be magnified at sites where nursery stock was interplanted with existing vegetation (Keefer Ecological Services Ltd. 2010) and likely resulted in some overcounts of "surviving" plugs at the plot scale. As such, most high survivorship estimates should be regarded as maximum rather than minimum estimates. That said, we can assume that sites with high estimated rates were, at the least, relatively amenable to revegetation efforts.

Of the sedge and sedge-like species planted under CLBWORKS-2, Kellogg's sedge (aka lenticular sedge; *Carex lenticularis* var. *lipocarpa*) generally showed the highest establishment rates (Figure 5-14). Median survivorship for this species exceeded 0.5 at five of the sites monitored. Columbia sedge (*C. aperta*) was the next most successful treatment (median survivorship >0.15 at 12 Mile, Arrow Park East, and Burton, with several instances of very high survivorship). Plantings of water sedge (*C. aquatilis*), woolgrass (*Scripus atrocinctus*), and small-fruited bulrush (*S. microcarpus*), all obligate wetland species, met with the least overall success; 93 and 91 per cent of plots sampled for water sedge and woolgrass, respectively, showed nil survivorship. Woolgrass did prove very successful, over a limited area, at Lower Inonoaklin (Figure 5-15). The low elevation habitat at this location, occupying the bottom of a flat, protected basin and fed by an upslope seepage, remains saturated for much of the growing season and appears to provide ideal conditions for this wetland species. As this combination of site characteristics is rare in the Arrow Lake Reservoir drawdown zone, opportunities for replicating this treatment success elsewhere are likely limited. That said, sporadic successes for woolgrass at Arrow Park East and Burton suggest that these sites may also offer suitable conditions within certain microsites (Figure 5-14).

Plugs of Kellogg's sedge generally survived better at mid than at low elevations at 9 Mile and Burton, but at low elevations at Nakusp, Arrow Park East, and Lower Inonoaklin. Results appeared comparable for the two elevation bands at 12 Mile, Arrow Park North, Fairhurst Creek, and Edgewood, with a single instance of high survivorship recorded for the high elevation band at 8 Mile (Figure 5-16).

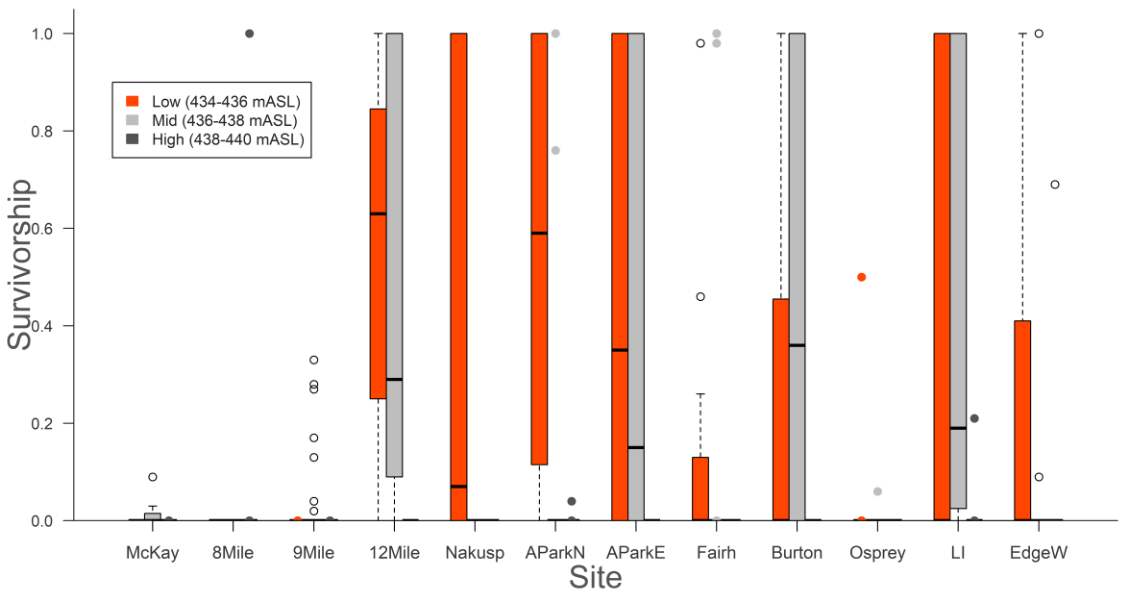


Figure 5-13: Variation in estimated survivorship of planted graminoids (species combined) across sites and elevation bands in Arrow Lakes Reservoir.

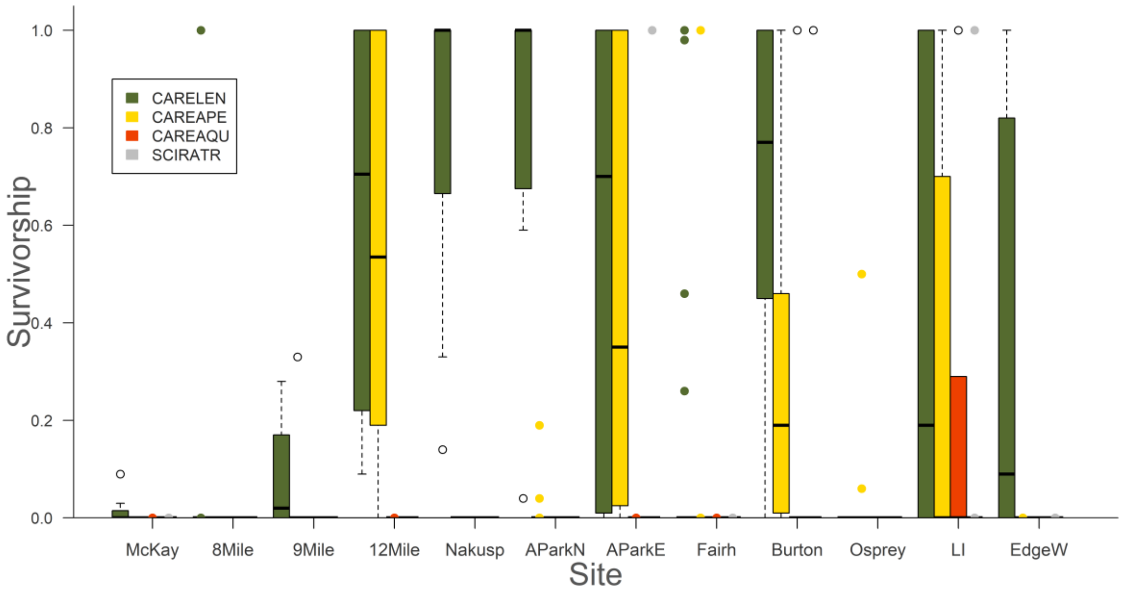


Figure 5-14: Variation in estimated survivorship of individual graminoid species planted at various sites in the Arrow Lakes Reservoir. CARELEN = Kellogg's sedge; CAREAPE = Columbia sedge; CAREAQU = water sedge; SCIRATR = woolgrass. Small-fruited bulrush (not shown) was assessed at four sites but live plants were only tallied in one polygon at Lower Inonoaklin (26% survivorship).

Figure 5-15: Woolgrass (*Scirpus atrocinctus*) at Lower Inonoaklin, planted in 2011. Photographed 19 May, 2017.

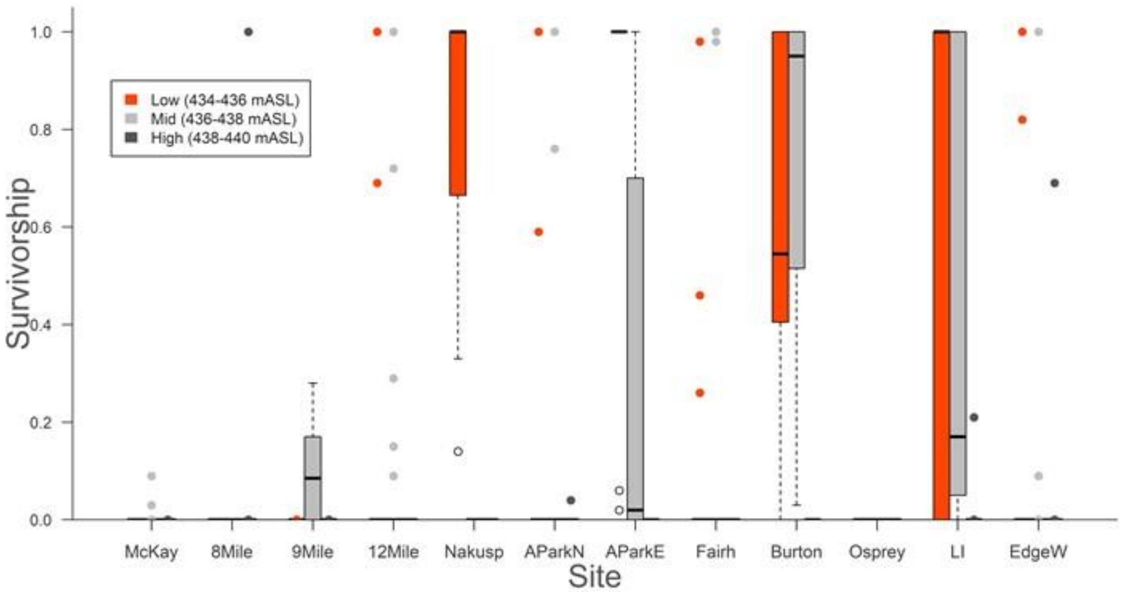


Figure 5-16: Variation in estimated survivorship of Kellogg's sedge seedlings across sites and elevation bands in Arrow Lakes Reservoir.

Shrub seedlings: Survivorship of black cottonwood (*Populus trichocarpa*) seedlings was assessed in nine treatment polygons (26 sample plots); that of red-osier dogwood (*Cornus stolonifera*) and willow (*Salix* spp.) in three plots each. The small samples for the latter two species reflect the general infrequency with which they were deployed in treatments. No surviving shrub seedlings were recorded at McKay Creek, Arrow Park North, or Lower Inonoaklin (Figure 5-17). 9 Mile, 12 Mile, and Burton had the most successful shrub (cottonwood) seedling establishment with several plot-specific survivorship estimates exceeding 0.8. Mid elevation sites tended to have the best shrub seedling survivorship overall, although instances of high survivorship were recorded for low and high elevation bands as well and trends were not well-defined (Figure 5-17).

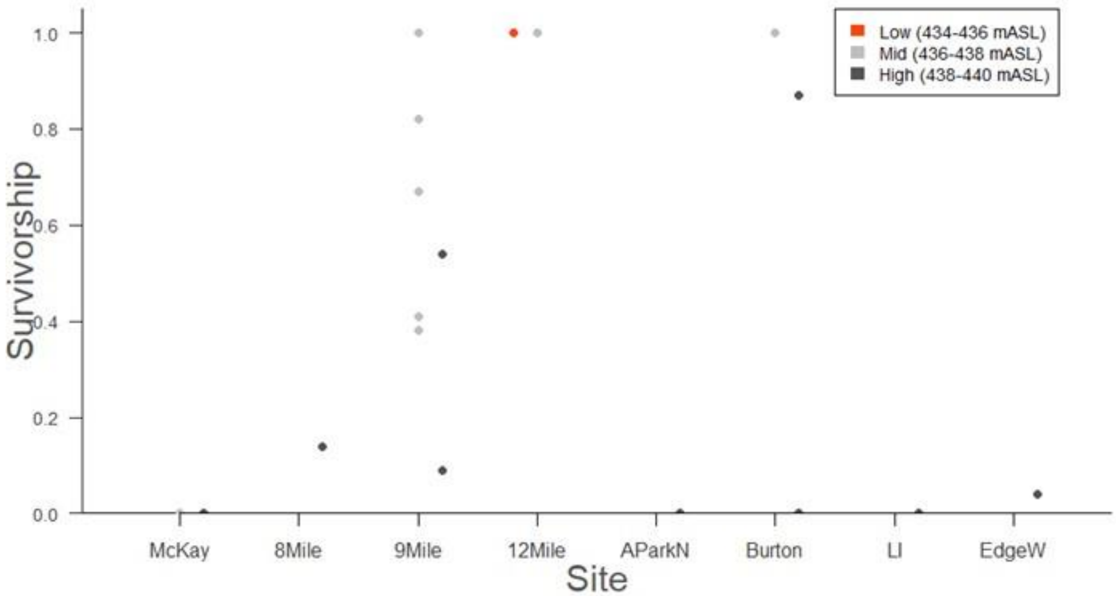


Figure 5-17: Variation in estimated survivorship of planted shrub seedlings (species combined) across sites and elevation bands in Arrow Lakes Reservoir. All non-zero values are associated black cottonwood; plugs of red-osier dogwood and those of willow did not register any survivorship in plots sampled.

Shrub cuttings (live stakes): Live stake treatments involving one or all of the same three deciduous species (black cottonwood, red-osier dogwood, and willow) were sampled at nine sites (Figure 5-18). Survivorship was highly variable, both within and across sites. Cuttings planted in high elevation sites typically performed better than at mid elevations, especially in the more northerly locations (Revelstoke Reach and Arrow Park North). Median survivorship (all species combined) exceeded 0.2 in high elevation plots at 9 Mile and 12 Mile, but was less consistent elsewhere. However, isolated instances of high survivorship were recorded at most sites, in both elevation bands (Figure 5-18).

Of the three species used in live staking, black cottonwood was the most widely-planted cutting and also exhibited the best survivorship six to eight years post-planting (Figure 5-19). Median survivorship rates for black cottonwood exceeded 0.5 at 9 Mile, 12 Mile, Lower Inonoaklin, and Edgewood, with at least one instance of high survivorship also recorded at McKay Creek, 8 Mile, and Arrow Park East. Red-osier dogwood stakes showed some survival success at 9 Mile, but generally failed to establish elsewhere. Likewise, willow cuttings had limited success, surviving plants being recorded in just a single plot at Arrow Park North (Figure 5-19).

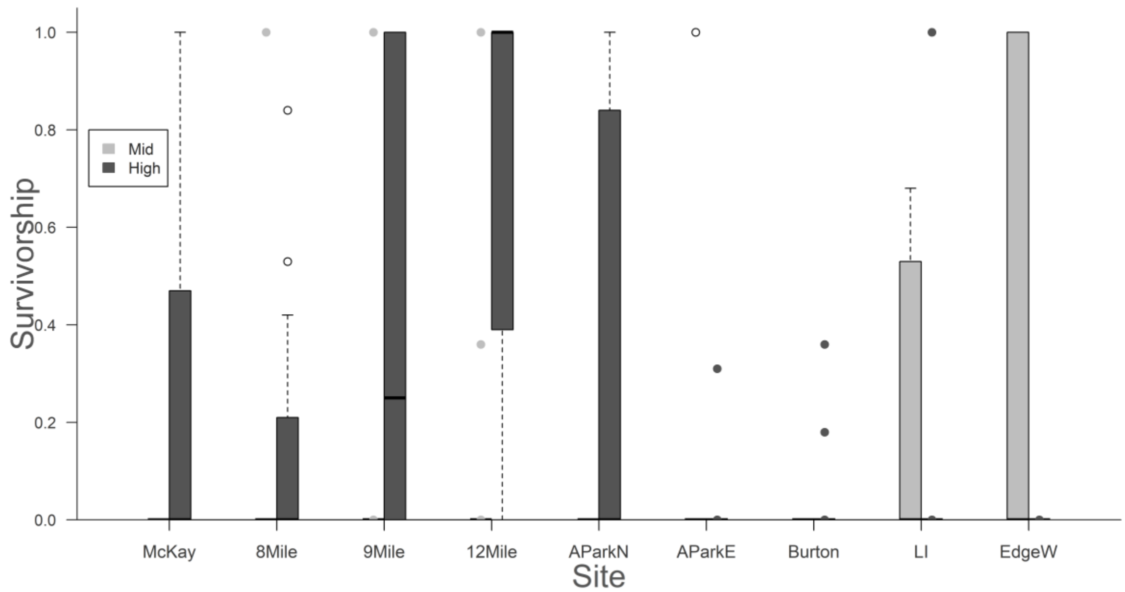


Figure 5-18: Variation in estimated survivorship of shrub live stakes (species combined) across sites and elevation bands in Arrow Lakes Reservoir.

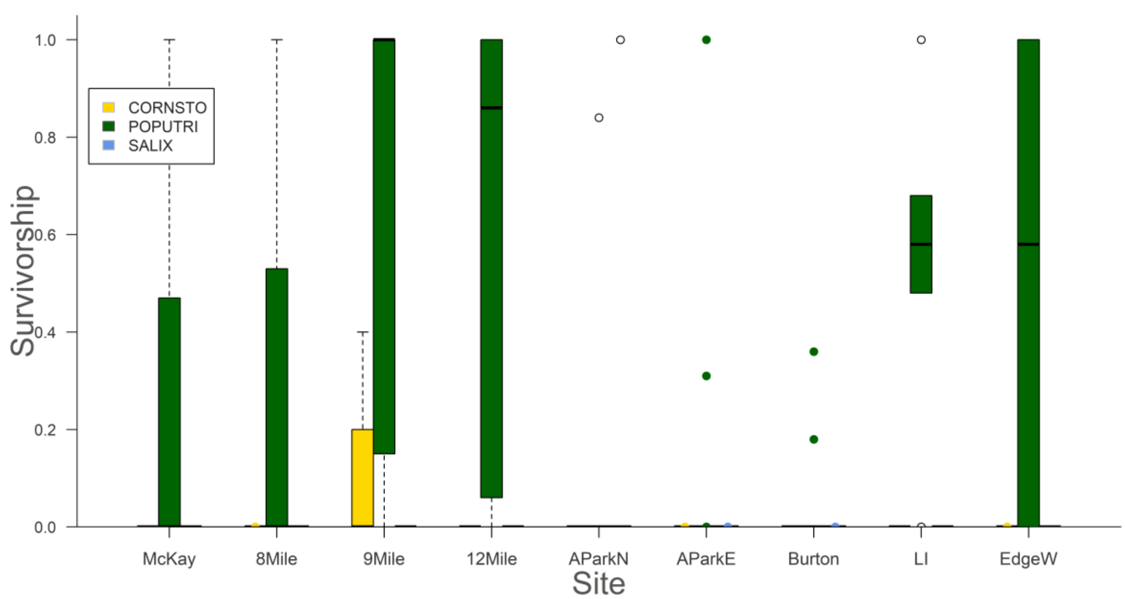


Figure 5-19: Variation in estimated survivorship of individual live stake species across sites and elevation bands in Arrow Lakes Reservoir. CORNSTO = red-osier dogwood; POPUTRI = black cottonwood; SALIX = willow spp.

5.3.2 Vigour

Kellogg's sedge seedlings: In 2017, six to eight years post-planting, Kellogg's sedge transplants showed the highest overall vigour (as classified on a subjective sliding scale from 0 [dead] to 4 [excellent]) at Burton, followed by Lower Inonoaklin and Arrow Park East (Table 5-5). A relatively high proportion (0.47 and 0.32) of sample plots at 9 Mile and Lower Inonoaklin showed 0 vigour (i.e., all dead), although a similarly high proportion (0.32) of plots at Lower Inonoaklin also showed good to excellent vigour. Overall, differences in vigour of Kellogg's sedge were not statistically significant among sites or elevation bands (Table 5-5).Among VCTs, Kellogg's sedge seedlings had relatively high failure rates in BE (sandy beach), BG (gravelly beach) and PC-Reed canarygrass (reed canarygrass mesic) compared to those in PA (redtop upland) and PC-Sedge (Table 5-5). For example, in BE, where the greatest number of samples were taken, 33 per cent of plots showed 0 vigour (i.e., all dead). However, with the exception of some plots with very low vigour ratings, seedlings that did successfully establish in the former community types showed comparable vigour ratings as elsewhere. Considered in combination, plantings made in the two PE (horsetail lowland) community types (PE-Foxtail and PE-Sedge) appeared to have the highest overall vigour ratings with no recorded failures, although the sample size in this instance was small (Table 5-5). Differences among VCTs were not statistically significant.

Columbia sedge seedlings: Vigour ratings for Columbia sedge typically ranged from 0 (dead) to high (3). Only at Arrow Park East were plants rated as very high (3.5) or excellent (4). The number of plots showing total failure was significantly higher than expected for 9 Mile, while the number of plots at 9 Mile with moderate vigour was significantly lower than expected. Plants at Edgewood, Fairhurst Creek, and Nakusp also had low to nil vigour, while those at 12 Mile, Arrow Park East, and Burton all appeared to fare better (Table 5-6).

Among VCTs, the PC-sedge community type, a mid-elevation habitat, provided the most favourable environments for Columbia sedge establishment and growth, yielding a significantly greater frequency of high vigour plots, and a lower frequency of failures, than expected by chance. Planting of this species appeared to fare less well in the lower-occurring, less stable habitats represented by BE, BG, and PE-Foxtail (Table 5-6).

Black cottonwood live stakes: Cottonwood stakes had the highest vigour ratings and lowest failure rates at 12 Mile and Lower Inonoaklin. Failure rates (frequency of plots with 0 vigour) were highest for 8 Mile, Arrow Park East, and Arrow Park North (Table 5-7).

Among VCTs, PA plots had generally the lowest failure rates (0.08) and the highest proportion of plots with live stake vigour rated as moderate to high (0.61). Both the PC-Reed canarygrass and PC-Sedge VCTs yielded much higher (0.60 and 0.63) failure rates, although both habitats also had several plots where vigour was rated as very high or excellent. BE and BG plots also yielded examples of successful establishment, with stakes in some plots showing high or very high vigour. However, total sample sizes (n=6 and n=4) for these VCTs were small (Table 5-7).

Table 5-5: Frequency of plots yielding different vigour ratings for Kellogg's sedge establishment in Arrow Lake Reservoir (2017). Data in bold were tested with χ^2. Italics indicating vigour significantly lower than expected (i.e., vigour and tested variable are not independent) based on analysis of the Freeman-Tukey deviates (at α=0.05). Frequencies are displayed, but χ^2 tests were performed on the actual counts.

Vigour	Site										
	12 Mile	8 Mile	9 Mile	Arrow Park E	Arrow Park N	Burton	Edgewood	Fairhurst Ck	Lower Inonoaklin	McKay Ck	Nakusp
dead (0)	0	0.50	**0.47**	**0.26**	0	***0.13***$^{\Delta}$	0.44	0	**0.32**	0.75	0
very low (1)*	0	0	**0**	**0.05**	0	**0**	0	0	**0.05**	0	0.14
low (1.5)*	0	0	**0**	**0.05**	0.13	**0.05**	0	0.40	**0.09**	0	0.29
mid (2)	0.25	0.50	**0.13**	**0.37**	0.38	**0.40**	0.22	0.60	**0.23**	0	0
mid-high (2.5)	0.25	0	**0.20**	**0.11**	0.38	**0.35**	0.11	0	***0***	0.25	0.43
high (3)**	0.50	0	**0.20**	**0.16**	0.13	**0.05**	0.22	0	**0.27**	0	0.14
excellent (4)**	0	0	**0**	**0**	0	**0.10**	0	0	**0.05**	0	0
χ2 (p-value)	21.8 (p=0.035)										

Vigour	Vegetation community									
	BE	BG	PA	PC - foxtail/horsetail	PC - reed canarygrass	PC - sedge	PC - willow	PE - foxtail	PE - sedge	RR
dead (0)*	**0.33**	**0.47**	**0.14**	0	0.50	**0.14**	0	0	0	0.33
very low (1)*	**0.05**	**0.07**	**0**	0	0	**0**	0	0	0	0
low (1.5)*	**0.02**	**0.13**	**0.43**	0	0	**0.06**	0	0.14	0	0
mid (2)	**0.19**	**0.13**	**0.14**	0	0.50	**0.42**	0	0.71	0	0
mid-high (2.5)	**0.26**	**0.13**	**0**	0.33	0	**0.19**	0	0	0.67	0
high (3)**	**0.14**	**0.07**	**0.29**	0.67	0	**0.14**	0	0	0.33	0.67
excellent (4)**	**0**	**0**	**0**	0	0	**0.06**	0	0.14	0	0
χ2 (p-value)	17.1 (p=0.038)									

Vigour	Elevation band		
	Low	Mid	High
dead (0)	**0.13**	**0.25**	0.71
very low (1)*	**0.02**	**0.02**	0.07
low (1.5)*	**0.10**	**0.07**	0
mid (2)	**0.23**	**0.31**	0.21
mid-high (2.5)	**0.21**	**0.21**	0
high (3)**	**0.27**	**0.13**	0
excellent (4)**	**0.04**	**0.02**	0
χ2 (p-value)	p > 0.1		

* merged for χ2 test

** merged for χ2 test

$^{\Delta}$ signicant at α = 0.1

Table 5-6: Frequency of plots yielding different vigour ratings for Columbia sedge establishment in Arrow Lake Reservoir (2017). Data in bold were tested with χ^2. Italics indicating values significantly lower than expected (i.e., vigour and tested variable are not independent) based on analysis of the Freeman-Tukey deviates (at α=0.05), while underscores indicate values significantly higher than expected. Frequencies are displayed, but χ^2 tests were performed on the actual counts.

Vigour	Site									
	12 Mile	9 Mile	Arrow Park E	Arrow Park N	Burton	Edgewood	Fairhurst Ck	Lower Inonoaklin	Nakusp	Osprey Landing
Dead (0)	**0.10**	**0.91**$^{\Delta}$	**0.26**	0.33	**0.27**	1.00	**0.80**	**0.57**	1.00	0
Low (1.5)	0.10	0	0	0.33	0	0	0	0	0	0
Mod. (2)*	**0.20**	**0.09**	**0.21**	0.33	**0.33**	0	**0**	**0.14**	0	0
Mod.-High (2.5)*	**0.40**	***0***	**0**	0	**0.13**	0	**0.20**	**0**	0	0
High (3)**	0.20	0	0.37	0	0.27	0	0	0.29	0	1
Very high (3.5)**	0	0	0.11	0	0	0	0	0	0	0
excellent (4)**	0	0	0.05	0	0	0	0	0	0	0
χ2 (p-value)	23.2 (p=0.01)									

Vigour	VCT							
	BE	BG	PA	PC - foxtail/horsetail	PC - sedge	PE - foxtail	PE - sedge	RR
Dead (0)	**0.75**	**0.88**	0	0	***0.12***	**0.78**	1.00	1.00
Low (1.5)	0	0.13	0	0	0	0	0	0
Mod. (2)*	**0.17**	**0**	1	0	**0.18**	**0.22**	0	0
Mod.-High (2.5)*	**0.04**	**0**	1	0	**0.12**	**0**	0	0
High (3)**	***0.04***	**0**	0	0	**0.48**	***0***$^{\Delta}$	0	0
Very high (3.5)**	**0**	**0**	0	0	**0.06**	***0***$^{\Delta}$	0	0
Excellent (4)**	**0**	**0**	0	1.00	**0**	***0***$^{\Delta}$	0	0
χ2 (p-value)	38.9 (p=0.0005)							

Vigour	Elevation band		
	Low	Mid	High
dead (0)	**0.63**	**0.36**	1.00
low (1.5)	**0.03**	**0.02**	0
Mod. (2)	**0.09**	**0.23**	0
Mod.-high (2.5)	**0.06**	**0.11**	0
High (3)*	**0.14**	**0.26**	0
Very high (3.5)*	**0.03**	**0.02**	0
Excellent (4)*	**0.03**	**0**	0
χ2 (p-value)	n.s.		

* merged for χ2 test
** Merged for χ2 test

Table 5-7: Frequency of plots yielding different vigour ratings for black cottonwood live stake establishment in Arrow Lake Reservoir (2017). Data in bold were tested with χ^2. Italics indicate values significantly lower than expected (i.e., vigour and tested variable are not independent) based on analysis of the Freeman-Tukey deviates (at α=0.05) while underscores indicate values significantly higher than expected. Frequencies are displayed, but χ^2 tests were performed on the actual counts.

Vigour	Site								
	12 Mile	8 Mile	9 Mile	Arrow Park E	Arrow Park N	Burton	Edgewood	Lower Inonoaklin	McKay Ck
Dead (0)	**0.18**	**0.60**	**0.25**	0.60	0.89	0	**0.38**	**0.14**	**0.62**
Mod. (2)*	**0**	**0**	**0.13**	0.40	0	1.00	**0.13**	**0.43**	**0**
Mod.-High (2.5)*	**0.09**	**0.10**	**0.25**	0	0	0	**0.38**	**0**	**0.08**
High (3)**	**0.09**	**0.10**	**0.25**	0	0.11	0	**0.13**	**0**	**0.08**
Very High (3.5)**¥	**0.27**	**0**	**0**	0	0	0	**0**	**0.29**	**0**
Excellent (4)**¥	**0.36**	**0.20**	**0.13**	0	0	0	**0**	**0.14**	**0.23**
χ2 (p-value)	18.3 (p=0.04)								

Vigour	VCT							
	BE	BG	PA	PC - reed canarygrass	PC - sedge	PC - willow	RR	SF
Dead (0)	0.17	0	***0.08***	**0.60**	**0.63**	0	1.00	1.00
Mod. (2)*	0	0.25	**0.31**	**0**	**0.13**	0	0	0
Mod.-High (2.5)*	0.33	0	**0.38**	**0.07**	**0**	0	0	0
High (3)**	0.17	0	**0.23**	**0.07**	**0.03**	1.00	0	0
Very High (3.5)**	0.33	0.50	**0**	**0.07**	**0**	0	0	0
Excellent (4)	0	0.25	***0***	**0.20**	**0.22**	0	0	0
χ2 (p-value)	27.8 (p=0.0005)							

Vigour	Elevation band		
	Low	Mid	High
Dead (0)	1.00	**0.41**	**0.47**
Mod. (0)	0	**0.17**	**0.09**
Mod.-High (2.5)	0	**0.17**	**0.07**
High (3)	0	**0.10**	**0.09**
Very High (3.5)	0	**0.10**	**0.05**
Excellent (4)	0	**0.03**	**0.23**
χ2 (p-value)	p > 0.1		

* merged for χ2 test
** merged for χ2 test
¥ result significant for 12 Mile before correction for multiple testing

5.3.3 Variables influencing survivorship

Regression trees were useful in highlighting several topo-edaphic and habitat variables potentially associated with high (or low) revegetation survivorship (Figure 5-20).

Revegetation species, along with community types (VCTs), were the leading variables driving survivorship rates. Treatments involving water sedge, woolgrass, small-fruited bulrush, red-osier dogwood, and willow were associated with low predicted success; survivorship characteristics of these species separate them early on in the regression tree from Columbia sedge, Kellogg's sedge, and black cottonwood.

The branch resulting in the highest predicted survivorship rate (0.86) included plantings of Kellogg's sedge in various community types (e.g., PA, PC-Sedge) at several sites in coarse-loamy, fine-clayey, fine-loamy, or fine-sandy-silty rooting substrates. Where Kellogg's sedge was sampled in substrates characterized by coarse-loamy, fine-loamy, fragmental, or sandy rooting zone particle sizes, predicted survivorship was higher for Arrow Park North, Burton, Edgewood, and Nakusp than for Arrow Park East, Lower Inonoaklin, and McKay Creek (Figure 5-20).

For plantings of Columbia sedge, black cottonwood, and willow, predicted survivorship was higher for Arrow Park East, Burton, Edgewood, and Lower Inonoaklin than for 8 Mile, Arrow Park North, McKay Creek, Nakusp, and Osprey Landing (Figure 5-20).

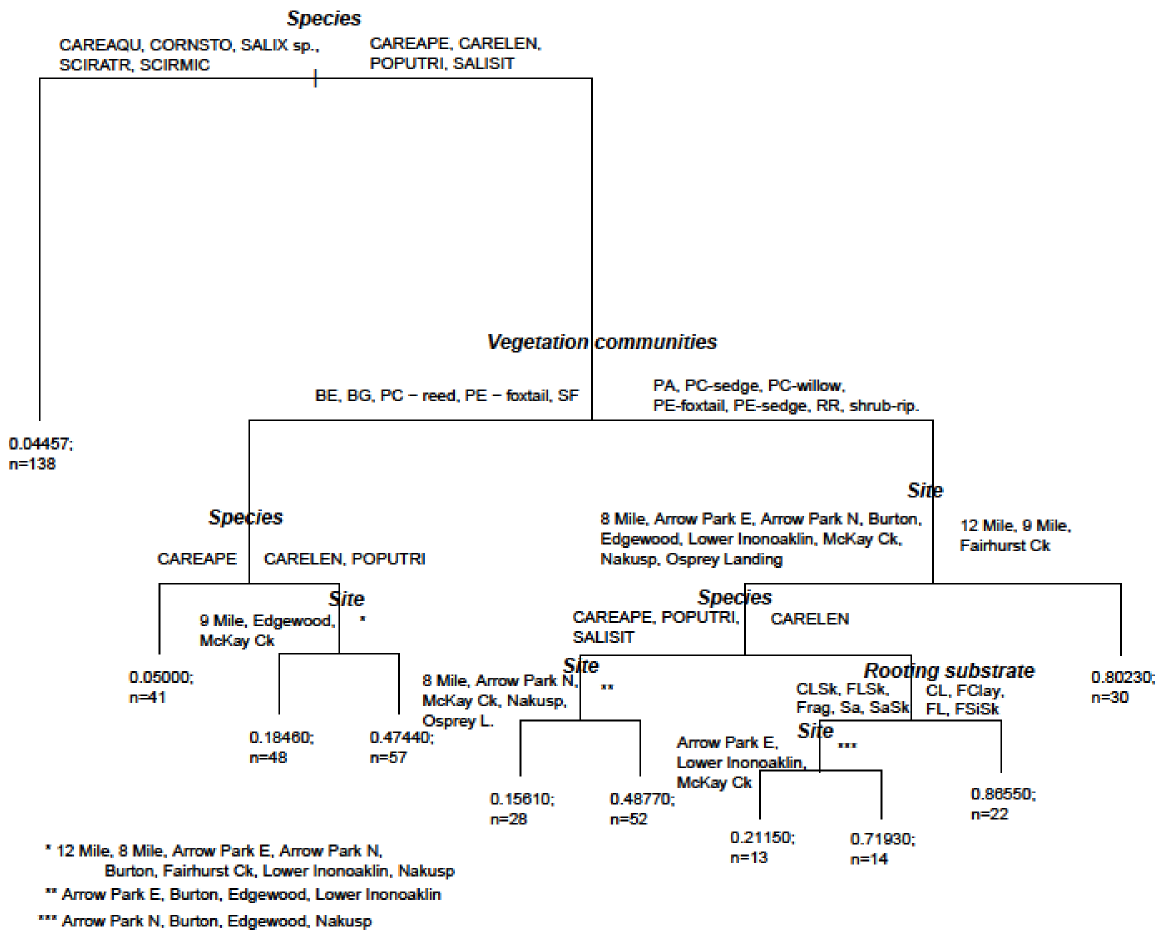


Figure 5-20: Regression tree showing the variables influencing survivorship of plantings in Arrow Lakes Reservoir. Numbers at each leaf indicate the predicted survivorship based on the split, and number of objects grouped at the leaf. The tree was pruned at 10 splits and pseudo-R^2 was 0.45. Variables included: elevation, band, site, treatment type, VCT, planted species, slope, and rooting particle size class. CAREAQU: water sedge; CORNSTO: red-osier dogwood; SALIX sp.: willow sp.; SCIRATR: woolgrass; SCIRMIC: small-fruited bulrush; CAREAPE: Columbia sedge; CARELEN: Kellogg's sedge; POPUTRI: black cottonwood; SALISIT: Sitka willow. CLSk: Coarse-loamy-skeletal; FLSk; fine-loamy-skeletal; Frag: fragmental; Sa: sandy; SaSk: sandy-skeletal; CL: coarse-loamy; FClay: fine-clayey; FL: fine-loamy; FSiSk: silty-skeletal.

The branch leading through the BE, BG, PC-Reed canarygrass, and PE-Foxtail VCTs resulted in very low survivorship predictions (0.05) for Columbia sedge, and in moderate survivorship for Kellogg's sedge and black cottonwood. For the latter two species sampled in these habitat types, better revegetation results were predicted for 12 Mile, 8

Mile, and Arrow Park East/North than for 9 Mile, Edgewood, or McKay Creek (Figure 5-20).

A classification tree (Figure 5-21) was also used to examine the variables influencing establishment success. In contrast to the regression tree (Figure 5-20), which looked at proportions of plants surviving, the response variable here was binary: for each planted species, the response was either 0 (no surviving individuals present) or 1 (some or all plants surviving).

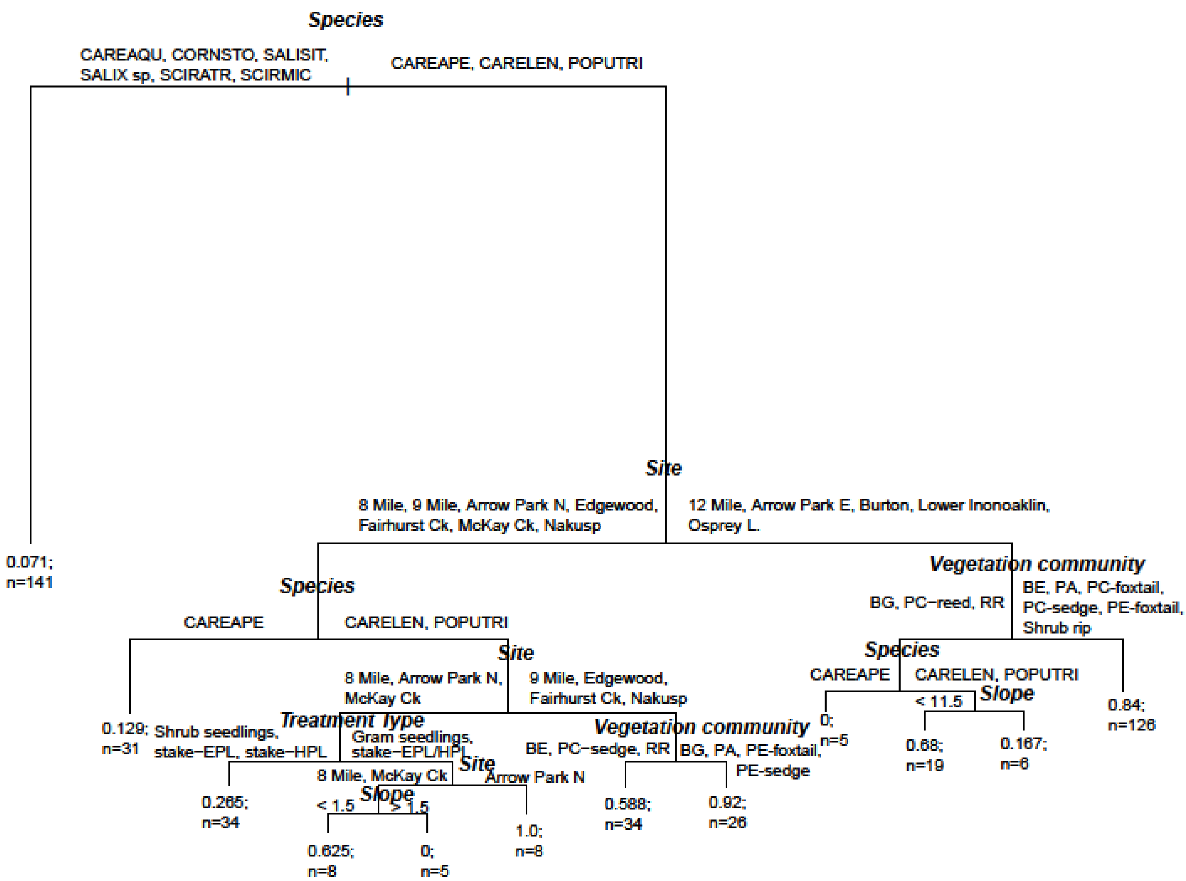


Figure 5-21: Classification tree showing the variables influencing survivorship of plantings in Arrow Lakes Reservoir. Numbers at each leaf indicate the predicted survivorship based on the split, and number of objects grouped at the leaf. The tree was pruned at 10 splits and pseudo-R^2 was 0.52. Variables included: elevation, band, site, treatment type, VCT, planted species, slope, and rooting particle size class. CAREAQU: water sedge; CORNSTO: red-osier dogwood; SALIX sp.: willow sp.; SCIRATR: woolgrass; SCIRMIC: small-fruited bulrush; CAREAPE: Columbia sedge; CARELEN: Kellogg's sedge; and POPUTRI: black cottonwood. EPL: excavator-planted stakes; HPL: hand-planted stakes; EPL/HPL: mix of excavator- and hand-planted stakes.

At certain sites (12 Mile, Arrow Park East, Burton, Lower Inonoaklin, and Osprey Landing), the BG, PC-Reed canarygrass, and RR VCTs were a predictor of Columbia sedge establishment failure. The same sites, when combined with a steep slope gradient (>11.5°), were also a predictor of low establishment probability for Kellogg's sedge and/or black cottonwood, although those species had good (0.68) predicted establishment on shallower slopes (Figure 5-21).

Kellogg's sedge and/or black cottonwood were also predicted to have good establishment in BG, PA, PE-Foxtail, and PE-Sedge community types at 9 Mile, Edgewood, Fairhurst Creek, and Nakusp; very high (1.0) establishment at Arrow Park North; and either moderate or no establishment at 8 Mile and McKay Creek, depending on the angle of slope (with failure occurring on slopes >1.5°). 8 Mile, 9 Mile, Arrow Park North, Edgewood, Fairhurst Creek, McKay Creek, and/or Nakusp yielded more favourable establishment predictions (0.13) for Columbia sedge than 12 Mile, Arrow Park E, Burton, Lower Inonoaklin, and/or Osprey Landing, where establishment was predicted to be nil (Figure 5-21).

5.3.4 Similarities/differences among treated sites

On the PCoA diagrams, sample plots (all treatments combined) displayed only weak segregation with respect to elevation, and elevation did not appear to exert a strong influence on the distribution of survivorship probabilities among samples. Two variables that did differentiate sample plots more clearly were rooting zone texture (Figure 5-22, top panel) and VCT (Figure 5-22, bottom panel). For example, plots characterized by sandy or otherwise coarse-textured substrates clustered toward the bottom left and left regions of the ordination, as did relatively xeric, well-drained VCTs (BE, BG, PA). These regions appeared to be associated with relatively low transplant survivorships. Plots supporting fine- to loam-textured soils, along with VCTs characterized by mesic moisture conditions (various sedge and grass associations including PC-Sedge), clustered in the right quadrant and seemed to be associated with a slight survivorship advantage. However, neither variable (substrate texture or community type) was unambiguously associated with overall revegetation performance; instances of low, medium, and high survivorship probabilities can be seen in all regions of the ordination (Figure 5-22).

Analysed on their own, Kellogg's sedge samples showed similar habitat relationships as for the pooled samples (better survivorship on mesic sites with fine- to loam-textured soils compared to xeric sites with poorly-anchored substrates; Figure 5-23). In contrast, good survival performance of black cottonwood transplants was most consistently associated with coarse, well-drained sandy substrates in PA and BG community types, with somewhat mixed results for similarly textured sites in PC-Reed canarygrass and BE VCTs (Figure 5-24).

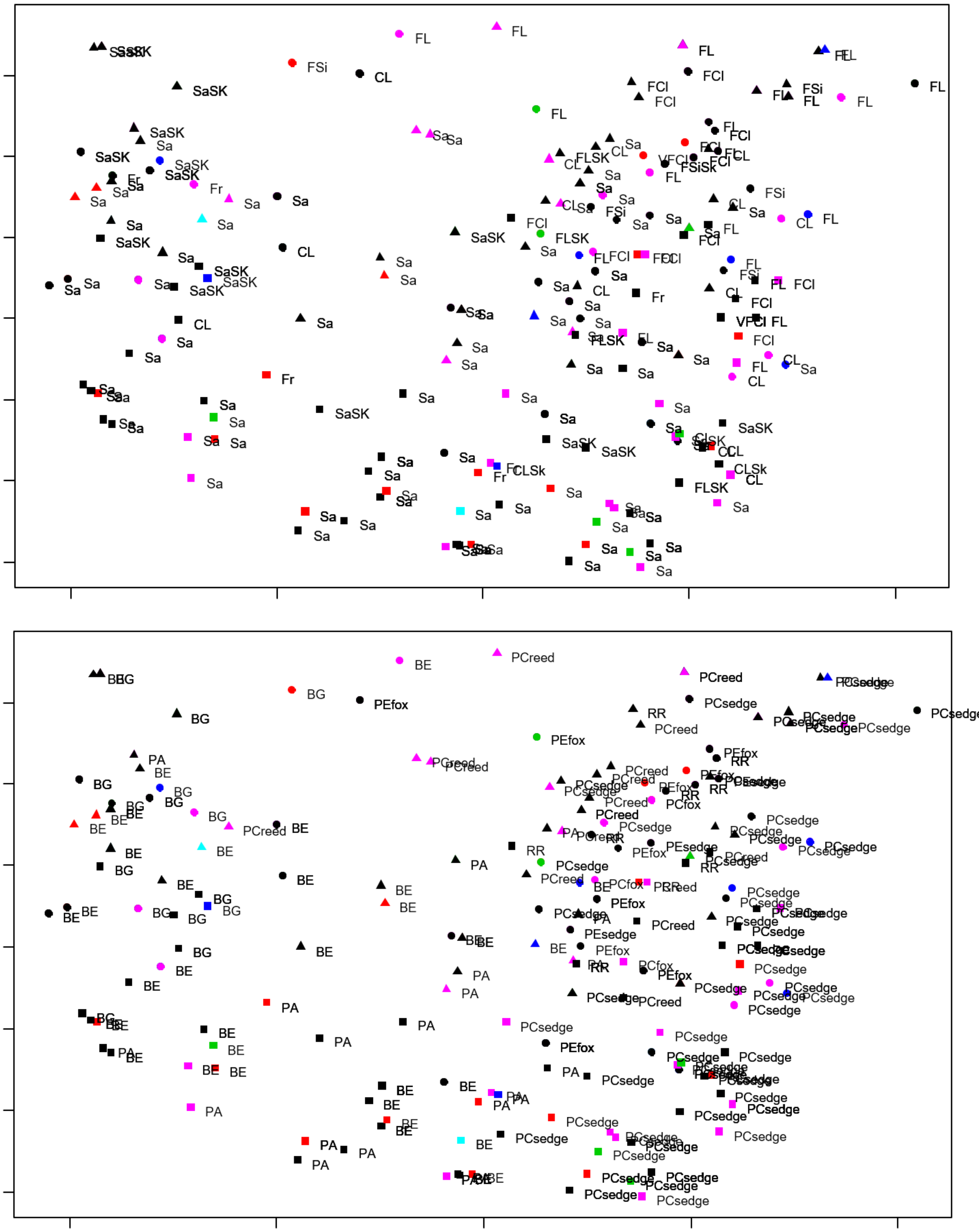
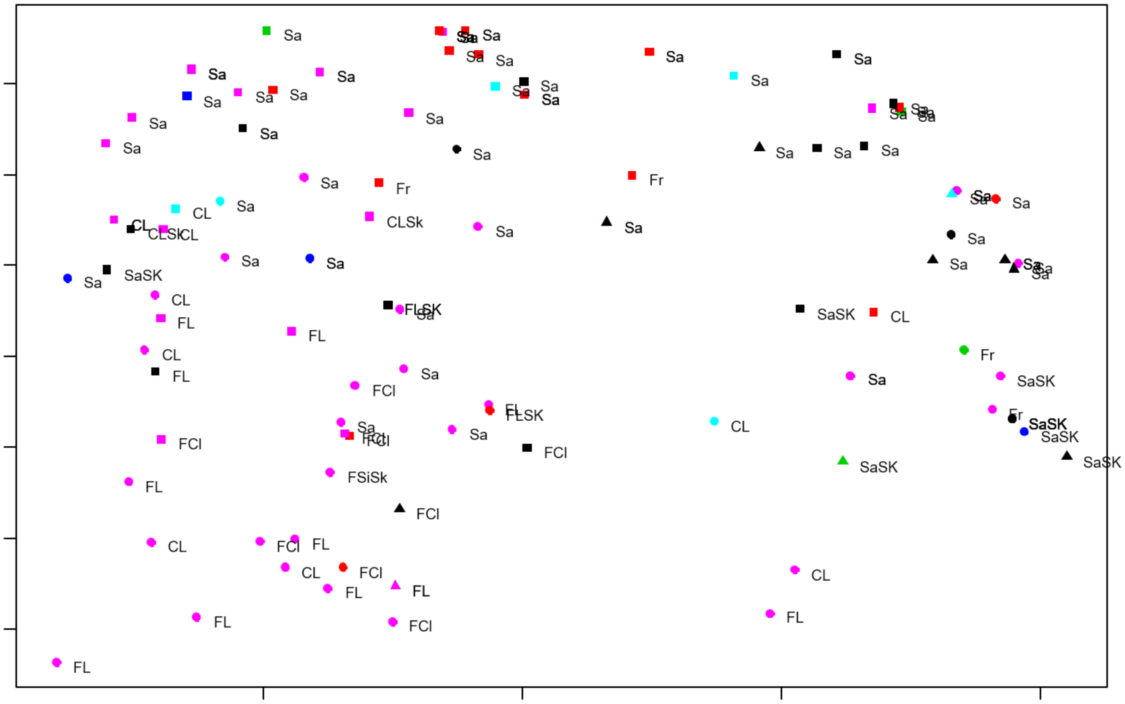


Figure 5-22: PCoA diagrams showing the similarities among plots based on habitat characteristics. Top: Labels code for rooting zone texture; shapes code for elevation band; colors code for survivorship. **Bottom:** Labels code for VCT; shapes code for elevation band; colors code for survivorship. o = low elevation; □ = mid elevation; Δ = high elevation. Black: 0% survivorship, red: 1-20% survivorship, green: 21-40% survivorship, blue: 41-60% survivorship, turquoise: 61-80% survivorship, and pink: 81-100% survivorship. CLSk: Coarse-loamy-skeletal; FLSK; fine-loamy-skeletal; FSi: fine-silty; Fr: fragmental; Sa: sandy; SaSk: sandy-skeletal; CL: coarse-loamy; FCl: fine-clayey; FL: fine-loamy; FSiSk: silty-skeletal.



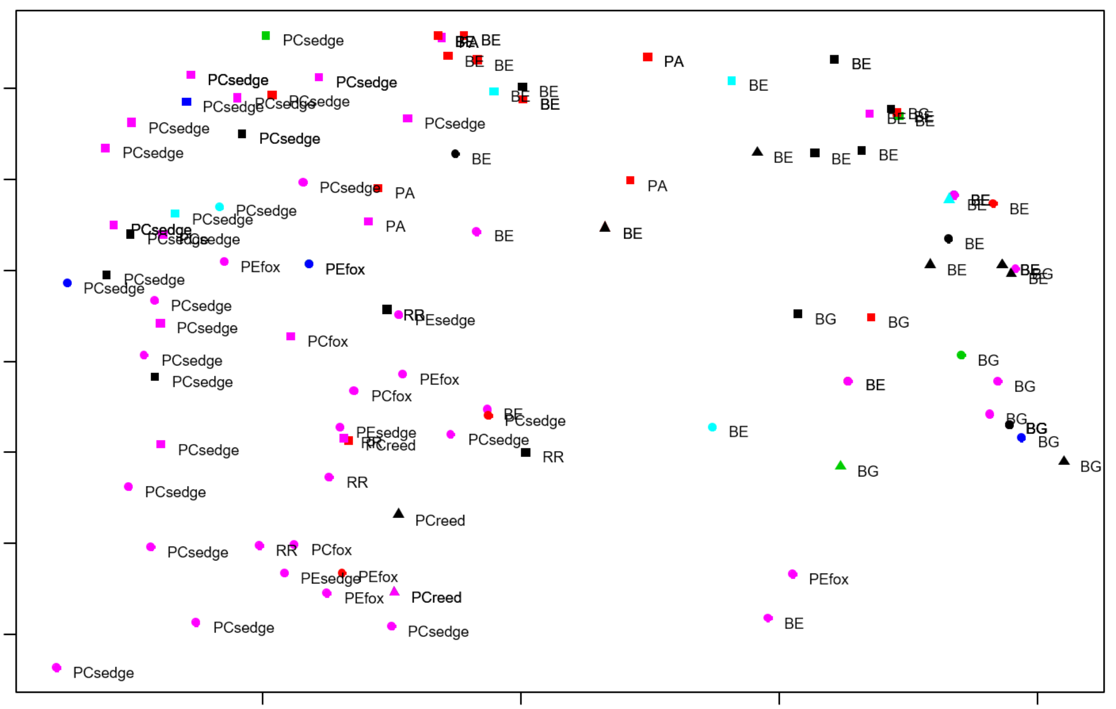


Figure 5-23: PCoA diagrams showing the similarities among plots (Kellogg's sedge only) based on habitat characteristics. Top: Labels code for rooting zone texture; shapes code for elevation band; colors code for survivorship. Bottom: Labels code for VCT; shapes code for elevation band; colors code for survivorship. o = low elevation; □ = mid elevation; Δ = high elevation. Black: 0% survivorship, red: 1-20% survivorship, green: 21-40% survivorship, blue: 41-60% survivorship, turquoise: 61-80% survivorship, and pink: 81-100% survivorship. CLSk: Coarse-loamy-skeletal; FLSK; fine-loamy-skeletal; FSi: fine-silty; Fr: fragmental; Sa: sandy; SaSk: sandy-skeletal; CL: coarse-loamy; FCl: fine-clayey; FL: fine-loamy; FSiSk: silty-skeletal.

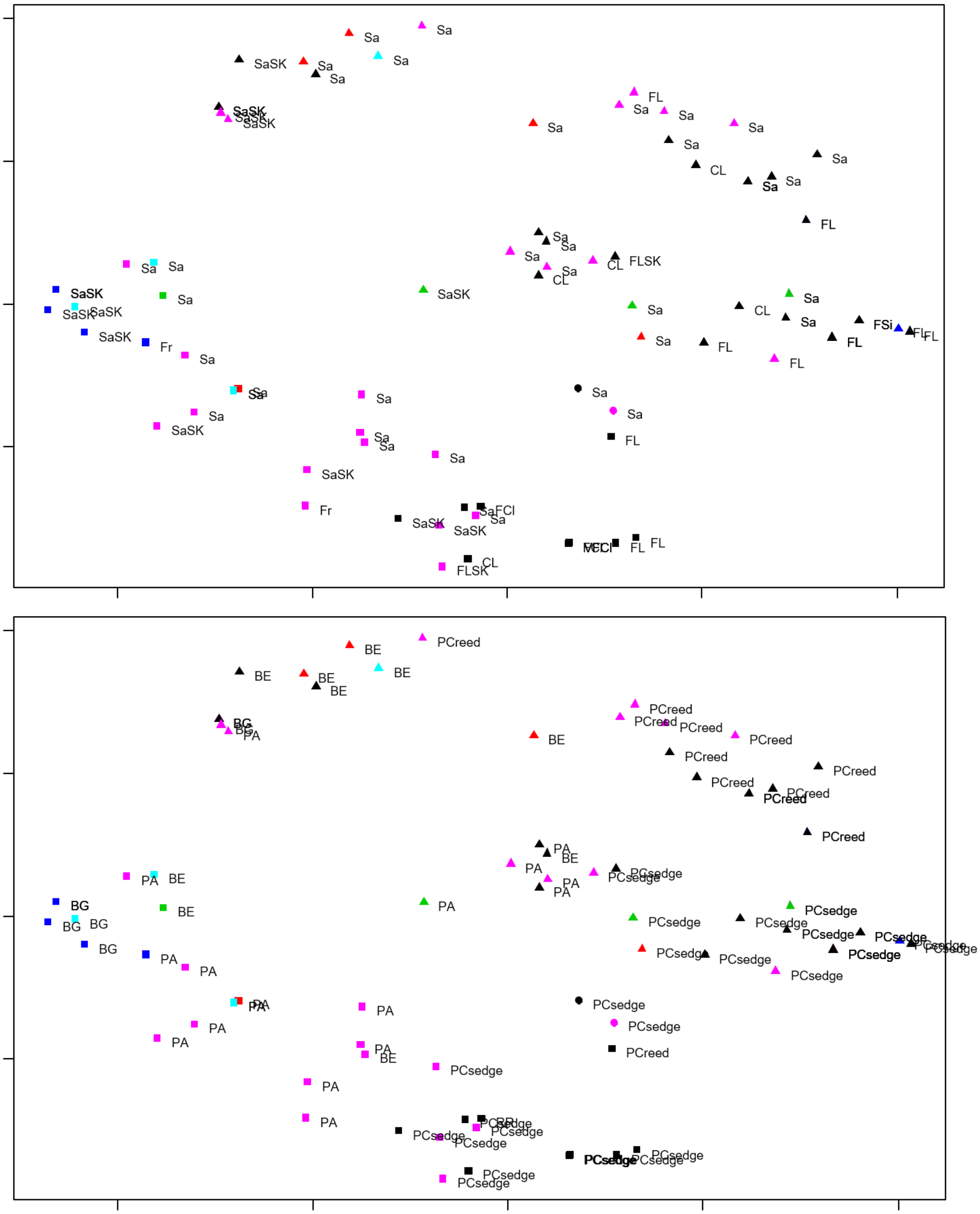


Figure 5-24: PCoA diagrams showing the similarities among plots (black cottonwood only) based on habitat characteristics. Top: Labels code for rooting zone texture; shapes code for elevation band; colors code for survivorship. Bottom: Labels code for VCT; shapes code for elevation band; colors code for survivorship. o = low elevation; □ = mid elevation; Δ = high elevation. Black: 0% survivorship, red: 1-20% survivorship, green: 21-40% survivorship, blue: 41-60% survivorship, turquoise: 61-80% survivorship, and pink: 81-100% survivorship. CLSk: Coarse-loamy-skeletal; FLSK; fine-loamy-skeletal; FSi: fine-silty; Fr: fragmental; Sa: sandy; SaSk: sandy-skeletal; CL: coarse-loamy; FCl: fine-clayey; FL: fine-loamy; FSiSk: silty-skeletal.

5.4 Management Hypotheses

5.4.1 Hypothesis H_{01}: Revegetation treatments between elevation 434m and 440m support continued natural recolonization of the drawdown zone.

There is currently no strong evidence to support this hypothesis: in general, revegetation treatments appear to be having a neutral to slightly positive impact with respect to the natural recolonization process. There was a statistically significant increase in shrub cover in treated vs. control plots. However, this difference was related to the introduction of shrub live stakes as part of revegetation activities rather than to natural recolonization. At some sandy beach sites, we have noted instances of root layering and rhizome spread by planted black cottonwood, resulting in the production of sucker shoots. This form of natural colonization may become more common (and important) as rooting systems become further established.

5.4.2 Hypothesis H_{02}: Reservoir operating conditions have no significant effect on vegetation establishment in revegetated areas between elevation 434m and 440m.

This hypothesis, and its four associated sub-hypotheses (Section 2.1), cannot be directly tested statistically due both to insufficient experimental replication (both temporal and spatial) and the confounded nature of the four aspects of reservoir operations (inundation depth, duration, timing, and frequency).

6.0 DISCUSSION

The 2017 results for CLBMON-12 are discussed below in relation to the specific management questions (Section 2.0), which have been addressed to a varying degree in previous reports (Enns *et al*. 2009; Enns and Enns 2012; Enns and Overholt 2013a, Miller et al. 2016). Most 2017 findings were consistent with those of the previous implementation year (Miller et al. 2016), which we re-summarize here while highlighting some of the new or relevant findings from the most recent investigations.

6.1 Community effects

As reported by Miller et al. (2015), revegetation treatments have resulted in some local increases in species cover and richness, both via infill planting of graminoids (primarily sedges) and shrubs (primarily black cottonwood) in previously vegetated habitats, and through the introduction of these taxa into otherwise unvegetated microsites. Surviving sedge plugs (primarily those of Kellogg's sedge and Columbia sedge) have contributed sporadically to the ground cover at various locations, while in areas such as 12 Mile (Revelstoke Reach) and Lower Inonoaklin (Arrow Lakes), planted cottonwood stakes have successfully taken root and now form small leafy stands several metres in height.

The live staking efforts, supplemented by plantings of cottonwood seedlings, had resulted in a statistically significant increase in shrub cover by 2017 compared to untreated controls. Most cover increases were limited to the PA, PC-Sedge, BG, and BE community types (VCTs), with the PA (redtop upland) VCT undergoing the most significant enhancement. In PA habitats, plots treated with shrub stakes or seedlings had a median shrub cover of ~4 per cent (ranging up to 15 per cent), compared to a median of <1 per cent (with highs of ~2 per cent) for control plots. These developing shrub stands may already be providing some structural values in the form of shade, as insect habitat, and as perching sites for birds.

Frequently, however, plantings have failed to establish or else have established only at low densities (typically contributing less than 1 per cent total cover in a 50 m^2 sample plot). Consequently, at the landscape level, the overall contributions from revegetation have not led to statistically significant differences versus untreated areas in terms of species composition, richness, and diversity. Going by these attributes, treated and non-treated areas remain generally indistinguishable. This may be because not enough time has passed since planting commenced (2008) for effects at this scale to become detectable. It should also be noted that this assessment assumes that the initial, pre-treatment vegetation was similar in the case of both treated and control sites. This assumption is probably generally valid (Enns and Overholt 2013). However, Enns and Overholt (2013) noted that early vegetation measurements were sometimes higher in control versus treatment plots as a result of planting being applied to very poor areas up to their boundaries, and adjacent controls having slightly better growing conditions. To the extent that treated sites were starting from a position of relative disadvantage compared to controls, this could have biased our results toward an underestimation of revegetation effectiveness.

In 2015, we reported that that there was little indication that planted plugs or stakes have succeeded at expanding their local footprint, either directly via new recruitment of juveniles into the population, or indirectly by moderating the environment in such a way as to facilitate the establishment of other species (Miller et al. 2016). However, during the course of 2017 ground surveys, we found anecdotal evidence to suggest that transplanted cottonwood stakes and seedlings have now begun to grow outward and to produce new stems through the suckering of underground rhizomes. This was especially apparent on some sandy beach sites, where hand excavations revealed the presence (in some cases) of networks of lateral roots connecting what initially appeared, from aboveground, to be separate individuals. While it may take many more years of stand development before we can determine if live staking on its own is an effective means of advancing local succession in barren areas of the drawdown zone, this is the first positive indication that planted shrub stands could become self-sustaining over time.

Likewise, many of the six to eight-year old transplants of Kellogg's sedge and Columbia sedge have now matured to the point where they have begun producing their own seed. We were unable to ascertain whether the small sedge germinants we observed in some sample plots were due to these transplants or to co-occurring, pre-existing sedges. However, the possibility that at least some seedlings had originated from transplant seed could not be discounted. We also observed that some larger sedge plants have begun to split into clusters of smaller plants, possibly due to root offsetting (a form of vegetative recruitment). This process of subdivision has led to the development of notable size class gradients (clumps ranging from small to large) within some of the higher density sedge plots. For long-lived perennial species like sedges, development of a complex size/age structure that includes both mature, reproductive clumps as well as juvenile recruits is significant, since it implies that the demographic conditions for a self-sustaining population may exist (Beissinger et al. 2002). Therefore, these trends are interesting to note and worthy of future monitoring.

That said, examples of vigorous sedge patches that could potentially become self-sustaining were mainly restricted to well-anchored, mesic sites that already supported some natural vegetation. Sedges transplanted onto barren beach sites have not shown much capacity for recruiting new individuals into interstitial spaces. These spaces remain bare and largely unmodified. For this reason, any community-scale benefits accruing from the introduction of sedges to previously barren areas are likely to be transitory (Miller et al. 2016). Implications are (i) that successional progression in such areas toward a more complex vegetation state is unlikely without the introduction of additional physical works (e.g., diking, windrows, mounding) designed to further ameliorate the environment; and (ii) in the absence of other physical works or operational changes to the current hydro-regime, revegetation treatments will likely need to be applied repeatedly to achieve meaningful changes in cover, composition, or diversity.

6.2 Survivorship

For 2017, the scale of field sampling was expanded to encompass numerous CLBWORKS-2 treatment polygons in the Arrow Lakes Reservoir drawdown zone not previously monitored under CLBMON-12. The expanded sampling yielded valuable new information on site-level treatment success and failures for a wide range of locations and habitat conditions. For example, of the various sedge and sedge-like (graminoid) species that were transplanted into the drawdown zone (Kellogg's sedge, Columbia sedge, water sedge, woolgrass, and small-fruited bulrush), only Kellogg's sedge and Columbia sedge succeeded in establishing with any consistency at multiple sites. However, the proportion of sampled treatment polygons where these two species showed at least some establishment success six to eight years post-planting was quite high (68.4 and 56.5 per cent, respectively). Likewise, black cottonwood stakes and seedlings showed relatively high establishment frequency, with at least some surviving transplants recorded in 52.3 and 77.8 per cent of sampled polygons, respectively.

Estimated survivorship within sample plots varied greatly across locations, with numerous samples showing minimal to no survivorship and others indicating 100 per cent establishment success.[2] Some, although not all, of this variation appeared to be tied to elevation, implying a possible operational effect (elevation can be regarded as a proxy for operating conditions because low elevations are inundated earlier, for longer periods, and to greater depth than high elevations). Thus, plantings of Kellogg's and Columbia sedge seemed to perform best at mid to low elevation in the drawdown zone, whereas cottonwood stakes showed comparable success at both mid and high elevation (low elevation sites were generally not treated with cottonwood).

Such results are consistent with the expected tolerances of these taxa to extended inundation. Both Kellogg's and Columbia sedge are found naturally at all reservoir elevations between 430 m and 440 m but are generally most abundant at mid elevation (434-438 m), where they not only tolerate, but likely benefit from, intermediate levels of seasonal inundation. At lower elevations, sedges have only a brief window of opportunity during the spring months to establish and grow before being flooded for the season. At higher elevations, they are more likely to encounter soil moisture deficits in combination with increased competition from aggressive perennials such as reed canarygrass. Black cottonwood, which likely copes less well with severe immersion but with deeper root systems capable of utilizing ground water sources, occurs naturally along upper elevation bands where the annual inundation periods are briefer and shallower.

However, because the original planting treatments were not replicated across elevation bands or across years, it is difficult to correlate variation in success to annual variations in the soft constraints operating regime, or to separate statistically the impacts of inundation on revegetation performance from other factors. Other habitat variables that appear to have been just as effective, if not more so, at predicting establishment success of out-plantings were geographic location, vegetation community type (VCT), and substrate texture. For example, live stakes performed better at 12 Mile and Lower Inonoaklin than at 8 Mile or north Arrow Park; sandy or otherwise coarse-textured substrates were associated with relatively high graminoid transplant failure rates compared to fine- to loam-textured soils; and mesic VCTs with a preexisting cover of sedges and grasses, such as PC-Sedge, had generally higher plug success rates than non-vegetated or sparsely vegetated beach habitats. In contrast, good survival performance of black cottonwood transplants was consistently associated with coarse, well-drained sandy substrates in PA and BG community types, with somewhat more mixed results for similarly textured sites in PC-Reed canarygrass and BE VCTs.

At the very local scale, however, it was usually some combination of location and habitat variable occurring in tandem that was most useful in predicting establishment success. For example, at certain sites (12 Mile, Arrow Park East, Burton, Lower Inonoaklin, and Osprey Landing), the BG, PC-Reed canarygrass, and RR VCTs were a predictor of Columbia sedge establishment failure. It is notable that the two latter community types are frequently associated with dense cover of reed canarygrass, competition with which may have inhibited establishment of this species. The same sites, when combined with a steep slope gradient, were also a predictor of low establishment probability for Kellogg's sedge and/or cottonwood, although both those species had good predicted establishment on shallower slopes.

[2] In most instances the exact starting densities of plantings were unknown, meaning that mortality could not be assessed directly. Instead, survivorship had to be estimated indirectly, using the reported average planting densities as a baseline. Therefore, survivorship values are best regarded as a relative rather than an absolute measure of revegetation effectiveness.

As with elevation, none of these variables was unambiguously associated with revegetation performance, and instances of low, medium, and high survivorship probabilities were recorded for almost all site-habitat combinations. This could imply, among other things, that a) revegetation success was generally insensitive to these particular ecological filters; or that b) the number of treatment replications across different elevations, habitat types, and years was insufficient to overcome the background noise generated by other environmental factors. Factors we did not consider, but which may also be important, include indirect operational effects such as erosive scouring, silt deposition, wave action, and floating wood debris; non-operational effects such as off-road vehicle traffic and other forms of human disturbance; the planting methods used (e.g., spring versus fall planting, machine versus hand planting, planting depths, age/size of cuttings and nursery stock, storage procedures), and pests. For example, meadow voles (sub-family Arvicolinae) were reported to be a significant detriment to cottonwood stake survival in Revelstoke Reach, where up to 1,284 live stakes were estimated to have been damaged or killed by girdling at ground-level (Keefer Ecological Services Ltd. 2011). Vole damage was particularly high on wet meadow sites supporting a dense cover of reed canarygrass (Keefer Ecological Services Ltd. 2011).

In summary, all drawdown zone habitats are not “created equal” with respect to their reclamation potential. Perhaps the main lessons to be drawn from the revegetation program to date are: (1) stocking with plugs and stakes can be an effective means of enhancing existing vegetation at sites with stable, moisture-retaining, moderately fertile substrates; and (2) in the absence of further site amelioration it may be quite difficult to coax vegetation to establish and thrive in more barren regions of the drawdown zone where plants do not always already naturally occur (there are likely good reasons why this is the case, even if those reasons are not immediately obvious to our eyes). Ultimately, revegetation effectiveness may be limited as much by the availability (and proper utilization) of suitable habitat areas in the drawdown zone as by the reservoir operating regime itself.

6.3 Operations

From a reclamation standpoint, opportunities still exist for enhancing the development of existing revegetation treatments through operational modifications. With respect to reservoir hydroperiod, program experience to date suggests the following tentative “axioms”:

(i) To facilitate development of functional riparian ecosystems, periodic, brief inundation at low elevations (i.e., 434-436 m) is likely necessary (to recharge soil moisture, protect establishing plants from summer drought, and maintain suitable growing conditions for adapted riparian species and communities).

(ii) Frequent full pool events can limit the capacity for shrub and tree establishment at upper elevations (i.e., >436 m).

(iii) Extended, deep inundation is unnecessary for transplant establishment and probably detrimental for all revegetation taxa.

(iv) Late summer and fall inundation can inhibit seed-set and dispersal for key reclamation species such as Kellogg’s sedge, resulting in lost reproductive opportunity and reduced establishment (and hence reclamation) potential.

In effect, the more that inundation cycles resemble natural spring/summer freshet cycles in both timing and duration, the more beneficial to revegetated communities they are likely to be. Soft constraints will be most effective at maintaining revegetated communities to the extent they are applied to limit not just the depth but also the duration of inundation during the summer and early fall growing season.

7.0 SUMMARY

In this final summary data report for CLBMON-12, we convey some of the incremental gains that have been made with respect to assessing the effectiveness of the Arrow Lakes revegetation program (CLBWORKS-2) at increasing the quantity and quality of vegetation in the drawdown zone.

In 2017, we increased the scope of field sampling to include survival assessments at several CLBWORKS-2 treatment sites not previously monitored under CLBMON-12. The most significant outcome of this expanded survey was a much more comprehensive cataloguing of revegetation successes and failures covering almost the full extent of treatment polygons. We were generally pleasantly surprised by the high proportion of sites that showed at least some instances of successful establishment (by both seedlings and shrub cuttings) six to eight years after planting. Because of their more limited scope in terms of treatment cataloguing, previous reports may have underestimated somewhat the success rate of planting efforts at the broader landscape scale.

That said, our overall conclusions are consistent with those reached in previous implementation years: revegetation efforts to date have met with decidedly mixed success. A portion of the stock (primarily Kellogg's sedge, Columbia sedge, and black cottonwood) planted between 2009 and 2011 has survived and taken root and, in limited areas, is growing vigorously. An estimated 76 per cent of treated polygons, representing about 82 ha of drawdown zone habitat, support at least some surviving transplants. The plantings in these areas may now be providing some ancillary ecological services such as increased erosion control, browse for waterfowl, and perching habitat for birds. For about one quarter of the treated areas (approximately 26 ha), survival of plantings has been minimal to non-existent. Establishment failures can probably be ascribed to a combination of environmental factors including prolonged inundation, infertile or unstable substrates, wave action and erosion/deposition, and soil moisture deficits. In otherwise barren areas where revegetated plants have taken hold, an apparent lack of new recruits suggests that revegetated populations may not be self-sustaining over the long term and may require repeated planting interventions to persist.

At the community level, revegetation activities have had a neutral to slightly positive impact on associated vegetation development (as represented by such metrics as per cent cover and species richness). However, we feel that insufficient time has elapsed since treatments were initiated for successional effects to manifest themselves (particularly in the case of developing cottonwood stands). Nevertheless, it is becoming evident that for many barren regions of the drawdown zone, additional physical modifications aimed at ameliorating site conditions will likely have to be applied in concert with repeated planting interventions if lasting community changes are to be achieved. From an operational standpoint, opportunities also exist for advancing vegetation establishment, namely by using soft constraints to control the timing, and limit the depth and duration, of summer inundation.

A further summary of the multi-year findings and study limitations associated with each management question (MQ) is provided in the Executive Summary tables for revegetated areas and existing vegetation (p. iii).

8.0 RECOMMENDATIONS

Insufficient replication of the 2008-2011 revegetation treatments across elevation bands, habitat types, and years has hampered our ability to test hypotheses around revegetation efficacy as it relates to operational (reservoir-related) and non-operational (environmental) factors. Physical works projects aimed at establishing vegetation in the Arrow Lake Reservoir drawdown zone should strive to ensure that adequate experimental replication (including spatial and temporal replication) is incorporated as an intrinsic component of any future revegetation prescriptions.

The current implementation year (2017) marks the last year of scheduled effectiveness monitoring under the CLBMON-12 program. However, current research confirms that transplanted vegetation continues to persist, and in some instances thrive, at a high proportion of the sites treated under CLBWORKS-2. Given that processes of successional development related to revegetation are still at an early ecological stage, it is our recommendation that effectiveness monitoring not be completely discontinued at this time. Rather, to retain the opportunity of gaining valuable lessons from continued long-term monitoring of reclamation processes, we recommend that monitoring be allowed to continue, albeit on a less intensive basis than previously. Specifically, we suggest that monitoring be scheduled to resume on a reduced five to 10 year cycle up to 2029 (for a total of 20 years of monitoring), with additional, interim sampling being undertaken if extreme events are triggered during this time. Furthermore, future monitoring should be limited to sites where successful transplant establishment is known to have occurred.

Future considerations for vegetation and revegetation monitoring in Arrow Lakes Reservoir can be discussed at the revegetation technical forum attended by agencies and First Nations following the completion of Year 2 of the CLBMON-35 program in 2019. The CLBMON-35 results will inform future direction of vegetation monitoring in Arrow Lakes Reservoir.

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10.0 APPENDICES

10.1 Summary of CLBWORKS-2 planting treatments

Revegetation work was conducted in the drawdown zone from 2008 to 2011. In 2008, this consisted mainly of fertilization trials at Burton and Nakusp sites to evaluate the effectiveness of fertilization in facilitating sedge establishment. A total of 16,200 nursery-raised seedlings consisting of 15,800 lenticular sedge and 400 Columbia sedge plugs were planted out in the spring, and a fertilizer blend of 15-9-18-4.7S-1.6 Cu-0.3B was applied at a rate of 370 kg/hectare. These trials were largely inconclusive due to an early inundation event that prevented proper root system development in the planted plugs (Keefer *et al.* 2008).

In 2009, 272,895 nursery-raised plugs were spring-planted and 188,905 plugs were fall-planted, totalling 461,800 sedge and grass seedlings across 39.52 ha. Species planted included lenticular sedge, Columbia sedge, water sedge (*Carex aquatilis*), woolgrass (*Scirpus atrocinctus*), small-fruited bulrush (*S. microcarpus*) and bluejoint reedgrass (*Calamagrostis canadensis*). In addition, approx. 19,000 live deciduous stakes (primarily black cottonwood but including 2,188 willow and 530 red-osier dogwood [*Cornus Canadensis*] stakes) were planted in the spring over 7 ha at a density of 2,047 stems/ha. In the fall, 5,080 nursery-raised deciduous seedlings (4,180 black cottonwood and 900 chokecherry [*Prunus virginiana*]) were planted in Revelstoke Reach (Keefer Ecological Services Ltd. 2011).

In 2010, over 200,000 sedge seedlings (104,160 lenticular sedge, 84,960 Columbia sedge, and 13,920 water sedge) were planted out at an average density of 13,245 stems/ha. The highest density of plantings was at Renata (42,500 stems/ha), a uniformly open, sandy site, while the lowest density (4,033 stems/ha) was at 9 Mile, a more highly vegetated, irregular site with fewer suitable microsites available for planting. A total of 6,191 live stakes (5,551 cottonwood and 640 red-osier dogwood) and 4,320 cottonwood seedlings were planted at elevations above 438 m in areas accessible to an excavator (Keefer Ecological Services Ltd. 2011).

In 2011, a total of 266,580 sedge and grass plugs were planted during late April and early May, resulting in 19.9 ha of treated area. As in previous years, lenticular sedge was the most planted species (233,280) followed by woolgrass (16,875), bluejoint reedgrass (10,125), water sedge (5,355) and Columbia sedge (945). The average stocking density of all sites was slightly over 13,000 plugs/ha. In addition, 4,347 black cottonwood live stakes were cut and planted at 8 Mile in Revelstoke Reach (3.8 ha) and 16,680 cottonwood seedlings were planted at various sites.

Protocols for seedling propagation, live stake preparation, and out-planting generally followed those developed by Keefer (2008) and Keefer *et al.* (2009). Sedge and grass seeds were collected during the summer prior to planting. Seeds were air-dried, cleaned with an air sorter, weighed, and stored. Seeds were either propagated in the fall and the seedlings cold stored over the winter, or else grown over the winter-spring and hot-lifted for immediate, on-site planting. Planting was carried out by teams of trained tree planters.

Live cottonwood and willow stakes were harvested from locally available material in early spring of the year they were to be planted, then immediately bundled and wetted with a sprinkler system to minimize any potential damage from desiccation and handling. Following bundling, stakes were soaked for 5-10 days then transferred to a refrigerated reefer to preserve freshness. Live stakes were planted by hand or, more typically, using excavator machines. The excavator was used to dig a soil pit to a depth of 60-70 cm. After an assistant placed a live stake in the hole, the excavator operator replaced and tamped down the soil. In 2011, the planting depth was increased to 100 cm, so that between 1/3 to 1/2 of most stakes' length was belowground (Keefer Ecological Services Ltd. 2011).

10.2 Summary descriptions of Vegetation Community Types (VCTs) identified for the Arrow Lakes Reservoir.

For the current study year, we retained the overall community classification system developed by Enns *et al.* (2007, 2010), but introduced some refinements to the community coding so that it aligned more closely with conditions observed on the ground. The original community descriptions (adapted from Enns *et al.* [2010]) are listed below, preceded by letter bullets. Recent refinements to this classification (Miller *et al.* [2016]) are described next, and are preceded by Roman Numeral bullets.

A. **BB** (Boulders, steep)**:** Uncommon but increasing toward the south, BB is usually derived from bouldery till and is steeply sloping. This type is usually non-vegetated to very sparsely vegetated with less than three per cent vegetation cover and is not considered vegetated at the landscape scale.

B. **BE** (Sandy beach)**:** This VCT consists of non-to sparsely vegetated sands or gravels on flat to gently undulating terrain. Typically fine-textured sands with a mixed silt content. It may occur at all elevations, and appears to be scoured by water currents. It is possible that BE is simply a frequently inundated low elevation PC types. Dust issuing from this type is a common occurrence. This vegetation type is very sparsely vegetated to non-vegetated. Annual Bluegrass, Reed Canarygrass, Pineapple Weed and Common Horsetail are some of the species that occur.

C. **BG** (Gravelly beach)**:** This sparsely-vegetated VCT is typically an alluvial or fluvial outwash plain, consisting of gravel and cobbles of various sizes, located always on gentle to flat areas of the reservoir. It may be adjacent to creeks and seepage that may provide water in the hot period of exposure in spring, summer or fall. Due to washing of fine materials over the surfaces, grit can collect between boulders, and some very drought and inundation tolerant plants occur, including willows, horsetail, Reed Canarygrass, sourweeds, and Redtop. Vegetation is almost always very sparse or absent.

D. **CL** (Cliffs and rock outcrops): Found on steep sparsely vegetated terrain at upper elevations, and derived from bedrock and colluvium, this type occurs in fewer than 10 polygons in the base map. CL has insufficient frequency of occurrence to be considered for landscape scale analysis.

E. **CR** (Cottonwood riparian)**:** This VCT mostly occurs near the 440 m ASL, but also throughout all elevations, especially in Revelstoke Reach, if the site is sheltered from scouring the soils are either remnants of, or persistent features of, well-drained alluvial fans. The CR vegetation type is often dominated by Black Cottonwood, with Trembling Aspen and occasionally very large specimens of Western Red Cedar, Douglas-fir and Western White Pine. Ponderosa pine occurs at the southern end of the Arrow Lakes portion of the reservoir, and Lodgepole Pine occurs at the northern end. There are highly variable assemblages of non-vascular and vascular plants in the CR, including horticultural species. A range of forested vegetation from wet to very dry forest types occurs, including Falsebox, Oregon-grape, Pinegrass, Trailing Bramble, bedstraws, peavines, and various mosses, liverworts, lichens. This type may be an important seed source for lower elevation sites.

F. **IN** (Industrial / residential / recreation)**:** This type occurs across all elevation bands in the DDZ. It is characterized by heavily disturbed soils and vegetation due to roads and a variety of land uses, including past settlement. Soils are variable, but are always compacted, and have weedy margins. This type is probably a major source of weed invasion into other vegetation types in the reservoir. It is dominated by a mix of drought and/or inundation tolerant opportunistic native and weedy vegetation, such as sourweed spp., Red and White Clover, Sweet Clover, knapweed spp., Cheatgrass, Pineappleweed and others.

G. **LO** (Log zone): Usually confined to high elevation, occasionally in sheltered coves and inlets, almost always at the top of the slope on convex to concave topography, dominated by logs and woody debris. LO is usually non-vegetated to very sparsely vegetated with less than three per cent vegetation cover and is not considered vegetated at the landscape scale. The LO type is not based on terrain; it is based on the presence of log debris.

H. LO was initially dropped as a monitored community type after 2010 due to its ephemeral nature (K. Enns, pers. comm. 2014), but was reintroduced to the study in 2014. The rationale for this inclusion was that woody debris accumulations, while not strictly a vegetation type, can have a significant influence on vegetation development (or lack thereof) within deposition zones in the upper elevation bands (Hawkes *et al.* 2013b). Furthermore, because woody debris can be picked up and dispersed to different locations with rising reservoir levels, its effects will vary over space and time, and thus serve as an important predictor of drawdown zone vegetation dynamics.

I. **PA** (Redtop upland)**:** This vegetation type occurs on raised, well drained microtopography (i.e. convex and moisture shedding) and can occur at a range of elevations including at the 433m elevation, although it is more common above 437m. It is relatively frequent, but often too small to map at the landscape level, and occurs on sloped or on well drained, sandy gravelly materials. It is physically disjunct from the CR type, which is usually flat or sloping but seldom convex. This type is usually somewhat variable, but displays a relatively high species richness compared to PC or PE, due to the presence of drought tolerant weedy species. While this type is often dominated by Reed Canarygrass, the species composition always includes at least a few species of agronomic and native grasses, including Redtop, Creeping Bentgrass, Blue Wildrye, Canada Bluegrass, Kentucky Bluegrass, and others. Various pasture and ditch weeds, such as sourweed, chickweed, Chicory, Oxen-eye Daisy also occur, in addition to somewhat dry forest-type mosses, such as Red-stemmed Feather Moss and Palm-tree Moss. Trees and shrubs usually occur.

J. **PC** (Reed Canarygrass mesic)**:** The Reed Canarygrass vegetation type is the mesic vegetation in the ALR and is both very common and widespread, occurring in all the map areas. It is relatively variable, and can be influenced by drainage, moisture regime, and slope position. Materials vary somewhat, but usually consist of gently sloping to flat anoxic, compacted sandy-silty to silty-sandy materials, often with quite coarse sand. Gravel depositional areas can have openings, which result in a few more species than the usual species composition for this VCT. The PC covers large parts of individual polygons and is dominated by Reed Canarygrass with minor amounts of Kellogg's Sedge, Common Horsetail, and Pennsylvania Bitter-cress. Reed Canarygrass can be monospecific and form very dense, mostly pure stands of 1 ha or larger in size, especially in Revelstoke Reach. This type has been heavily grazed by geese in the Arrow Lakes, and in this this condition it can be invaded by several species of sedges, grasses, cranesbill, bedstraw, and other inundation-tolerant or requiring plants.

K. **PE** (Horsetail lowland): This vegetation type occurs mainly at low to middle elevations. Physical site characteristics differ from RR sites (below) in that PE occurs in depressional topography, and water is not continuously supplied from upslope via ground water supplies, but rather mainly from reservoir water. PE can be boulder, but is always relatively compacted, non-aerated and has significantly higher silt fractions in the soil compared to its typical neighbor, the more mesic PC type. PE is less common throughout the reservoir than PC, usually occurs down-slope of PC and is less variable. Species richness is medium, dominated by Kellogg's Sedge, Purslane Speedwell, Annual Bluegrass, Reed Canarygrass, and horsetails. It can have very low covers of several inundation tolerant plants including Shortawn Foxtail, and Nodding Chickweed. It appears that annual plants occur sporadically in this type and the species composition varies both annually and seasonally.

L. **PO** (Ponds): This type occurs in backwaters, large deep depressional areas, cut-off oxbows or channels, and very rarely on flat stretches of beach. POs vary in water depth, but are usually deep enough to comprise permanent to semi-permanent features, i.e. they are not just shifting minor depressional areas caused by scouring, but possible old ponds or wetlands. They have standing brackish to slow moving water present most of the year. The areas may dry out in very dry successive years. The vegetation can be species poor and mainly consists of edge-dwelling and aquatic macrophytes. Species include Floating-leaved Pondweed, Common Spike-rush, Baltic Rush, Rocky Mountain Pond-lily, Marsh Cinquefoil, Water Smartweed, Eurasian Water-milfoil, and other semi-emergent to emergent plants.

M. **RR:** (Reed – rill): This type is always associated with continuous sources of fresh water as an underground stream or seep entering the reservoir. It is usually topographically depressional. Water may originate from open streams upslope, but may also continuously percolate through surficial materials in the DDZ. Materials usually have some fine textured and compacted component, often boulders with silts in interstitial spaces. The silts are usually also mixed with sands, and these can be cemented and embedded with fine to coarse gravels. The RR type usually has dense, but patchy cover of mixed semi-aquatic or riparian species, with barren areas. Species include rushes, reeds, and sedges, Swamp Horsetail and occasionally willows. The type can be species poor, if recent scouring has taken place.

N. **RS**: (Willow – Red Osier Dogwood – stream entry): Occurs from high to low elevation along incoming stream channels, usually gullied and undulating and almost always bouldery to gravelly with fine sand and silt deposits (i.e., mixed materials). RS is very gently sloping to moderately steeply sloped. The RS water supply is seasonal with a high flow in spring and fall freshet, and very low to completely dry during summer and winter. The effect of this water supply and its physical influence on the vegetation of RS is difficult to distinguish from the effects of the soft constraints operating regime. RS originated as minor, somewhat ephemeral, fluvial channels.

O. **SF:** (Slope failure): Usually silty sands that have slumped in response to slope failure. Buried vegetation may occur. Approximately five polygons delineated. SF has insufficient frequency of occurrence to be considered for landscape scale analysis. SF appears to be derived from very sandy till and or glaciofluvial terrace edges and escarpments.

P. **SS** (Steep sand): With the exception of the Lower Arrow Lake narrows, this VCT is not common, occurring only in small areas throughout the reservoir. It consists of steep, sandy banks, often with peeling or failing slopes. Stepped patterns may occur that correspond to the typical full pool events in the reservoir. This type consist of only a few species of plants, with very low cover, including Reed Canarygrass, Common Horsetail, and Short-awn Foxtail.

Q. **WR** (Silverberry river entry): Occurs only in river entries with year-round water flow, from highest elevation locations to the lowest elevation, and is usually flat (although the sides of the river channels are included). Mainly bouldery and frequently inundated with river water. The effect of a continuous river entry water supply is dramatically greater than the influence of the soft constraints operating regime. WR is often non-vegetated to very sparsely vegetated with less than three per cent vegetation cover and is not considered vegetated at the landscape scale. WR persists as a major, active fluvial channel.

I. **PC–Willow** (formerly included with PA–Redtop upland). The existing classification does not distinguish various common, and potentially diagnostic, vegetation features such as the willow thickets occurring in flat or depressional topography at mid elevations, usually in conjunction with PC–Reed Canarygrass mesic. By default, previous surveys typically (and apparently incorrectly based on the VCT definitions) assigned these shrublands to the "PA–Redtop upland" VCT—a high elevation association occurring on convex, well drained substrates and characterized by drought tolerant, weedy species. As a result, the abundance and extent of PA–Redtop upland proper has generally been subject to overestimation, while lower elevation shrublands have generally gone unrecognized.

II. **PC–Sedge** (formerly included with PC–Reed Canarygrass mesic). This refinement of the PC type describes the widespread, mixed stands of reed canarygrass, Kellogg's sedge (*Carex lenticularis*), and/or Columbia sedge (*C. aperta*) found mainly at mid elevation. Rushes (*Juncus* spp.) are also a frequent component.

III. **PC–Foxtail/horsetail** (formerly included with PC–Reed Canarygrass mesic). This association consists of mixed stands of reed canarygrass, little meadow-foxtail (*Alopecurus aequalis*), and horsetails (mainly *Equisetum arvense*), and is typically found on sandy sites at low elevations in the drawdown zone.

IV. **PC–Reed Canarygrass** (formerly included with PC–Reed Canarygrass mesic). We use this modifier to delimit the (nearly) pure stands of reed canarygrass that dominate large segments of the drawdown zone at mid and upper elevations in Revelstoke Reach and, to a lesser extent, Arrow Lakes. This VCT is characterized by dense cover of reed canarygrass, low species diversity, and heavy thatch cover at ground level.

V. **Shrub riparian** (formerly included with PA–Redtop upland or CR–Cottonwood riparian). This riparian shrub association (consisting primarily of willows, alders, and young cottonwoods saplings) occurs as a marginal strip at the top of the drawdown zone, usually adjacent to and below the upland CR–Cottonwood riparian forest.

VI. **PE–Foxtail** (formerly included with PE–Horsetail lowland). Various low elevation floodplain and seepage associations have by default been lumped with the "PE–Horsetail lowland" type despite not strictly meeting the definitions for that type (Appendix 10.2). These are typically moist to wet, sloping sites with predominantly mineral soils, supporting a ruderal mix of annual herbs and low-statured grasses and rushes. Presence of the tufted grass, little meadow-foxtail, is a common diagnostic feature. Other frequent species include marsh yellow cress (*Rorippa palustris*), purslane speedwell (*Veronica peregrina*), nodding chickweed (*Cerastium nutans*), narrow-leaved montia (*Montia linearis*), and Canada bluegrass (*Poa compressa*). The nationally rare species moss grass (*Coleanthus subtilis*) comprises a notable element on some flat and depressional sites.

VII. **PE–Sedge** (formerly included with PE–Horsetail lowland). The PE–Sedge designation is here assigned to the characteristic, Kellogg's sedge-dominated, "tussocked" phase of the original PE–Horsetail lowland VCT.

10.3 Field data form used in 2017

Project ID CLBMON-12: Arrow Lakes Reservoir Monitoring of Revegetation Efforts | Sheet No.________/________

Date: | Surveyors: | Plot #: | Site:

VCT: | Garmin # | Wpt. #: | UTM:

Plot Photo # (N, E, S, W, down):

Structural Stage: sparse/pioneer herb low_shrub tall_shrub pole/sapling young_forest

Aspect: ° | Slope: | Plot type (circle one): Treated Control Survivorship (5x10m) Stake polygon

Gen. Surface topography: concave convex straight

Microtopraphy: smooth channelled gullied mounded tussocked

Prim. Water Source: precip. surface_seep stream_sub-irrigation stream_flooding

Soil Moisture: very_xeric xeric subxeric submesic mesic subhygric hygric subhydric hydric

Surface Substrate (%): rock (>7.5cm) ______ mineral (<7.5cm) ______ org. ______ wood (>10cm) ______ water ______

Rooting Zone Texture - coarse fragments (particles >2m): (a) >70% (b) <70 and >35% (c) <35%

Rooting Zone Texture - fine fragments (particles <2mm), for (b) and (c) above; refer to key in FMDTE):

sandy coarse-loamy fine-loamy coarse-silty fine-silty fine-clayey very-fine-clayey

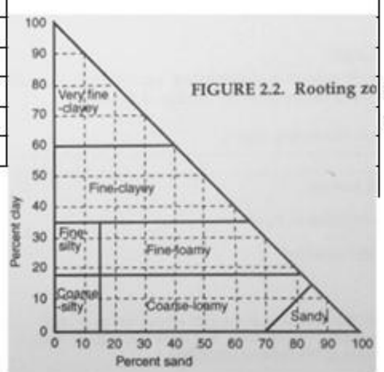
Recent evidence of scouring, erosion, or deposition:

Evidence of non-operational site disturbance (e.g. ATV use, road building):

Vegetaion Cover	%	SHRUB LAYER (B)				Vigour Codes
Shrub Layer (B)		Species	B1	B2	Tot	0. dead
Herb Layer (C)						1. poor
Moss Layer (D)						2. fair
						3. good
						4. excellent

HERB LAYER (C)			PLANTING SURVIVAL
Species	%	Notes	5x10m Plot
			Species No. Stems Vigour
			Stake Polygon
			Species No. Stems Vigour
			Polygon dimension:
			UTMs:

Notes



10.4 Multivariate regression trees (MRT)

Multivariate regression trees (De'ath and Fabricus 2000) were used to explore and predict relationships between species compositionand environmental characteristics. Trees were built by partitioning the independent variables (e.g., elevation, community type) into clusters (the leaves) that contained the most homogeneous groups of objects (i.e. plots). Splits were created by seeking the threshold levels of independent variables that produce groups with highest homogeneity, by minimizing the sums of squares within groups (De'ath and Fabricius 2000). The models yielded pseudo-R^2 values corresponding to the proportion of variance explained by each split, and by the tree as a whole (1-the deviance of the tree / by overall sum of squares).

Each cluster of the MRT also represents a species assemblage, and its environmental values define its associated habitat. Thus, they can predict species composition at sites for which only environmental data are available (De'ath 2002). Species associated with each cluster of environmental characteristics were identified using an indicator index value, defined as the product of relative abundance and relative frequency of occurrence of the species/guild within a group (De'ath 2002).

10.5 Univariate regression trees (URT)

Univariate regression trees were used to explore the relationships between the density of live stakes, plugs, or seedlings and a series of topo-edaphic environmental variables. Regression trees deal well with continuous or discrete variables, nonlinear relationships, complex interactions, missing values, and outliers (De'ath and Fabricius 2000), and are useful methods to explore relationships and patterns between response variable(s) of interest and a series of independent variables. A regression tree is built by partitioning the independent variables (e.g., elevation, soil moisture) into a series of boxes (the leaves) that contain the most homogeneous groups of objects (i.e. plots). Splits are created by seeking the threshold levels of independent variables that produce groups with highest homogeneity, by minimizing the sums of squares within groups (De'ath and Fabricius 2000). The length of the vertical lines associated with each split graphically approximates the proportion of total sum of squares explained by each split; the longer the line is, the more variance the split is explaining (De'ath and Fabricius 2000). The value shown at each terminal leaf corresponds to the average value of the dependent variable (here, density). The method allows computing a pseudo-R2 that corresponds to the proportion of variance explained by the tree (1-the deviance of the tree / by overall sum of squares).

For the 2017 analysis, the environmental variables considered were: elevation band, site, treatment type, VCT, slope, and rooting particle size class.

10.6 MRT results (species composition)

Table 10-1: Results of the multivariate regression tree analysis, with the nine "leaves" that were formed, along with the characteristic variables explaining the branch splits and the indicator plant species for each branch.

Leaf	Variable	Indicator Species	Indval	*p*
1	Arrow Park E, Edgewood, Lower Inonoaklin, Nakusp; Control plots; BE, BG, PA, Shrub riparian	--	--	--
2	12 Mile, 9 Mile, McKay Creek; Control plots; BE, BG, PA, Shrub riparian	common horsetail	0.23	0.005
		tall hawkweed	0.19	0.033
3	High and Mid elevations; Treated; BE, BG, PA, Shrub riparian; 12 Mile, 9 Mile, 8 Mile, McKay Creek, Arrow Park E, Arrow Park N, Edgewood, Lower Inonoaklin, Nakusp	black cottonwood	0.53	0.001
4	Low elevations; Treated; BE, BG, PA, Shrub riparian; 12 Mile, 9 Mile, 8 Mile, McKay Creek, Arrow Park E, Arrow Park N, Edgewood, Lower Inonoaklin, Nakusp	Kellogg's sedge	0.24	0.011
5	High elevations; PC-reed, PC-sedge, PC-willow, RR; 12 Mile, 9 Mile, 8 Mile, McKay Creek, Arrow Park E, Arrow Park N, Edgewood, Lower Inonoaklin, Nakusp	thick-headed sedge	0.25	0.006
		reed canarygrass	0.25	0.001
		Columbia sedge	0.24	0.009
		green sorrel	0.17	0.042
		Bebb's willow	0.17	0.023
6	Low and mid elevations; PC-reed, PC-sedge, PC-willow, RR; 12 Mile, 9 Mile, 8 Mile, McKay Creek, Arrow Park E, Arrow Park N, Edgewood, Lower Inonoaklin, Nakusp	--	--	--
7	Burton, Fairhurst; BE, BG, PA, PC-reed, PC-sedge, PC-willow, RR, shrub riparian	quackgrass	0.31	0.001
		St. John's-wort	0.16	0.043
8	Burton, Fairhurst; PC-foxtail, PE-foxtail, PE-sedge	bluntleaf yellowcress	0.71	0.001
		red sand-spurry	0.63	0.001
		little meadow-foxtail	0.54	0.001
		marsh yellow cress	0.5	0.001
		purslane speedwell	0.48	0.001
		oxe-eye daisy	0.23	0.006
9	Arrow Park E, Arrow Park N, Lower Inonoaklin, Nakusp	small-flowered forget-me-not	0.47	0.002
		narrow-leaved montia	0.41	0.002
		annual bluegrass	0.3	0.003
		nodding chickweed	0.29	0.005
		thread rush	0.17	0.045

10.7 Species list

Table 10-2: Plant species recorded in Arrow Lakes Reservoir drawdown zone (including adjacent upland riparian forests) within the CLBMON-33 and CLBMON-12 monitoring areas, 2010-2017.

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
AGROGIG	*Agrostis gigantea*	redtop	Grass	Rev, Arr
AGROSCA	*Agrostis scabra*	hair bentgrass	Grass	Arr
AGROSTO	*Agrostis stolonifera*	creeping bentgrass	Grass	Rev, Arr
AIRACAR	*Aira caryophyllea*	silver hairgrass	Grass	Arr
ALNUINC	*Alnus incana*	mountain alder	Shrub	Arr
ALOPAEQ	*Alopecurus aequalis*	little meadow-foxtail	Grass	Rev, Arr
ALOPPRA	*Alopecurus pratensis*	meadow-foxtail	Grass	Rev, Arr
AMELALN	*Amelanchier alnifolia*	saskatoon	Shrub	Rev, Arr
ANAPMAR	*Anaphalis margaritacea*	pearly everlasting	Forb (per.)	Rev, Arr
ANTEHOW	*Antennaria howellii*	Howell's pussytoes	Forb (per.)	Arr
ANTHODO	*Anthoxanthum odoratum*	sweet vernalgrass	Grass	Arr
ARABTHA	*Arabidopsis thaliana*	mouse-ear	Forb (ann.)	Rev
ARCTUVA	*Arctostaphylos uva-ursi*	kinnikinnick	Shrub	Arr
ARENSER	*Arenaria serpyllifolia*	thyme-leaved sandwort	Forb (ann.)	Arr
ARNICA	*Arnica sp.*	arnica	Forb	Arr
ATHYFIL	*Athyrium filix-femina*	lady fern	Pteridophyte	Arr
BETUPAP	*Betula papyrifera*	paper birch	Tree	Arr
BOTRMUL	*Botrychium multifidum*	leathery grape fern	Forb (per.)	Arr
BROMINE	*Bromus inermis*	smooth brome	Grass	Rev
BROMTEC	*Bromus tectorum*	cheatgrass	Grass	Arr
CALACAN	*Calamagrostis canadensis*	bluejoint reedgrass	Grass	Rev, Arr
CALASTR	*Calamagrostis stricta*	slimstem reedgrass	Grass	Rev
CARDPEN	*Cardamine pensylvanica*	Pennsylvanian bittercress	Forb (ann.)	Rev, Arr
CAREAPE	*Carex aperta*	Columbia sedge	Sedge/ sedge-like	Rev, Arr
CAREAQU	*Carex aquatilis*	water sedge	Sedge/ sedge-like	Rev
CAREATH	*Carex atherodes*	awned sedge	Sedge/ sedge-like	Arr
CAREAUR	*Carex aurea*	golden sedge	Sedge/ sedge-like	Rev
CAREBEB	*Carex bebbii*	Bebb's sedge	Sedge/ sedge-like	Arr
CARECRW	*Carex crawfordii*	Crawford's sedge	Sedge/ sedge-like	Rev, Arr
CAREDEW	*Carex deweyana*	Dewey's sedge	Sedge/ sedge-like	Arr
CAREFLA	*Carex flava*	yellow sedge	Sedge/ sedge-like	Rev
CARELEN	*Carex lenticularis*	lakeshore sedge	Sedge/ sedge-like	Rev, Arr
CAREPAC	*Carex pachystachya*	thick-headed sedge	Sedge/ sedge-like	Rev, Arr
CAREPEL	*Carex pellita*	woolly sedge	Sedge/ sedge-like	Arr
CARESIT	*Carex sitchensis*	Sitka sedge	Sedge/ sedge-like	Rev, Arr
CARESTI	*Carex stipata*	awl-fruited sedge	Sedge/ sedge-like	Arr
CAREUTR	*Carex utriculata*	beaked sedge	Sedge/ sedge-like	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
CAREVIR	*Carex viridula*	green sedge	Sedge/ sedge-like	Rev, Arr
CAREX	*Carex sp.*	sedge	Sedge/ sedge-like	Rev, Arr
CASTMIN	*Castilleja miniata*	scarlet paintbrush	Forb (per.)	Rev, Arr
CENTSTO	*Centaurea stoebe*	spotted knapweed	Forb (per.)	Rev, Arr
CERAFON	*Cerastium fontanum*	mouse-ear chickweed	Forb (per.)	Rev, Arr
CERANUT	*Cerastium nutans*	nodding chickweed	Forb (ann.)	Rev, Arr
CHENALB	*Chenopodium album*	lamb's-quarters	Forb (ann.)	Arr
CICHINT	*Cichorium intybus*	chicory	Forb (per.)	Arr
CIRCALP	*Circaea alpina*	enchanter's-nightshade	Forb (ann.)	Arr
CIRSARV	*Cirsium arvense*	Canada thistle	Forb (per.)	Arr
CIRSVUL	*Cirsium vulgare*	bull thistle	Forb (per.)	Arr
COLESUB	*Coleanthus subtilis*	Moss grass	Grass	Rev, Arr
COLLLIN	*Collomia linearis*	narrow-leaved collomia	Forb (ann.)	Arr
COMAPAU	*Comarum palustre*	marsh cinquefoil	Forb (per.)	Rev, Arr
CONYCAN	*Conyza canadensis*	horseweed	Forb (ann.)	Arr
CORNSTO	*Cornus stolonifera*	red-osier dogwood	Shrub	Rev, Arr
CRATDOU	*Crataegus douglasii*	black hawthorn	Shrub	Arr
CYTISCO	*Cytisus scoparius*	Scotch broom	Shrub	Arr
DACTGLO	*Dactylis glomerata*	orchard-grass	Grass	Arr
DANTSPI	*Danthonia spicata*	poverty oatgrass	Grass	Rev, Arr
DAUCCAR	*Daucus carota*	wild carrot	Forb (per.)	Arr
DESCCES	*Deschampsia cespitosa*	tufted hairgrass	Grass	Arr
DESCDAN	*Deschampsia danthonioides*	annual hairgrass	Grass	Arr
DRABVER	*Draba verna*	common draba	Forb (ann.)	Arr
ELEOACI	*Eleocharis acicularis*	needle spike-rush	Sedge/ sedge-like	Rev
ELEOCHA	*Eleocharis sp.*	spike-rush	Sedge/ sedge-like	Arr
ELEOPAL	*Eleocharis palustris*	common spike-rush	Sedge/ sedge-like	Arr
ELEOPAR	*Eleocharis parvula*	small spike-rush	Sedge/ sedge-like	Arr
ELYMREP	*Elymus repens*	quackgrass	Grass	Rev, Arr
EPILANG	*Epilobium angustifolium*	fireweed	Forb (per.)	Arr
EPILBRA	*Epilobium brachycarpum*	tall annual willowherb	Forb (ann.)	Arr
EPILCIL	*Epilobium ciliatum*	purple-leaved willowherb	Forb (per.)	Rev, Arr
EPILLAT	*Epilobium latifolium*	broad-leaved willowherb	Forb (per.)	Rev
EPILOBI	*Epilobium sp.*	willowherb	Forb	Arr
EQUIARV	*Equisetum arvense*	common horsetail	Pteridophyte	Rev, Arr
EQUIFLU	*Equisetum fluviatile*	swamp horsetail	Pteridophyte	Arr
EQUIHYE	*Equisetum hyemale*	scouring-rush	Pteridophyte	Rev, Arr
EQUIPAL	*Equisetum palustre*	marsh horsetail	Pteridophyte	Rev, Arr
EQUISYL	*Equisetum sylvaticum*	wood horsetail	Pteridophyte	Rev
EQUIVAR	*Equisetum variegatum*	northern scouring-rush	Pteridophyte	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
ERIGPHI	*Erigeron philadelphicus*	Philadelphia fleabane	Forb (per.)	Rev, Arr
ERODCIC	*Erodium cicutarium*	common stork's-bill	Forb (ann.)	Arr
ERYSCHE	*Erysimum cheiranthoides*	wormseed mustard	Forb (ann.)	Arr
FESTRUB	*Festuca rubra*	red fescue	Grass	Arr
FESTUCA	*Festuca sp.*	fescue	Grass	Arr
FRAGVIR	*Fragaria virginiana*	wild strawberry	Forb (per.)	Rev, Arr
GALETET	*Galeopsis tetrahit*	hemp-nettle	Forb (ann.)	Rev, Arr
GALIPAL	*Galium palustre*	marsh bedstraw	Forb (ann.)	Arr
GALITRD	*Galium trifidum*	small bedstraw	Forb (ann.)	Arr
GALITRF	*Galium triflorum*	sweet-scented bedstraw	Forb (per.)	Arr
GALIUM	*Galium sp.*	bedstraw	Forb	Rev, Arr
GERABIC	*Geranium bicknellii*	Bicknell's geranium	Forb (ann.)	Arr
GERANIU	*Geranium sp.*	geranium	Forb	Arr
GEUMMAC	*Geum macrophyllum*	large-leaved avens	Forb (per.)	Arr
GLYCSTR	*Glyceria striata*	fowl mannagrass	Grass	Rev, Arr
GNAPULI	*Gnaphalium uliginosum*	marsh cudweed	Forb (ann.)	Arr
HIERACI	*Hieracium sp.*	hawkweed	Forb (per.)	Rev
HIERAUR	*Hieracium aurantiacum*	orange-red king devil	Forb (per.)	Rev
HIERCAE	*Hieracium caespitosum*	yellow king devil	Forb (per.)	Rev, Arr
HIERFLO	*Hieracium floribundum*	king devil hawkweed	Forb (per.)	Rev, Arr
HIERGLO	*Hieracium glomeratum*	yellowdevil hawkweek	Forb (per.)	Arr
HIERHIR	*Hierochloe hirta*	northern sweetgrass	Grass	Rev, Arr
HIERLAC	*Hieracium lachenalii*	European hawkweed	Forb (per.)	Arr
HIERPIO	*Hieracium piloselloides*	tall hawkweed	Forb (per.)	Rev, Arr
HORDBRA	*Hordeum brachyantherum*	meadow barley	Grass	Arr
HYPEPER	*Hypericum perforatum*	common St. John's-wort	Forb (per.)	Rev, Arr
HYPORAD	*Hypochaeris radicata*	hairy cat's-ear	Forb (per.)	Rev, Arr
JUNCARC	*Juncus arcticus*	arctic rush	Rush	Arr
JUNCART	*Juncus articulatus*	jointed rush	Rush	Rev, Arr
JUNCBAL	*Juncus balticus*	Baltic rush	Rush	Arr
JUNCBUF	*Juncus bufonius*	toad rush	Rush	Arr
JUNCENS	*Juncus ensifolius*	dagger-leaf rush	Rush	Rev, Arr
JUNCFIL	*Juncus filiformis*	thread rush	Rush	Rev, Arr
JUNCINT	*Juncus interior*	inland rush	Rush	Arr
JUNCTEN	*Juncus tenuis*	slender rush	Rush	Rev, Arr
JUNCUS	*Juncus sp.*	rush	Rush	Arr
LACTBIE	*Lactuca biennis*	tall blue lettuce	Forb (per.)	Arr
LACTUCA	*Lactuca sp.*	lettuce	Forb	Arr
LATHSYL	*Lathyrus sylvestris*	narrow-leaved everlasting peavine	Forb (per.)	Arr
LEPICAM	*Lepidium campestre*	field pepper-grass	Forb (ann.)	Arr
LEUCVUL	*Leucanthemum vulgare*	oxeye daisy	Forb (per.)	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
LIMOAQU	*Limosella aquatica*	water mudwort	Forb (ann.)	Arr
LINUCAT	*Linum catharticum*	fairy flax	Forb (per.)	Rev
LOGFARV	*Logfia arvensis*	field filago	Forb (ann.)	Arr
LUPIPOY	*Lupinus polyphyllus*	large-leaved lupine	Forb (per.)	Arr
LYSITHY	*Lysimachia thyrsiflora*	tufted loosestrife	Forb (per.)	Arr
MAHOAQU	*Mahonia aquifolium*	tall Oregon-grape	Shrub	Arr
MAIASTE	*Maianthemum stellatum*	star-flowered false Solomon's-seal	Forb (per.)	Rev
MATRDIS	*Matricaria discoidea*	pineapple weed	Forb (ann.)	Arr
MEDILUP	*Medicago lupulina*	black medic	Forb (ann.)	Rev, Arr
MEDISAT	*Medicago sativa*	alfalfa	Forb (per.)	Rev, Arr
MELIALB	*Melilotus alba*	white sweet-clover	Forb (ann.)	Arr
MENTARV	*Mentha arvensis*	field mint	Forb (per.)	Arr
MICRGRA	*Microsteris gracilis*	pink twink	Forb (ann.)	Arr
MIMUGUT	*Mimulus guttatus*	yellow monkey-flower	Forb (per.)	Arr
MONTFON	*Montia fontana*	blinks	Forb (ann.)	Arr
MONTLIN	*Montia linearis*	narrow-leaved montia	Forb (ann.)	Arr
MYCEMUR	*Mycelis muralis*	wall lettuce	Forb (ann.)	Arr
MYOSDIS	*Myosotis discolor*	common forget-me-not	Forb (ann.)	Arr
MYOSLAX	*Myosotis laxa*	small-flowered forget-me-not	Forb (per.)	Arr
MYOSOTI	*Myosotis sp.*	forget-me-not	Forb	Rev, Arr
MYOSSCO	*Myosotis scorpioides*	European forget-me-not	Forb (per.)	Rev, Arr
MYOSSTR	*Myosotis stricta*	blue forget-me-not	Forb (ann.)	Arr
OENOVIL	*Oenothera villosa*	yellow evening-primrose	Forb (per.)	Arr
OSMORHI	*Osmorhiza sp.*	sweet-cicely	Forb	Arr
PACKPAP	*Packera paupercula*	Canadian butterweed	Forb (per.)	Rev, Arr
PACKPSE	*Packera pseudaurea*	streambank butterweed	Forb (per.)	Arr
PERSAMP	*Persicaria amphibia*	water smartweed	Forb (per.)	Rev, Arr
PHALARU	*Phalaris arundinacea*	reed canarygrass	Grass	Rev, Arr
PHLEPRA	*Phleum pratense*	common timothy	Grass	Rev
PINUCON	*Pinus contorta*	lodgepole pine	Tree	Arr
PINUMON	*Pinus monticola*	western white pine	Tree	Rev, Arr
PLAGSCO	*Plagiobothrys scouleri*	Scouler's popcornflower	Forb (ann.)	Arr
PLANLAN	*Plantago lanceolata*	ribwort plantain	Forb (per.)	Rev, Arr
PLANMAJ	*Plantago major*	common plantain	Forb (per.)	Arr
PLANTAG	*Plantago sp.*	plantain	Forb (per.)	Arr
POA	*Poa sp.*	bluegrass	Grass	Arr
POA ANN	*Poa annua*	annual bluegrass	Grass	Rev, Arr
POA BUL	*Poa bulbosa*	bulbous bluegrass	Grass	Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
POA COM	*Poa compressa*	Canada bluegrass	Grass	Rev, Arr
POA PAL	*Poa palustris*	fowl bluegrass	Grass	Rev, Arr
POA PRA	*Poa pratensis*	Kentucky bluegrass	Grass	Rev, Arr
POAPAL	*Poa palustris*	fowl bluegrass	Grass	Arr
POLYAVI	*Polygonum aviculare*	common knotweed	Forb (ann.)	Arr
POLYGON	*Polygonum sp.*	knotweed	Forb	Arr
POPUTRE	*Populus tremuloides*	trembling aspen	Tree	Arr
POPUTRI	*Populus trichocarpa*	black cottonwood	Tree	Rev, Arr
POTENOR	*Potentilla norvegica*	Norwegian cinquefoil	Forb (ann.)	Rev, Arr
PRIMULA	*Primula sp.*	primrose	Forb	Rev
PRUNUS	*Prunus sp.*	cherry	Shrub	Arr
PRUNVUL	*Prunella vulgaris*	self-heal	Forb (per.)	Rev, Arr
PTERAQU	*Pteridium aquilinum*	bracken fern	Pteridophyte	Arr
PYROASA	*Pyrola asarifolia*	pink wintergreen	Forb (per.)	Rev
RANUACR	*Ranunculus acris*	meadow buttercup	Forb (per.)	Rev, Arr
RANUFLA	*Ranunculus flabellaris*	yellow water-buttercup	Forb (per.)	Arr
RANUGME	*Ranunculus gmelinii*	small yellow water-buttercup	Forb (per.)	Arr
RANUMAC	*Ranunculus macounii*	Macoun's buttercup	Forb (per.)	Arr
RANUNCU	*Ranunculus sp.*	buttercup	Forb	Arr
RANUREP	*Ranunculus repens*	creeping buttercup	Forb (per.)	Arr
RHAMPUR	*Rhamnus purshiana*	cascara	Shrub	Arr
RHINMIN	*Rhinanthus minor*	yellow rattle	Forb (per.)	Rev, Arr
RIBES	*Ribes sp.*	currant or gooseberry	Shrub	Rev
ROBIPSE	*Robinia pseudoacacia*	black locust	Tree	Arr
RORICUR	*Rorippa curvipes*	blunt-leaved yellowcress	Forb (ann.)	Arr
RORIPAL	*Rorippa palustris*	marsh yellowcress	Forb (ann.)	Rev, Arr
RORISYL	*Rorippa sylvestris*	creeping yellowcress	Forb (per.)	Arr
ROSA	*Rosa sp.*	rose	Shrub	Rev
ROSAACI	*Rosa acicularis*	prickly rose	Shrub	Arr
ROSACAN	*Rosa canina*	dog rose	Shrub	Arr
ROSAGYM	*Rosa gymnocarpa*	baldhip rose	Shrub	Arr
ROSANUT	*Rosa nutkana*	Nootka rose	Shrub	Arr
ROSAWOO	*Rosa woodsii*	prairie rose	Shrub	Rev
RUBUIDA	*Rubus idaeus*	red raspberry	Shrub	Arr
RUBUPAR	*Rubus parviflorus*	thimbleberry	Shrub	Arr
RUMEACO	*Rumex acetosa*	green sorrel	Forb (per.)	Rev, Arr
RUMEACT	*Rumex acetosella*	sheep sorrel	Forb (per.)	Arr
RUMECRI	*Rumex crispus*	curled dock	Forb (per.)	Rev, Arr
RUMETRI	*Rumex triangulivalvis*	willow dock	Forb (per.)	Arr
RUMEX	*Rumex sp.*	dock	Forb	Arr
SAGIPRO	*Sagina procumbens*	bird's-eye pearlwort	Forb (per.)	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
SALIBEB	*Salix bebbiana*	Bebb's willow	Shrub	Rev, Arr
SALIFAR	*Salix farriae*	Farr's willow	Shrub	Rev
SALILAS2	*Salix lasiandra var. lasiandra*	Pacific willow	Shrub	Rev, Arr
SALIPRO	*Salix prolixa*	Mackenzie willow	Shrub	Rev
SALISCO	*Salix scouleriana*	Scouler's willow	Shrub	Rev, Arr
SALISIT	*Salix sitchensis*	Sitka willow	Shrub	Rev, Arr
SALIX	*Salix sp.*	willow	Shrub	Rev, Arr
SCHEPRA	*Schedonorus pratensis*	meadow fescue	grass	Arr
SCIRATR	*Scirpus atrocinctus*	wool-grass	Sedge/ sedge-like	Rev, Arr
SCIRMIC	*Scirpus microcarpus*	small-flowered bulrush	Sedge/ sedge-like	Arr
SCLEANN	*Scleranthus annuus*	annual knawel	Forb (ann.)	Arr
SEDULAN	*Sedum lanceolatum*	lance-leaved stonecrop	Forb (per.)	Arr
SILELAT	*Silene latifolia*	white cockle	Forb (per.)	Arr
SISYMON	*Sisyrinchium montanum*	mountain blue-eyed-grass	Forb (per.)	Rev, Arr
SOLICAN	*Solidago canadensis*	Canada goldenrod	Forb (per.)	Rev, Arr
SOLIDAG	*Solidago sp.*	golden rod	Forb	Rev
SORBAUC	*Sorbus aucuparia*	European mountain ash	Shrub	Arr
SORBSCO	*Sorbus scopulina*	western mountain-ash	Shrub	Rev, Arr
SPERRUB	*Spergularia rubra*	red sand-spurry	Forb (ann.)	Rev, Arr
SPIRDOU	*Spiraea douglasii*	hardhack	Shrub	Rev, Arr
STELLAR	*Stellaria sp.*	starwort	Forb	Arr
SYMPCII	*Symphyotrichum ciliolatum*	Lindley's aster	Forb (per.)	Rev, Arr
TARAOFF	*Taraxacum officinale*	common dandelion	Forb (per.)	Rev, Arr
TELLGRA	*Tellima grandiflora*	fringecup	Forb (per.)	Arr
THLAARV	*Thlaspi arvense*	field pennycress	Forb (per.)	Arr
THUJPLI	*Thuja plicata*	western redcedar	Tree	Arr
TRAGDUB	*Tragopogon dubius*	yellow salsify	Forb (per.)	Arr
TRIFARV	*Trifolium arvense*	hare's-foot clover	Forb (per.)	Arr
TRIFAUR	*Trifolium aureum*	yellow clover	Forb (per.)	Rev, Arr
TRIFCAM	*Trifolium campestre*	low hop-clover	forb (ann.)	Arr
TRIFDUB	*Trifolium dubium*	small hop-clover	Forb (per.)	Arr
TRIFHYB	*Trifolium hybridum*	alsike clover	Forb (per.)	Rev, Arr
TRIFOLI	*Trifolium sp.*	clover	Forb	Rev, Arr
TRIFPRA	*Trifolium pratense*	red clover	Forb (per.)	Rev, Arr
TRIFREP	*Trifolium repens*	white clover	Forb (per.)	Rev, Arr
TRIOPER	*Triodanis perfoliata*	Venus' looking-glass	Forb (per.)	Arr
VERBTHA	*Verbascum thapsus*	great mullein	Forb (per.)	Arr
VEROBEC	*Veronica beccabunga*	American speedwell	Forb (per.)	Arr
VERONIC	*Veronica sp.*	speedwell	Forb	Rev
VEROPER	*Veronica peregrina*	purslane speedwell	Forb (ann.)	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
VEROSER	*Veronica serpyllifolia*	thyme-leaved speedwell	Forb (per.)	Rev, Arr
VICIA	*Vicia sp.*	vetch	Forb	Arr
VICIAME	*Vicia americana*	American vetch	Forb (per.)	Rev, Arr
VICICRA	*Vicia cracca*	tufted vetch	Forb (per.)	Rev, Arr
VIOLA	*Viola sp.*	violet	Forb	Arr
VIOLARV	*Viola arvensis*	European field pansy	Forb (ann.)	Arr
VIOLNEP	*Viola nephrophylla*	northern bog violet	Forb (per.)	Rev, Arr
VIOLPAL	*Viola palustris*	marsh violet	Forb (per.)	Rev
VULPBRO	*Vulpia bromoides*	barren fescue	Grass	Arr
VULPOCT	*Vulpia octoflora*	six-weeks grass	Grass	Arr