Columbia River Project Water Use Plan

Kinbasket and Arrow Reservoirs Revegetation Management Plan

Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

Implementation Year: 10

Reference: CLBMON-9

Final Comprehensive Report

Study Period: 2008 - 2019

LGL Limited environmental research associates
Sidney, BC

April 20, 2020

EA3914

Monitoring Program No. CLBMON-9
Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

Final Report

Prepared for

BC Hydro

BC Hydro Generation
Water Licence Requirements
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Burnaby, BC

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17 April 2020

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Suggested Citation

Miller, M.T. and V.C. Hawkes. 2020. CLBMON-9 Kinbasket Reservoir monitoring of revegetation efforts and vegetation composition analysis: Final Report—2008-2019. Unpublished Report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 59 pp. + App.

Cover photos

From left to right: looking north up Canoe Reach; east Canoe *Equisetum* wetlands; Mica Dam; Bush Arm in fall 2007. Photos © Virgil C. Hawkes.

EXECUTIVE SUMMARY

The operation of Kinbasket Reservoir for power generation negatively impacts vegetation in the upper elevations of the reservoir. In 2007, a reservoir wide revegetation program (CLBWORKS-1) was initiated to offset the operational impacts to benefit littoral productivity, wildlife habitat, shoreline erosion, archaeological site protection, and shoreline aesthetics. CLBMON-9 was initiated in 2008 to monitor the effectiveness of the revegetation program at enhancing sustainable vegetation growth in the drawdown zone. Since 2009, effectiveness monitoring has occurred in semi-alternating years, with 2018 marking the seventh year of monitoring under the CLBMON-9 program.

Early results of effectiveness monitoring (2009-2013) suggested that the revegetation treatments applied during the initial four years of CLBWORKS-1 (2008-2011) were unlikely to meet the program objectives of increasing the areal extent and diversity of vegetation; improving wildlife habitat; and increasing productivity within the drawdown zone of Kinbasket Reservoir. Most plantings (seedling plugs and live stakes) sampled in random plots showed low to nil survivorship after three years. Moreover, treatments showed no statistically significant effects on per cent cover of vegetation, species richness, or species diversity at the landscape scale. Numerous factors likely contributed to the difficulties in plant establishment, some of which may have been related to planting methodology, while others appeared directly linked to the reservoir operating regime (i.e., timing, frequency, duration, and depth of inundation) and various attendant factors (e.g., erosion, sedimentation, and woody debris deposition).

Commencing in 2015, the focus of monitoring shifted to effectiveness assessments of several new CLBWORKS-1 projects implemented after 2012, specifically:

(1) 2013 sedge planting trials at Km88, Bush Arm;
(2) 2014 woody debris removal and log-boom exclosure trials at Canoe Reach;
(3) 2015 mound and windrow construction trials at Bush Causeway, Bush Arm.

The sedge plug treatments Km88 continue to perform well in each of three treatment units (TUs) five years after planting. 2018 establishment estimates were slightly below the targeted densities of 10,000-15,000 plugs per ha for two of the three TUs, and in line with the target density of 5,000-10,000 per ha for another TU. Estimated per cent survival was around 35% for all treatment applications. Compared to the less successful 2008-2011 planting treatments, the Km88 plantings appear to have benefited from the relatively amenable site conditions characterizing this location as well as from the use of older, larger nursery stock.

At Canoe Reach, vegetation on driftwood-covered shorelines has, in several locations, responded positively to the removal of woody debris within a year of clearing, with significant increases observed over time in both total cover and species richness relative to untreated controls. The most marked positive response was at Valemount Peatland (North), a highly impacted, remnant wetland site with moist, nutrient-rich, highly organic soils supported by seepage inflows from an adjacent upslope wetland. Because it focuses on facilitating the regeneration of existing vegetation, as opposed to introducing new vegetation, targeted woody debris removal (in combination with debris exclusion measures) has the potential to yield immediate ecological returns (with a low up-front investment) and thus may be a cost-effective alternative to direct stocking for treating multiple sites over a wide geographic area in a short time frame. As in the case of direct revegetation, the effectiveness of this approach will be constrained by the original quality and condition of sites targeted for treatment.

At Bush Causeway, elevated mounds and windrows constructed in 2015 out of local wood debris and mineral soil are currently showing evidence of successful plant colonization (both natural and via planted live stakes), with over 70 species recorded in 2018. Adjacent wood-choked ponds that were cleaned of wood debris during mound construction are also showing indications of vegetative recovery, with various sedge species as well aquatic macrophyte genera being observed to have established in or adjacent the ponds. However, the constructed habitats are situated at high elevation in the drawdown zone and have yet to undergo an inundation cycle due to the series of relatively low water years in Kinbasket since 2015. Consequently, the structural integrity and vegetation responses of the mounds, windrows, and ponds to seasonal flooding remain untested and unknown.

In 2018, a comprehensive follow-up survey was conducted of all the original (2008-2011) CLBWORKS-1 treatment polygons, including some polygons not previously assessed under CLBMON-9. This expanded inventory included soil assays and helped fill in existing data gaps around both revegetation performance and the topo-edaphic site conditions prevailing at the different treatment sites. During this inventory, we came across several localized but notable instances of surviving graminoid (primarily sedge) plugs that had gone undetected in previous random samples of treatment areas, suggesting that previous summary reports may have slightly underestimated the rate of graminoid establishment at some locales. However, these instances were too limited in number and area to materially alter the overall extent and diversity of vegetation (as per the program objectives). Where transplants did survive, an apparent lack of new recruits suggests that revegetated populations will not be self-sustaining over the long term and will likely require repeated planting interventions to persist. Topo-edaphic comparisons of microsites with and without successful sedge establishment revealed that substrate conditions strongly influence the probability of plug survival. Specifically, a high percentage of the variation in establishment rates could be explained by the amount of Potassium (K), sodium (Na), and organic matter content. Surprisingly, these edaphic factors were more important at explaining the variation in establishment rates than elevation (which can be regarded as a general proxy for inundation depth and duration). This finding could be highly useful for informing future decisions around site selection in subsequent transplant trials or where other physical site improvements are being considered.

Insufficient time has elapsed since some treatments (e.g., woody debris removal and debris mounding) were implemented for successional processes to manifest themselves fully. Nevertheless, it is becoming increasingly evident that planting interventions on their own, in the absence of additional physical modifications aimed at ameliorating local site conditions, are unlikely to achieve the long-term revegetation objectives identified for the Kinbasket Reservoir drawdown zone (BC Hydro 2008). From an operational standpoint, substantial opportunities also exist for advancing vegetation establishment, namely by using operational constraints to control the timing, and limit the depth and duration, of summer inundation.

The status of CLBMON-9 after Year 7 (2018) 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-10. Supporting documentation pertaining to existing vegetation can be found in Hawkes et al. (2013), Hawkes et al. (2017). The status of this second set of MQs after Year 7 has also been updated and summarized in the table below, following the summaries for revegetation MQs.

Key Words: CLBMON-9, CLBWORKS-1, revegetation, effectiveness monitoring, sedge, live stake, woody debris, log-boom exclosure, mounds, drawdown zone, Kinbasket Reservoir

Revegetated Areas

Management Question (MQ)	Summary of Key Results
MQ1. What is the quality and quantity of vegetation in revegetated areas compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?	<u>Summary Findings</u> The 2008-2011 revegetation treatments did not substantially increase the quality or quantity of vegetation in the drawdown zone of Kinbasket Reservoir at the landscape scale. No statistically significant differences were detected in the percent cover of vegetation between treatment and control plots in any of the nine vegetation communities that were sampled. Analysis of other vegetation variables, such as species richness, species diversity, and biomass also showed similar trends to percent cover, with little or no statistically significant differences between treatment and control plots. Nevertheless, at a local scale, patches of surviving sedge transplants (e.g., at Yellow Jacket Creek and Km77) may be providing some ancillary wildlife services in the form of increased habitat structure and cover, shading, and browse. As of 2018, the 2013 sedge trial at Km88 Big Bend (Bush Arm) continued to perform well with ~27,000 sedge plugs now established over 3.3. ha. This treatment was applied to an area of the drawdown zone that already supported well-established vegetation communities. Thus, while it may have succeeded in elevating species richness and cover at the local scale, it has not necessarily resulted in a larger vegetated area than existed before. The main ecological effect to date has likely been to tilt the balance of community composition toward a more graminoid-intensive phase, particularly at the lower sites which otherwise tend to be dominated by short-statured annuals. At Canoe Reach, vegetation on driftwood-covered shorelines has, in several locations, responded positively to the removal of woody debris within a year of clearing, with significant increases observed over time in both total cover and species richness relative to untreated controls. Because it focuses on facilitating the regeneration of existing vegetation, as opposed to introducing new vegetation, targeted woody debris removal (in combination with debris exclusion measures) has the potential to yield immediate ecological returns (with a low up-front investment) and thus may be a cost-effective alternative to direct stocking for treating multiple sites over a wide geographic area in a short time frame. At the Bush Causeway, elevated mounds and windrows constructed in 2015 out of local wood debris and mineral soil are currently showing evidence of successful plant colonization (both natural and via planted live stakes), with over 70 species recorded in 2018. Adjacent wood-choked ponds that were cleaned of wood debris during mound construction are also showing indications of vegetative recovery, with various sedge species as well aquatic macrophyte genera being observed to have established in or adjacent the ponds. <u>Sources of Uncertainty/ Limitations</u> The recency of revegetation treatments (7 to 10 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 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 sedge stands, once they start to fill in, will create safe sites for germination of other species). 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. For example, at Bush Causeway, the constructed habitats are situated at high elevation in the drawdown zone and have yet to undergo an inundation cycle due to the series of relatively low water years in Kinbasket since 2015. Consequently, the structural integrity and vegetation responses of the mounds, windrows, and ponds to seasonal flooding remain untested and unknown. To capture long-term successional trajectories and to better determine if revegetated areas of Kinbasket are indeed self-sustaining, it is

Revegetated Areas

Management Question (MQ)	Summary of Key Results
	recommended that further, targeted monitoring (focusing on high survival areas only) be undertaken at reduced intervals until 2030 (for a total of 15 years of monitoring in the case of physical works implemented in 2015) In the case of black cottonwood plantings, other rationales for suggesting this extended time frame include: (i) Riparian cottonwood generally reaches flowering age between 8 and 10 years (Zasada and Phipps 1990); the surviving live stakes at Bush Causeway, now four years old, may be approaching reproductive maturity but likely would not yet have had time to begin recruiting new seedlings into the population. (ii) In Arrow Lakes, it was observed (Miller et al. 2018) 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. This is an important operational finding that, in the case of Kinbasket Reservoir introductions, would require subsequent monitoring to confirm. In the case of sedge plantings, our rationale for considering an 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> Mortality rate for black cottonwood, willow, and red-osier dogwood live stakes planted between 2008 and 2011 was close to 100 percent; shrub seedlings also failed to survive except in low numbers at a few scattered locations. Survivorship of graminoid transplants was also generally low to negligible except for a few localized instances of vigorous establishment (e.g., at Yellow Jacket Creek, Ptarmigan Creek, Km77) covering <1 ha of terrain. The proportion of sampled treatment polygons (n=91) where 0 surviving transplants were observed in 2018 (seven to 10 years post-planting) was 64%. <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 some 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 remediation and expansion of vegetation communities in the drawdown zone?	<u>Summary Findings</u> The widespread treatment failures can be ascribed generally to the physiological challenges posed by prolonged summer inundation (and associated anoxia) combined with soil moisture deficits at other times of the year, repeated cycles of flooding and exposure, generally infertile substrates, erosive forces and wave scouring, sediment deposition, and woody debris abrasion and/or deposition. 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.

Revegetated Areas

Management Question (MQ)	Summary of Key Results
	Sources of Uncertainty/ Limitations 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. Physical works projects aimed at establishing vegetation in the Kinbasket 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-1, at increasing the quality and quantity of vegetation in the drawdown zone?	Summary Findings The 2008-2011 revegetation trials involving shrub seedlings and live stakes were unsuccessful. Of the various sedge, sedge-like, and grass species that were transplanted into the drawdown zone (Kellogg's sedge, Columbia sedge, water sedge, wool-grass, small-fruited bulrush, and bluejoint reedgrass), only Kellogg's sedge and Columbia sedge appear to have been successful in any measurable degree, and this is true only for very limited areas in Bush Arm and Canoe Reach (e.g., portions of Km77, Km88 Big Bend, Chatter Creek, Yellow Jacket Creek, and Ptarmigan Creek). It remains unclear if these introduced populations will become self-sustaining over the long term or if they can modulate local environmental conditions enough to facilitate the establishment of other species, thereby advancing community succession. At Canoe Reach, impacted sites have responded positively to the removal of woody debris within a year of clearing, with significant increases observed over time in both total cover and species richness relative to untreated controls. Because it focuses on facilitating the regeneration of existing vegetation, as opposed to introducing new vegetation, targeted woody debris removal (in combination with debris exclusion measures) has the potential to yield immediate ecological returns (with a low up-front investment) and thus may be a cost-effective alternative to direct stocking for treating multiple sites over a wide geographic area in a short time frame. As in the case direct revegetation, the effectiveness of this approach will be constrained by the original quality and condition of sites targeted for treatment. At Bush Causeway, elevated mounds and windrows constructed in 2015 out of local wood debris and mineral soil are currently showing evidence of successful plant colonization (both natural and via planted live stakes), with over 70 species recorded in 2018. Adjacent wood-choked ponds that were cleaned of wood debris during mound construction are also showing indications of vegetative recovery, with various sedge species as well aquatic macrophyte genera being observed to have established in or adjacent the ponds. However, the constructed habitats are situated at high elevation in the drawdown zone and have yet to undergo an inundation cycle due to the series of relatively low water years in Kinbasket since 2015. Consequently, the structural integrity and vegetation responses of the mounds, windrows, and ponds to seasonal flooding remain untested and unknown. Sources of Uncertainty/ Limitations A longer time series of data is required to address this question completely (see comments to MQ1, above).
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?	Summary Findings The planting program has shown modest benefits beyond what would occur through natural colonization, primarily relating to the increase in sedge densities at various locations that supported some pre-existing plant cover. There has been relatively little success in getting vegetation to establish on sites that were previously devoid of vegetation, and any gains there are likely to be transitory (due to a lack of ongoing recruitment). Despite this inherent inertia, the potential does exist for some of these areas to become revegetated through natural colonization processes should conditions change, such as in the case of sites impacted by woody debris. For example, at Valemount Peatland in Canoe Reach, the mere act of removing woody debris from an accumulation zone was sufficient to trigger a rapid rebound in plant cover and species richness.

Revegetated Areas

Management Question (MQ)	Summary of Key Results
	At Bush Arm, the constructed mounds/windrows and cleared ponds supported, after three years, ~25 taxa not previously recorded in the near vicinity during pre-physical works (2015) baseline sampling. The presence of these novel elements on/in the constructed features and ponds provides some early evidence that physical works have been effective at increasing small-scale habitat heterogeneity and, in turn, local species richness. Additional opportunities for physical works trials involving mounding and windrow construction have been identified in Bush Arm (Hawkes 2016) that, if implemented, will provide additional insights into the relative efficacy of this approach. Sources of Uncertainty/ Limitations The study design did not include an assessment of the natural colonization potential under different potential operational scenarios, therefore direct comparisons with revegetation establishment rates are difficult.
MQ6. Is there an opportunity to modify operations to more effectively maintain revegetated communities at the site level in the future?	Summary Findings In theory, opportunities exist for modifying operations to help restoration goals, but due to operational constraints this idea has not been adequately tested. 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 control the timing, and limit not just the depth but also the duration, of inundation during the summer and early fall growing season. With respect to the hydroperiod, program experience to date suggests the following precepts: (i) To facilitate development of functional riparian ecosystems, periodic, brief inundation at low elevations (e.g., 746-750 m) is likely necessary to recharge soil moisture, protect establishing plants from summer drought, and maintain suitable growing conditions for flood-adapted riparian species and communities. (ii) Full pool events, such as those experienced between 2011 and 2012, strongly limit the capacity for shrub and tree establishment at upper elevations (i.e., > 452 m). (iii) Deep, prolonged summer inundation is unnecessary for transplant establishment and growth and probably detrimental of 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. Sources of Uncertainty/ Limitations 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, distribution and vigour) of existing vegetation communities (as identified by Hawkes et al. 2007) in relation to elevation in the drawdown zone?	Summary Findings 21 community types have been described for the drawdown zone to date, and the composition and distribution of 19 of these communities relative to substrate and elevation have been described. Sources of Uncertainty/ Limitations Not all areas of the drawdown zone with existing vegetation have been mapped, which may underestimate the total area of existing vegetation. It may also underestimate the number of vegetation communities that occur in the drawdown zone.
MQ2. What is the cover, abundance and biomass of existing vegetation communities (as identified by Hawkes et al. 2007) in relation to elevation in the drawdown zone?	Summary Findings Each vegetation community has been characterized relative to spatial extent and elevation (in GIS) and metrics of species distribution (cover, diversity and evenness) have been computed. Sources of Uncertainty/ Limitations Not all areas of the drawdown zone with existing vegetation have been mapped (see comment above under MQ1). Biomass was not assessed across elevations due to the practical difficulties in obtaining reliable estimates of this metric for 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?	Summary Findings The vegetation communities have developed in the drawdown zone under various operating conditions and appear to be generally adapted to annual variation in the hydroregime. For example, certain high elevation communities (e.g., WS and BS) which were knocked back by deep reservoir inundation and surcharge in 2012 and 2013, appear to be undergoing a rebound. This resilience notwithstanding, reservoir operations, by limiting the number of growing degree days available for plant establishment and growth, inherently act to limit the species richness, diversity and spatial extent of vegetation in the drawdown zone. A reduction in the maximum elevation and duration of inundation would function to maintain and likely expand existing vegetation, particularly at higher elevations (i.e., those >748 m ASL). Sources of Uncertainty/ Limitations The impacts of other non-measured factors such as rates of erosion and sedimentation related to reservoir operations and the effect on existing vegetation requires study, as do the effects of wave energy (fetch, wave action) on the drawdown zone at different elevations. The relationship between wood debris accumulation and scour has been reported, but not directly studied. We know that removing wood from the drawdown zone provides an opportunity for vegetation to naturally establish and develop, but not knowing the probability of wood debris accumulation or the mechanisms responsible for the inputs of wood into the system contributes to uncertainty regarding how the operating regime of Kinbasket Reservoir affects the within-community quality and quantity of exiting vegetation communities. We also know that there are elements of the natural environment that are likely to influence vegetation growing in the drawdown zone and that are not related to reservoir operations (e.g., debris flows, avalanches, and fire). Other influences (e.g., erosion, sedimentation) are related to reservoir operations, but the relative effect of these natural and reservoir-related factors was not studied in detail under CLBMON-9. Some factors (e.g., wood debris deposition and perhaps erosion in some places) could be assessed through a further review of available LiDAR and associated data with an aim to address some of these uncertainties.

Existing Vegetation

Management Question (MQ)	Summary of Key Results
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)?	<u>Summary Findings</u> Year-over-year data since 2007 suggest that there have been subtle impacts to the spatial extent, structure, and composition of existing vegetation communities resulting from reservoir operations since 2007. For example, several sites at various elevations, but especially at low and mid elevations, have undergone moderate turnovers in species abundance and composition from one sample year to the next. These species turnovers often appear to be precipitated by sediment transport; as sediment becomes deposited on a microsite during flooding, it buries the existing vegetation and creates microsite openings for new colonizers to establish. Diversity of communities such as Lady's thumb-Lamb's-quarter (LL), Cottonwood-Clover (CT), and Clover-Oxeye daisy (CO) has tended to trend in nonparallel directions, evidently in response to the sequence of high water events that occurred following 2007. In general, richness and diversity appear to have declined over time in communities situated at elevations ≥ 750 m ASL. The decline was most apparent after 2012 following two successive years of reservoir surcharge and periods of increased duration of inundation at these elevations. Declines in species richness and diversity were also observed in some lower elevations (748 and 749 m ASL) and, overall, the trend appears to be one of declining richness and diversity over time. Nevertheless, at present it appears that most communities are persisting in the drawdown zone, with no notable turnovers in terms of the primary community dominants. <u>Sources of Uncertainty/ Limitations</u> The longer-term effects of the operating regime on the structure of existing vegetation communities may not be realized over a 10 year period due to the relatively slow rates of vegetation succession.

ACKNOWLEDGEMENTS

The following individuals are gratefully acknowledged for their contribution to and support of this project in 2018/2019. Mark Sherrington and Margo Sadler (BC Hydro project management and technical assistance), Pascale Gibeau (statistical analysis), Julio Novoa (GIS), Sergei Yazvenko, Keegan Meyers, Jeremy Gatten, Jamie Fenneman, and Bryan Kelly-McArthur (data collection), and David Polster and Carrie Nadeau (subject matter experts).

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1.0 INTRODUCTION

Natural seasonal flooding of rivers and lakes creates or influences a variety of riparian plant communities (Junk et al. 1989; Johnson 2002; Nilsson and Svedmark 2002). These floodplain communities have disproportionately high biodiversity that in turn provides high quality habitat for many wildlife species across a wide range of taxa (Naiman and Décamps 1997; Johnson 2002; Hawkes and Gregory 2012). The construction of dams, however, has transformed most of the world's large rivers. By the end of the 20th century, about 45,000 large dams (at least 15 m in height) had been built on rivers worldwide (WCD 2000). While dams can provide several benefits such as flood control, power generation and management of water supply for irrigation, industrial use and urban consumption (Poff et al. 1997; Wu et al. 2004), they are also associated with numerous environmental impacts. Dams act as physical barriers to fish movement and plant hydrochory (water-based dispersal), trap fine sediment, and typically disrupt a river's natural flood pulse flow regime (Poff et al. 1997; Nilsson and Berggren 2000; Nilsson and Svedmark 2002). These effects impact upstream and downstream habitat and alter numerous ecological processes that sustain both terrestrial and aquatic biodiversity (Nilsson and Berggren 2000; Johnson 2002; Wu et al. 2004).

Two major hydrological changes generally occur with dam construction. First, downstream water flow regimes can be produced that are quite different from undammed rivers because of diurnal and seasonal variations in demands for water or power (Nilsson and Berggren 2000). The changed flow regimes often result in substantially altered shorelines, vegetation changes, and declines in native aquatic species (Junk et al. 1989; Hill et al. 1998; Johnson 2002; New and Xie 2008). Secondly, dams create reservoirs that modify water level fluctuations and permanently flood areas upstream of the dam (Hill et al. 1998; Nilsson and Berggren 2000). This generally leads to loss of the original plant community as existing shorelines are submerged, leading new shoreline vegetation to develop at higher elevations that often have poor soils without riparian seed banks (Hill et al. 1998; Johnson 2002; New and Xie 2008). For example, Yang et al. (2012) reported a decrease of 73.49%, 70.41% and 57.04% in vegetation family, genera and species respectively within the Three Gorge Dam drawdown area compared to pre-dam surveys. An additional upstream change is replacement of a stabilized shoreline with a new, erodible shoreline (Hill et al. 1998).

Reservoirs, particularly those associated with hydroelectric power generation, are usually managed to maintain water levels with regulated minimum and maximum levels. The "drawdown" zone consists of the exposed part of the shoreline below the top water line (Abrahams 2005). The environments occurring within a drawdown zone are generally challenging for most plant species. Although all water bodies experience some level of seasonal, annual or longer-term fluctuations in water levels (known as the hydroperiod), these cycles typically follow predictable patterns to which the littoral plant species are adapted (Poff et al. 1997). For example, a freshwater body's typical hydroperiod is a flood event in the spring and early summer (the summer freshet) followed by low water in the late summer and early fall (Abrahams 2006). The receding shorelines provide habitat for numerous plant species over the course of the growing season, many of which are specifically adapted to these habitats. Conversely, in reservoir systems, water levels are typically maintained at low levels through the winter and early spring to allow spring freshet waters to be captured. Water levels are then allowed to rise (often dramatically) throughout the late spring, summer, and fall, inundating vegetation as it attempts to establish and grow (Abrahams 2006).

Reservoirs managed for hydro-electric power typically have extreme fluctuations in water levels with associated drawdown zones measured in tens of metres (Abrahams 2005; Lu et al. 2010). These water level fluctuations produce repeated cycles of succession that consist of disturbance, colonization and growth (Abrahams 2005). While high plant recruitment can occur during low reservoir levels, there is often high plant mortality when reservoir levels rise (Johnson 2002). The extreme magnitude of water fluctuation can lead to a decline in the species richness of all herbs, a loss of the rare plant component, and an invasion by exotics (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, accumulating large woody debris and its associated scouring, and high rates of erosion and sediment deposition provide additional challenges to vegetation establishment in the drawdown zone (Johnson 2002; Abrahams 2005). For example, many plants in the 30 m drawdown zone of the Three Gorges Dam in China died, resulting in a mainly unvegetated drawdown zone that experienced soil erosion and landslides (Yang et al. 2012).

Kinbasket Reservoir in southeastern British Columbia is 216 km long and holds a licensed volume of 12 million-acre feet (MAF)1 (BC Hydro 2005). Water level elevations are managed under a regime that permits a normal annual minimum of 707.41 m above sea level (ASL) and a normal maximum of 754.38 m ASL—a difference of almost 47 m. The large variations in water levels result in only sparse vegetation cover throughout much of the drawdown zone, which in turn impacts ecosystem functioning, 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). The WUP CC further recognized that the most promising opportunity for accomplishing these objectives lay in enhancing vegetation along the riparian/wetland interface because this is the only area likely to be substantially affected by changes in BC Hydro operations.

In lieu of operational changes, the WUP CC supported a reservoir-wide revegetation program for Kinbasket Reservoir to maximize plant growth in the drawdown zone (BC Hydro 2005). The program was proposed as a multi-year project to facilitate development of long-term ground cover. The challenges to natural vegetation establishment in the drawdown zone described above also apply to replanted areas. As part of the water use planning process, a study was undertaken to identify areas with the highest potential for successful vegetation establishment (Moody and Carr 2003). While most of the shorelines of Kinbasket Reservoir appeared to be unsuitable for enhancement due to coarse substrates and steep slopes, 68 sites were found with existing plant cover, the two largest

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[1] MAF = million acre feet. An acre foot is a unit of volume commonly used in the United States in reference to large-scale water resources, such as reservoirs, aqueducts, canals, sewer flow capacity and river flows. It is defined by the volume of water necessary to cover one acre of surface area to a depth of one foot. Since the area of one acre is defined as 66 x 660 feet, the volume of an acre foot is exactly 43,560 cubic feet. Alternatively, this is approximately 325,853.4 U.S. gallons, or 1,233.5 cubic metres or 1,233,500 litres.

sites being Bush Arm (1,169 ha) and Canoe Reach (698 ha). An additional 1,802 ha of shoreline were identified as having either high or moderate potential for revegetation.

As a result of these findings, the program CLBWORKS-1 (“Kinbasket Reservoir Revegetation Program Physical Works”) was initiated in 2007 to improve existing vegetation communities and replant currently barren areas within the upper portion (~741 to 754 m ASL) of the drawdown zone. Between 2008 and 2011, a total of 69.15 ha in 19 treatment areas in the drawdown zone of Kinbasket Reservoir were planted with a combination of nursery-raised seedling plugs and live stakes (Keefer et al. 2009; 2010; 2011; Keefer Ecological Services Ltd. 2012). Eight different revegetation prescriptions were applied during this time, but seedling plug treatments, particularly those involving Kellogg’s sedge (*Carex kelloggii*) alone or mixed with other species, dominated the planting regime (Hawkes et al. 2013).

A multi-year effectiveness monitoring program, CLBMON-9 “(Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis”), was initiated in 2008 to assess the effectiveness of revegetation prescriptions implemented under CLBWORKS-1 at enhancing the quality and quantity of vegetation in the drawdown zone of Kinbasket Reservoir for ecological and social benefits (BC Hydro 2008). Several plant community metrics (e.g., species richness and diversity, per cent cover) were assessed biannually and compared between treatment and control plots using a random sample design (Yazvenko 2008, 2009; Yazvenko et al. 2009; Fenneman and Hawkes 2012; Hawkes et al. 2013). As the planting treatments showed limited initial success, commencing in 2013 various supplemental CLBWORKS-1 trials (e.g., woody debris removal) were undertaken in Canoe Reach and Bush Arm aimed at enhancing vegetation in the upper elevations of the drawdown zone. Those trials were simultaneously monitored under CLBMON-9 beginning in 2015.

This report synthesizes key results of the CLBMON-9 monitoring program from 2008 to 2018. The report is organized around three main components: (1) effectiveness of the initial 2008-2011 revegetation trials at various locations in Kinbasket Reservoir (2) outcomes of the 2013 sedge trial at Km88 (Bear Island); and (3) post-treatment vegetation responses to physical works trials in Canoe Reach and at Bush Causeway (Bush Arm), including large woody debris removal, log-boom exclusions, and mound construction.

1.1 Management Questions and Hypotheses

The following specific management questions relating to revegetation effectiveness were addressed (BC Hydro 2008):

1. What is the quality and quantity of vegetation in revegetated areas compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?
2. 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)?
3. What environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation), may limit or improve the remediation and expansion of vegetation communities in the drawdown zone?

4. What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-1, at increasing the quality and quantity of vegetation in the drawdown zone?
5. 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?
6. Is there an opportunity to modify operations to more effectively maintain revegetated communities at the site level in the future?

The management hypotheses and sub-hypotheses corresponding to the management questions above were (BC Hydro 2008):

H_{01}: Revegetation treatments between elevation 741 m and 754 m 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 areas.

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 741 m and 754 m.

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.

1.2 Summary of Early Results

Despite some early high survivorship (e.g., one year post-treatment), most plantings (seedling plugs and live stakes) in the random sample plots showed low to nil survivorship after three years. Moreover, treatments showed no statistically significant effects on per cent cover of vegetation, species richness, or species diversity within the drawdown zone (Hawkes et al. 2013). Thus, none of the management hypotheses stated above (Section 1.1) could be rejected.

Statistical hypothesis testing required that a random sampling design be employed during monitoring (BC Hydro 2008). 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. Therefore, one of the objectives for 2018, the final monitoring year (Section 3.1.6.4), was to carry out a comprehensive inventory of all the original CLBWORKS-1 revegetation treatments (rather than just a random sample) to fill in some of the existing data gaps around revegetation survivorship/establishment seven to 10 years post-treatment as well as the topo-edaphic site conditions prevailing at the different treatment sites.

1.3 Recent Revegetation Approaches

Based on these initial results, Hawkes et al. (2013) made several suggestions for increasing revegetation effectiveness moving forward. Among these was a recommendation that revegetation prescriptions be specifically developed for areas of the drawdown zone where plants are most likely to survive and grow. This could include currently vegetated sites, protected bays, seepage areas, wet depressions, areas with abundant topographic featuring, soil accumulation zones, areas protected from sediment loading, and areas free of woody debris scouring.

In 2013, such an approach was taken in the stocking of 3.3 hectares of drawdown zone habitat at Km88 Big Bend, a shallowly sloped bay in Bush Arm that is partially protected from wave action and woody debris scouring due to its location on the leeward side of Bear Island (Adama 2013, 2015). Plantings consisted of plugs of Kellogg's sedge (*Carex kelloggii*) and Columbia sedge (*C. aperta*), two species found naturally occurring at the site. Treatments were distinguished from previous iterations of CLBWORKS-1 by the use of older (>1-year-old), larger nursery stock, planted over a larger area and at higher densities (Adama 2015). Initial (2014) post-treatment monitoring at Km88 found that survival rates during the first year were high (Adama 2015). Revegetation effectiveness monitoring at this site continued under CLBMON-9 until 2018.

A second recommendation was to explore the potential efficacy of reducing woody debris accumulations in facilitating natural regeneration of previously vegetated sites (Hawkes et al. 2013). Woody debris is removed from the drawdown zone of Kinbasket Reservoir annually as part of CLBWORKS-16. Removal is generally accomplished through in-situ piling and burning. In 2014, an opportunity was identified (Addendum #3 to CLBWORKS-1 Kinbasket Revegetation Physical Works) to conduct a woody debris removal trial in Canoe Reach. For this trial, woody debris deposits were mechanically cleared from five pre-selected locations in Canoe Reach. At the Valemount Peatland site, debris removal was paired with the strategic placement of a log-boom to prevent further debris accumulations. Treatment outcomes were assessed in 2014 and again in 2015 and 2018 under CLBMON-9.

A BC Hydro technical review of revegetation efforts in Kinbasket and Arrow Lakes Reservoirs was held in December 2014 to look at past and new approaches to revegetation. Both CLBMON-9 and the associated monitoring project for Arrow Lakes (CLBMON-12) were discussed during this meeting as ecological context for the site-specific revegetation projects in both reservoirs. One of the new approaches put into place as an outcome of the technical review was the construction of wood debris structures (elevated mounds and windrows) at Bush Arm as a pilot project under CLBWORKS-1 (Debris Mound and Wind Row Construction Pilot Program; BC Hydro 2015b).

As part of this initiative, five new physical works sites in Bush Arm were identified under CLBWORKS-1 to serve as trial areas for testing the effectiveness of artificial mounds at increasing topographic heterogeneity (and, in the process, vegetation establishment) within the drawdown zone (BC Hydro 2015b, Hawkes 2016). The five proposed sites were Bush Causeway (north and south ends), Goodfellow Creek, Hope Creek, and Chatter Creek (Figure 3-3). In 2015, trials were undertaken at two of these sites (Bush Causeway North and Bush Causeway South). There, locally occurring woody debris and surficial material (soil) were used to construct elevated mounds and windrows to a height exceeding the maximum operating elevation of the reservoir, with the aim of creating a series of small non-inundated islands and peninsulas where vegetation could establish and which could eventually provide added habitat value for wildlife (Hawkes 2016). At Bush Causeway south, several small wood-choked ponds were also cleared of debris (with the aim of recreating functional wetland habitat), and a log-boom was installed to exclude further debris accumulation.

To accommodate monitoring of these new physical works trials, the 2015 scope of services for CLBMON-9 (BC Hydro 2015a) adopted several changes in approach from previous project phases. A primary focus, commencing in 2015, was to implement a revegetation monitoring study that would:

- monitor the response of existing vegetation communities at woody debris-removal sites and to the placement of debris exclusion booms;
- monitor the success of new (2013) sedge plantings at Km88 (Bush Arm);
- document the species composition of existing vegetation communities adjacent to and under the proposed debris mounds and windrows locations prior to construction;
- monitor the establishment of vegetation (both natural and planted) on top of and adjacent to constructed debris mounds and windrows to:
    - (a) assess natural establishment of vegetation on the physical works;
    - (b) assess success of planted vegetation on the physical works;
    - (c) assess erosion and wave action effects on the physical works.

1.4 Objectives

The objectives of CLBMON-9, as per the project terms of reference (BC Hydro 2008) and as updated in the 2015 scope of services (BC Hydro 2015a), are as follows:

1. Determine the species composition (i.e., diversity, distribution and vigour) of existing vegetation communities (as classified by Hawkes et al. 2007) to identify species that have been successfully surviving long-term inundation.

2. Evaluate the cover, abundance and biomass of existing vegetation communities (as classified by Hawkes et al. 2007) relative to elevation in the drawdown zone (across the elevation gradient of 741 m–754 m ASL).

3. Monitor the response of existing vegetation communities at the local (site) level to the continued implementation of the normal operating regime for Kinbasket Reservoir and other environmental variables.

4. Assess the long-term effectiveness of the revegetation program to expand 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.
5. Assess the costs and benefits of the revegetation prescriptions applied under CLBWORKS-1 (Kinbasket Reservoir Revegetation Program Physical Works).
6. Test the response of constructed woody debris and soil mounds/ windrows in full reservoir pool conditions including:
    - (a) Inform BC Hydro on how reservoir operations affect the structural integrity of mounds and windrows and determine if mitigation strategies can be developed to reduce these impacts (i.e. the effectiveness of the mounds and windrows in increasing topographic heterogeneity in the drawdown zone);
    - (b) Monitor natural establishment of vegetation and success of planted vegetation on constructed woody debris and soil mounds/ windrows; and
    - (c) Inform BC Hydro on to what extent constructed woody debris and soil mounds/ windrows exclude floating woody debris from the parts of the drawdown zone shoreward of the constructed islands and windrows.

As indicated by objectives 1-3 above, the CLBMON-9 program was initially designed for simultaneous monitoring of both revegetated sites and existing vegetation areas (i.e., areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials). However, objectives 1-3 have largely been addressed through the associated project CLBMON-10 (Kinbasket Reservoir Inventory of Vegetation Resources). While the primary focus of CLBMON-10 is on inter-community changes in existing vegetation communities at the landscape scale, monitored using aerial photography, that study also monitored existing vegetation at the site (local) scale (Hawkes et al. 2013a, Hawkes and Gibeau 2017). Therefore, since 2011 the focus of CLBMON-9 has been on assessing the effects of revegetation efforts at the site level through plot-based monitoring (Hawkes et al. 2013).

2.0 STUDY AREA

The approximately 216 km long Kinbasket Reservoir is located in southeastern B.C., within the Rocky and Monashee Mountain ranges (Figure 2-1). The Mica hydroelectric dam located, 135 km north of Revelstoke, B.C., spans the Columbia River and impounds Kinbasket Reservoir. The Mica powerhouse was completed in 1973, has a generating capacity of 1,805 MW, and Kinbasket Reservoir has a licensed storage volume of 12 million-acre feet (MAF; BC Hydro 2007). The normal operating range of the reservoir is between 707.41 m and 754.38 m elevation but can be operated to 754.68 m ASL with approval from the Comptroller of Water Rights.

Kinbasket Reservoir spans two biogeoclimatic (BEC) zones: the Interior Cedar-Hemlock (ICH) zone and the Sub-Boreal Spruce (SBS) zone. Four subzone/variants characterize the ICH, and one subzone/variant characterizes the SBS zone. Of the six variants, all but the ICHvk1 and ICHmk1 occurred in the study area (Figure 2-1).

Since 2008, vegetation sampling for CLBMON-9 has occurred in 15 specific regions or “landscape units” of Kinbasket Reservoir (Figure 2-1). Some, though not all, of the regions correspond to revegetation treatment areas (CLBWORKS-1); other areas represent locations of aerial photo acquisition under CLBMON-10. Beginning in 2015, sampling was confined to Canoe Reach and Bush Arm (northwest and southeast portions of Figure 2-1), including woody debris removal and log-boom sites in Canoe Reach, the 2013 sedge trials at Km88, and five locations of proposed physical works in Bush Arm (Figure 2-2).

2.1 Physiography[2]

The Columbia Basin is characterized by steep valley side slopes and short tributary streams that flow into the Columbia River from all directions. The headwaters of the Columbia River begin at Columbia Lake in the Rocky Mountain Trench. The river flows northwest along the Trench for about 250 km before it empties into Kinbasket Reservoir behind Mica Dam. From Mica Dam, the river continues southward for about 130 km to Revelstoke Dam and then flows almost immediately into Arrow Lakes Reservoir behind Hugh Keenleyside Dam. The entire drainage area upstream of Hugh Keenleyside Dam is approximately 36,500 km2.

The Columbia River valley floor elevation extends from approximately 800 m ASL near Columbia Lake to 420 m ASL near Castlegar. Approximately 40 per cent of the drainage area within the Columbia River Basin is above 2000 m ASL. Permanent snowfields and glaciers predominate in the northern high mountain areas above 2500 m ASL; about 10 per cent of the Columbia River drainage area above Mica Dam exceeds this elevation.

Most of the watershed remains in its original forested state. Dense forest vegetation thins above 1500 m ASL and tree lines are generally at about 2000 m ASL. The forested lands around Kinbasket Reservoir have been and are being logged, with recent and active logging occurring on both the east and west sides of the reservoir.

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[2] From BC Hydro (2007) after BC Hydro (1983)

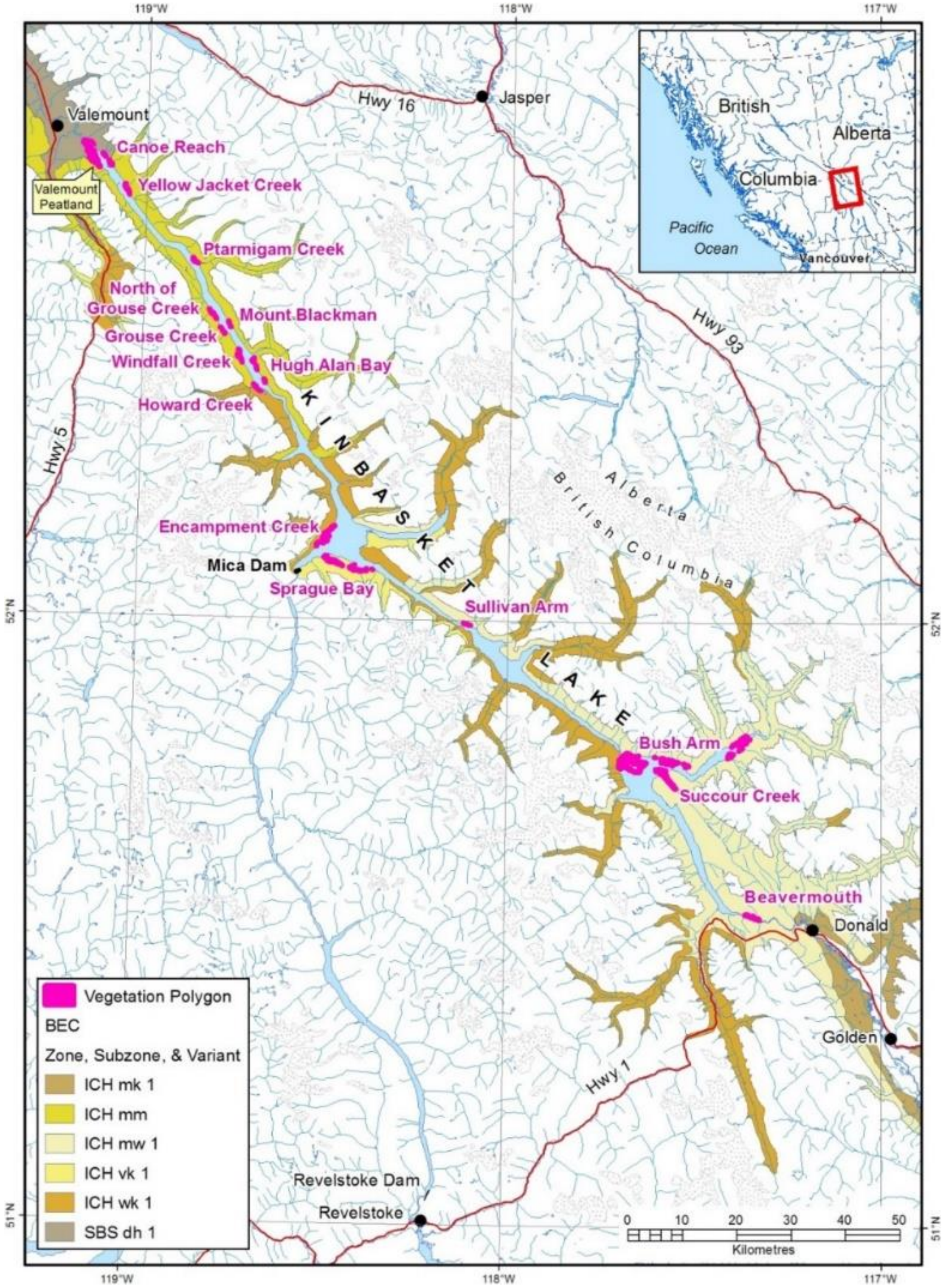

Figure 2-1: **Location of Kinbasket Reservoir and historical CLBMON-9 monitoring locations (pink).** Landscape unit names (e.g., Beavermouth, Encampment Creek) were assigned to each area sampled in 2007. Pink areas also denote the locations of aerial photograph acquisition. BEC (Biogeoclimactic Ecosystem Classification) zones after Braumandl and Curran (2002)

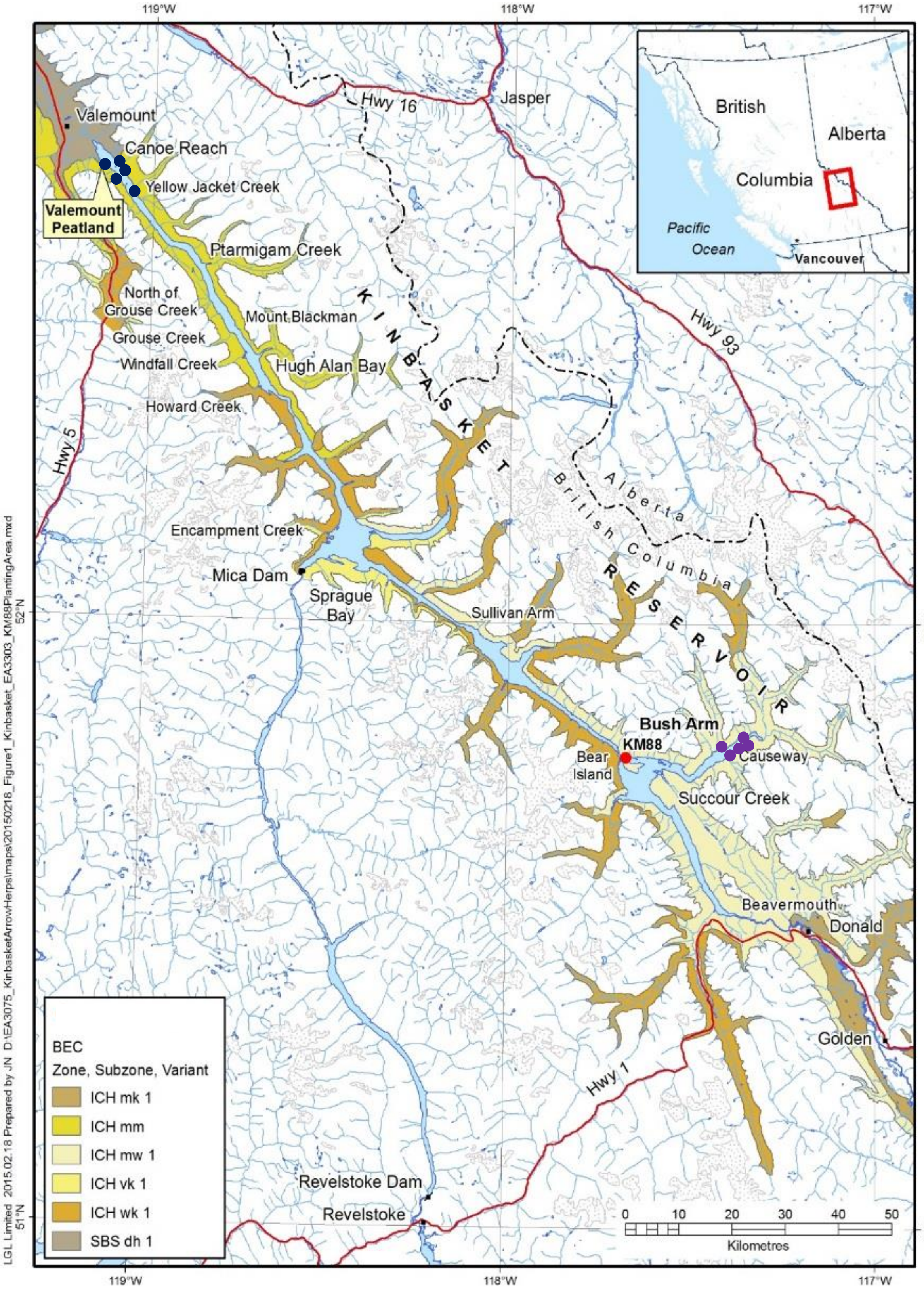

Figure 2-2: General location of the woody debris removal experimental treatments in Canoe Reach (blue dots), the Km88 sedge planting area (red dot), and the Bush Arm physical works sites (purple dot)

2.2 Climate[3]

Precipitation in the basin occurs from the flow of moist low-pressure weather systems that move eastward through the region from the Pacific Ocean. More than two-thirds of the precipitation in the basin falls as winter snow, resulting in substantial seasonal snow accumulations at middle and upper elevations in the watersheds. Summer snowmelt is complemented by rain from frontal storm systems and local convective storms.

Temperatures in the basin tend to be more uniform than does precipitation. With allowances for temperature lapse rates, station temperature records from the valley can be used to estimate temperatures at higher elevations. The summer climate is usually warm and dry, with the average daily maximum temperature for June and July ranging from 20°C to 32°C. The average daily minimum temperature in summer ranges from 7°C to 10°C. The coldest month is January, when the average daily maximum temperature in the valleys is near 0°C and average daily minimum is near -5°C.

During the spring and summer months, the major source of stream flow in the Columbia River is water stored in large snowpacks that developed during the previous winter months. Snowpacks often accumulate above 2000 m ASL through the month of May and continue to contribute runoff long after the snowpack has been depleted at lower elevations. Runoff begins to increase in April or May and usually peaks in June to early July, when approximately 45 per cent of the runoff occurs. Severe summer rainstorms are not unusual in the Columbia Basin. Summer rainfall contributions to runoff generally occur as short-term peaks superimposed upon high river levels caused by snowmelt. These rainstorms may contribute to annual flood peaks. The mean annual local inflow for the Mica, Revelstoke and Hugh Keenleyside projects is 577 m3/s, 236 m3/s and 355 m3/s, respectively.

2.3 Habitat

Most of the study area (i.e., the upper portion of the drawdown zone between 741 m and 754 m ASL) is comprised of steep slopes with cobble, gravel and sandy substrates. Areas that are less steep and/or are protected from the scouring action of coarse woody debris and waves allow for the accumulation of finer materials (e.g., silt, fine organic material) and support a wider variety of habitats, including grasslands, shrubs and wetlands dominated by swamp and marsh horsetail, various sedges, wool-grass, willows, common reed and rushes (see Hawkes et al. [2007] and Hawkes and Muir [2008] for a detailed description of habitat types).

The northern end of the reservoir, Canoe Reach, is ecologically sensitive due to presence of a vast remnant peatland. The Valemount Peatland, near the town of Valemount, B.C., is situated entirely within the ICHmm. Historically, this peatland was likely a combination of sedge and horsetail fen and a swampy forest dominated by spruce (Ham and Menezes 2008, Yazvenko 2008a, pers. obs.). Currently, most of its surface is covered by diverse plant communities ranging from typical wetlands (i.e., dominated by sedges, horsetails and other wetland plants) to more disturbed types dominated by non-wetland plants. Large areas are virtually devoid of vegetation and are covered by a mass of wood chips that are probably the result of the decay of floating logs (descriptions in Hawkes et al. [2007]). Other notable

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[3] From BC Hydro (2007) after BC Hydro (1983)

habitats in the northern end include wetlands and ponds on the gently sloping banks along the eastern side of the reservoir. The habitats around Mica Creek, including Sprague Bay and Encampment Creek, are composed primarily of low-gradient, silty flats or sloping shorelines of cobble and/or gravel.

The southern end of the reservoir includes mainly Bush Arm and the areas north of its mouth. It is characterized by an abundance of habitats on flat or gently sloping terrain that was created by sedimentation from Bush River and other inflowing streams. Another feature of these habitats is their protection from wind and wave action by the islands and peninsulas that protrude along the shoreline. This combination creates the largest variety of valuable habitats in the entire reservoir. Extensive fens and other wetlands have been identified in this area (Hawkes et al. 2007), and a high diversity of plants is supported by this variety of habitats.

2.4 Reservoir Operations

A hydrograph of Kinbasket Reservoir is provided in Figure 2-3 illustrating the variation in reservoir operations across years of sampling associated with CLBMON-9. Figure 2-4 provides a summary of the annual variation in water levels between 1977 and 2018.

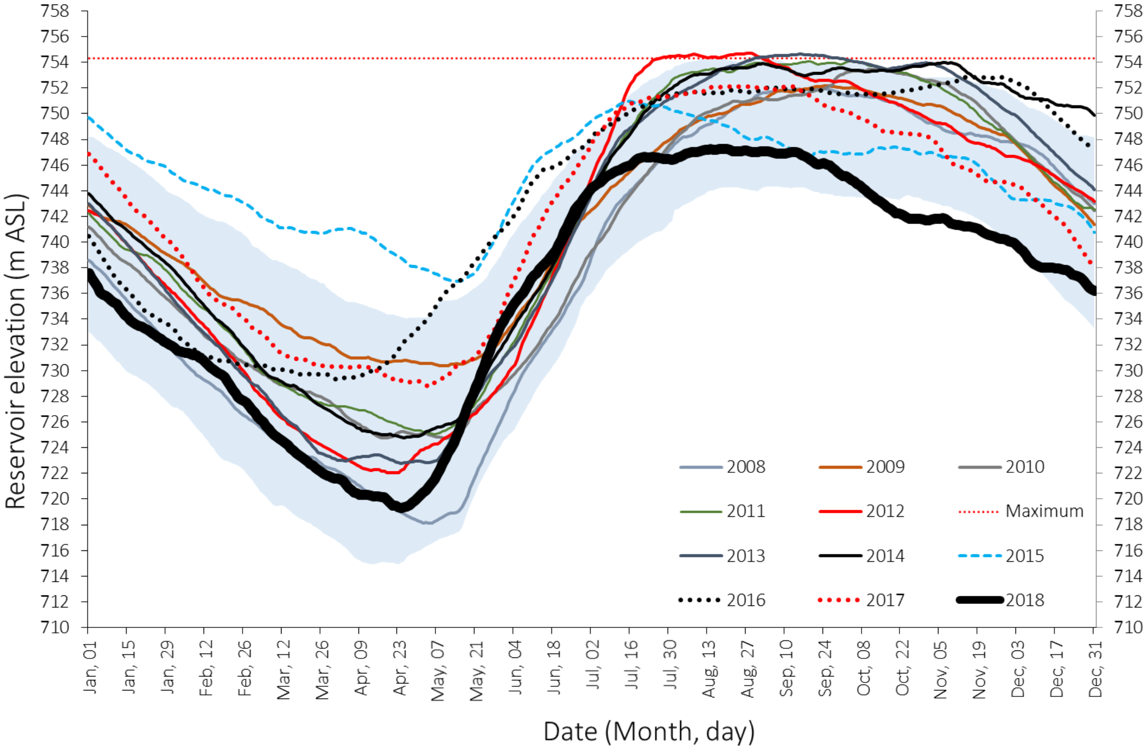

Figure 2-3. Kinbasket Reservoir elevations (m ASL), 2007 to 2018. The shaded area indicates the 10th and 90th percentile (1976 to 2018). The red dashed horizontal line indicates the operating maximum.

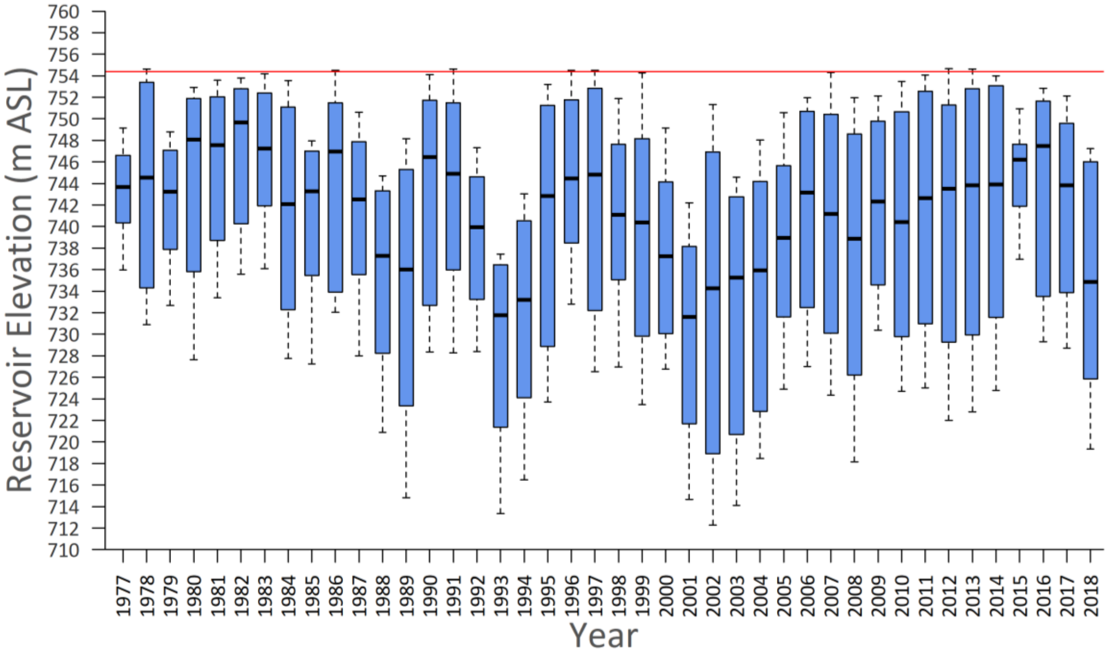

Figure 2-4. **Annual variation in Kinbasket Reservoir elevations between 1976 and 2018.** The normal maximum of 754.38 m ASL is shown by the horizontal red line

3.0 TREATMENTS AND MONITORING

The treatments applied under CLBWORKS-1, and monitored under CLBMON-9, are reviewed below under the two subheadings of Revegetation Trials and Physical Works Trials, reflecting the dual (but related) approaches taken since 2008 to increase vegetation establishment in the drawdown zone of Kinbasket Reservoir.

3.1 Revegetation Trials (2008-2011)

During this initial phase, a total of 69.15 ha in 19 treatment areas around Bush Arm and Canoe Reach was planted by Keefer Ecological Services (Keefer et al. 2007, 2008, 2010, 2011). Plug seedling treatments, particularly those involving Kellogg's sedge (*Carex kelloggii*) alone or mixed with other species, dominated the planting regime, although eight different revegetation prescriptions involving sedges, grasses, and shrubs were applied during this time. Outplanted material consisted of a mix of nursery-grown seedling plugs and locally harvested live stakes.

3.1.1 2008 Planting Activities[4]

In 2008, CLBWORKS-1 plantings were implemented on seven sites in Bush Arm. Initial treatments included sedge and deciduous seedling planting, live staking and direct sowing of Kellogg's sedge (*Carex kelloggii*), alsike clover (*Trifolium hybridum*), and bluejoint reedgrass (*Calamagrostis canadensis*) seed (Keefer et al. 2008). Planting prescriptions primarily targeted shoreline environments where vegetation levels, and likely species diversity, were depressed. Approximately 14,000 live stakes were planted including willow

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[4] From Keefer Ecological Services (2012)

(*Salix* spp.), black cottonwood (ssp. *trichocarpa*) and red-osier dogwood (*Cornus stolonifera*). Stakes were planted at or above 751 m elevation. A small number of willows, wild rose (*Rosa* sp.) and black cottonwood seedlings were planted on two sites at or above 751 m. A total of 43,000 sedge seedlings (Kellogg's sedge, wool-grass (*Scirpus atrocinctus*) and small-fruited bulrush (*S. microcarpus*) were planted on three sites between 746 m and 754 m in elevation and on a variety of substrates, including sand, silt and clay. Seeds were applied at five debris management sites using three native seed mixes developed specifically for the program (Keefer et al. 2008). The upland seed mix and alsike clover were applied to a portion of one site where they were inter-sown with planted Kellogg's sedge seedlings and planted as a mix with sedge seed. Kellogg's sedge seeds coated with a hydrophilic polymer were applied to a small portion of three sites.

To assist with planting site selection, a reconnaissance level survey was undertaken in 2007 on polygons delineated by Moody and Carr (2003) to assess plant community types and site characteristics, including soil attributes. Sites were chosen based on 2007 site verification data (Keefer et al 2007), access considerations, and whether debris management activities had been conducted in the fall of 2007. Other criteria for site selection included recreation values, wildlife habitat, the potential to protect sites from erosion with vegetation cover, the protection of archaeological resources, and the need to cluster treatment sites for cost effectiveness. Further information on prescription development is contained in Keefer et al. (2008). Site-specific details on physical conditions, revegetation methods, treatment distributions, planting densities, and planting success are currently being catalogued under CLBMON-35.

3.1.2 2009 Planting Activities[5]

In 2009, plantings were implemented on eight sites in Canoe Reach from Canoe Mouth south to Windfall Creek. Treatments included live staking, sedge planting, deciduous seedling planting, direct sowing, and fertilization.

A total of 1,540 live stakes (900 black cottonwood, 566 willow, and 74 red-osier dogwood) were planted over 0.73 ha. A total of 193,821 individual sedge seedlings were planted over 19.00 ha, Kellogg's sedge was the most widely used with 89,550 seedlings planted, followed by small-fruited bulrush (27,734), bluejoint reedgrass (26,775), wool-grass (25,560), water sedge (*C. aquatilis*) (13,402), and Columbia sedge (*C. aperta*) (10,800). A total of 8,784 deciduous seedlings, consisting of mountain alder (*Alnus incana* subsp. *tenuifolia*) and three species of willow (*Salix scouleriana*, *S. bebbiana*, and an unidentified willow sp.), were planted over 2.97 ha at Canoe Mouth, Valemount Peatland, and Yellow Jacket Creek.

Direct sowing treatments consisted of operational and experimental trials over 8.0 ha at five sites. Three different seed mixes (upland, wetland, buffer) were used for these trials (Keefer et al. 2010). All sites were broadcast fertilized with an Arrow blend (16N-20P-12K-7S) of fertilizer following planting.

The results of treatments implemented in Bush Arm in 2008 guided prescriptions for 2009 (Keefer et al. 2008). Good survival and growth of sedge seedlings resulted in an expansion of this treatment in 2009, while promising survival of deciduous seedlings observed in 2008

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[5] From Keefer Ecological Services (2012)

resulted in further implementation of this treatment. Only modest success was achieved with live stakes in 2008; thus, the prescribed use of this treatment was reduced in 2009.

Treatments were stratified by delineating three elevation zones: lower (741-745.9 m ASL), middle (746-750.9 m ASL), and upper (> 751 m ASL). Due to the uncertainty around the revegetation potential of the lower band, all activities on these sites were designed as research trials. Mid-elevation sites were planted primarily as operational trials, with prescriptions that included seedling planting, seeding and fertilization. Treatments on upper zone sites included live stake planting, deciduous seedling planting, and the construction of modified brush layers on unstable slopes and on sites that had substrates too coarse for live staking.

Further information on prescription development is contained in Keefer et al. (2010). Site-specific details on physical conditions, revegetation methods, treatment distributions, planting densities, and planting success are catalogued in Hawkes et al. (2019).

3.1.3 2010 Planting Activities[6]

The 2010 prescriptions for Kinbasket Reservoir incorporated lessons learned from planting and site selection in previous years. The 2010 planting plan was developed based on 2009 site verification activities, discussion with BC Hydro regarding modifications to previous standards, and adaptations from past CLBWORKS-1 and 2 observations (Keefer et al. 2011).

For 2010, revegetation efforts were focused exclusively in Bush Arm. Five sites were treated with sedge and deciduous seedling planting. In total, 149,430 sedges were planted over 10.84 ha and 8,820 deciduous seedlings were planted over 5.53 ha. Kellogg's sedge was the most widely planted sedge with 96,210 seedlings planted followed by wool-grass (27,735), water sedge (15,780), Columbia sedge (5,970), and small-fruited bulrush (3,735). Black cottonwood was the most used deciduous seedling with 4,755 seedlings planted, followed by mountain alder (2,800), and Bebb's willow (1,265).

As in 2009, treatments were stratified into three elevation zones: lower (741-745.9 m ASL), middle (746-750.9 m ASL), and upper (> 751 m ASL). Sedge seedling planting was prescribed mainly in the middle elevation zone, with limited planting in the lower and upper zones. Only small research trial plantings were prescribed for the lower zone. Sedge planting in the upper zone was integrated with deciduous seedling plantings within non-vegetated openings.

Further information on prescription development is contained in Keefer et al. (2011). Site-specific details on physical conditions, revegetation methods, treatment distributions, planting densities, and planting success are catalogued in Hawkes et al. (2019).

3.1.4 2011 Planting Activities[7]

In 2011, planting was focused on Bush Arm and consisted of sedge and deciduous seedlings, and live stakes. A total of 161,225 sedge seedlings (2 sites, 6.84 ha), 2,280 willow seedlings (2 sites, 0.59 ha, species unknown) and 987 black cottonwood live stakes (1 site, 1.10 ha) were planted. The planting of deciduous seedlings and live stakes was limited to the upper elevation band (> 751 m). Monitoring of live stakes planted in 2008 and 2009

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[6] From Keefer Ecological Services (2012)

[7] From Keefer Ecological Services (2012)

showed that survival of hand-planted stakes remained low and most plantations were functionally dead. In 2011, live stakes were machine planted among stakes that were hand planted in 2008, to assess if the machine planting method would result in better survival than hand planting. Further information on prescription development is contained in Keefer Ecological Services (2012).

The planting effort from 2008 to 2011 is summarized in Table 3-1. Site-specific details on physical conditions, revegetation methods, treatment distributions, planting densities, and planting success are catalogued in Hawkes et al. (2020).

Table 3-1. **Summary of CLBWORKS-1 revegetation effort from 2008 to 2011, including treatment methods and total number of hectares treated by each method.** ATV = ATV-spread seed; BL = brush layer; EPL = excavator-planted live stakes; HPL = hand-planted live stakes; PS = plug seedling; HS = hand seeding; ST = seeding trials.

Treatment Method	Prescription	No. Hectares Planted				
		2008	2009	2010	2011	Total
ATV	Bluejoint reedgrass		0.52			0.52
BL	Black cottonwood		0.01			0.01
EPL	Mixed hardwood				1.10	1.10
HPL	Black cottonwood		0.02			0.02
	Mixed hardwood		0.43			0.43
	Willow	1.60				1.60
	Mixed hardwood	7.66				6.28
	Mixed hardwood stakes/willow plugs		0.21			0.21
PS	Alder/willow		0.56			0.56
	Black cottonwood/mountain alder			2.10		2.10
	Black cottonwood/mountain alder/willow			2.02		2.02
	Bluejoint reedgrass		0.19			0.19
	Bluejoint reedgrass/Kellogg's sedge				0.96	0.96
	Columbia sedge		0.20		0.12	0.31
	Mixed hardwood		1.47			1.47
	Kellogg's sedge	0.48	1.38	0.17	4.37	6.40
	Kellogg's/Columbia sedge			1.33		1.33
	Kellogg's sedge/cottonwood/alder/willow			1.41		1.41
	Kellogg's sedge/wool-grass			5.86		5.86
	Kellogg's/water/Columbia sedge/wool-grass			0.74		0.74
	Kellogg's sedge/wool-grass/water sedge				1.27	1.27
	Mixed hardwood		0.72			0.72
	Mixed	0.02				0.02
	Mixed (willow/cottonwood/rose/Kellogg's sedge)	0.06				0.06
	Mixed		15.06			15.06
	Mixed		0.20			0.20
	Small-fruited bulrush	0.07	0.57	0.14		0.78
	Small-fruited bulrush/water sedge		0.13			0.13
	Water sedge		0.10	0.41		0.51
	Water sedge/Kellogg's sedge/wool-grass/small-fruited bulrush			0.66		0.66
	Water sedge/small-fruited bulrush		0.35			0.35
	Water sedge/wool-grass		0.03			0.03
	Wetland mix		0.09			0.09
	Willow				0.59	0.59
	Willow/bluejoint reedgrass	0.17				0.17

Treatment Method	Prescription	No. Hectares Planted				
		2008	2009	2010	2011	Total
	Wool-grass	0.08	0.21	0.11		0.40
	Wool-grass/Columbia sedge/small-fruited bulrush		0.01			0.01
HS	BC Hydro upland mix		0.29			0.29
	BC Hydro wetland mix		0.94			0.94
	Bluejoint reedgrass		4.23			4.23
ST	BC Hydro upland/BC Hydro wetland mix		0.07			0.07
	BC Hydro upland/wetland mix, Kellogg's sedge		3.06			3.06
	BC Hydro wetland mix		0.54			0.54
	Kellogg's sedge coated seed		1.55			1.55
	Kellogg's sedge pellet seed		0.24			0.24
	Kellogg's sedge seed	0.14	1.37			1.51
	Upland mix	0.73				0.73
	Total no. hectares ATVS		0.52			0.52
	Total no. hectares BL		0.01			0.01
	Total no. hectares EPL				1.10	1.10
	Total no. hectares HPL	7.88	0.08			7.96
	Total no. hectares HPL/PS	1.38	0.59			1.97
	Total no. hectares PS	0.88	21.28	14.97	7.30	44.43
	Total no. hectares HS		5.46			5.46
	Total no. hectares ST	0.87	6.83			7.70
	Total No. Hectares	11.01	34.77	14.97	8.40	69.15

3.1.5 2013 Planting Activities (Km88 Sedge Trial)[8]

In the spring of 2013, 3.3 hectares (ha) of drawdown zone habitat at Km88 site were planted with nursery-raised seedlings (plugs) of Kellogg's sedge (*Carex kelloggii*) and Columbia sedge (*C. aperta*). The stock consisted of 68,020 unused plugs leftover from the initial phase of the revegetation program, which was postponed after 2012 due to poor plant survival and establishment (Adama 2015). The goal of the Km88 planting prescription was to introduce seedlings at a site (or sites) in the reservoir where they would have a high chance of establishment.

The Km88 area was identified as a potential planting site based on the following features (Adama 2013):

1. The presence of the KS (Kellogg's sedge) community type (Hawkes et al. 2007) suggested that Kellogg's sedge and Columbia sedge should establish here;
2. Soils are mineral as opposed to organic, gravel or rocky. Previous plantings on rocky or organic soils has resulted in poor survival. Survival was anticipated to be higher on mineral soils based on the life history requirements of the two *Carex* species;
3. Km88 had been identified as a high value site for wildlife and vegetation resources (Hawkes et al. 2007); and
4. Km88 is located on a south facing aspect and the prevailing winds come from the north. Consequently, the site was in the lee of the wind and is less prone to

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[8] From Adama (2015)

woody debris accumulation. This was an important consideration as many previously planted sites had been blanketed with large amounts of wood debris, reducing the efficacy of the revegetation effort and creating conflict with the debris program (Keefer Ecological Services 2012).

Five potential treatment polygons were identified of which two were retained as controls and three were planted. Two polygons were planted with Kellogg's sedge and one polygon was treated with a mixture of Kellogg's and Columbia sedge. The planting objectives were to increase the extent of the Kellogg’s sedge (KS) community down to 746 m ASL and to increase the density of sedges in the polygons to between 5,000 and 15,000 plants per ha. Sedges were planted at ~23,000 plugs per ha across the three treatment units (0.5, 0.82, and 1.95 ha) (Adama 2013).

Further information on prescription development is contained in Adama (2015). Site-specific details on physical conditions, revegetation methods, treatment distributions, planting densities, and planting success are catalogued in Hawkes et al. (2019).

3.1.6 Effectiveness Monitoring (2008-2018)

The study design for monitoring revegetation effectiveness followed the methods implemented by Yazvenko (2009) and subsequently modified by Fenneman and Hawkes (2012) and Hawkes et al. (2013). Methods are summarized below.

Monitoring was stratified based on five variables:

1. **Geographic area.** Two reservoir regions—Canoe Reach and Bush Arm—were sampled.
2. **Vegetation communities.** Sampling was stratified among community types using the classification system developed in 2007 (Hawkes et al. 2007; Table 3-2). Twelve of the most common community were sampled. We also sampled in two non-vegetated habitat types (DR and WD) (Table 3-2). In 2014 two additional communities (not included in Table 3-2) were added: the DI (Disturbed) and SW (Shrub-Willow) communities. The vegetation community codes in Table 3-2 are referred throughout this document.
3. **Elevation.** We blocked elevation bands into three strata:
   - 741-745 m ASL (Low elevation zone)
   - 746-750 m ASL (Mid elevation zone)
   - 751-754 m ASL (High elevation zone)
4. **Revegetation prescription.** Assessments of revegetation effectiveness focused on four prescription types that had the highest sample sizes and number of replicates:
   - hand-planted stakes
   - hand-planted stakes and plug seedlings
   - hand seeding
   - plug seedlings

Table 3-2. **The 19 vegetation communities classified for the 13 m drawdown zone of Kinbasket Reservoir (741 m to 754 m ASL).** Note that only the BC and SH communities align with site series classifications used in BC (Mackenzie and Moran 2004); the remainder are unique to the drawdown zone of Kinbasket Reservoir.

Code	Common Name	Scientific Name	Drainage	Typical Location
LL	Lady's thumb – Lamb's quarter	*Persicaria maculata – Chenopodium album*	imperfectly to moderately well	lowest vegetated elevations
CH	Common horsetail	*Equisetum arvense*	well	above LL or lower elevation on sandy, well-drained soil
TP	Toad rush - Pond water-starwort	*Juncus bufonius - Callitriche stagnalis*	imperfectly	above LL, wet sites
KS	Kellogg's sedge	*Carex Kelloggii* (syn. *Carex lenticularis* spp. *licocarpa*)	imperfectly to moderately well	above CH
BR	Bluejoint reedgrass	*Calamagrostis canadensis*	moderately well	above CH, often above KS
MA	Marsh cudweed - Annual hairgrass	*Gnaphalium uliginosum - Deschampsia danthonioides*	Imperfectly to moderately well	common in the Bush Arm area
RC	Canary reedgrass	*Phalaris arundinacea*	imperfectly to moderately well	similar elevation to CO community
RD	Common reed	*Phragmites australis*	poor	Above BR and below CO
CO	Clover - Oxeye daisy	*Trifolium* spp. - *Leucanthemum vulgare*	well	typical just below shrub line and above KS
CT	Cottonwood - Clover	*Populus balsamifera* spp. *trichocarpa-Trifolium* spp	imperfectly to well drained	above CO, below MC and LH
MC	Mixed conifer	*Pinus monticola, Pseudotsuga menziesii, Picea engelmanni X glauca, Tsuga heterophyla, Thuja plicata*	Well	above CT along forest edge
LH	Lodgepole pine - Annual hawksbeard	*Pinus contorta - Crepis tectorum*	well to rapid	above CT along forest edge, very dry site
BS	Buckbean - Slender sedge	*Menyanthes trifoliata-Carex lasiocarpa-Scirpus atrocintus, S. microcarpus*	Very poor to poor	wetland association
WB	Wool-grass - Pennsylvania buttercup	*Scirpus atrocinctus - Ranunculus pensylvanicus*	imperfectly to poor	wetland association
SH	Swamp horsetails	*Equisetum variegatum, E. fluviatile, E. palustre*	poor	wetland association
WS	Willow - Sedge wetland	*Salix - Carex* species	Very poor to poor	wetland association
DR	Driftwood	Long linear bands of driftwood, very little vegetation	n/a	whole logs and large pieces of logs without bark
WD	Wood debris	Thick layers of wood debris, no vegetation	n/a	typically small pieces similar to bark mulch
FO	Unclassified forest	Any forested community	n/a	Above drawdown zone (>756 m ASL)
DI	Disturbance	n/a	n/a	n/a

5. **Treatment and control sites.** For every combination of elevation, vegetation community, and treatment type, treatment plots were matched with untreated controls to derive a series of paired (treatment and control) samples. Controls were established in 10 x 20 m sites that were selected in two ways: (a) by the CLBWORKS-1 team within areas subjected to treatments and (b) within control (reserved) polygons in areas as similar as possible to treatment areas (in terms of vegetation community and elevation). Controls sites were selected to represent vegetation that was similar to that being treated and were presumed to be uninfluenced by seed contamination from adjacent treated areas.

Although efforts were made to sample all strata combinations (community x elevation x planting prescription) occurring in each reservoir region, not all combinations of strata were available in all geographic regions, due both to the differential distribution of vegetation communities in the drawdown zone and to the spatially inconsistent application of planting prescriptions.

3.1.6.1 Vegetation Plots

At each predetermined sample location (marked with a capped rebar stake at the time of establishment), the researcher made three random tosses of a 0.71 m x 0.71 m (0.5-m^2) quadrat frame. Natural or anthropogenic factors influencing vegetation establishment were recorded, including wildlife grazing/browsing, human-influenced disturbance (e.g., ATV use), and erosion. Vegetation within each quadrat was identified to species, or in some cases, to genus, and the percentage cover was visually estimated following MuellerDombois and Ellenberg (1974). Data on surface substrate texture and stand structure were recorded using standardized methodologies (Luttmerding et al. 1990). Vegetation cover was enumerated by layer:

A1: Dominant trees
A2: Main canopy trees
A3: Sub-canopy trees
B1: Tall Shrubs (woody plants 2 m to 10 m tall)
B2: Low Shrubs (woody plants less than 2 m high)
C: Herbs (forbs and graminoids)
D: Moss, lichen, seedlings and substrate surface

Total species cover was visually estimated for each quadrat, and a mean per cent cover per quadrat was computed in office.

The survivorship of plants used in the revegetation program was assessed in three 5 x 5 m subplots centred on the 0.5-m^2 quadrat. Only revegetated areas were assessed for survivorship. The subplots were positioned to represent the overall condition of the plants in each site. Within these subplots, the number of observable seedlings or stakes observed was recorded, as well as the total number of individuals alive versus dead.

3.1.6.2 Soil Sampling

Soil samples were obtained for a subset of vegetation plots (both treatment and control plots) and later tested in lab for: organic matter; total carbon (C); inorganic carbon; organic carbon; total Nitrogen (N); Phosphorus (P); Potassium (K); Magnesium (Mg); and Calcium (Ca).

3.1.6.3 Vegetation Biomass and Nutrient Analysis

Vegetation samples were collected at each treatment and control site for analysis of nutrient content. Within each of the three quadrats at each sample location, a 0.5 m x 0.5 m (0.25-m^2) subplot was installed, from which all aboveground vegetation matter was collected (clipped) and dried. Laboratory analysis of the biomass samples included determination of the following: sample total weight; inorganic Carbon (%); organic Carbon (%); total Nitrogen (%); sample weight dry ash (P, K, Mg, Ca); Phosphorus (%); Potassium (%); Magnesium (%); and Calcium (%).

3.1.6.4 2018 Reassessment of 2008-2011 Trials

After a 5-year break in monitoring, during which attention was focused on other CLBWORKS-1 restoration initiatives (Section 1.3, and below), a final follow-up survey of the 2008-2011 plantings was conducted in 2018 (Miller and Hawkes 2019). The 2018 objective was to carry out as comprehensive an inventory as logistically possible of the original CLBWORKS-1 revegetation polygons to assess transplant performance (survivorship and vigour) seven to 10-years post-treatment. A total of 91 polygons were surveyed. The inventory included some polygons that had not been previously surveyed under CLBMON-9 due to the random sub-sampling approach adopted in the original study design (Yazvenko et al. 2009). Assessments in 2018 included the conducting of ground inspections to characterize site-specific vegetation and topo-edaphic conditions; and the collection of soil samples to gain a better understanding of potentially limiting site factors (data that will be used to inform the ongoing BC Hydro study, CLBMON-35: Arrow Lakes and Kinbasket Reservoirs Plant Response to Inundation).

A total of 85 CLBWORKS-1 revegetation polygons were assessed in 2018, encompassing both Canoe Reach and Bush Arm. From west to east, general areas visited were: Canoe River Mouth, Valemount Peatland, Dave Henry Creek North, Dave Henry Creek South, Yellow Jacket Creek, Ptarmigan Creek, Windfall Creek, Km88 Peatland, Km 79, Km 77, Prattle/Chatter Creeks, and Hope/Goodfellow Creeks.

The presence or absence of signs of successful revegetation was noted for each assessed polygon. For each polygon that exhibited successful establishment, a set of one to 10 50-m^2 sample plots was subjectively located within a representative area or areas of establishment. Polygon size and/or terrain heterogeneity was used to determine the number of plots sampled. For each sample plot, the number and vigour of surviving plugs and stakes were recorded, and site information pertaining to associated vegetation and topo-edaphic features was recorded as follows:

- Number and vigour of surviving sedge plugs (Kellogg's and Columbia sedge)
- Associated plant species covers
- Vegetation structural stage (sparse/pioneer, herb, low shrub, tall shrub)
- Aspect and slope
- General surface topography (straight, convex, concave)
- Microtopography (smooth, channelled, gullied, mounded, terraced)
- Primary water source (precipitation, stream flooding, stream sub-irrigation, surface seep)
- Soil moisture regime (xeric to hydric)
- Surface substrate (% rock, mineral soil, organics, wood, water)
- Rooting zone texture (fragmental, sandy, coarse-loamy, coarse-silty, fine-silty, fine-clayey, very-fine-clayey)
- Evidence of non-operational disturbance.

For a subsample of plots, soil was collected at rooting level from three representative locations within the plot using a soil corer. The three soil subsamples were then combined into a single sample for future lab nutrient analyses. For comparative purposes, some 50-m^2 plots were also established in adjacent microsites representing minimal or failed revegetation establishment, where the same site information was recorded. Paired soil samples were also collected from these poorly performing microsites for future soil nutrient comparisons with successful microsites.

For additional comparative purposes, 12 supplemental soil-sample plots were established within notably vigorous natural *Carex* patches at Canoe River Mouth, Yellow Jacket Creek, and Ptarmigan Creek.

A total of 165 50-m^2 plots were sampled in Canoe Reach and Bush Arm (including Km88, below), from which a total of 69 soil samples were collected and submitted for lab nutrient analyses.

Soil samples were tested (in lab) for the following parameters: Calcium (mg/Lsoil dry); total, inorganic, and organic Carbon (% dry); Potassium (mg/Lsoil dry) Magnesium (mg/Lsoil dry); Sodium (mg/Lsoil dry); total Nitrogen (mg/Lsoil dry); organic matter (% dry); and soil particle size (texture).

3.1.6.5 Km88 Big Bend Sedge Trial (2013)

In 2015, sampling of the three Km 88 sedge treatment units (Adama 2015; Figure 3-1) was conducted using randomly located 1-m^2 or 25-m^2 subplots. A total of 30 subplots (10 in each treatment unit) were sampled. The number of live sedge plants (Kellogg's and Columbia sedge) in each plot was recorded, together with plant height and vigour and the total number of reproductive (flowering) plants. The same vegetation cover and substrate information was recorded as described above for belt transects at Bush Arm/Canoe Reach. Surviving numbers were estimated by extrapolating live densities within the subplots to the entire treated area (Hawkes and Miller 2016).

In 2018, to increase count estimation accuracy, surviving plugs were enumerated within a single large (1000-m^2) polygon covering a large portion of each treated area. Three smaller (50-m^2) subplots were then established near the centre point of each polygon). At three of the subplots, soil was collected at rooting level from three representative locations within the subplot following the same procedure described above (3.1.6.4). For comparative purposes, soil samples were also collected from two sites in adjacent, non-treated vegetation (TU 4; Figure 3-1). One of these samples was intentionally situated in a vigorous vegetation patch having high covers of both sedge species; the other sample was taken from relatively unproductive microsite with minimal sedge cover. The soil samples were combined with those collected under the broader 2018 inventory (3.1.6.4) for use in the subsequent metanalysis of topo-edaphic limiting factors.

At each 50-m^2 subplot, regardless of whether a soil collection was made, the following site information was recorded:

- Number and vigour of surviving sedge plugs (Kellogg's and Columbia sedge)
- Associated plant species covers
- Vegetation structural stage (sparse/pioneer, herb, low shrub, tall shrub)
- Aspect and slope
- General surface topography (straight, convex, concave)
- Microtopography (smooth, channelled, gullied, mounded, terraced)
- Primary water source (precipitation, stream flooding, stream sub-irrigation, surface seep)
- Soil moisture regime (xeric to hydric)
- Surface substrate (% rock, mineral soil, organics, wood, water)

- Rooting zone texture (fragmental, sandy, coarse-loamy, coarse-silty, fine-silty, fine-clayey, very-fine-clayey)
- Evidence of non-operational disturbance.

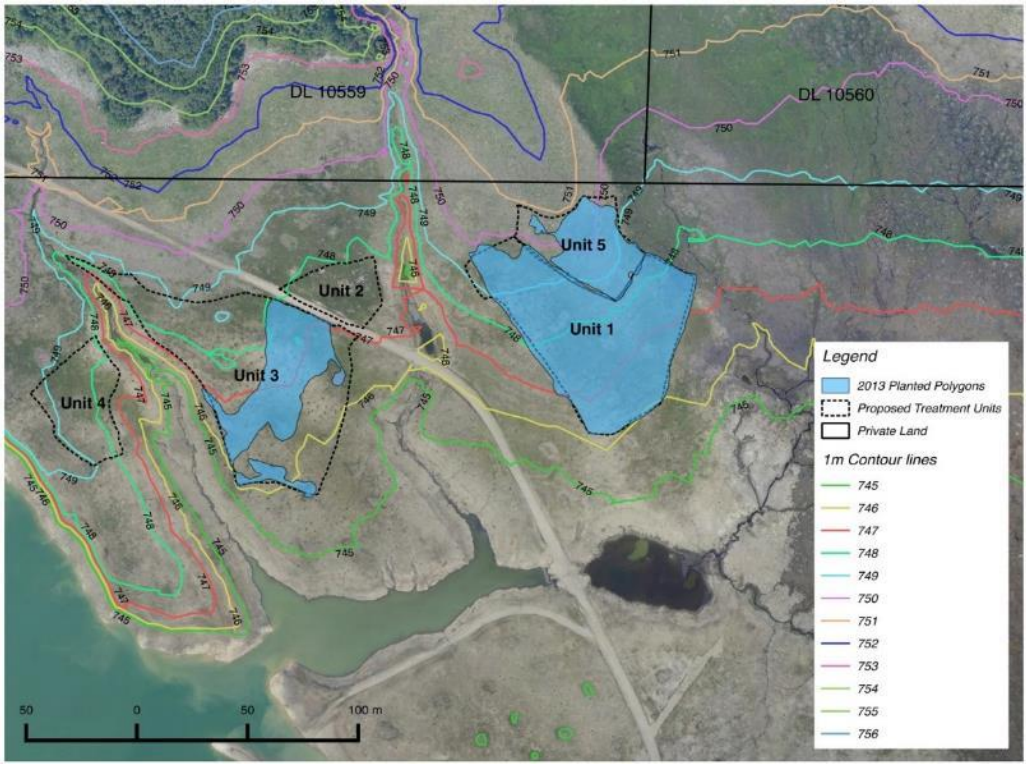

Figure 3-1: Treatment unit (TU) boundaries showing areas planted with sedges in 2013, Kinbasket Reservoir (from Adama 2015)

3.2 Physical Works (2012-2015)

3.2.1 Woody Debris Removal and Boom Exclosure (Canoe Reach)

To test whether vegetation naturally re-establishes following the removal of coarse woody debris, wood removal trials were applied at five sites at Canoe Reach under CLBWORKS-16 from 2012 to 2014, and subsequently monitored under CLBMON-9.[9] In 2012, Valemount Peatland South (VP-S) was cleared of woody debris, and in 2014 four additional sites were cleared at Canoe Reach (YJ, VP-N, Packsaddle Creek North, and Packsaddle Creek South; Figure 3-2). Areas identified for woody debris removal were all situated near the top of the drawdown zone between 752 and 755 m ASL (the primary zone of deposition). A log-boom exclusion was also installed at VP-N in 2014 as a trial to prevent debris from reaccumulating following high water events (Figure 3-2).

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[9] In 2018, a sixth site in Canoe Reach (Pond 12) was also cleared of coarse woody debris (Wood et al. 2019) but has not been monitored under CLBMON-9.

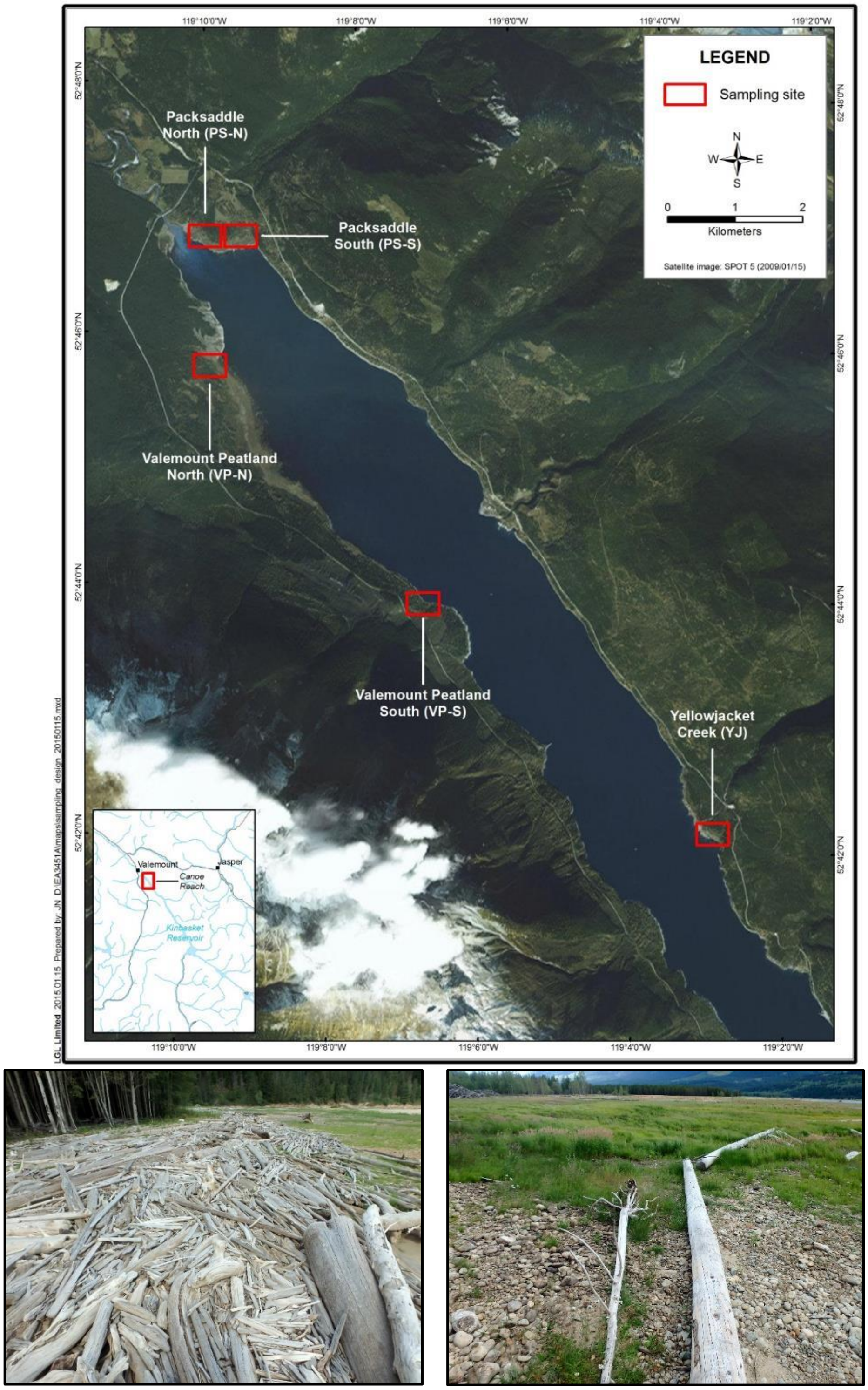

Figure 3-2: **Location of woody debris removal sites in Canoe Reach, Kinbasket Reservoir, 2014.** Lower left: woody debris accumulation at Packsaddle Creek. Lower right: log-boom installation at Valemount Peatland (North) to prevent re-encroachment of woody debris following spring wood removal. Woody debris pile from removal operation is partly visible at upper left of photo

To facilitate effectiveness monitoring, control (non-treated) sites were established adjacent to wood removal areas in 2014. However, this study design was subsequently compromised as a result of repeated treatment applications and, in some areas, the inadvertent treatment of control areas. For example, both the treatment and control sites at Packsaddle Creek North and South were re-cleared/cleared of woody debris in 2016. Similarly, the treatment site at Yellow Jacket Creek was re-cleared of wood debris in 2017.

3.2.2 Constructed Mounds, Boom Exclosure, and Baseline Conditions (Bush Arm)

The goal of this pilot project was to design, build, and assess the efficacy of elevated debris mounds and windrows for establishing self-sustaining riparian vegetation communities. It was hypothesized that planted mounds and windrows will promote the natural establishment of vegetation in the upper elevations of the drawdown zone (i.e., 750 to 754 m ASL) and that vegetation will naturally establish at wood debris removal sites. Further, it was hypothesized that terrestrial or wetland habitat behind the elevated mounds and windrows will be protected from erosion via wind and wave action and from scouring and compaction associated with wood debris (Hawkes 2016).

To test these hypotheses, and to assess the extent to which disturbance factors (e.g., woody debris, erosion, deposition, wave action, wind, and human activity) impact the effectiveness of the mounds and windrows, BC Hydro drafted the following objectives for CLBWORKS-1 in 2015:

1. Identify potential sites for assessing the application of windrows and mounds for enhancing vegetation and wildlife habitat in Kinbasket Reservoir;
2. Prepare site-specific construction specifications and restoration prescriptions for each pilot area;
3. Implement the restoration prescriptions at each site as per the site-specific construction specifications;
4. Specify pre- and post-treatment monitoring requirements (to be carried out under CLBMON-9 and CLBMON-11A) that will assess the efficacy of constructed debris mounds and windrows for establishing self-sustaining riparian vegetation communities. This will include an assessment of the:
    a. structural integrity of constructed wood debris and soil mounds and windrows in full reservoir pool conditions with the active natural processes on the reservoir (e.g., wave erosion); and
    b. the methods to establish vegetation on constructed wood debris and soil mounds/ windrows;
5. Inform BC Hydro on how reservoir operations affect the structural integrity of wood debris and soil mounds/ windrows and determine if mitigation strategies can be developed to reduce these impacts;
6. Test methods to establish vegetation on constructed wood debris and soil mounds/ windrows;
7. Inform BC Hydro on to what extent constructed wood debris and soil mounds/ windrows exclude floating woody debris from the parts of the drawdown zone shoreward of the constructed islands and windrows;
8. Establish vegetation on the constructed mounds/ windrows and integration with the Kinbasket Debris Removal Program (CLBWORKS-16); and

9. Assess the effectiveness of the CLBWORKS-1 program including the effects of treatment methods and site-specific attributes using a cataloguing approach.

In the fall of 2015, seven mounds/windrows were constructed in two areas of the upper drawdown zone at Bush Causeway using locally available materials (woody debris mixed with soil). To create the base for the mounds the ground was excavated to a depth of approximately 1 m. Large logs were placed at the face of the mound (facing the reservoir). The sill and base logs were anchored into place by inserting one end of the base logs into the soil and compressing the sill log into the soil with the excavator bucket. Large root wads were inserted into the face of the mound to form a protective barrier. The root wads and logs were covered with layers of smaller wood debris and soil set aside during excavation (Hawkes 2016).

Large woody debris was also removed from three adjacent, wood-choked ponds, with the aim of restoring some pre-existing wildlife habitat to a functioning condition (Hawkes 2016). Approximately 43 sedges of three wetland species (*Carex utriculata, C. aquatilis,* and *C. lasiocarpa*) were translocated from adjacent habitat into an area cleared of wood debris and on the edge of one of the rehabilitated wetlands (Hawkes 2017).

Following mound construction in the fall of 2015, and again in the spring and fall of 2016, the mounds and adjacent cleared areas were stocked with locally harvested live stakes (primarily of black cottonwood). A total of 106 live stakes (black cottonwood) were planted between fall 2015 and fall 2016 (Hawkes 2017).

To protect wetland habitats and wood debris mounds at the Bush Causeway North site, a 312-m long log-boom was installed in June 2016 (Hawkes 2017). The boom was constructed of 22 logs and 12 lock blocks and extended from the causeway near the bridge over the Bush River to a high point just above the drawdown zone to the northwest. The installation of the log-boom does not preclude an assessment of the integrity of the mounds following a high water event as the mounds will still be inundated and subject to wind and wave action (Hawkes 2017).

3.2.3 Effectiveness Monitoring (2014-2018)

3.2.3.1 Canoe Reach

At Canoe Reach, belt transects were established and sampled in June 2014 to capture any initial within-season vegetation response to the clearing of woody debris. Transects were 20 m x 0.5 m, divided into 10 contiguous 1-m^2 quadrats to allow for subsampling and to increase accuracy of cover estimates (after Hawkes et al. 2007).[10]

Sampling at each of the five debris-cleared sites (including the log-boom installation at Valemount Peatland) was replicated among treated and control transects spanning an approximately 300 m linear area of shoreline. At each site, three belt transects were overlaid across the cleared area, orientated in a linear line parallel to the elevation contour. Three matching control transects were situated in the untreated accumulation zone immediately adjacent and at a similar elevation to the cleared area.

During the June survey, it was noted that the area protected behind the log-boom exclosure appeared especially lush and showed a diversity of regenerating species. As

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[10] For 2015, the sample dimension was changed to 5 contiguous 2-m^2 quadrats in order to reduce estimation time.

some late-summer species were still emerging, a second follow-up visit was conducted in July in order to compile a more comprehensive list of regenerating species (Hawkes and Miller 2016).

The same five sites were resampled in 2015 to document responses one-year post-treatment. Sampling entailed relocating the belt transects established in 2014, re-recording species covers and surface substrates, and collecting soil samples for lab analysis (Hawkes and Miller 2016).

Following 2015, the experimental design of the trials was compromised due to the uncoordinated treating of experimental controls and re-treatment of experimental treatments (Wood et al. 2017). In 2017 and 2018, resampling was therefore restricted to the woody debris removal and the log-boom installation site at Valemount Peatland.

3.2.3.2 Bush Arm

In 2015, pre-treatment (baseline) monitoring was conducted at the five proposed physical works sites in Bush Arm. The proposed sites were at Bush Causeway North, Bush Causeway South (both of which were subsequently treated in fall 2015), Goodfellow Creek, Hope Creek, and Chatter Creek (Figure 3-3). The sampling approach was similar to that for woody debris removal sites and boom exclosures in Canoe Reach, modified to take advantage of the pre-treatment status of this site by implementing an experimental block (BACI) design.

Using GIS, a treatment polygon was delineated in each of the five proposed treatment areas. A second, adjoining polygon was delineated adjacent to the treatment polygon to serve as a control. The control polygon was similar in terms of elevation, substrate type, and vegetative cover to the treatment polygon (Hawkes 2016; Figure 3-3).

Vegetation and soils within each treatment and control polygon were sampled within a series of belt transects, following a similar approach used to sample woody debris removal treatments in Canoe Reach (8). Belt transects were 20 m x 0.5 m, divided into 5 contiguous 2-m^2 quadrats to allow for sub-sampling and to increase accuracy of plant cover estimates. The number of transects assessed at each site was a function of polygon size and the local elevational gradient. Where possible, the two 2-m elevation bands between 750 m ASL and 754 m ASL (750-752 m and 752-754 m) were sampled at each location, with a target of six replicates established per band. Sampling entailed establishing transects parallel to the contour line, recording the per cent cover of all plant species, characterizing substrates, and collecting soil samples for later lab analysis (Hawkes and Miller 2016).

Preliminary post-construction monitoring of constructed debris mounds and transplanted vegetation at Bush Causeway occurred in 2016 under CLBWORKS-1 (Hawkes 2017). Post-treatment monitoring of the mounds (and adjacent controls) continued under CLBMON-9 in 2017 and 2018. Monitoring in both years entailed resampling of baseline transects established in 2015 and, in 2018, an assessment of vegetation presence (both transplanted and naturally established) on the mounds. For this assessment, the number of surviving live stakes was tallied and all plant species growing along the base, mid, and upper zones of the mounds were recorded. A brief visual assessment was made of the three cleared ponds. This included compiling a cursory list of aquatic macrophytes re-establishing in two of the ponds and recording photos of the recovering habitats. (Miller and Hawkes 2019).

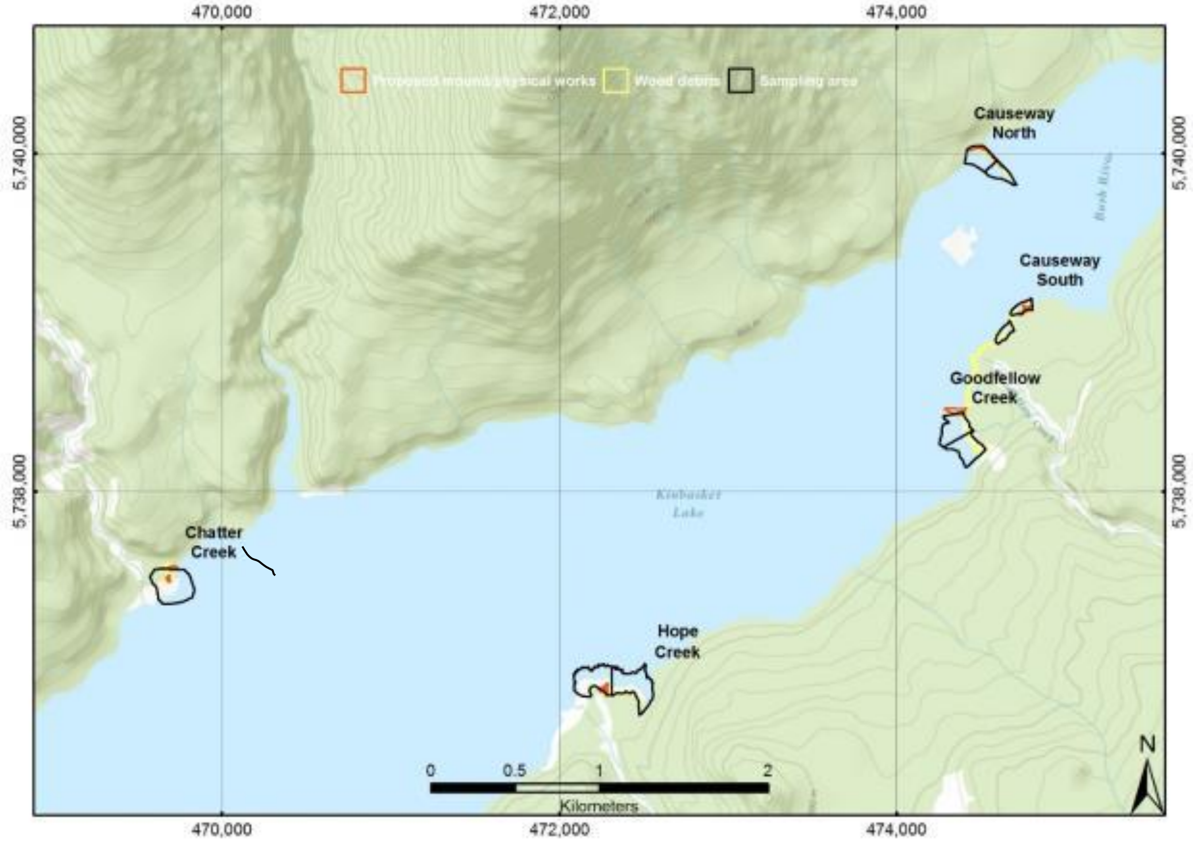

Figure 3-3: **Location of proposed physical works locations in Bush Arm, Kinbasket Reservoir.** The Causeway North and Causeway South sites were treated in 2015 (from Hawkes [2016]).

Baseline monitoring of the proposed Goodfellow, Hope, and Chatter Creek sites was also repeated in 2018 (i.e., the transects established in 2016 were resampled; Miller and Hawkes 2019).

4.0 RESULTS

4.1 Revegetation Trials (2008-2011)

4.1.1 Survivorship and Vigour

Effectiveness monitoring between 2008 and 2013 indicated that, overall, the 2008-2011 transplants performed poorly at most treatment sites. Survivorship of woody live stakes was essentially nil across all sites. By 2011, < 40 per cent of plugs planted in 2009 were recorded as still surviving (Fenneman and Hawkes 2012). By 2013 (Hawkes et al. 2013), few of the polygons that received plug seedlings in 2009 still contained live plugs (for some notable exceptions, see 4.1.4). Individual survivorship rates were difficult to derive for sample plots because only the surviving plugs were visible; plugs that had died in previous years had either rotted or floated away, making it impossible to determine precisely how many plugs were in the ground originally (N_0). Instead, we assumed an N_0 of ~58 plugs per 25-m^2 plot based on the average planting densities reported by Keefer et al. (2011). Using this extrapolation, the average survivorship of plugs four years after planting ($t = 4$) was 4 per cent. For plugs planted in 2010 and 2011 ($t = 3$ and $t = 2$), survivorship was 7 per cent and 44 per cent, respectively (Appendix 9.1: Figure 9-1). Two of the polygons sampled were planted with plugs twice: first in 2010 and again in 2011. In those polygons, only three per cent of planted plugs were still surviving in 2013.

The vigour of surviving plug seedlings also declined steadily with time since planting. The percentage of revegetation sites assessed as having overall “good” or “moderate” vigour dropped from 75 per cent for sites that were planted in 2011 to 8 per cent for sites that were planted in 2010 and 14 per cent for sites that were planted in 2009. Similarly, the number of sites assessed as exhibiting “poor” vigour increased from 25 per cent for 2011 sites to 92 per cent for 2010 sites to 86 per cent for 2009 sites. The slightly better results for 2009 plugs versus 2010 plugs in our sample was due entirely to successful establishment of plugs within one polygon at Yellow Jacket Creek (Canoe Reach).

The trends in both live deciduous stake and sedge plug seedling survivorship suggest that there is considerable mortality and loss of vigour during the years following revegetation of the drawdown zone, with mortality exceeding 95 per cent after four years of planting. The mortality of stakes and plugs can probably be attributed to a combination of natural attrition, prolonged inundation, erosion, heavy sedimentation, anaerobic substrate conditions, and woody debris scouring. These abiotic pressures are ongoing, therefore continuing declines in transplant survivorship can be expected. However, because those transplants that have successfully established are by now more robust and hence better equipped to deal with prevailing reservoir conditions, we can expect to see a stabilizing of numbers and a leveling out of the mortality curve.

4.1.2 Cover, Richness, and Diversity

Not surprisingly given the low transplant survivorship, revegetation did not have a significant measurable impact on associated vegetation community indices. There was actually a general decrease in both total per cent cover and species richness in treatment plots since 2011, mirroring a similar trend in control plots. We found no statistically significant differences over time between treatment and control plots either in cover of vegetation, species richness, or species diversity within any plant community, elevation band, or region of the reservoir (Appendix 9.1: Figure 9-2 to Figure 9-9). Except for a few isolated instances (4.1.4), it thus does not appear that either the quality or quantity of native vegetation in the Kinbasket Reservoir drawdown zone has substantially increased as a result of the planting program.

4.1.3 Results Summary (2008-2011)

Table 1-1 summarizes the status of the management questions at the end of the 2013 monitoring year. Despite some early high survivorship (e.g., one year post-treatment), most plantings (seedling plugs and live stakes) in the random sample plots showed low to nil survivorship after three years. High attrition rates were attributed to a combination of wet and dry stress, erosion, sedimentation, and impacts from woody debris accumulation (Hawkes et al. 2013). By the end of the 2013 monitoring period it was evident that few of the initial treatments were establishing successfully to any meaningful degree. Moreover, treatments showed no statistically significant effects on per cent cover of vegetation, species richness, or species diversity within the drawdown zone (Hawkes et al. 2013).

Table 4-1: Status of CLBMON-9 management questions and hypotheses in 2013 (adapted from Hawkes *et al*. 2013).

Management Question (MQ)	2013 MQ Response	Key Findings
1. What is the quality and quantity of vegetation in revegetated areas compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass, and cover?	No significant difference.	Some sedge plugs surviving in limited areas, but no significant differences detected in quality or quantity of vegetation between treated and untreated sites.
2. 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)?	Low to nil survival.	Steep decline in survivorship of plug seedlings and live stakes each year following planting; ~4 per cent of plugs surviving 4 yrs. after planting; large-scale mortality of live stakes.
3. What environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation), may limit or improve the remediation and expansion of vegetation communities in the drawdown zone?	The current operating regime is the most important, though not the only, variable limiting revegetation success in the drawdown zone. Several more years of field data, and likely a change in research direction, are needed to identify environmental conditions (e.g., woody debris removal) that would improve remediation and expansion of vegetation communities.	Under the current operating regime, revegetation success has been low and declining over time for all combinations of region, elevation, and planting prescription. Revegetation success of CLBWORKS-1 is likely limited by a combination of timing, frequency, duration and depth of inundation; erosion, sedimentation, and woody debris accumulation and scouring; choice of species used for revegetation; and choice of sites targeted for revegetation.
4. What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-1, at increasing the quality and quantity of vegetation in the drawdown zone?	Most are ineffective. Statistical assessment hampered by small sample sizes and lack of replication/stratification associated with CLBWKS-1.	Widely variable results among individual sites and treatments, but the sedge plug treatment (PS) appears to be the only treatment type to have achieved moderate success in limited locales.
5. 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?	Ongoing, but approaching ability to answer this MQ (anticipated response: “NO”). A review of the effectiveness of the current revegetation program is presented in this report.	There has been a small amount of moderately successful plug establishment in limited areas, indicating that the revegetation program has resulted in a minor net benefit with respect to size and productivity of some vegetated areas. However, opportunities may exist for facilitating natural colonization processes through targeted physical works that could potentially create greater benefits than the revegetation program. For example, reducing woody accumulation and taking other measures to promote natural regeneration may be a more effective long-term approach to achieving revegetation objectives than out-planting, as discussed in Sections 6.0 and 7.0 of this report.

Management Question (MQ)	2013 MQ Response	Key Findings
6. Is there an opportunity to modify operations to more effectively maintain revegetated communities at the site level in the future?	No, it is unlikely that modifying operations at this point will have any desired effects, because the revegetation treatments have already largely failed.	Under the current operating regime, revegetation success has been low and declining over time for all combinations of region, elevation, and planting prescription. Preliminary results suggest that adjusting the timing and reducing the duration and depth of inundation could translate into increased success for future revegetation attempts.

4.1.4 2018 Reassessment of 2008-2011 Trials

The extensive 2018 inventory of original CLBWORKS-1 revegetation treatments yielded informative new data on 91 treatment polygons, some of which had not been previously assessed under the CLBMON-9 semi-random sampling design (Miller and Hawkes 2019). Most notably, we recorded several instances of vigorous, surviving plug transplants at locations not previously known to have had successful establishment (Figure 4-1,Figure 4-2). This includes treatments in both Canoe Reach (e.g., Yellow Jacket, Ptarmigan Creek) and Bush Arm (e.g., Chatter Creek, Km77). Surviving plugs were also recorded at Canoe River Mouth, Windfall Creek, Km79, Km88 peatland, Prattle Creek, and Hope Creek, though at lower densities and/or vigour relative to the other locations. Kellogg's sedge was the most widely recorded transplanted graminoid species, but instances of Columbia sedge (e.g., Km77), wool-grass (e.g., Km88 peatland), water sedge (e.g., Hope Creek), and bluejoint reedgrass (e.g., Ptarmigan Creek, Yellow Jacket Creek) were also observed (Appendix 9.2: Table 9-1).

These newly obtained observations of treatment survivorship, while mostly highly localized, nevertheless suggest that previous estimates of revegetation establishment in Kinbasket had been somewhat underestimated (Hawkes et al. 2013). Importantly, these data can be used to inform models of species-specific responses to reservoir operations in Kinbasket and Arrow Lakes that are currently under development as part of CLBMON-35 (Hawkes et al. 2018, Miller and Hawkes 2020).

Appendix 9.2 (Figure 9-10) shows a comparison of soil parameters (average texture and nutrient content values) between sample plots with at least some successful revegetation establishment and those where revegetation treatments failed to take hold. Successful microsites tended to have slightly higher silt and clay content, and slightly lower sand and gravel content, than unsuccessful microsites, implying that soil water holding capacity may be a limiting factor influencing plug establishment. Successful microsites also had higher average volumes of Potassium (K), Magnesium (Mg), and Sodium (Na), suggesting that these elements may be nutritionally limiting. In contrast, unsuccessful microsites tended to have higher average total Carbon (C) and higher Nitrogen (N) content, implying that these elements are not limiting. A univariate regression tree model (De'ath and Fabricius 2000; Miller et al. 2018) was used to examine these relationships further using the density of surviving sedge plugs (Kellogg's sedge, Columbia sedge, and wool-grass combined) as the dependent variable (Figure 4-3).

Independent variables included elevation, site location, slope, heat load (derived from aspect), microtopography (straight/concave/convex), substrate texture (percent sand/silt/clay content), soil moisture, and soil nutrient content (total C, inorganic C, organic

C, N, Na, Ca, K, Mg, and organic matter). Topo-edaphic site conditions were predicted to have a significant impact on the probability of plug survival. Specifically, a high percentage of the variation in establishment rates could be explained by soil factors including sodium (Na), clay, silt, carbon (C), and organic matter contents, with Na explaining the largest proportion of the variation (Figure 4-3).

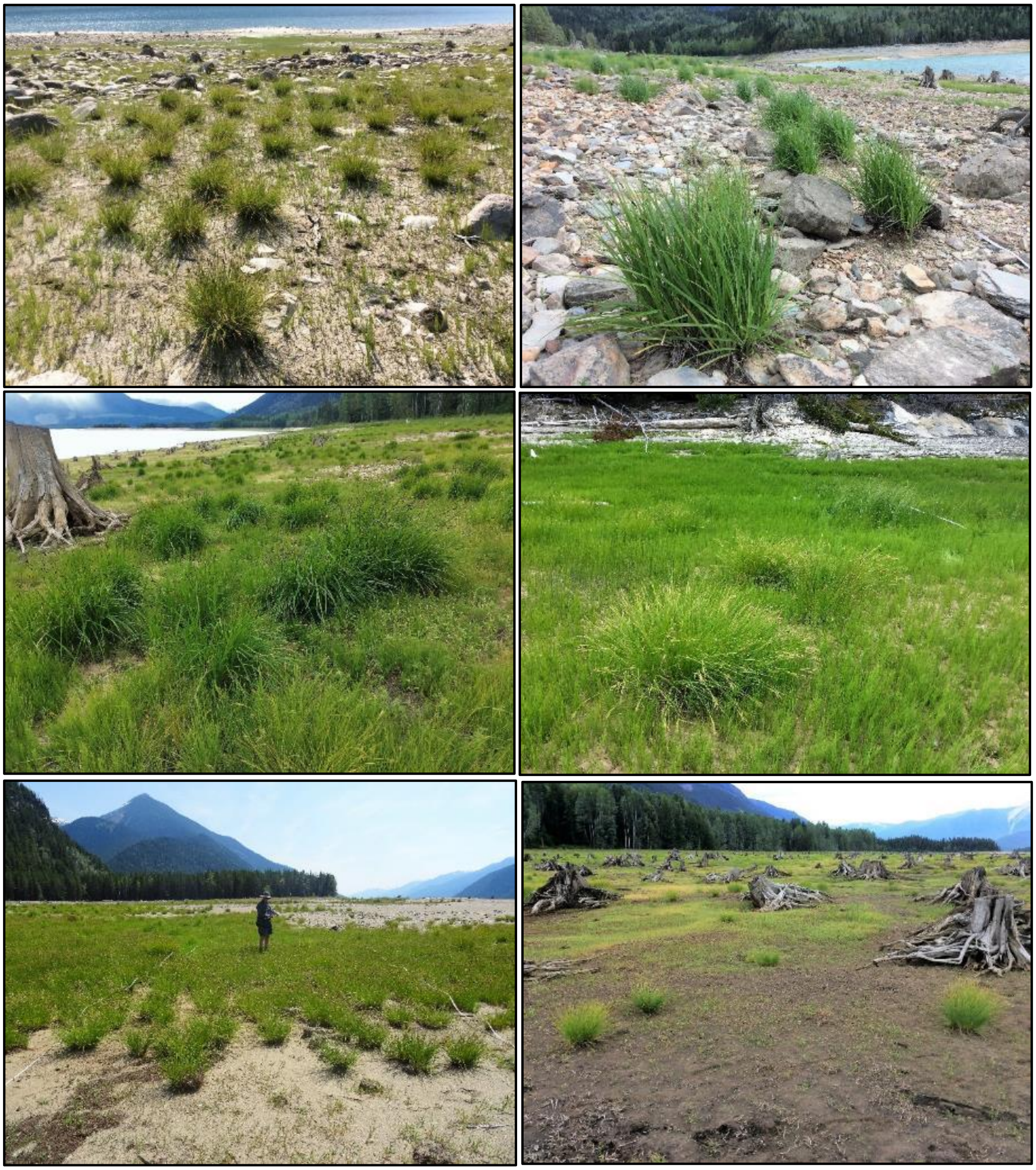

Figure 4-1. Examples of sedge establishment associated with the CLBWORKS-1 (2008-2011) revegetation treatments. Clockwise from top left: Kellogg's sedge, Yellow Jacket Creek; Columbia sedge, Km 77; Kellogg's sedge, Chatter Creek; Kellogg's sedge, Km 88 peatland; Kellogg's sedge, Ptarmigan Creek; Kellogg's sedge, Km 77. Photographed June 2018.

Figure 4-2. Examples of sedge establishment associated with the CLBWORKS-1 (2008-2011) revegetation treatments. Clockwise from top left: water sedge, Hope Creek; Kellogg’s sedge, Hope Creek; Kellogg’s sedge, Km 79; Columbia sedge, Km 79; Kellogg’s sedge, Ptarmigan Creek; Kellogg’s sedge, Yellow Jacket Creek. Photographed June 2018.

Similar results were obtained by a model that included only the density of Kellogg’s sedge (the most widely encountered individual treatment) as the dependent variable (Figure 4-4). Na content and other soil factors continued to account for the largest proportion of variation in surviving stem density. However, in this instance, potassium (K) replaced C as a predictor of variability, particularly at Km77, Km79, and Ptarmigan Creek in low Na environments having some organic matter content (Figure 4-4).

In an analogous model that substituted the percent cover of Kellogg's sedge (including naturally occurring Kellogg's sedge) for standing stem counts, the existence of a stream-fed, subsurface moisture source was the most important predictor of high cover values (Figure 4-5). In this case, Na was the most important limiting factor on dry to mesic soils where precipitation was the primary water source.

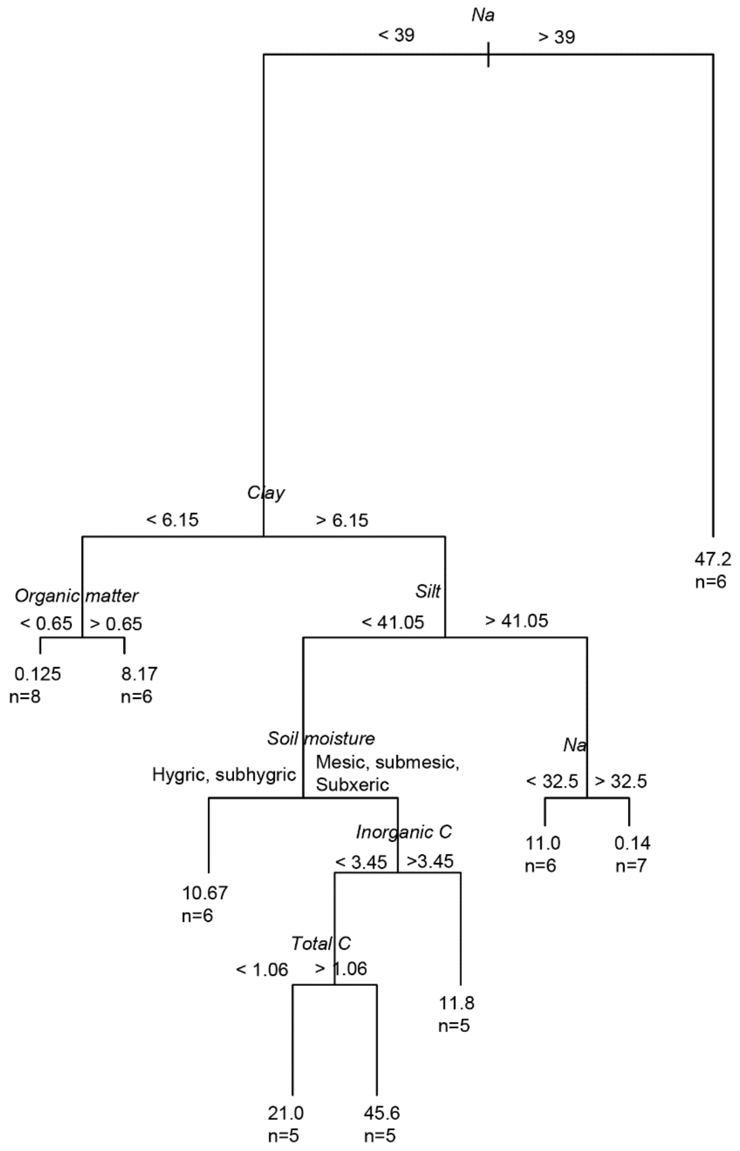

Figure 4-3. **Regression tree showing the variables influencing the establishment rate of sedge plugs (Kellogg's sedge, Columbia sedge, wool-grass) in Kinbasket Reservoir.** The length of the vertical lines associated with each split graphically approximates the proportion of the variance the split is explaining. Numbers at each leaf indicate the predicted average surviving stem densities and number of sample plots. The pseudo-R^2 was 68.5%. Total number of plots was 54.

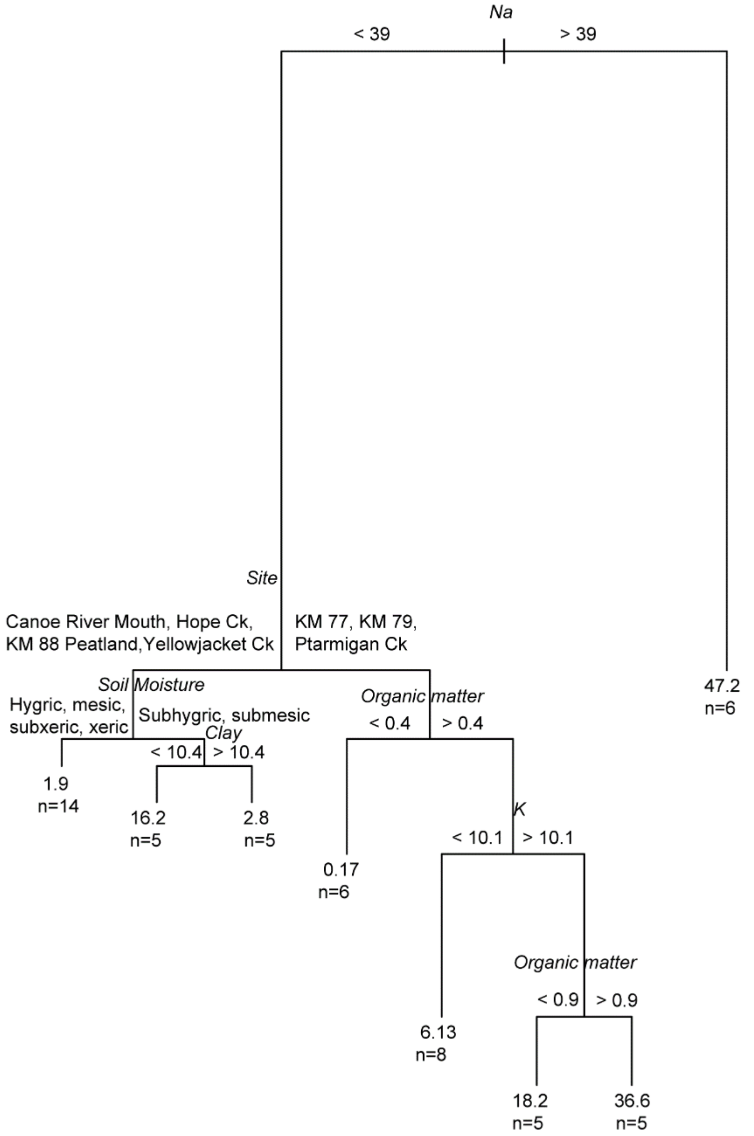

Figure 4-4. **Regression tree showing the variables influencing the establishment rate of Kellogg's sedge (*Carex kelloggii*) plugs in Kinbasket Reservoir.** The length of the vertical lines associated with each split graphically approximates the proportion of the variance the split is explaining. Numbers at each leaf indicate the predicted average surviving stem densities and number of sample plots. The pseudo-R^2 was 70%. Total number of plots was 54.

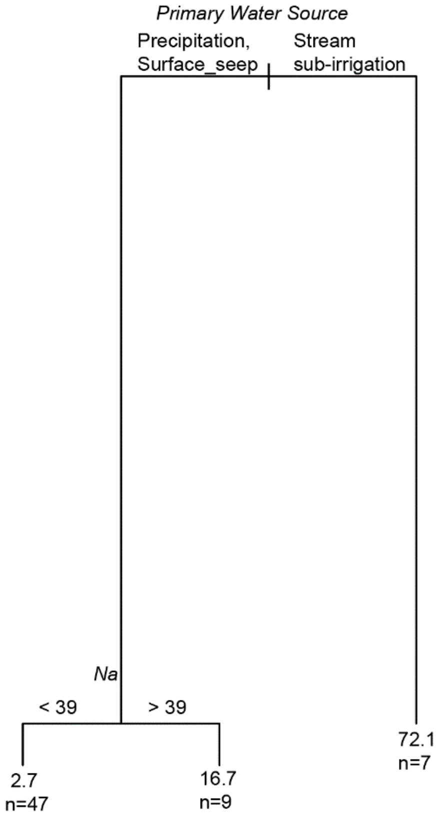

Figure 4-5. **Regression tree showing the variables influencing the % cover of Kellogg's sedge (*Carex kelloggii*) in Kinbasket Reservoir.** The length of the vertical lines associated with each split graphically approximates the proportion of the variance the split is explaining. Numbers at the terminal nodes are the average cover and number of plots. The pseudo-R^2 was 92%. One outlier (Ptarmigan 14-1, the only sample with stream sub-irrigation and 0 cover), was removed to increase goodness of fit.

4.2 Km88 Big Bend Sedge Trial (2013)

Two years post-planting, the sedge seedling plugs at Km88 were performing well both in terms of survivorship and reproductive development (Hawkes and Miller 2016). In random quadrat samples at each of the three treatment units (TU-1, TU-3, and TU-5), average estimated surviving plug densities (per ha) were approximately 29,000, 15,000, and 9,000 respectively (Table 4-3). In the case of TU-1, sample densities were similar to the original stocking densities reported by Adama (2015; Table 4-3).

By 2015, sedge plugs in TU-5 (the higher situated treatment) appeared to be growing more rapidly than in TU-1 and TU-3. While there were advancements in plant height at all three TUs between 2014 and 2015, plugs in TU-5 continued to be the tallest (Appendix 9.3: Figure 9-11). Height differences between units in 2015 were statistically significant at $\alpha=0.1$ (F=9.38, p=0.0003).

General plant vigour, as represented on a qualitative scale of "good," "moderate," and "poor," also tended to be higher in TU-5 (Appendix 9.3: Figure 9-12). The relative proportion of plants in each vigour class differed significantly across treatment units in 2015 (χ^2=8.83, p=0.065). Vigour appeared to decrease in TU-1 between 2014 and 2015, with far fewer plugs but appeared to increase at both TU-3 and TU-5 (Appendix 9.3: Figure 9-12). The yearly differences were less apparent when values were averaged across treatment units (Appendix 9.3: Figure 9-12).

Differences in the timing and duration of inundation affecting the different TUs likely accounted for some of the variation in sedge plug performance in the years immediately following planting (Hawkes and Miller 2016). In 2013, the higher planted elevation bands (748-749 m), corresponding to TU-5, were inundated from 143 to 153 days, while the lower elevation bands (746-747 m), corresponding to TU-1 and TU-3, were inundated for 161 to 167 days, a differential of 13 to 18 days (Table 4-2). In 2014, the higher planted elevation bands were inundated from 171 to 180 days, while the lower elevation bands were inundated for 189 to 204 days, a difference of about 20 days (Table 4-2). In both years, the total inundation period for all elevations exceeded the 30-year baseline norm by a substantial margin (Table 4-2). These inundation patterns imply that the sedge plantings at Km88 initially experienced somewhat truncated growing seasons—and potentially higher physiological stresses related to prolonged inundation—compared to those experienced over time by the established native vegetation.

Table 4-2. **The number of days seedlings were inundated by elevation band in 2013, 2014, and 2015.** Difference between days inundated in each year and the 30-year baseline (1977 to 2006) provided in brackets.

Elevation (m ASL)	2013	2014	2015	30-year baseline
745	175 (47)	213 (85)	201 (73)	128
746	167 (50)	204 (87)	188 (71)	117
747	161 (56)	189 (84)	130 (25)	105
748	153 (64)	180 (91)	80 (-9)	89
749	143 (68)	171 (96)	56 (-19)	75
750	131 (66)	163 (98)	30 (-35)	65
751	119 (66)	143 (90)	0 (-53)	53
Mean	150 (60)	180 (90)	98 (8)	90

In 2018, five years after planting, the plugs continued to perform well both in terms of survivorship and reproductive development (Figure 4-6). In sample polygons at each of the three treatment units (TU-1, TU-3, and TU-5), estimated surviving plug densities (per ha) were approximately 7,190, 9,310, and 8,440 respectively. These establishment rates are slightly below the targeted densities of 10,000-15,000 plugs per ha for TU-1 and TU-3, and in line with the target density of 5,000-10,000 per ha for TU-5 (Adama 2015). Based on the reported initial stocking densities, this places the estimated survival rate for all TUs at ~35% after five years. By comparison, survivorship at several other Kinbasket sites was nil or minimal after a similar period (Hawkes et al. 2018), making this one of the more successful transplant initiatives under CLBWORKS-1. Sedge vigour was rated “good” overall for TU-1 and TU-3, and “moderate to good” for TU-5.

Table 4-3: **Estimated density of sedge plugs per hectare at time of planting in 2013, estimated surviving densities in 2018, and estimated per cent survival five years after planting.** 2013 data from Adama (2015).

Treatment unit	2013 stocking density/ha	2015 surviving plugs/ha	2018 surviving plugs/ha	Estimated per cent survival
TU-1	25,454 ± 4,345	29,000 ± 8,834	7,190	28%
TU-3	25,000 ± 4,234	15,000 ± 6832	9,310	37%
TU-5	20,714 ± 7,300	9,000 ± 6379	8,440	41%
All	23,738 ± 1,952	17,666 ± 4,657	8,313	35%

Figure 4-6: **Sedge planting treatment at Km 88, Bush Arm.** Planted plugs of Kellogg's sedge are visible mixed with an existing ground cover of annual forbs, primarily Scouler's popcorn flower (*Plagiobothrys scouleri*). Photographed 28 June 2018.

While many planted sedges at Km88 had, by 2018, reached reproductive maturity and were producing inflorescences and seed, there was minimal evidence to suggest that new plant cohorts had begun recruiting into the population. Likewise, there was minimal indication that the planting treatments had resulted yet in wholescale community changes or advances in succession; the ground cover of annuals presently in place (Figure 4-6) continues to resemble that which existed prior to the treatment applications (Adama 2015). This result underscores the general inertia of this system and the difficult challenge of effecting directional changes in reservoir drawdown vegetation in the absence of operational changes and/or additional physical modifications via physical works.

4.3 Woody Debris Removal and Boom Exclosure (Canoe Reach)

A proportional graph of surface substrate composition illustrates the difference in the amount of driftwood cover at the Canoe Reach study sites (pre- and post-clearing; Figure 4-7). Woody debris accounted for almost all of the surface cover in the uncleared controls whereas it was largely absent from the treated sites—until it began to reintrude onto some of the latter sites in 2015 (Figure 4-7).

One to two months following the clearing of woody debris in the spring of 2014, herb cover in cleared areas appeared to be higher relative to non-treated controls at PS-N, similar relative to controls at PS-S, and lower relative to controls at both VP-N and YJ (Appendix 9.4: Figure 9-13). Species richness increased relative to controls at three of the five treated sites (PS-N, PS-S, and VP-N; Appendix 9.4: Figure 9-14). At PS-N, the median species richness of treated transects immediately following clearing was around six-fold that of untreated transects. At Yellow Jacket Creek, the opposite trend was observed with fewer herb species recorded in treated than in control transects (Appendix 9.4: Figure 9-14).

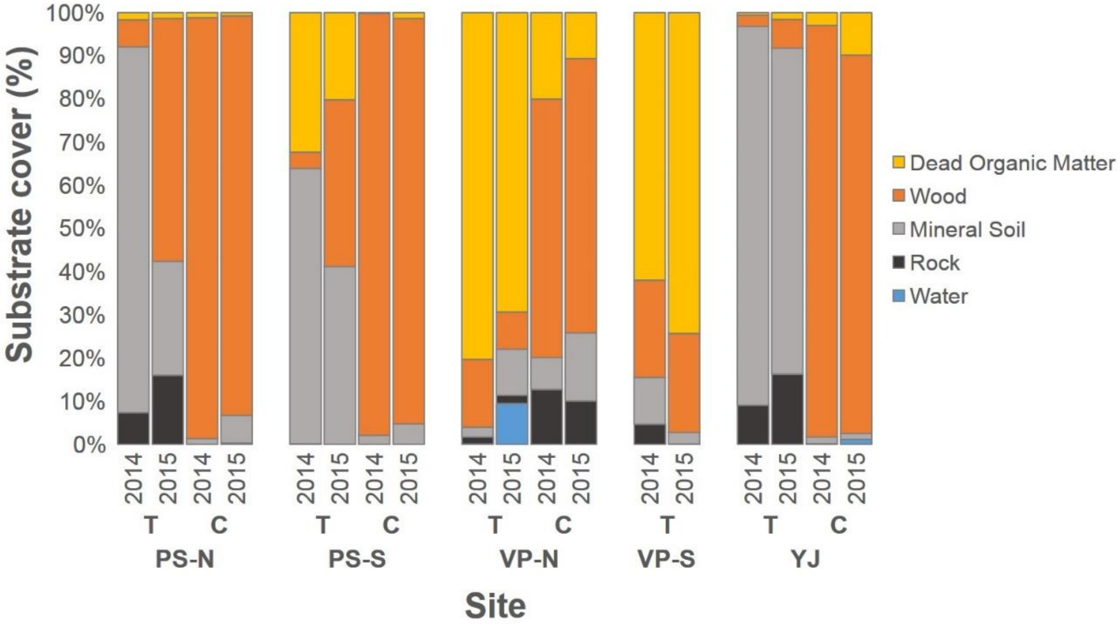

Figure 4-7: **Proportion of ground covered by each class of substrate (organic matter, decaying wood, mineral soil, rock, water) in sample transects at each of the Canoe Reach debris removal sites, 2014 and 2015.** PS-N: Packsaddle Creek-North; PS-S: Packsaddle Creek-South; VP-N: Valemount Peatland (North); VP-S: Valemount Peatland (South); YJ: Yellow Jacket Creek. No untreated control area was available for sampling at VP-S.

The somewhat inverted response observed at Yellow Jacket Creek was likely due to the relative high productivity of the control site, as evidenced by the rather vigorous plant growth occurring up through the dense log cover (Figure 4-8). Underneath the woody debris at this site, which occurs on a natural seepage area, the largely wetland vegetation was supported by moist to wet, organic soils. By comparison, the treated substrate was drier, rockier, lower in organic content (Figure 4-7), and relatively unproductive (Figure 4-8). One year after debris removal the treated area was exhibiting a comparable level of species richness to the non-treated area. However, the year-to-year increase in overall herb cover lagged that of the non-treated area. These results suggest that the immediate effects of removing woody debris are likely to vary from site to site and will be strongly influenced by the initial starting conditions (e.g., presence/absence of a soil seed bank).

Figure 4-8: **Left: vegetation growing through woody debris deposits at Yellow Jacket Creek control site, Canoe Reach, Kinbasket Reservoir.** Right: regenerating treatment site, Yellow Jacket Creek. Photographed 21 June 2015

During the winter of 2014/2015, substantial amounts of woody debris were redeposited onto some previously cleared areas, especially at PS-N and PS-S (Figure 4-9). As a result, some of the 2014 gains with respect to species richness did not carry over into 2015. At PS-N, this trend was actually reversed; herb richness declined in the treated site relative to both the 2014 value and to the control (Appendix 9.4: Figure 9-14).

Figure 4-9: **Fresh (winter 2014/2015) woody debris deposits on previously cleared site at Packsaddle Creek-South (PS-S).** This site was mechanically cleared of debris in the spring of 2014. Photographed 21 June 2015.

In contrast, at VP-N—the site where a log-boom exclosure was installed in conjunction with woody debris removal—species richness was substantially higher in 2015, both compared to the control and to the 2014 values (Appendix 9.4: Figure 9-14). Herb cover at this site also appeared to increase more rapidly in cleared than in non-cleared areas between 2014 and 2015 (Appendix 9.4: Figure 9-13). This site, which receives seepage inflows from an existing shrubby wetland just outside the drawdown zone, is both wetter and more nutrient (N and K) rich than the other drawdown zone sites. The soil here is also very high in total organic carbon (Appendix 9.4: Figure 9-15). These factors could help account for our observation that one year following debris removal, VP-N was beginning to show signs of rapid recovery toward a functioning semi-wetland community (Figure 4-10). A detailed floristic survey of the log-boom exclosure area, conducted on 20 July 2015, yielded a total of 62 established and regenerating vascular plant species. Subsequent surveys in 2017 and 2018, which encompassed slightly more area, added another 50 species for a total of 112 species (Appendix 9.4: Table 9-2).

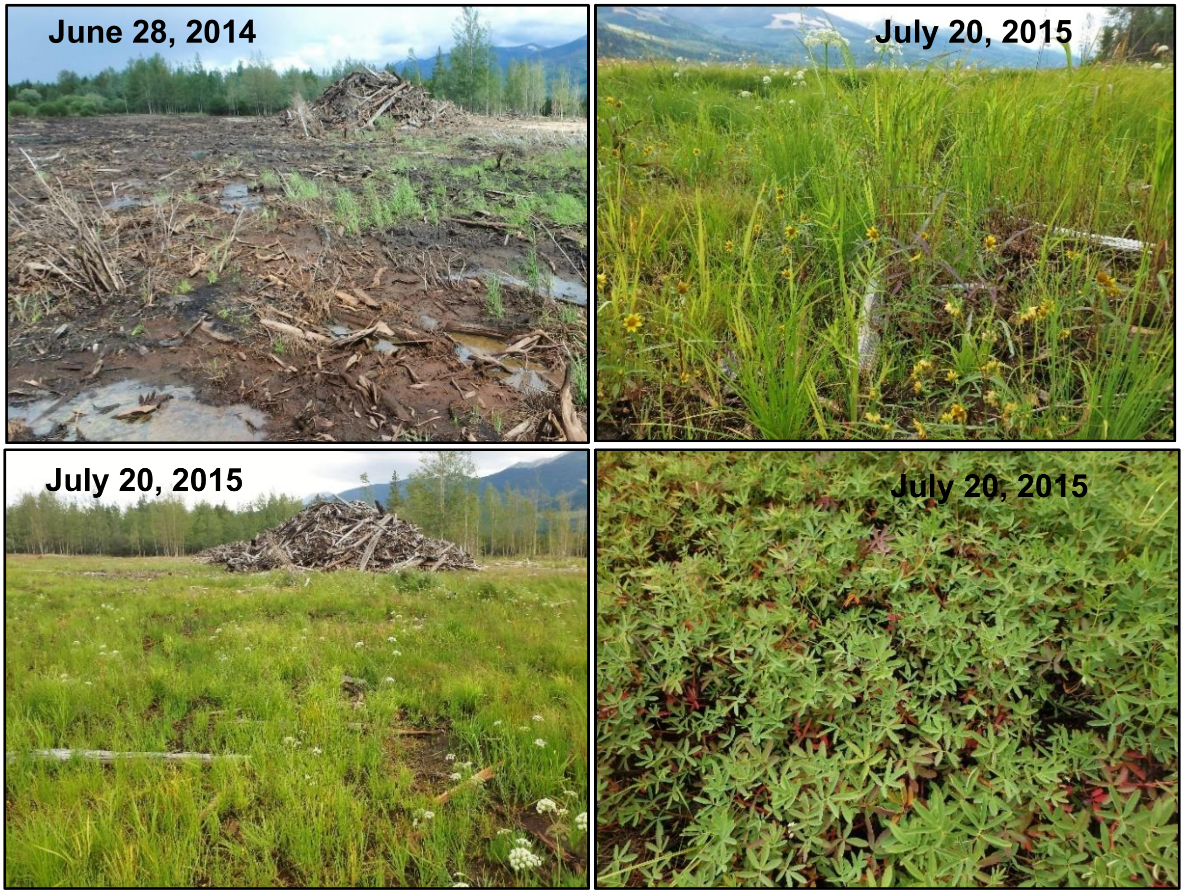

Figure 4-10: **Vegetation recovery two months (upper left panel) and 15 months (other panels) following removal of woody debris at the Valemount Peatland (North) (VP-N) site, Canoe Reach.** Upper right panel: nodding beggarticks (*Bidens cernua*) and Douglas' water-hemlock (*Cicuta douglasii*). Lower right panel: marsh cinquefoil (*Comarum palustre*).

The initial (within-season) positive response of species richness to clearing at some sites suggests that the removal of dense debris accumulations (Figure 3-2) had an immediate beneficial effect on seed germination (through release of the dormant seed bank) and/or encouraged the re-emergence of dormant rhizomes. Of the herb species recorded in the June 2014 transects (control and treated combined, VP-S excluded), 17 were unique to the treated transects. About half of these were annual species and about half were perennials (Appendix 9.4: Table 9-3).

Of the herb species recorded in the June 2015 transects (control and treated combined, VP-S excluded), 36 were unique to the treated transects, two thirds of which were perennials. In terms of broad taxonomic groupings, two thirds were forbs, and one third were graminoids (i.e., grasses and sedges; Appendix 9.4: Table 9-3). Furthermore, in 2015 we recorded 27 new additions to the treated transects—species that were not observed in the same transects in 2014. A similar proportion (about two thirds) of these were perennials, although the ratio of grasses to forbs was slightly higher (Appendix 9.4: Table 9-4).

In 2016, the treatment sites at Packsaddle Creek North (PS-N) and South (PS-S) were inadvertently re-cleared of wood debris as part of CLBMON-16 operations (reported in Wood et al. 2018). The non-treated controls at PS-N and PS-S were also cleared, causing further detriment to the experimental design. Similarly, the treatment site at Yellow Jacket Creek was re-cleared of wood debris prior to survey in 2017 (Wood et al. 2018). In 2018, the control plot at Valemount Peatland North was treated and all coarse woody material was removed prior to surveys. Consequently, several of the sites were dropped from monitoring because, in the absence of a suitable control, it would not be possible to infer treatment effects.

At Yellow Jacket Creek, species richness increased more gradually over time but, by 2016, had drawn even with control plots in terms of total richness (Figure 4-11). Cover within both treated and control transects increased gradually over time, but increased more markedly in the controls (Figure 4-11). As noted above, the control in this instance was, originally, a naturally more productive site than the treated area, which likely accounts for the observed difference in vegetation trajectories. Nevertheless, the 2014 woody debris removal appears to have continued to exert a positive effect on the cleared site up until at least 2016, the last year that monitoring was conducted for this treatment prior to it being re-disturbed.

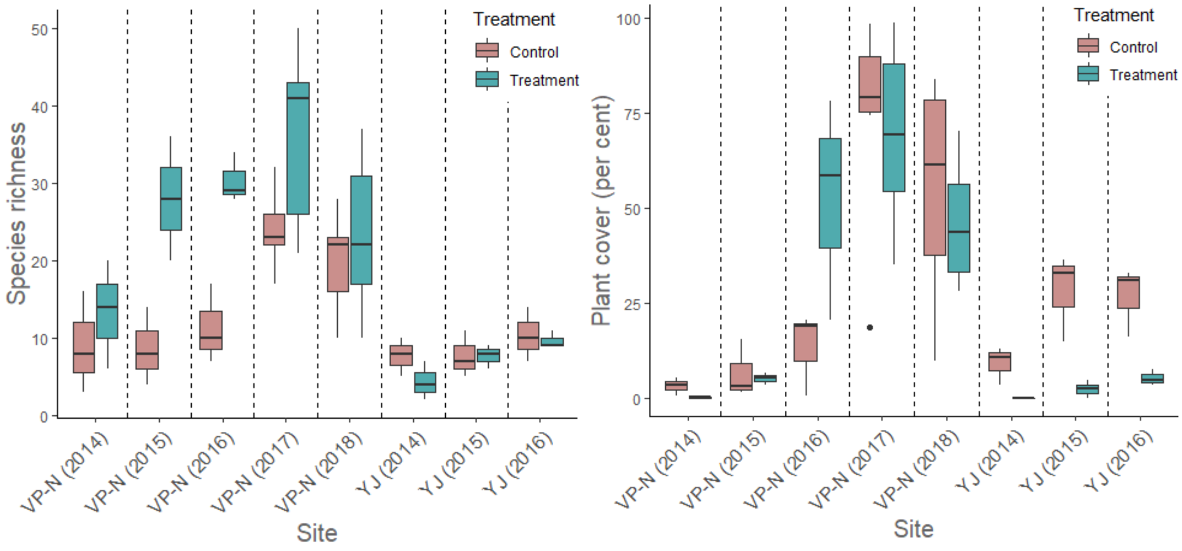

Figure 4-11. Number (left panel) and per cent cover (right panel) of plant species recorded at woody debris removal transects and untreated control transects from 2014 to 2018 at Valemount Peatland North (VP-N) and from 2014 to 2016 at Yellow Jacket Creek (YJ).

Following the 2014 clearing of woody debris from the remnant wetland at Valemount Peatland North, species richness of sample transects rapidly increased year to year until 2017, both in absolute terms and relative to untreated controls (Figure 4-11). Richness then appeared to decrease slightly from 2017 to 2018 (Figure 4-11). There is no obvious external explanation for the decline (reservoir inundation was not a factor in either year). The result could be due in part to inherent GPS error (in heterogenous habitats, transects laid down in a slightly different spot from one year to the next could have produced differing species totals).

As with richness, cover showed marked increases year over year within the newly cleared transects at Valemount Peatland North, with values peaking in 2017 before declining slightly in 2018 (possibly for the same reason noted above for richness; Figure 4-11). Richness and cover in the control transects also both underwent substantial gains after 2016, by 2018 matching or exceeding that of the treatments (Figure 4-11). We ascribe the site-wide increases to the mutually beneficial effects accruing from the sequence of low water years that commenced in 2015 and the subsequent multi-year release from inundation.

In 2016, the reservoir maximum was high enough to briefly inundate the Valemount Peatland log-boom exclosure. However, the exclosure has not yet been fully tested by high reservoir levels and it is still unknown how effective it will prove to be at protecting the regenerating vegetation at this site from heavy wood deposition during high water events.

4.4 Constructed Mounds and Boom Exclosure (Bush Causeway)

As of July 2018, ~83 plant species had colonized the constructed mounds and adjacent mound footprints at Bush Causeway (Figure 4-12, Appendix 9.5: Table 9-5). The lower fringes of the mounds (including the recovering mound construction footprints) supported the greatest array of establishing plants, with about 70 taxa recorded. Of these, 17 (~25%) were naturalized exotic species. The middle portions of mounds supported about 50 species, while the tops of mounds supported about 40 species (Appendix 9.5: Table 9-5). Anecdotal observation indicated that individual mounds varied with respect to plant cover, with narrower mounds (windrows) tending to show sparser establishment than the more rounded mounds.

Most species occurring on mounds were ones occurring in the immediate drawdown zone area and presumably sprouted from the seed/rhizome bank contained in the original mound fill. In the case of willows (*Salix* spp.), some informal (non-enumerated) translocation of rootstock occurred through a combination of hand and excavator placement during soil transfer. A high proportion (~64 percent) of species documented from the area in baseline surveys (Appendix 9.5: Table Table 9-6) were present on the mounds and/or mound footprints. Both herbaceous and woody species (e.g., willows) were present on all zones of the mounds; thus, the mound substrate mix (wood debris combined with mineral soil) appears to be generally supportive of different plant structural stages. However, the constructed habitats are situated at high elevation in the drawdown zone and have yet to experience reservoir inundation (due to the series of relatively low water years in Kinbasket that has followed mound construction). Consequently, the physical and vegetation responses of the mounds to seasonal inundation remain untested and unknown.

A total of 36 surviving, and 42 non-surviving, cottonwood stakes were counted within sample polygons on three constructed mounds (Figure 4-12), for an estimated stake survival rate (to date) of 46%.

Figure 4-12. **Constructed mounds, Bush Causeway (north site), illustrating current state of establishing planted and natural vegetation.** Leaf-bearing live stakes are visible in the top left and bottom right panels. Photographed July 2018.

The three Bush Causeway ponds that were cleaned of wood debris and subsequently protected behind a log-boom placement are exhibiting signs of vigorous regrowth with respect to both riparian and aquatic macrophyte vegetation. Wetland-associated genera observed in or along the edges of ponds in 2018 included *Carex*, *Potamogeton*, *Hippuris*, *Sparganium*, *Myriophyllum*, *Alisma*, *Equisetum*, and *Persicaria* (Figure 4-13). As in the case of the mounds, the log-boom has not yet been exposed to a full-scale inundation event; therefore, there has been no opportunity yet to assess its long-term effectiveness at excluding wood debris from reaccumulating in the upstream ponds. Similarly, the biophysical responses of the ponds to seasonal inundation remain untested and unknown.

Figure 4-13. **Regenerating wetland vegetation in ponds partially cleaned of large woody debris in 2015 at Bush Causeway.** Clockwise from top left: overview of cleaned pond with log-boom (in background), *Carex utriculata*, *Alisma gramineum*, *Carex aquatilis*, *Sparganium* sp. Photographed July 2018.

The list of plant species recorded on the constructed mounds/windrows and cleared ponds in 2018 (Appendix 9.5: Table 9-6includes ~25 taxa not previously recorded in the near vicinity during pre-physical works (2015) baseline sampling (Appendix 9.5: Table Table 9-6). These new contributions to the local drawdown zone flora include such notable additions as *Betula papyrifera*, *Hippuris vulgaris*, *Sium suave*, and *Shepherdia canadensis* (Table 4-4). The presence of these novel elements on/in the constructed features and ponds provides some early evidence that physical works have been effective at increasing small-scale habitat heterogeneity and, in turn, local species richness.

Table 4-4 Plant species in 2018 that were unique to the constructed mounds/ponds, versus those recorded to date only in the untreated (2015 baseline) transect samples.

Unique Species (mounds/ponds)	Unique Species (2015 baseline)
Betula papyrifera	*Braya humilis*
Carex aurea	*Carex crawfordii*
Carex interior	*Coeloglossum viride*
Chamerion angustifolium	*Eleocharis elliptica*
Cirsium vulgare	*Eleocharis mamillata*
Dichanthelium acuminatum	*Elymus repens*
Epilobium ciliatum	*Equisetum fluviatile*
*Galeopsis tetrahit**	*Equisetum palustre*
Hippuris vulgaris	*Equisetum pratense*
Lamium sp.	*Erucastrum gallicum*
Myriophyllum sp.	*Erysimum cheiranthoides*
Persicaria amphibia	*Juncus alpinoarticulatus*
*Plantago major**	*Lobelia kalmia*
Platanthera stricta	*Medicago sativa*
Potamogeton sp.	*Persicaria maculosa*
Primula mistassinica	*Poa compressa*
Ranunculus sceleratus	*Populus trichocarpa* ssp. *balsamifera*
Shepherdia canadensis	*Rubus pubescens*
Sium suave	*Salix commutata*
Sparganium sp.	*Salix melanopsis*
	Salix sitchensis
	Symphyotrichum subspicatum
	Triantha glutinosa
	Trifolium aureum
	Trifolium repens
	Vicia cracca
	Viola macloskeyi
	Zigadenus elegans

5.0 Discussion

Revegetation ecology in reservoir drawdown zones is an emerging field; therefore, there is relatively little literature available to guide revegetation efforts (Abrahams 2006, Keefer et al. 2008, Yang et al. 2012). Consequently, each revegetation project must rely on both the existing literature as well as on a more generalized understanding of restoration principles, such as plant science, soils, geomorphology and horticulture, to help guide the project (Keefer et al. 2008). More than most habitats, reservoir drawdown zones provide particularly challenging conditions within which to establish plant communities through revegetation efforts (Nilsson 1981, Abrahams 2006; Liu and Willison 2013). Reservoir drawdown and reflooding sets back and alters successional processes, creates continued disturbance in the system, and affects physical and chemical parameters of the substrates (Abrahams 2006). These factors, in combination with the scant existing literature on the revegetation of drawdown zones, have necessitated a trial-and-error program in which a variety of revegetation treatments are applied. In this way, the most effective and successful treatments can be determined and subsequently applied more widely throughout the reservoir.

The original aim of this monitoring program was to assess the overall effectiveness of planting treatments applied to the Kinbasket Reservoir shoreline during the first four years of the CLBWORKS-1 program (2008–2011). In the program terms of reference, BC Hydro (2008) identified a set of Management Questions (MQs) designed to help guide this assessment. In the following section, we discuss our findings relating to the 2008-2011 treatments, as well as the later (2013) sedge transplant trial undertaken at Km88 Big Bend, within the context of the MQs. We also use the MQs to inform discussion, where relevant, of the vegetation responses to supplemental physical works (woody debris removal, log-boom exclosures, and mound construction) applied at Canoe Reach and Bush Causeway between 2013 and 2015.

5.1 Management Questions

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

The 2008-2011 revegetation treatments did not substantially increase the quality or quantity of vegetation in the drawdown zone of Kinbasket Reservoir at the landscape scale. No statistically significant differences were detected in the percent cover of vegetation between treatment and control plots in any of the nine vegetation communities that were sampled. Analysis of other vegetation variables, such as species richness, species diversity, and biomass also showed similar trends to percent cover, with little or no statistically significant differences between treatment and control plots. These results imply that the 2008-2011 planting program did not achieve the primary objective of increasing the areal extent and diversity of vegetation within the drawdown zone of Kinbasket Reservoir, while also failing to meet some of the broader revegetation goals (e.g., improved wildlife habitat, increased productivity).

We note, however, that as of 2018 all the planted stands were 10 years old or less and thus may still be developing; we are only able to evaluate the initial stages of the developmental trajectory. Those few sites (identified in the next section) that experienced some survivorship success conceivably could, in the future, develop community characteristics that distinguish them from non-treated areas. Consequently, an argument can be made for continuing to monitor (say, at 5-year intervals) locations where there has been a small degree of establishment success, on the chance that doing so helps to resolve the still unanswered question of whether revegetated areas can improve the quality of the drawdown zone environment in measurable ways.

At Km88, our observations indicate that the treated communities retain the same overall vegetation characteristics with respect to species composition and diversity as they did prior to planting, aside from the obvious addition of the two sedge species to areas where these did not grow before (e.g., the low-elevation Marsh Cudweed—Annual Hairgrass community type in Treatment Units 1 and 3). While establishing Kellogg's and Columbia sedge is an important step in expanding the vegetation cover at Km88, it is unclear if these introductions are capable on their own altering the successional trajectory of the sites toward something more resembling a mature KS (Kellogg's Sedge) community type. That association includes several additional species including wool-grass (*Scirpus atrocinctus*), yellow sedge (*Carex flava*) and toad rush (*Juncus bufonius*), clover (*Trifolium* spp.), and narrow-leaved collomia (*Collomia linearis*) (Hawkes *et al* 2007). Thus, the planting of additional species may be required to reach the targeted objective, an action that could be considered now that the 2013 seedlings have demonstrated reasonable survivorship over the first 5 years (Adama 2015).

There are, unfortunately, few examples of successful riparian reclamation in other northern temperate zone reservoirs on which to base predictions about post-reclamation community development; most research remains at the experimental stage (e.g., Allen and Klimas 1986; Jackson et al. 1995; Johansson and Nilsson 2002; MacKillop 2003; Abrahams 2006; Lu et al. 2010; Yang et al. 2012; Liu and Willison 2013). However, plant responses to reservoir drawdown and reflooding are bound to be site- and species-specific (Hawkes et al. 2018). Teasing out these responses probably calls for a more experimental approach than the rather non-systematic one with which CLBWORKS-1 revegetation treatments were applied around Kinbasket Reservoir. The experience that has been gained from this process should nonetheless be used in an adaptive management framework to make constructive modifications to the program so that better results can be achieved in the future.

5.1.2 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)?

Treatment survivorship was variable but, in general, extremely low. The mortality rate for black cottonwood, willow, and red-osier dogwood live stakes was close to 100 percent; shrub seedlings (of mountain alder, black cottonwood, choke cherry, red-osier dogwood, wild rose, and willow) also failed to survive except for a very small number of cottonwood seedlings at a few scattered locations (Ptarmigan Creek, Goodfellow Creek, and Hope Creek; Miller and Hawkes 2019). Survivorship of graminoid transplants was also generally low to negligible in random samples monitored from 2009 to 2013 (Fenneman and Hawkes 2012, Hawkes et al. 2013). The proportion of sampled treatment polygons (n=91) where 0 surviving transplants were observed in 2018 (seven to 10 years post-planting) was 64%. The widespread failures can probably be ascribed generally to the physiological challenges posed by prolonged summer inundation (and associated anoxia) combined with soil moisture deficits at other times of the year, repeated cycles of flooding and exposure, generally infertile substrates, erosive forces and wave scouring, sediment deposition, and woody debris abrasion and/or deposition.

A comprehensive re-inventory in 2018 of all original CLBWORKS-1 treatment polygons, some of which had not been previously assessed under the CLBMON-9 random sampling design, yielded informative new data (Miller and Hawkes 2019). Most notably, we recorded several instances of vigorous, surviving graminoid plug transplants at locations not previously known to have had successful establishment, including microsites in both Canoe Reach (e.g., Yellow Jacket, Ptarmigan Creek) and Bush Arm (e.g., Chatter Creek, Km77, Km79, Km88 peatland; Miller and Hawkes 2019). Kellogg’s sedge was the most widely recorded surviving transplant, but successful instances of Columbia sedge (e.g., Km77), wool-grass (e.g., Km88 peatland), water sedge (e.g., Hope Creek), and bluejoint reedgrass (e.g., Ptarmigan Creek, Yellow Jacket Creek) were also observed. Although localized, these instances of successful establishment imply that previous estimates of survivorship may have been somewhat underestimated (Hawkes et al. 2013). Their fortuitous discovery in the final year of monitoring provided a late opportunity to directly relate, via statistical modeling, sedge establishment rates at the local level with topo-edaphic site conditions, including soil moisture and nutrient regimes (see MQ3, next section).

At Km88 Big Bend, the 2013 sedge plug treatments continue to perform well both in terms of survivorship and reproductive development. The 2018 establishment estimates were slightly below the targeted densities of 10,000-15,000 plugs per ha for treatment units 1 and 3, and in line with the target density of 5,000-10,000 per ha for treatment unit 5. Estimated per cent survival was around 35% for all treatment units. Sedge vigour was rated good to moderate overall.

The positive results at Km88 Big Bend are encouraging considering the unusually long inundation periods that prevailed in 2013 and 2014 and which led to predictions of elevated mortality for 2015 (Adama 2015). Two factors that may be contributing to the relatively high initial survival rates are site selection and plant size. The identification of ecologically suitable and capable transplant sites was a central focus of prescription development (Adama 2013), and as a result transplanted plugs have likely benefited from the comparatively moderate environmental conditions prevailing at the Km88 site—a gently-sloped, sheltered, debris-free bay on the lee side of Bear Island supporting an existing cover of Kellogg’s and Columbia sedge (as well as other species). Additionally, because of the extra year spent in nursery storage, the plugs outplanted at Km88 Big Bend were a year older and larger than those employed in earlier revegetation trials (Keefer *et al*. 2010). Larger seedlings are likely to have greater leaf area, higher root and shoot biomass, and greater root growth potential. Under stress (such as prolonged inundation), such traits could confer a survival advantage (Steed and Dewald 2003; Hough-Snee 2010, Adama 2015).

Identifying tolerance levels of the various treatments to specific elements of the operating regime is challenging without benefit of data from controlled experiments (such as those conducted in the Arrow Lakes Reservoir—see Jackson et al. [1995]), due, in part, to the large number of potentially confounding factors at work (Fenneman and Hawkes 2012). Nevertheless, it can be assumed that tolerance limits are species-specific and are constrained by the life history attributes of the taxon or taxa in question. For example, Naiman and Décamps (1997) grouped riparian plants into four broad categories of functional adaptations:

1) Invaders—produce large numbers of wind- and water-disseminated propagules that colonize alluvial substrates;
2) Endurers—resprout after breakage or burial of either the stem or roots from floods;
3) Resisters—withstand flooding for long periods during the growing season;
4) Avoiders—lack adaptations to prolonged flooding; individuals germinating in an unfavorable habitat do not survive.

Applying this classification to some of the more widely-planted species under CLBWORKS-1 (e.g., Kellogg's and Columbia sedge, black cottonwood, and Scouler's willow), the two sedges might qualify as resisters (they have a demonstrated capacity to withstand fluctuating water levels), cottonwood as either an endurer (it can develop adventitious roots from broken branches) or an avoider (it has only a moderate tolerance to anaerobic conditions and a low tolerance to both water stress and exposure to drought) depending on the elevation band and water table proximity, and Scouler's willow as an avoider (it is primarily an upland species not typically found in the drawdown zone).

While coarse, this classification scheme is useful for understanding current drawdown zone plant community development and distributional patterns within the context of reservoir disturbance, and for predicting plant responses to disturbance regimes over the long term. It also offers a possible explanation for the poor performances overall of Scouler's willow and black cottonwood, though not necessarily for that of Kellogg's sedge.

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

The Kinbasket Reservoir drawdown zone presents particularly challenging conditions within which to establish plant communities through revegetation efforts. This is due to a combination of factors:

- the prolonged (but not continuous) seasonal inundation of most of the zone;
- the counter-seasonal fluctuation of water levels, in which the reservoir is held at low water during the spring and then the water gradually increases throughout the summer (opposite of the cycle that most plants are adapted to);
- summer moisture-deficits (prior to inundation);
- the powerful fetch and associated wave energy affecting exposed shorelines;
- shoreline freezing during winter drawdown as ice subsides onto the shore;
- the inter-annual variation in the rates and timing of inundation;
- the often-extreme rates of erosion and deposition;
- the low nutrient availability in many of the soils due to the removal of the organic soil layer; and
- the abundance of large woody debris that collects in some areas and precludes plant growth or scours existing vegetation.

Prevailing conditions in the reservoir may have impacted reclamation success to different degrees and in different ways, depending on the revegetation treatment in question. For example, we observed deciduous stake mortality because of woody debris accumulation (and its subsequent removal) in upper elevation bands at some sites in the upper elevation band (e.g., Windfall Creek [Fenneman and Hawkes 2012]). In turn, many sedge plug treatments appear to have been lost as a consequence of being completely buried under deposits of fine sediment transported during the course of inundation. In some areas, seedling plugs have experienced “pedestaling,” whereby the substrate around the plug bases erodes away exposing the root wads and killing the plants.

Figure 5-1. Examples of reduced sedge establishment success under conditions of sedimentation (left) and slope erosion leading to root pedastaling (right). Photographed in June 2018.

It is quite evident from their widespread distribution in the reservoir that many naturally occurring species such as Kellogg’s sedge are able to cope with, and even thrive under, the hydrologic regime of the reservoir once they become naturally established. However, the capacity of transplanted stakes and plugs to adjust to such a regime change may be considerably less, especially if seedlings have not attained sufficient aboveground biomass prior to inundation to adequately uptake the oxygen needed to fuel respiration, or the necessary root structure required to cope with prolonged desiccation (Fenneman and Hawkes 2012).

At Km88, the factors most likely to limit transplant establishment success are the timing and duration of inundation, both of which have varied markedly on an annual basis since 2013. In both 2013 and 2014, total inundation time at all planted elevation bands substantially exceeded (by >70 days in the case of lower elevations) the previous 30-year norms. That is, in the initial stages, sedge plantings at Km88 experienced somewhat truncated growing seasons—and potentially higher physiological stresses related to prolonged inundation—compared to those experienced over time by the established native vegetation. Plugs in the lower elevation bands, which were inundated for 13 to 20 days longer than the higher bands, were subjected to particularly long inundations (and potential anoxia). This appears to have impacted on survival rates; as of 2018 the lower elevation plantings (TU-1) had a survival rate of 28 %, while those in the highest elevation (TU-5) had a 41 % survival rate.

Various authors have observed or suggested impacts on benthic and riparian plant communities associated with the rafting or stranding of logs (Pease 1974; Bell and Kallman 1976c; Conlan 1977; Duval *et al*. 1980; Sedell and Duval 1985). Impacts on plant communities may result from scouring of both hard and soft substrates, compaction of soft substrates, shading and other alterations in the light environment, deposition of bark and woody debris, and toxic or sublethal effects associated with increased oxygen demand and release of log leachates (Sedell and Duval 1985). Bell and Kallman (1976) reported that logs stored in the Nanaimo River estuary had adverse impacts on eelgrass (*Zostera marina*) meadows as well as on macrobenthic and microbenthic algae. Damage to emergent vegetation has also been observed in coastal areas used for log handling (Duval *et al*. 1980). In Kinbasket Reservoir, floating woody debris frequently accumulates as thick deposits on shoreline areas as a result of wave and wind action or during the winter drawdown cycle (Figure 5-2). Such deposits can scour or bury existing drawdown zone vegetation, inhibiting both short- and long-term growth potential and, as noted above, seriously impact revegetation efforts.

Figure 5-2. **Woody debris accumulation zones in Canoe Reach, north Kinbasket Reservoir.** Photographed in late summer of 2013.

We believe that revegetation success has been limited by a combination of the operation-related factors listed above, together with the choice of species employed for revegetation and, in some cases, the choice of sites targeted for revegetation. For example, Scouler's willow (*Salix scouleriana*), the principle willow species used for in staking trials, is in fact better adapted to upland habitats (forest edges, clearings, roadsides) than to wetlands or areas that are subject to periodic inundation, and thus may not been an appropriate choice for the revegetation program. Species such as Sitka willow (*Salix sitchensis*) or Pacific willow (*S. lucida* ssp. *lasiandra),* which are prevalent within the drawdown zone of Kinbasket Reservoir, may have provided more suitable stock for staking. Their incorporation into the project may have increased the stake survivorship. Furthermore, the collection of the stakes from roadsides and other upland habitats, rather than from existing populations within the drawdown zone (Keefer et al. 2008), may have reduced the likelihood of collecting stakes from individuals that are more ecologically adapted to reservoir conditions (Fenneman and Hawkes 2012).

From our 2018 topo-edaphic comparison of microsites with and without successful sedge establishment, we determined that substrate conditions can have quite a profound impact on the probability of plug survival. Specifically, a high percentage of the variation in establishment rates could be explained by edaphic factors including sodium (Na), potassium (K), clay, silt, carbon, and organic matter contents. Surprisingly, these edaphic factors were more important at explaining the variation than elevation (which can be regarded as a general proxy for inundation depth and duration). Just as unexpected was an apparent positive correlation with increased Na given the documented intolerance of most plant species to saline soils. For almost all terrestrial plants (other than C4 species), Na^+ is not essential for either growth and development or for reproduction. However, there is evidence that at low levels, Na^+ not only is harmless but can be very useful, particularly when K^+ is deficient (Subbarao et al. 2003). This is because, in hydrated form, Na^+ and K^+ are chemically and structurally very similar; thus, many of the roles that K^+ plays in plant cells, including some of the metabolic ones, can be fulfilled by Na^+ (Maathius 2013).

In a similar model that substituted the percent cover of Kellogg's sedge (including naturally occurring Kellogg's sedge) for standing stem counts, the existence of a stream-fed, subsurface moisture source was the most important predictor of high cover values. In this case, Na was the most important limiting factor on dry to mesic soils where precipitation was the primary water source. Our interpretation is that, in those areas where Kellogg's sedge (and other sedges) have established successfully, summer moisture and potassium deficiency are potential important limiting factors with the latter being compensated for, to some degree, by the presence of tolerable concentrations of sodium in the substrate. This hypothesis needs further testing, but as a preliminary finding could be highly useful for informing future decisions around site selection in subsequent transplant trials or where other physical site improvements are being considered.

Another non-operational effect worth noting is the possible negative impact that grazing by waterfowl (mainly Canada geese) is having on the demographic success of sedge plugs at low elevations. We observed that most plugs situated near the May/June waterline (Km88) had been heavily browsed in 2015, resulting in the seasonal loss of both photosynthetic foliage as well as reproductive structures (flowering stems). The extent to which grazing pressure may be interacting with inundation timing and duration to limit long term establishment success remains unclear.

5.1.4 MQ4: What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-1, at increasing the quality and quantity of vegetation in the drawdown zone?

To date, only those revegetation treatments involving Kellogg's sedge and Columbia sedge plug transplants appear to have achieved any measurable degree of early establishment success, and this is true only for very limited areas in Bush Arm and Canoe Reach (e.g., portions of Km77, Km79, Km88, Yellow Jacket Creek, and Ptarmigan Creek). It remains unclear if these introduced populations will become self-sustaining over the long term or if they can modulate local environmental conditions enough to facilitate the establishment of other species, thereby advancing community succession. We note that effectiveness assessments have been hampered by the overall low establishment success of treatments and by a general lack of replication and stratification in the treatments available for monitoring.

At Canoe Reach, we found that vegetation showed a positive response overall to woody debris removal, with increases observed in both per cent cover and species richness at most treated sites. As might be expected, the strength of the initial response (relative to non-treated controls) varied from site to site, likely reflecting idiosyncratic differences in existing substrates (e.g., soil texture and nutrient regimes), water inputs, and the prior presence of seed banks and/or remnant vegetative propagules (e.g., rhizomes). The most marked positive response was at Valemount Peatland (North), a highly impacted, remnant wetland site with moist, nutrient-rich, highly organic soils supported by seepage inflows from an adjacent upslope wetland and, judging by the diversity of recently emerged species, possessing an active seed/propagule bank. Floristic inventories of this area 2014 have yielded 112 established and regenerating vascular plant species—nearly equalling the cumulative total of 128 species recorded to date for the entire Canoe Reach drawdown zone (Hawkes and Gibeau 2015) and on par with some of the most productive sites in Kinbasket Reservoir.

By comparison, driftwood sites where the initial vegetation response to debris removal was more muted (i.e., Packsaddle and Yellow Jacket Creek sites) tended to be sandy/gravelly beach-type habitats with relatively xeric, nutrient-poor soils and naturally limited vegetation development. Post-clearing, species recorded in treated transects but not in control transects consisted primarily of ruderal species such as lambs-quarters (*Chenopodium album*), lady's-thumb (*Persicaria maculosa*), common knotweed (*Polygonum aviculare*), and clovers (*Trifolium* spp.). In some transects, species cover and richness actually appeared to undergo a decline after the first year, likely as a consequence of the sites being partially to completely reburied by woody debris during the subsequent fall/winter inundation cycle.

Thus, this approach to vegetation enhancement is likely to be most effective when paired with debris exclosures (in the form of log-booms) and when the area to be selected for treatment show indications of being naturally productive in the absence of debris loading. For example, experience suggests that certain community types, such as WS (Willow – Sedge Wetland), BS (Buckbean – Slender Sedge), and SH (Swamp Horsetails) are likely to respond more rapidly to clearing than more sparsely vegetated habitat types such as CH (Common Horsetail) or CT (Cottonwood – Clover). The former types are all associated with moist to wet soil conditions (i.e., wetlands) while the latter tend to be associated with drier, coarse, rocky sites.

The outcome at Yellow Jacket Creek, where the control area produced higher relative gains in total cover than did the treatment area after clearing, provides another case in point. Here, the area left experimentally uncleared was on a productive moist seepage site that, despite being heavily impacted by driftwood, was supporting a diverse complex of willows and graminoids (many of them wetland indicator species). In contrast, the area cleared was on a course gravel-cobble substrate that supported a mainly ruderal species assemblage more characteristic of the CT community type. From an experimental perspective, these inherent differences imply that the two sites were probably not an ideal pairing. From a management perspective, it seems likely that the immediate restoration payoff would have been greater had the control site been cleared of its debris, rather than vice versa.

Thanks to the previous vegetation characterizations and mapping that have already occurred under CLBMON-9 and 10, good information is now available on the general distribution and frequency of the different community types within the reservoir drawdown zone and could be used to identify sites with high recovery potential. On a more summary level, potential treatment areas can be said to include wetlands and other formerly vegetated sites where a viable seed bank is likely to persist; shallow ponds and depressional areas; protected bays and inlets; sites with nutrient-rich, moist soils; and sites where wood deposition does not recur on a regular basis (i.e., located outside of the primary deposition zones). Cueing off coarse biophysical filters such as these, it should be relatively straightforward to identify potential target areas using historical and recent aerial photo records. Promising areas could subsequently be ground-surveyed to confirm community type, substrate quality, and seed bank or other regenerative potential, then catalogued for future management reference.

The third revegetation approach covered by this report—construction of elevated mounds and windrows to create topographic heterogeneity and new opportunities for plant establishment—has shown early promise with respect to plant colonizations. At the Bush Causeway pilot project, implemented in 2015, > 70 different species have been recorded growing on the constructed mounds/windrows and cleaned ponds, including a number of taxa not previously recorded from the surrounding drawdown zone habitat. The presence of these novel elements on/in the mound features and cleaned ponds provides some early evidence that physical works have been effective at increasing small-scale habitat structure (and wetland integrity) and, in turn, local species richness. However, the constructed habitats are situated at high elevation in the drawdown zone and have yet to undergo an inundation cycle due to the series of relatively low water years in Kinbasket since 2015. Consequently, the structural integrity and vegetation responses of the mounds, windrows, and ponds to seasonal flooding remain untested and unknown. For example, will the debris piles remain anchored in place or disassemble and float away following successive high water events? Similarly, there have been no opportunities to assess the effectiveness of the log-boom installation at preventing wood debris from reaccumulating in the upstream ponds.

5.1.5 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?

Via instances of successful plug establishment in some localized areas, the 2008-2011 revegetation program can be said to have produced a net benefit with respect to size and productivity of vegetated areas. Likewise, in 2013, a total of 3.3 ha at Km88 were stocked to a density of approximately 23,000 plants per ha. Five years later, the density of surviving plants was estimated to be around 8,300/ha, or slightly under 1 stem per m^2. By this measure, implementation of the revegetation program at Km88 has so far resulted in greater immediate benefits than could be achieved through natural colonization alone.

The Km88 treatments were (intentionally) applied to an area of the drawdown zone that already supported well-established vegetation communities (spanning the KS, MA, and RC community types). Thus, while treatments may have succeeded in elevating species richness and cover at the local scale, they have not necessarily resulted in a larger vegetated area than existed before. The main ecological effect to date has likely been to tilt the balance of community composition toward a more graminoid-intensive phase, particularly at the lower sites which otherwise tend to be dominated by short-statured annuals. Localized increases in sedge cover, even if these turn out to be ephemeral at a time scale of 10 or more years, may already be providing some ancillary wildlife services in the form of increased habitat structure and cover (for both aquatic as well as terrestrial organisms), shading, and browse. For example, we found indications in 2015 that local waterfowl populations (most likely Canada geese) have been preferentially utilizing sedge plantings in some of the treatment units as a spring food source.

An assessment of how the establishment rate from the planting program directly compares with that of natural colonization rates was not part of the present study design. Nevertheless, from our monitoring activities within permanent vegetation sites (both for CLBMON-9 and CLBMON-10), we can infer that natural colonization plays an active and ongoing role in structuring local reservoir community dynamics. Individual plants species can occur in a range of sizes and ages on the same microsite, with a high proportion of the local population often consisting of seedling and juvenile stages. For example, dense carpets of Kellogg's sedge germinants were frequently encountered at lower elevations during surveys (the vast majority of germinants do not survive the subsequent summer inundation and are short-lived).

Several sites at various elevations, but especially at low and mid elevations, have undergone moderate turnovers in species abundance and composition from one sample year to the next. These species turnovers often appear to be precipitated by sediment transport; as sediment becomes deposited on a microsite during flooding, it buries the existing vegetation and creates microsite openings for new colonizers to establish (Hawkes et al. 2010, 2013). Colonization (and re-colonization) presumably occur via a combination of vegetative spread, regeneration of remnant individuals, transported seeds and vegetative propagules, and germination from the soil seed bank (Naiman and Décamps 1997; Jansson et al. 2000; Casanova and Brock 2000; Capon and Brock 2006; Liu et al. 2006), although the relative importance of these different processes in increasing the size of vigour of vegetated areas in the Kinbasket Reservoir drawdown zone is presently unclear.

At the landscape scale, the distribution and extent of vegetation communities in the drawdown zone has remained relatively static since 2007 (Hawkes et al. 2013). At this larger scale, natural colonization events appear infrequent under present operating conditions. This may be because most of the available suitable shoreline is already at least partially established with vegetation cover, leaving uninhabited only those areas that are inherently inimical to plant establishment as a result of either rocky substrates, inadequate soil formation, low nutrient levels, low water-holding capacity, high erodibility, exposure to wave action, steep gradients, or exposure to woody debris scouring and accumulation.

Despite this inherent inertia, the potential does exist for some of these areas to become revegetated through natural colonization processes should conditions change, such as in the case of sites impacted by woody debris. In this context, we surmise that the soil seed bank (and the supply of vegetative propagules and remnant vegetative fragments) within the drawdown zone may be an important untapped resource (Naiman and Décamps 1997; Lu et al. 2010). For example, at Valemount Peatland in Canoe Reach, we saw that the mere act of removing woody debris from an accumulation zone was sufficient to trigger a rapid rebound in plant cover. We hypothesize that long-standing woody debris accumulations, which form an effective barrier to currents and wave action, may create temporary "safe sites" or settlement areas for plant propagules including rhizome fragments and floating seeds. Some of the retained propagules become buried in the soil below the logs where they form a persistent propagule bank; when the woody cover is removed, the seeds/fragments are released from dormancy and germinate/regenerate. In most situations, recently vacated sites are probably typically reburied by debris before regenerating vegetation has a chance to become fully established (hence the justification for installing debris exclosures such as log-booms).

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

There is little doubt that the operating regime in place since the commencement of the planting program has had a negative impact on the revegetation success to date. Most transplanted plants have clearly been unable to cope with the combination of inundation timing, frequency, duration and depth, or with the by-products of these factors such as attendant erosion, woody debris scouring, and droughty conditions.

Due to the high reservoir levels that prevailed for several years commencing in 2011 (Figure 2-4), the drawdown zone experienced a decrease in the average number of available mid-summer growing days in the years immediately following the first implementation of CLBWORKS-1. There are reasons to suspect that the reduced growing times (and increased inundation times) negatively impacted the survivorship of transplants, considering the effects observed on natural vegetation (Hawkes and Gibeau 2017) and the likelihood that recently transplanted stock has reduced physiological tolerance to prolonged inundation. It is fairly evident that from an operational perspective, a more effective way to maintain revegetated communities would be to improve basic environmental conditions for planting treatments. With respect to the hydroperiod, program experience to date suggests the following precepts (Miller et al. 2018):

(v) To facilitate development of functional riparian ecosystems, periodic, brief inundation at low elevations (e.g., 746-750 m) is likely necessary to recharge soil moisture, protect establishing plants from summer drought, and maintain suitable growing conditions for flood-adapted riparian species and communities.

(vi) Full pool events, such as those experienced between 2011 and 2012, strongly limit the capacity for shrub and tree establishment at upper elevations (i.e., > 452 m).

(vii) Deep, prolonged summer inundation is unnecessary for transplant establishment and growth and probably detrimental of all revegetation taxa.

(viii) 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. Operational adjustments 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. The inundation regime of 2015, which saw Kinbasket Reservoir peak in mid-July after reaching a relatively low annual maximum of 750.79 m ASL (Figure 2-4), appeared to benefit vegetation in several respects (M. Miller, pers. obs.) and could provide a useful template for operations moving forward (Miller et al. 2016). We predict that, if sustained over time, this inundation pattern will lead to higher cover of grasses and deciduous shrubs at mid to upper elevations, and higher sedge and annual herb cover at lower elevations.

The non-experimental nature of the planting program, combined with the recent history of variable reservoir operations (also unreplicated in space and time), limits our ability to test hypotheses or to recommend specific targets around inundation timing, frequency, duration and depth. Annually replicated planting treatments in conjunction with a succession of different inundation cycles will be needed to address this question fully.

6.0 Summary

In this final summary data report for CLBMON-9, we review the incremental insights that have been gained with respect to the effectiveness of the Kinbasket Reservoir revegetation program (CLBWORKS-1) at increasing the quantity and quality of vegetation in the drawdown zone.

Early results of effectiveness monitoring (2009-2013) suggested that the revegetation treatments applied during the initial four years of CLBWORKS-1 (2008-2011) were unlikely to meet the program objectives of increasing the areal extent and diversity of vegetation; improving wildlife habitat; and increasing productivity within the drawdown zone of Kinbasket Reservoir. Most plantings (seedling plugs and live stakes) monitored in random plots showed low to nil survivorship after three years. Moreover, treatments showed no statistically significant effects on per cent cover of vegetation, species richness, or species diversity at the landscape scale. Numerous factors likely contributed to the difficulties in plant establishment, some of which may have been related to planting methodology, while others appeared directly linked to the reservoir operating regime (i.e., timing, frequency, duration, and depth of inundation) and various attendant factors (e.g., anoxia, erosion, sedimentation, woody debris deposition, moisture deficiency, and nutrient deficiency).

In 2018, we widened the scope of field sampling to include survival and top-edaphic assessments at several CLBWORKS-1 treatment sites not previously monitored under CLBMON-9. The outcome of this expanded survey was a more comprehensive cataloguing of revegetation successes and failures covering almost the full extent of treatment polygons. During this inventory, we came across a few localized but notable instances of surviving graminoid (primarily sedge) plugs that had gone undetected in previous random samples of treatment areas, suggesting that previous summary reports may have underestimated slightly the success rate of planting efforts at the local scale. The plantings in these areas, along with a second and more successful sedge trial undertaken in 2013 at Km88 (Bush Arm), may now be providing some ancillary ecological services such as increased erosion control and browse for waterfowl. That said, an apparent lack of new recruits in otherwise barren areas suggests that revegetated populations may not be self-sustaining over the long term and may require repeated planting interventions to persist.

Other CLBWORKS-1 pilot projects implemented since 2013 in Canoe Reach and Bush Arm—woody debris removal, log boom exclosures, and artificial mounding to increase habitat heterogeneity—have shown some early initial successes (with respect to localized increases in plant diversity and cover) and appear to offer promising alternatives to direct stocking for treating multiple sites over a wide geographic area in a short time frame. However, most of these trials have not yet been subjected to reservoir inundation due to the series of relatively low water years in Kinbasket since 2015. Hence, their responses to, and long-term effectiveness under, typical operating conditions remain untested and unknown.

Nevertheless, it is becoming increasingly evident that planting interventions on their own, in the absence of additional physical modifications aimed at ameliorating local site conditions, are unlikely to achieve the long-term revegetation objectives identified for the Kinbasket Reservoir drawdown zone (BC Hydro 2008). From an operational standpoint, substantial opportunities also exist for advancing vegetation establishment, namely by using operational 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).

7.0 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 Kinbasket 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.

2018 marked the final year of scheduled effectiveness monitoring under the CLBMON-9 program. However, current research confirms that transplanted vegetation continues to persist, and in some instances thrive, at a select proportion of sites treated under CLBWORKS-1 (primarily Km88 Big Bend, Km77, Chatter Creek, Yellow Jacket Creek, and Ptarmigan Creek). Given that successional development related to revegetation is still at an early ecological stage, and to retain the opportunity of gaining valuable lessons from long-term observations 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 frequency cycle up to 2025 (for a total of 10 years of monitoring in the case of the Bush Causeway pilot project), with additional, interim sampling being undertaken if extreme events are triggered during this time. Furthermore, future monitoring should be limited to those sites where successful transplant establishment is known to have occurred.

Future considerations for vegetation enhancement and revegetation monitoring in Kinbasket 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 2020. The CLBMON-35 results will inform future direction of vegetation monitoring in Kinbasket Reservoir.

8.0 References

Abrahams, C. 2005. The ecology and management of drawdown zones. British Wildlife 16:395–402.

Abrahams, C. 2006. Sustainable shorelines: the management and revegetation of drawdown zones. Journal of Practical Ecology and Conservation 6:37–51.

Adama, D. 2015. CLBWORKS-1 Kinbasket Reservoir Revegetation Program, 2014 Post-planting Report. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 20 pp + Appendices.

Adama, D. B. 2013. CLBWORKS-1 Revegetation Plan for Kinbasket Reservoir Phase 4A 2013. LGL Report EA3484. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 14 pp + Appendices.

Allen, H.H., and C.V. Klimas. 1986. Reservoir shoreline revegetation guidelines. Technical Report E-86-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., NTIS No. AD A175 368.

BC Hydro. 2005. Consultative Committee Report: Columbia River Water Use Plan, Volumes 1 and 2. Report prepared for the Columbia River Water Use Plan Consultative Committee by BC Hydro, Burnaby, B.C. 924 pp.

BC Hydro. 2008. Columbia River Water Use Plan – Kinbasket and Arrow Lakes Reservoirs Revegetation Management Plan. Monitoring Program Terms of Reference. Monitoring Study No. CLBMON-9 – Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. 24 pp.

BC Hydro. 2015a. Appendix A: Scope of Services for CLBMON-9. BC Hydro. 2008. Columbia River Water Use Plan – Kinbasket and Arrow Lakes Reservoirs Revegetation Management Plan. Monitoring Program Terms of Reference. Monitoring Study No. CLBMON-9 – Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. 24 pp.

BC Hydro. 2015b. Columbia River Project Water Use Plan. Kinbasket and Arrow Reservoirs revegetation management plan. Physical works terms of reference. CLBWORKS-1 Kinbasket Revegetation Physical Works Addendum 4. 11 pp.

Borkowska, L. 2014. A seed bank inside a clonal plant: the case of the sedge *Carex cespitosa* on an unmowed grassland. Plant Ecology 215:1423-1432.

Capon, S.J., and M.A. Brock. 2006. Flooding, soil seed bank dynamics and vegetation resilience of a hydrologically variable desert floodplain. Freshwater Biology 51(2):206–223.

Casanova, M.T., and M.A. Brock. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? Plant Ecology 147:237–250.

De’ath, G. and K.E. Fabricius. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81: 3178-3192.

Fenneman, J.D. and V.C. Hawkes. 2012. CLBMON-9 Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Annual Report - 2011. LGL Report EA3271. Unpublished report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 78 pp. + Appendices.

Hawkes, V.C. 2016. CLBWORKS-1 Kinbasket Reservoir revegetation program: year 7 – 2015. Debris mound and wind row construction pilot program. Annual Report. Draft report by LGL Limited environmental research associates, Sidney, B.C. for BC Hydro Generations, Water License Requirements, Burnaby, B.C., 33 pp.

Hawkes, V.C. 2017. CLBWORKS-1 Kinbasket Reservoir revegetation program: year 8 – 2015. Debris mound and wind row construction pilot program. Fall 2016 Update. Annual Report. Unpublished report by LGL Limited environmental research associates, Sidney, B.C. for BC Hydro Generations, Water License Requirements, Burnaby, B.C., 33 pp.

Hawkes, V.C., T.G. Gerwing, and P. Gibeau. 2018. CLBMON-35 Arrow Lakes and Kinbasket Reservoirs plant response to inundation. Final Report 2017. LGL Report EA3797. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 39 pp + Appendices.

Hawkes, V.C., and P.T. Gregory. 2012. Temporal changes in the relative abundance of amphibians relative to riparian buffer width in western Washington, USA. Forest Ecology and Management 274:67–80.

Hawkes, V.C., C. Houwers, J.D. Fenneman, and J.E. Muir. 2007. CLBMON-10 Kinbasket and Arrow Lakes reservoir revegetation management plan: Kinbasket Reservoir inventory of vegetation resources. Annual Report – 2007. LGL Report EA1986. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water Licence Requirements, Burnaby, BC. 82 pp.

Hawkes, V.C. and M.T. Miller. 2016. CLBMON-09 Kinbasket Reservoir monitoring of revegetation efforts and vegetation composition analysis: year 5 – 2015. Annual Report. Unpublished report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 41 pp. + Appendices.

Hawkes, V.C., M.T. Miller, J.E. Muir, and P. Gibeau. 2013. CLBMON-9 Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Annual Report – 2013. LGL Report EA3453. Unpublished report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 70 pp. + Appendices.

Hawkes, V.C. and J.E. Muir. 2008. CLBMON-10 Kinbasket Reservoir Inventory of Vegetation Resources. Annual Report – 2008. LGL Report EA1986. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 77 pp.

Hill, N.M., P.A. Keddy, and I.C. Wisheu 1998. A hydrological model for predicting the effects of dams on the shoreline vegetation of lakes and reservoirs. Environmental Management 22:773–736.

Hough-Snee, N. W. 2010. The Effects of Flooding Depth, Fertilization, and Initial Seedling Size on the Growth and Biomass Allocation of Two Wetland Sedges, Carex obnupta and Carex stipata. M.Sc Thesis. University of Washington: School of Forest Resources. 73 pp.

Jackson, J.L., K. Hennebury, and D. Baker. 1995. Reclaiming reservoirs—native species revegetation of shorelines. Proceedings of the 19th Annual British Columbia Mine Reclamation Symposium. Unpublished report. BC Hydro, Corporate Safety and Environment and University of Northern British Columbia, Faculty of Natural Resources and Environmental Studies. 13 pp.

Jansson, R., C. Nilsson, M. Hynesius, and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10(1):203–224.

Johnson, W.C. 2002. Riparian vegetation diversity along regulated rivers: contribution of novel and relict habitats. Freshwater Biology 47:749–759.

Johansson, M.E., and C. Nilsson. 2002. Responses of riparian plants to flooding in free-flowing and regulated boreal rivers: an experimental study. Journal of Applied Ecology 39:971–986.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Canadian Special Publication Fisheries and Aquatic Sciences 106:110–127.

Keefer Ecological Services Ltd. 2012. CLBWORKS-1 Kinbasket Reservoir Revegetation Program Physical Works Report – 2011 Unpublished report prepared by Keefer Ecological Services Ltd., Cranbrook, BC, for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 36 pp. + Apps.

Keefer, M.E., R. Moody, K. Dixon, and A. Kennedy. 2011. Kinbasket Reservoir Revegetation Program Physical Works Report (2010). Report prepared by Keefer Ecological Services for BC Hydro. 41 pp. + Appendices.

Keefer, M.E., R. Moody, T.J. Ross, A. Chapman, and J. Meuleman. 2010. Kinbasket Reservoir Revegetation Program Physical Works Report (2009). Report prepared by Keefer Ecological Services for BC Hydro. 39 pp. + Appendices.

Keefer, M.E., T.J. Ross, T. Ehlers, and J. Meuleman. 2008. CLBWORKS-1 Kinbasket Reservoir Revegetation Program Physical Works Report (2008). Report prepared by Keefer Ecological Services for BC Hydro. 53 pp. + Appendices.

Liu, G.H., W. Li, J. Zhou, W.Z. Liu, D. Yang, and A.J. Davy. 2006. How does the propagule bank contribute to cyclic vegetation change in a lakeshore marsh with seasonal drawdown? Aquatic Botany 84(2):137–143.

Liu, Y., and J.H. Willison. 2013. Prospects for cultivating white mulberry (Morus alba) in the drawdown zone of the Three Gorges Reservoir, China. Environmental Science and Pollution Research International 20:7142–7151.

Lu, Z.J., L.F. Li, M.X. Jiang, H.D. Huang, and D.C. Bao. 2010. Can the soil seed bank contribute to revegetation of the drawdown zone in the Three Gorges Reservoir Region? Plant Ecology 209:153–165.

Luttmerding, H.A., D.A. Demarchi, E.C. Lea, D.V. Meidinger, and T. Vold. 1990. Describing Ecosystems in the Field (Second Edition). MOE Manual 11. Province of British Columbia, Ministry of Environment, Lands and Parks, in cooperation with Ministry of Forests. Victoria, B.C.

Maathius, F.J.M. 2013. Sodium in plants: perception, signalling, and regulation of sodium fluxes. Journal of Experimental Botany. 65: 849-858.

MacKillop, S. 2003. Investigations of revegetation strategies using woody species for fish habitat enhancement and aesthetic improvement in the drawdown zone at Buttle Lake, British Columbia. M.Sc. thesis, Royal Roads University, Victoria, B.C. 102 pp.

Miller, M.T., P. Gibeau, and V.C. Hawkes. 2018. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Final Report – 2017. LGL Report

EA3545C. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 50 pp + Appendices.

Miller, M.T and V.C. Hawkes. 2019. CLBMON-09 Kinbasket Reservoir monitoring of revegetation efforts and vegetation composition analysis: year 6 (part 1) – 2018. Interim Report. Unpublished report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 26 pp.

Miller, M.T. and V.C. Hawkes. 2020. CLBMON-35 Arrow Lakes and Kinbasket Reservoirs plant response to inundation. Year 2 (2019) Report. LGL Report EA3797. Draft report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 32 pp + Appendices.

Moody, A., and W. Carr. 2003. Mica-Revelstoke-Keenleyside Water Use Plan: potential areas for vegetation establishment in Kinbasket Reservoir. BC Hydro Contract Report.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons. Toronto. 547 pp.

Naiman, R.J., and H. Décamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics. 28: 621–658.

New, T., and Z. Xie. 2008. Impacts of large dams on riparian vegetation: applying global experiences to the case of China's Three Gorges Dam. Biodiversity Conservation17: 3149–3163.

Nilsson, C. 1981. Dynamics of the shore vegetation of a North Swedish hydro-electric reservoir during a 5-year period. Acta Phytogeogr. Suec. 69. Uppsala.

Nilsson, C., and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. BioScience 50(9): 783–792.

Nilsson, C., and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management 30(4):468–480.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. BioScience 47:769–984.

Steed, J. E., and L. E. DeWald. 2003. Transplanting sedges (Carex spp.) in southwestern riparian meadows. Restoration Ecology 11:247–256.

Subbarao, G.V., O. Ito, W.L. Berry and R.M. Wheeler. Sodium—a functional plant nutrient. Critical Reviews in Plant Sciences 22:391-416.

Wood, C.M., Hentze, N., V.C. Hawkes, and N. Johnston. 2018. CLBMON-11A. Kinbasket and Arrow Lakes Reservoirs: Wildlife Effectiveness Monitoring of Revegetation Efforts and Physical Works Trials in Kinbasket Reservoir. Annual Report – 2017. LGL Report EA3451D. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 74 pp. + Appendices.

Wood, C.M., N. Hentze, F. Papini, R. Waytes, and V.C. Hawkes. 2019. CLBMON-11A. Kinbasket and Arrow Lakes Reservoirs: Wildlife Effectiveness Monitoring of Revegetation Efforts and Physical Works Trials in Kinbasket Reservoir. Final Report – 2018. LGL Report EA3451F. Unpublished report by Okanagan Nation Alliance, Westbank, B.C., and LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generation, Water Licence Requirements, Burnaby, B.C. 31 pp. + Appendices.

Wu, J., J. Huang, X. Han, X. Gao, F. He, M. Jiang, Z. Jiang, R.B. Primack, and Z. Shen. 2004. The Three Gorges Dam: an ecological perspective. Frontiers in Ecology and the Environment 2(5):241–248.

Yang, F., W.-W. Liu, J. Wang, L. Liao, and Y. Wang. 2012. Riparian vegetation's responses to the new hydrological regimes from the Three Gorges Project: clues to revegetation in reservoir water-level-fluctuation zone. Acta Ecologica Sinica 32(2012):89–98.

Yazvenko, S.B. 2008. CLBMON-9 Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Annual Report - 2008. Prepared for BC Hydro by LGL Limited, Sidney. 70 pp. + App.

Yazvenko, S.B. 2009. CLBMON-9 Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Sampling Design. Prepared for BC Hydro by LGL Limited, Sidney, B.C. 19 pp. + Appendices.

Yazvenko, S.B., Hawkes, V.C., and Gibeau, P. 2009. CLBMON-9 Kinbasket Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. Annual Report - 2009. LGL Report EA3073. Unpublished report by LGL Limited, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Castlegar, B.C. 83 pp. + Apps.

Zasada, J.C. and H.M. Phipps. 1990. *Populus balsamifera* L.: balsam poplar. In Silvics of North America: hardwoods. Vol. 2. Edited by R.M. Burns and B.H. Honkala. U.S. Dep. Agric. Agric. Handb. 654. Pp. 518-529.

9.0 APPENDICES

9.1 Revegetation Trials (2008-2011)

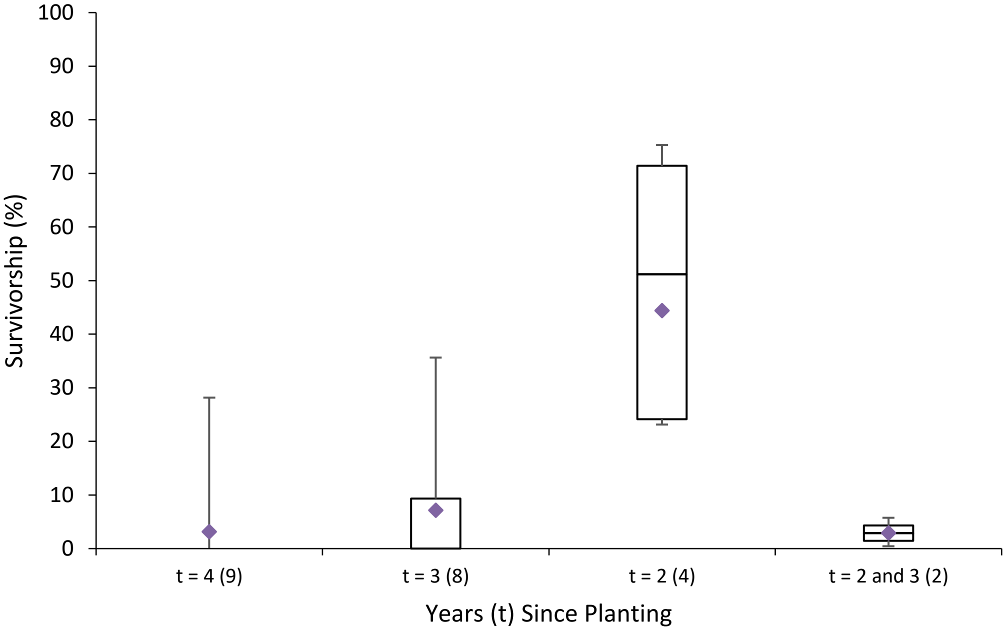

Figure 9-1. **Survivorship in 2013 of plug seedlings (PS) planted in 2009, 2010, and 2011 (t = 4, t = 3, t = 2), and in plots treated first in 2010 and again in 2011 (t = 2 and 3).** Purple diamonds indicate average survivorship. Numbers in parentheses are the sample size for that year.

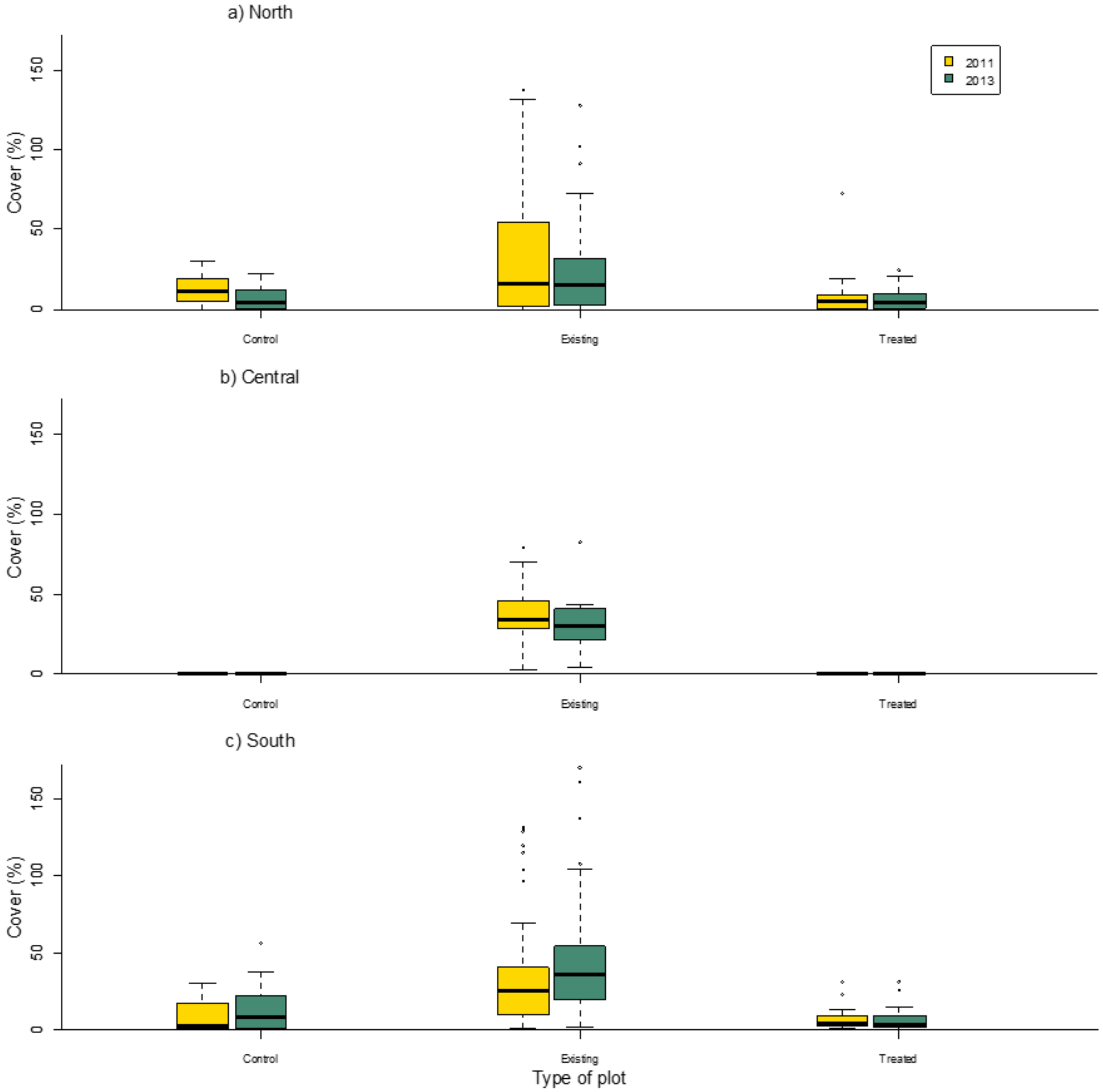

Figure 9-2. Per cent cover of vegetation in control, existing, and treated sites across different regions (north, central, south) of Kinbasket Reservoir in 2011 and 2013. "Existing" sites are areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials.

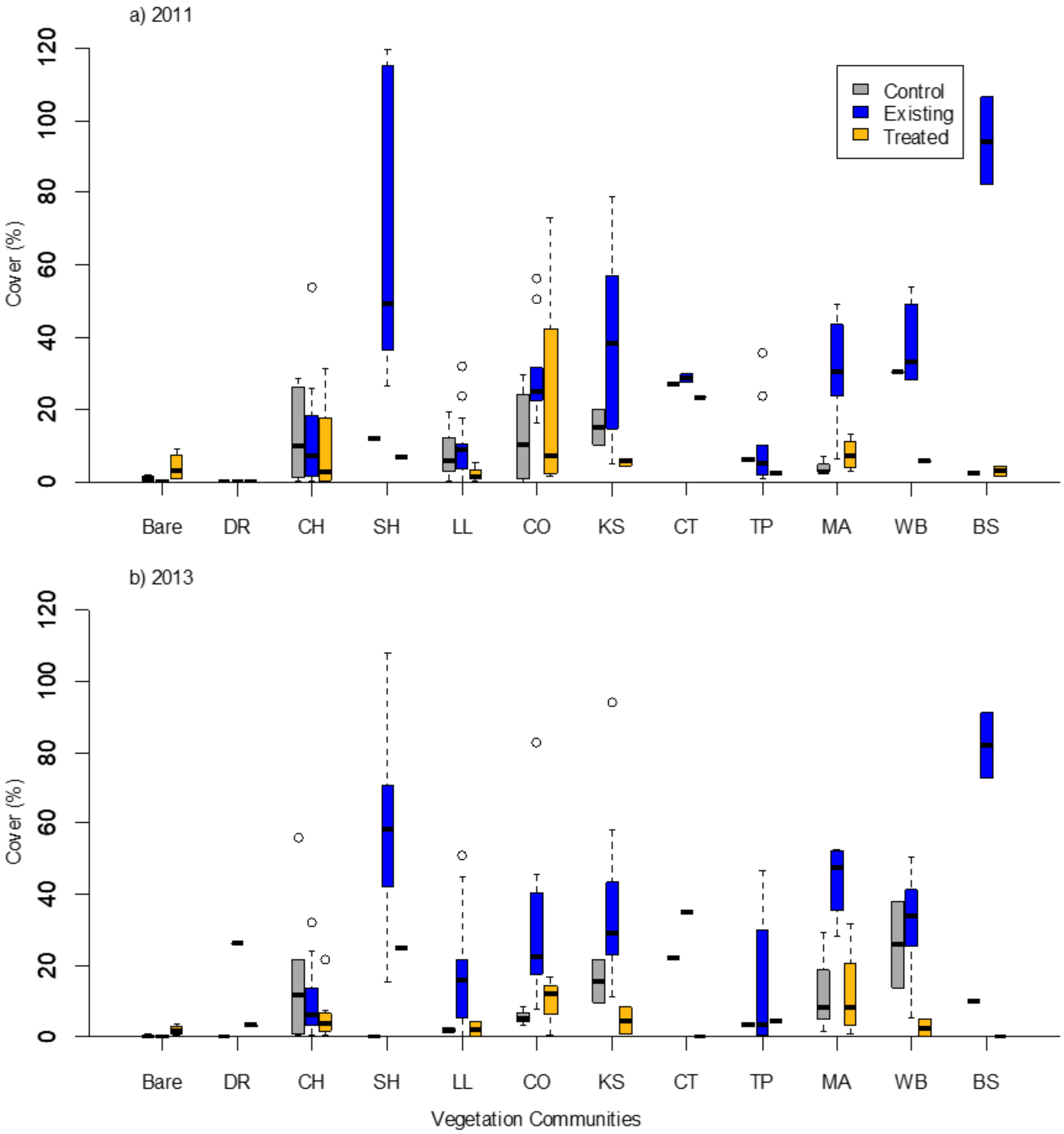

Figure 9-3. **Per cent cover of vegetation in control, existing, and treated sites across different vegetation communities sampled in 2011 (upper) and 2013 (lower)**. See Table 3-2 for vegetation community codes. “Existing” sites are areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials.

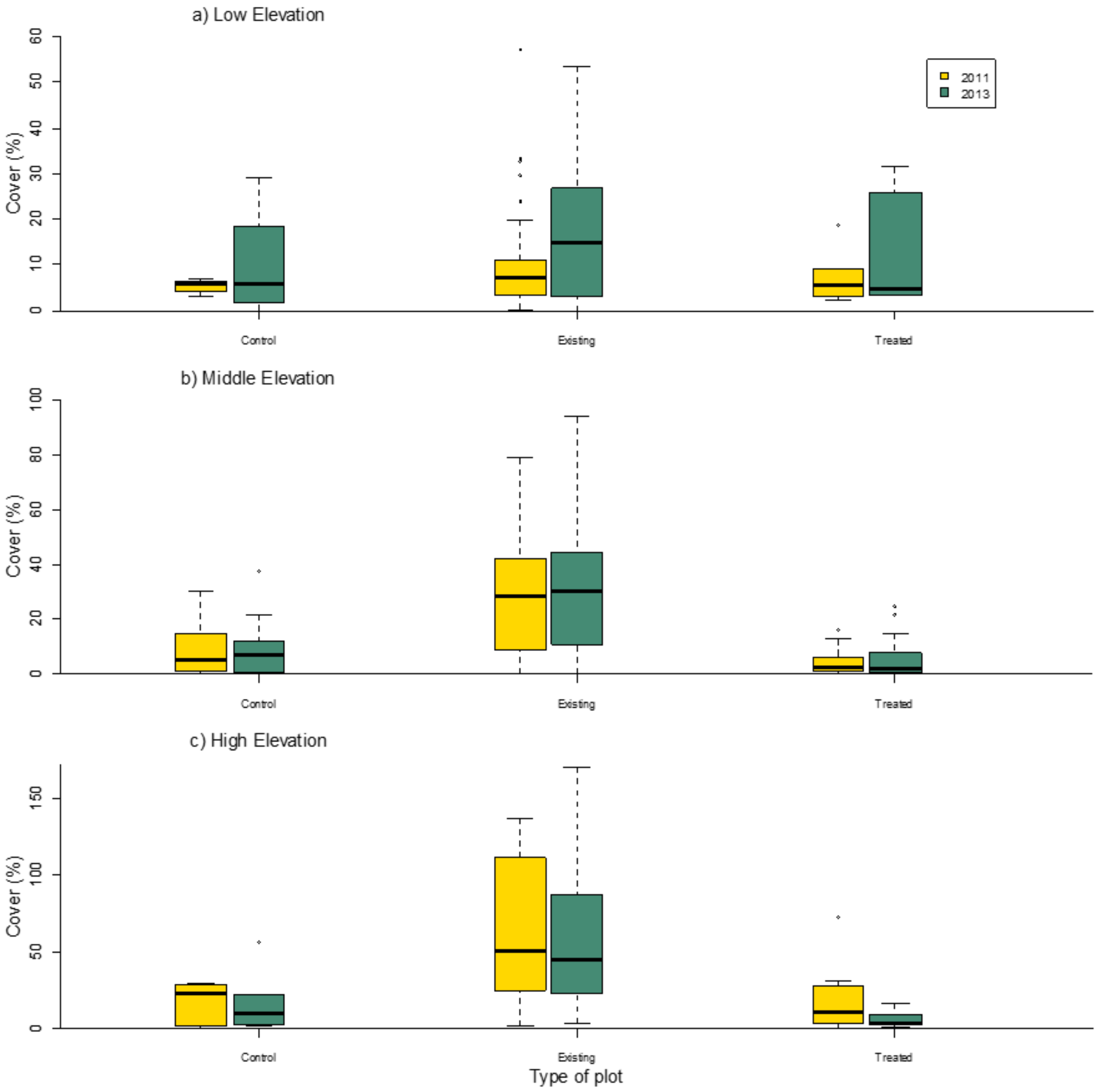

Figure 9-4. **Per cent cover of vegetation in control, existing, and treated sites across elevation bands within the drawdown zone of Kinbasket Reservoir in 2011 and 2013**. Low = 741–745 m ASL; Mid = 746–750 m ASL; High = 751–754 m ASL. Note different scales on y-axis for different elevation bands. “Existing” sites are areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials.

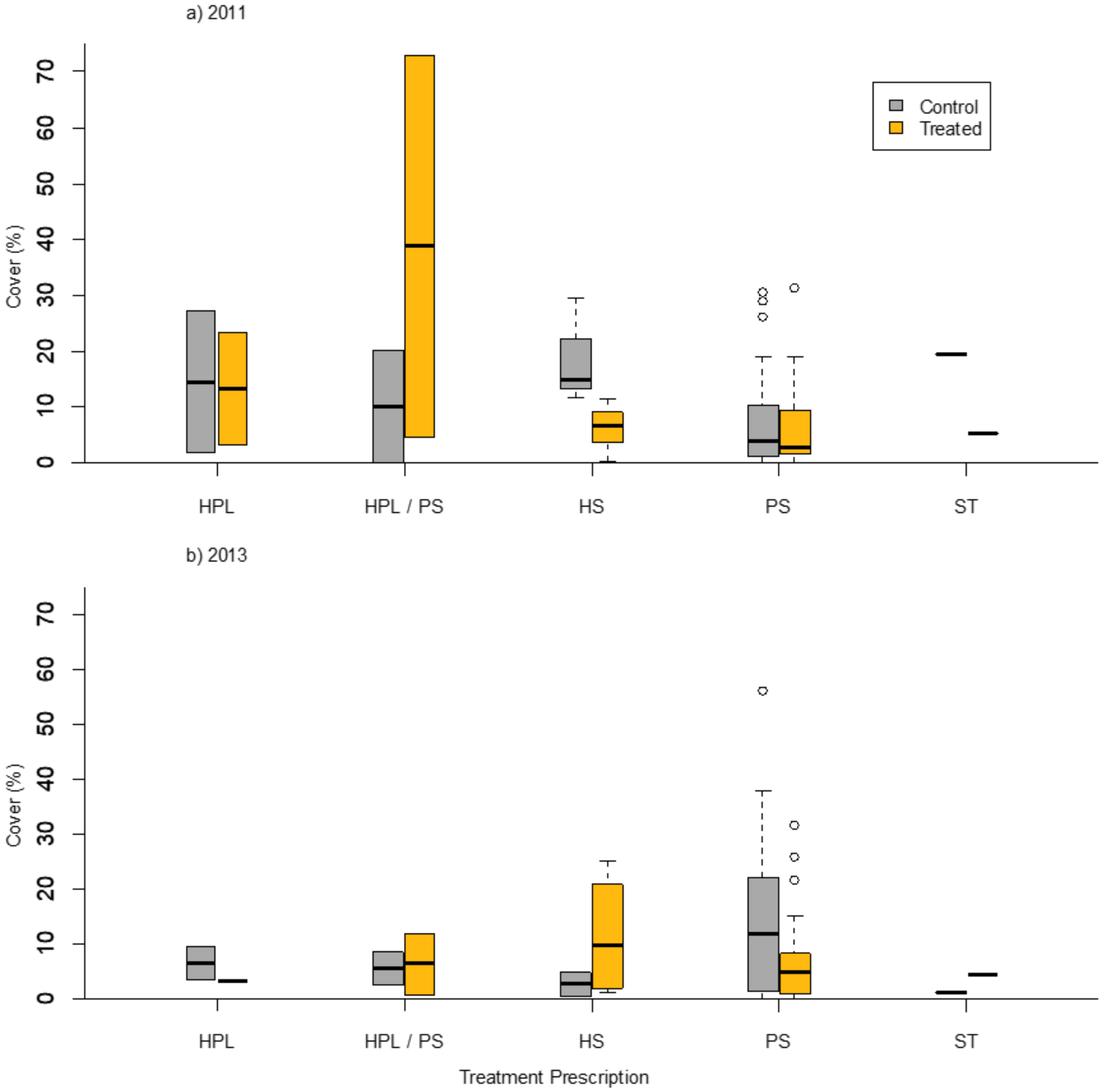

Figure 9-5. **Per cent cover of vegetation for different treatment types in 2011 (upper) and 2013 (lower).** PS = plug seedlings; HPL = hand-planted stakes; HPL/PS = hand-planted stakes and plug seedling; HS = hand seeding; ST = seed trials.

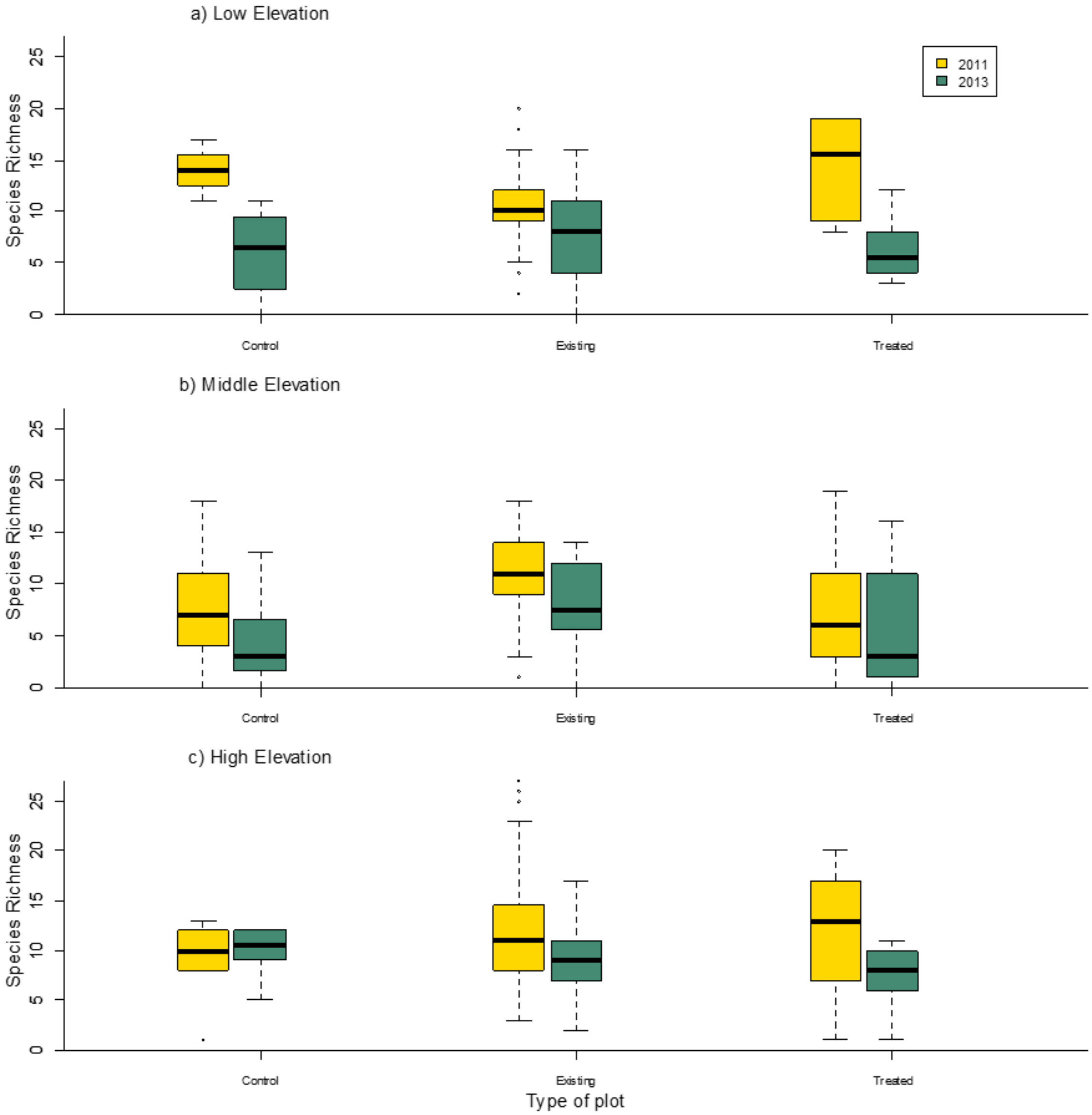

Figure 9-6. **Species richness of vegetation in control, existing, and treated sites across different elevation bands within the drawdown zone of Kinbasket Reservoir in 2011 and 2013.** See Figure 9-4 for strata ranges. "Existing" sites are areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials

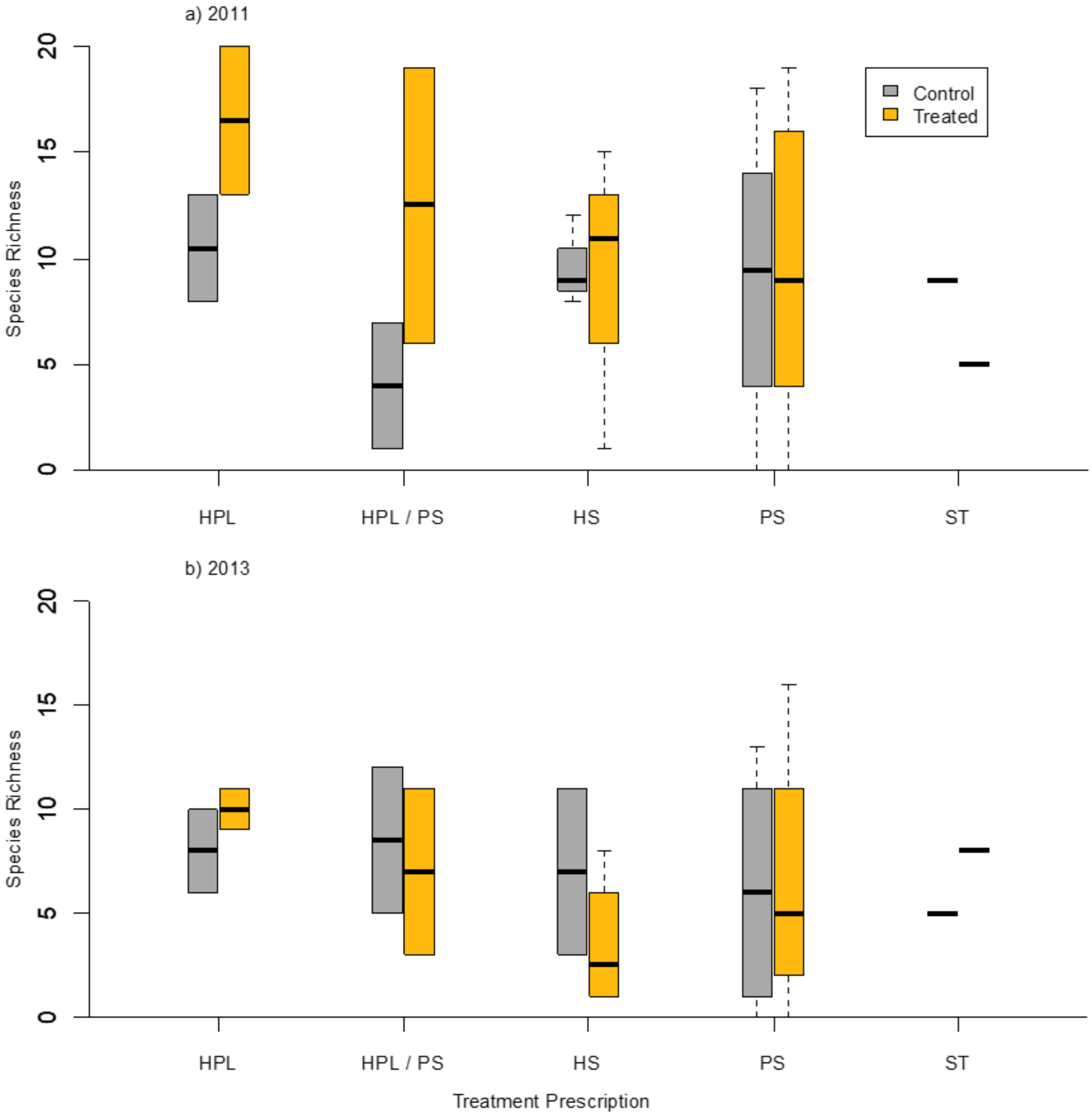

Figure 9-7. **Species richness of vegetation for different treatment types in 2011 (upper) and 2013 (lower).** PS = plug seedlings; HPL = hand-planted stakes; HPL/PS = hand-planted stakes and plug seedling; HS = hand seeding; ST = seed trials.

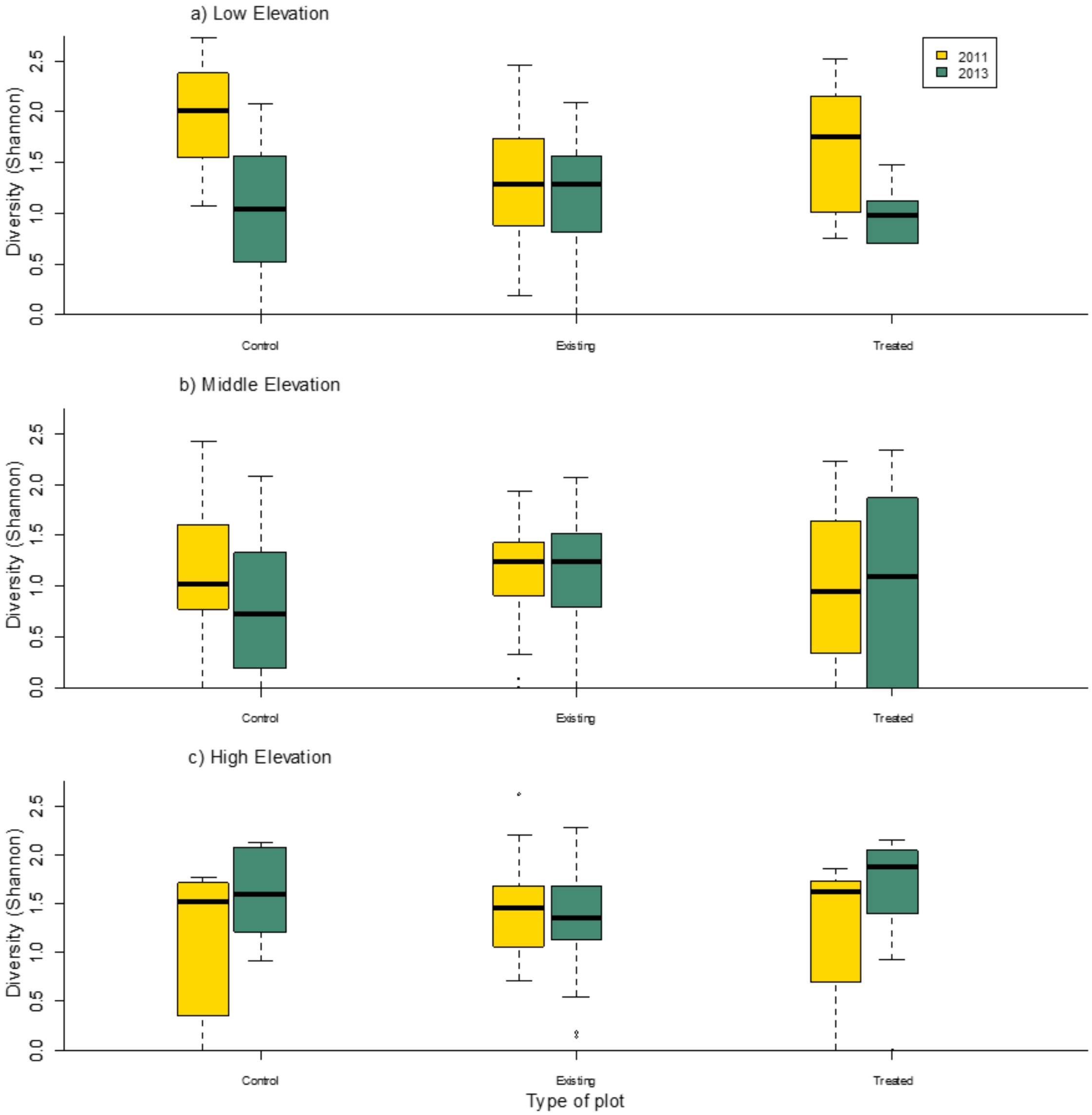

Figure 9-8. **Species diversity (Shannon's index) of vegetation in control, existing, and treated sites across different elevation bands within the drawdown zone of Kinbasket Reservoir in 2011 and 2013.** See Figure 9-4 for strata ranges. "Existing" sites are areas of natural vegetation occurring within the same strata as, but not directly associated with, the revegetation trials.

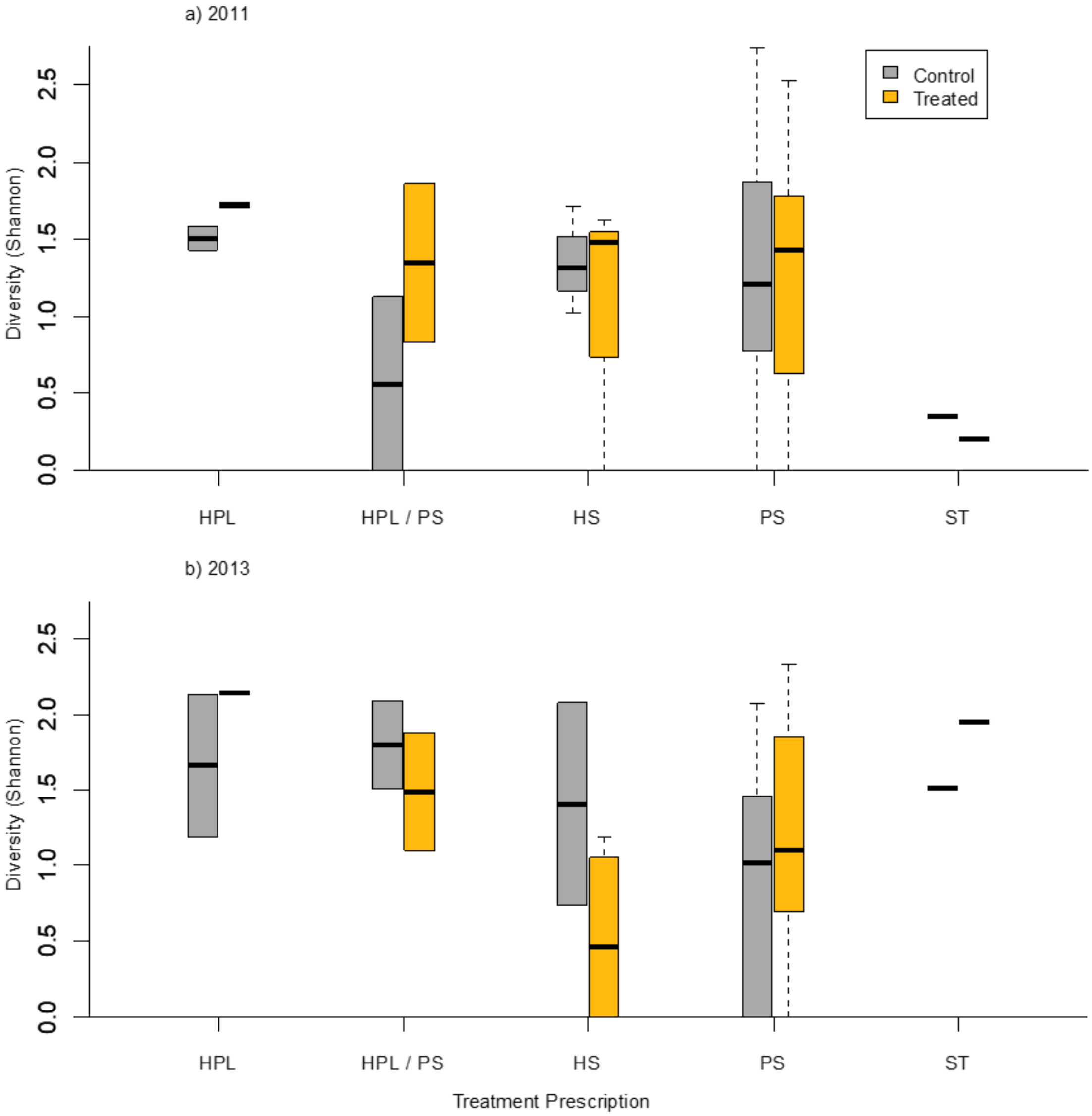

Figure 9-9. **Species diversity (Shannon's Index) of vegetation for different treatment types in 2011 (upper) and 2013 (lower).** PS = plug seedlings; HPL = hand-planted stakes; HPL/PS = hand-planted stakes and plug seedling; HS = hand seeding; ST = seed trials.

9.2 2018 Reassessment of 2008-2011 Trials

Table 9-1. **Revegetation treatments exhibiting survivorship at sites surveyed in 2018, listed by CLBWORKS-1 polygon (2008-2011) or MC unit.** MC numbers correspond to the original treatment units defined by Moody and Carr (2005) in the Columbia Water Use Plan (BC Hydro 2005).

Location	CLBWORKS-1 Polygon#/MC#	Revegetation Species Observed	Highest Recorded Density (50-m^2 plot)	Highest Recorded Vigour
Canoe River Mouth	67	Kellogg's sedge	9	3
Canoe River Mouth	80	speckled alder	3	3
Chatter Creek	85	Kellogg's sedge	62	3
Dave Henry South	30	Kellogg's sedge	2	2
Dave Henry South	85	Columbia sedge	1	2
Goodfellow Ck.	88I	black cottonwood	2	2
Hope Ck.	8, 26A, 26C, 31, 34A, 35B,	Kellogg's sedge	40	3
Hope Ck.	23, 26A, 34A, 34C	water sedge	16	2
Hope Ck.	35B	wool-grass	60	2
Hope Ck.	87C	red-osier dogwood	2	4
Hope Ck.	87C	black cottonwood	14	2
Km 77	84	Kellogg's sedge	45	3
Km 77	84	Columbia sedge	20	4
Km 79	83F, 83G	Kellogg's sedge	50	3
Km 79	83G	Columbia sedge	1	3
Km 79	83F	black cottonwood	27	3
Km 88 (peatland)	2, 3, 32D, 32E	Kellogg's sedge	12	3
Km 88 (peatland)	2	Columbia sedge	7	4
Km 88 (peatland)	2, 3, 32D, 32E	wool-grass	7	4
Km 88 (peatland)	32E	water sedge	1	2
Prattle Ck.	86	Kellogg's sedge	10	2
Ptarmigan Ck.	11, 13	Kellogg's sedge	50	4
Ptarmigan Ck.	11, 13	bluejoint reedgrass	6	3
Ptarmigan Ck.	12	water sedge	2	3
Ptarmigan Ck.	13	Columbia sedge	3	2
Windfall Ck.	7	Kellogg's sedge	4	1
Windfall Ck.	6	bluejoint reedgrass	1	2
Yellow Jacket Ck.	18, 19	Kellogg's sedge	60	4
Yellow Jacket Ck.	19, 21	Columbia sedge	2	4
Yellow Jacket Ck.	18	bluejoint reedgrass	3	4

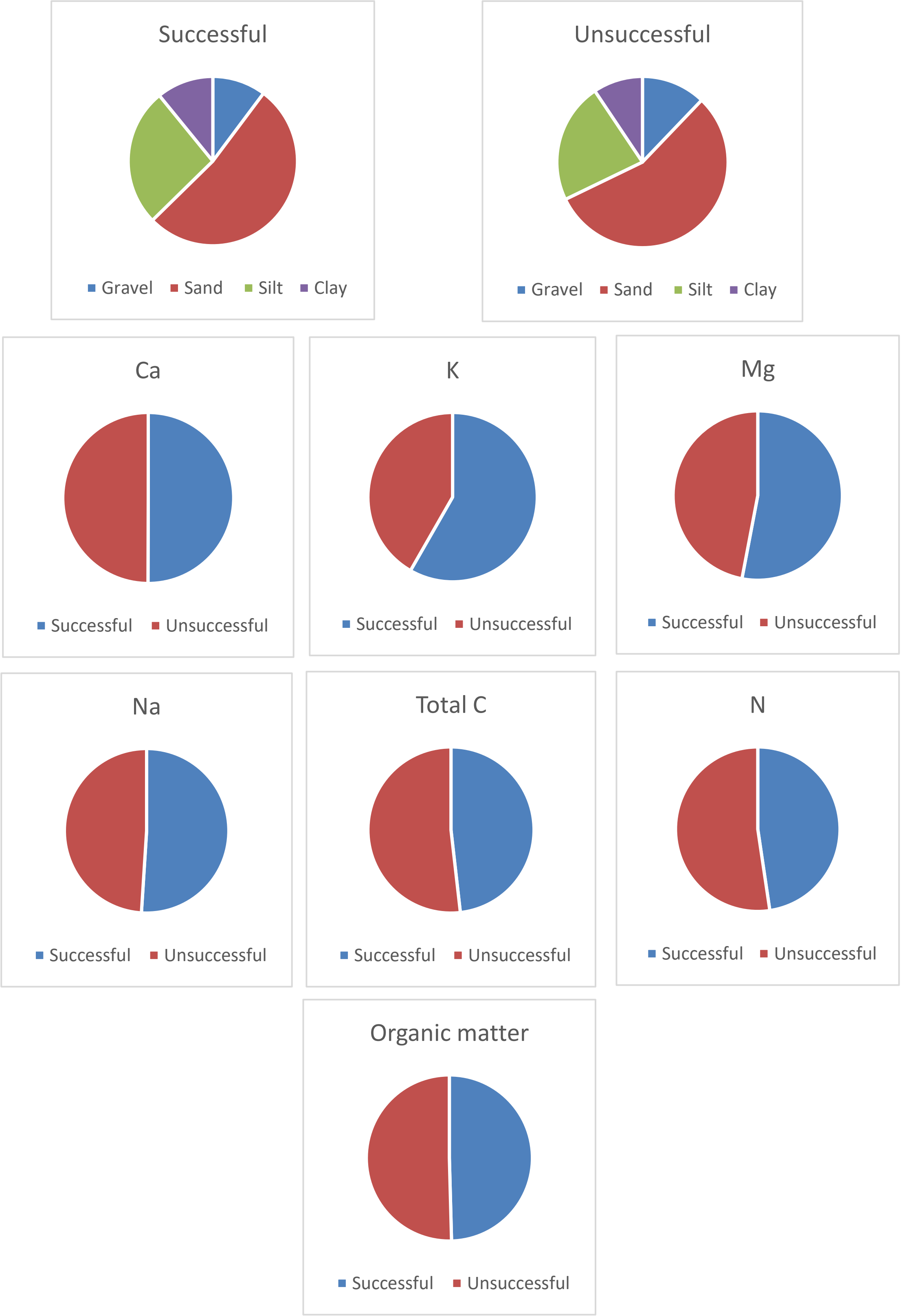

Figure 9-10. Comparison of soil parameters (average texture and nutrient content) between microsites supporting some successful revegetation establishment in 2018, and microsites with no apparent surviving revegetation.

9.3 Km88 Sedge Trial (2013)

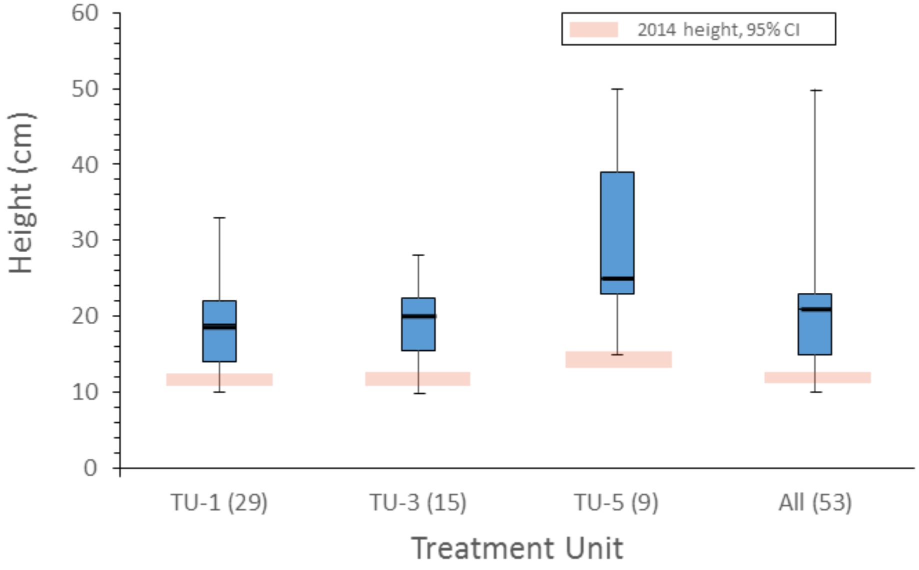

Figure 9-11. **Sedge plant heights (cm) at Km88 in 2015 (two years post-planting).** Sample size shown in () after TU number. Overlain are the 2014 heights (bands representing the 90 per cent confidence intervals) from Adama (2015).

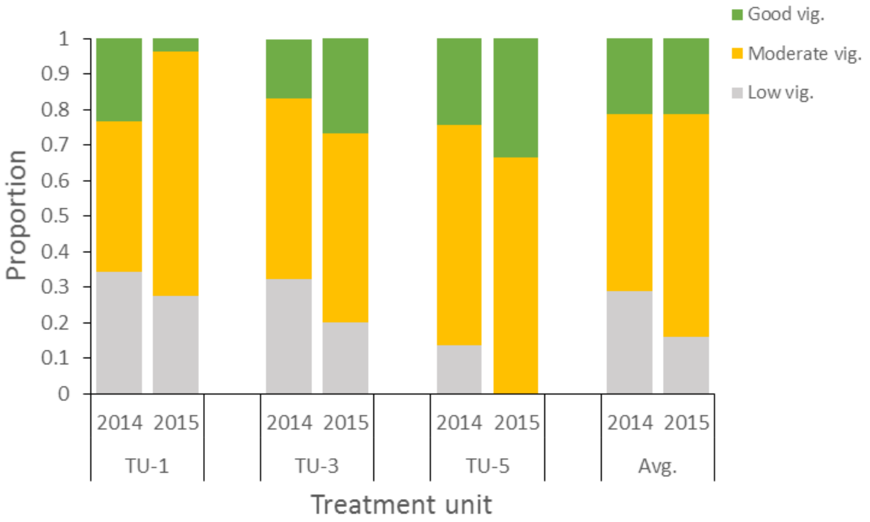

Figure 9-12. **Vigour of sedge plants at Km88 in 2015 (two years post-planting).** Vigour was classified on a scale of “good,” “moderate,” or “poor.” Shown are the proportions of sedge plants in each vigour category for each treatment unit, as well as the overall average, in 2014 and 2015.

9.4 Woody Debris Removal and Boom Exclosure (Canoe Reach)

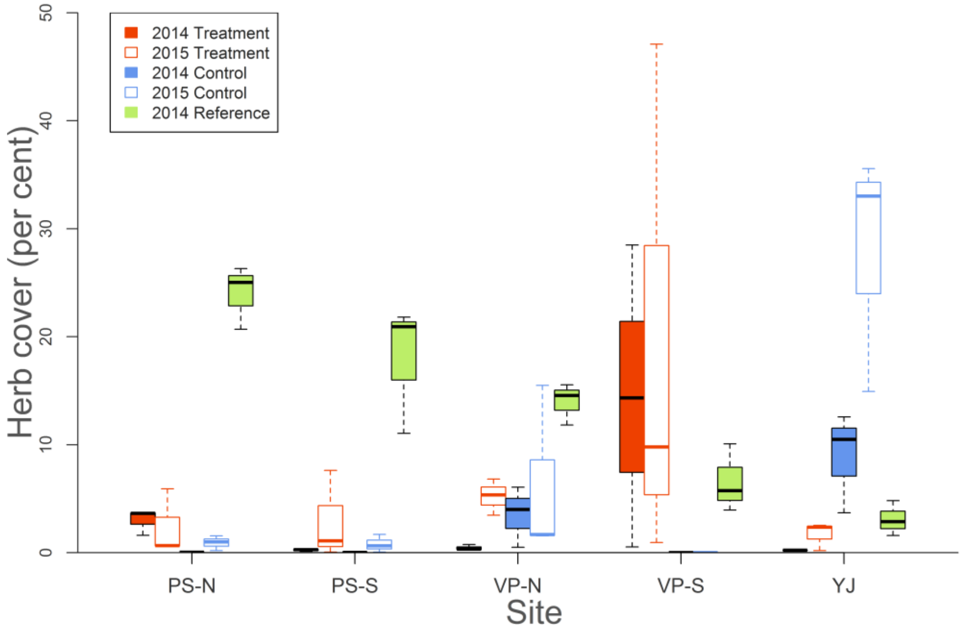

Figure 9-13: Variation in per cent cover of the herb layer in control, treatment, and forest reference transects at the five woody debris removal sites in Canoe Reach, in 2014 and 2015. Note that no study control was available for VP-S.

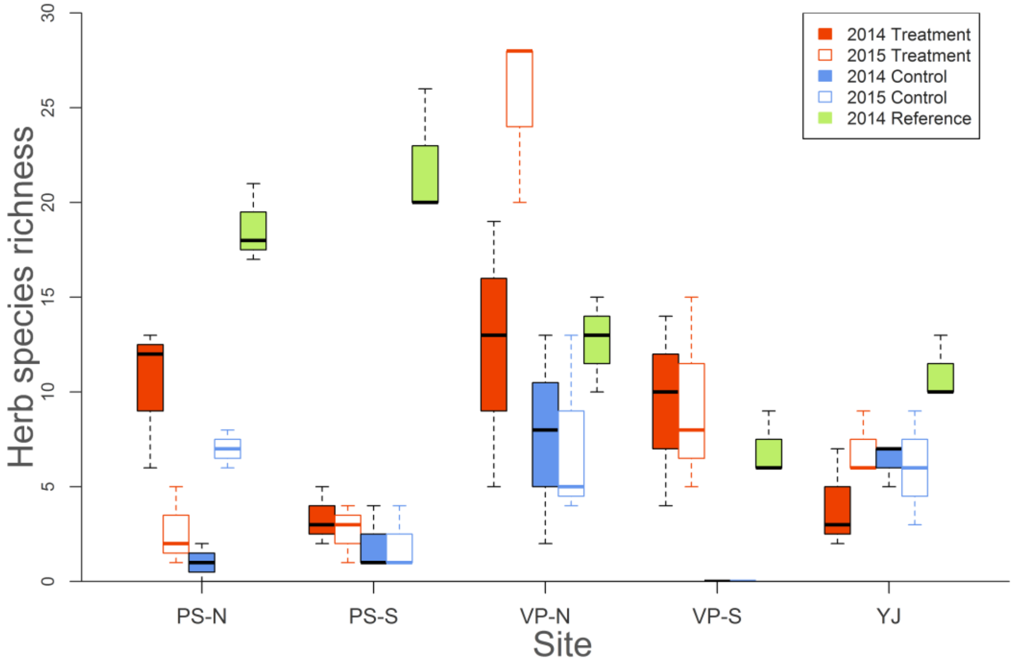

Figure 9-14: **Total number of herb species per transect (control, treatment, and forest reference) at the five woody debris removal sites in Canoe Reach, in 2014 and 2015.** Note that no study control was available for VP-S.

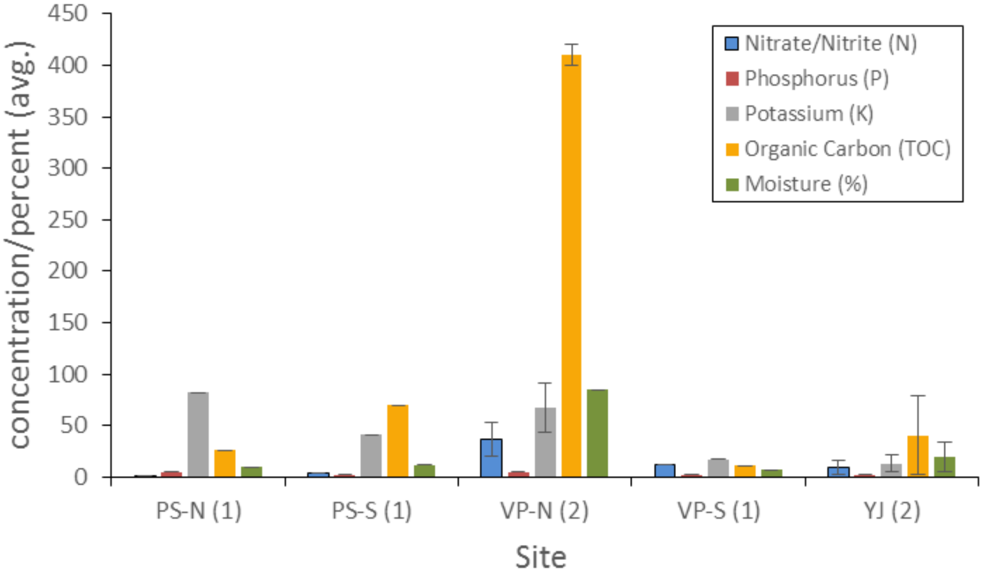

Figure 9-15. **Nutrient concentrations and soil moisture values obtained from soil samples collected at Canoe Reach woody debris removal sites and untreated control sites, June 2015.** For PS-N and PS-S, data correspond to forest reference sites; other data are from sites in the drawdown zone. Sample sizes shown in () after the site name. Standard error bars displayed for n>1. Units for N, P, K: mg/kg. Units for TOC: g/kg. Units for moisture: per cent.

Table 9-2. **Vascular plant species list resulting from the mid-summer (July 20, 2015) floristic inventory of the log-boom exclosure site at Valemount Peatland (North) (VP-N), Canoe Reach.** Species marked with an * were recorded during subsequent surveys in 2017 or 2018.

Species	
Agrostis scabra	*Hordeum jubatum**
Agrostis stolonifera	*Hypericum boreale**
Alopecurus aequalis	*Hypericum canadense*
*Alnus incana**	*Juncus alpinoarticulatus*
*Anaphalis margaritacea**	*Juncus bufonius*
Arnica chamissonis	*Juncus ensifolius*
*Athyrium filix-femina**	*Junucs filiformis**
*Betula papyrifera**	*Leucanthemum vulgare*
Bidens cernua	*Lysimachia thyrsiflora*
Calamagrostis canadensis	*Mentha arvensis**
Calamagrostis stricta	*Menyanthes trifoliata**
Callitriche palustris	*Myosotis laxa**
Cardamine pensylvanicus	*Myosotis scorpioides*

Carex aquatilis	Myriophyllum sibiricum
Carex bebbiana	Parnassia palustris*
Carex brunescens*	Persicaria amphibia
Carex crawfordii	Persicaria maculosa
Carex flava	Picea engelmannii x glauca
Carex interior*	Plantagao major
Carex kelloggii	Poa compressa
Carex lasiocarpa*	Poa palustris
Carex limosa*	Poa pratensis*
Carex stipata	Populus balsamifera ssp. Trichocarpa*
Carex tonsa*	Populus tremuloides*
Carex utriculata*	Potamogeton obtusifolius
Cerastium fontanum	Potentilla biennis
Cerastium nutans*	Potentilla norvegica
Cicuta douglasii	Ranunculus gmelinii
Carex viridula	Ranunculus pensylvanicus
Chamerion angustifolium*	Ranunculus sceleratus
Cirsium vulgare	Rhinanthus minor*
Comarum palustre	Rorippa palustris
Conyza canadensis*	Rosa acicularis*
Crepis tectorum	Rubus idaeus*
Cystopteris fragilis*	Rumex crispus
Deschampsia cespitosa	Sagina procumbens
Drosera rotundifolia*	Salix bebbiana*
Eleocharis mamillata	Salix planifolia
Eleocharis palustris*	Salix prolixa*
Elymus repens*	Salix sitchensis*
Epilobium ciliatum	Salix sp.
Equisetum arvense	Scirpus atrocinctus
Equisetum fluviatile	Sium suave
Equisetum palustre	Sparganium emersum
Equisetum scirpoides*	Sparganium natans
Euphrasia nemorosa	Stellaria longifolia*
Fragaria virginiana*	Taraxacum officinale
Galeopsis tetrahit	Trifolium aureum
Galium trifidum	Trifolium hybridum
Geum macrophyllum*	Trifolium pretense*
Glyceria boreale	Typha latifolia
Glyceria grandis	Utricularia intermedia
Glyceria striata	Veronica peregina*
Hieracium maculatum*	Vicia cracca*
Hieracium piloselloides*	Viola macloskeyi

Table 9-3: **Herb species absent from control (uncleared) transects but recorded in treated (cleared) transects in 2014 and 2015 surveys at Canoe Reach, Kinbasket Reservoir.** Perennial species are shown in bolded text.

Species		
2014 sample	2015 sample	
Cardamine pensylvanica	***Agrostis stolonifera***	*Persicaria maculosa*
Chenopodium album	*Bidens cernua*	***Poa compressa***
Cicuta douglasii	*Callitriche palustris*	***Potamogeton pusillus***
Cirsium vulgare	*Cardamine pensylvanica*	***Ranunculus gmelinii***
Crepis tectorum	***Carex crawfordii***	*Ranunculus pensylvanicus**
Erysimum cheiranthoides	***Cicuta douglasii***	*Ranunculus sceleratus*
Juncus ensifolius	***Deschampsia cespitosa***	*Rorippa palustris**
Mimulus guttatus	*Deschampsia danthonioides*	***Rumex crispus***
Poa compressa	***Eleocharis mamillata***	***Scirpus atrocinctus***
Polygonum aviculare	***Epilobium ciliatum***	***Sium suave***
Persicaria maculosa	*Galum trifidum*	***Sparganium emersum***
*Rorippa palustris******	***Glyceria striata***	***Trifolium pratense***
Rumex acetosela*	***Juncus alpinoarticulatus***	***Trifolium repens***
Trifolium pretense	*Juncus bufonius*	***Triglochin palustris***
Utricularia intermedia	***Juncus ensifolius***	***Typha latifolia***
Veronica beccabunga	***Leucanthemum vulgare***	***Utricularia intermedia***
Viola macloskeyi	***Lysimachia thyrsiflora***	***Veronica beccabunga***
	Myosotis scorpioides	***Viola macloskeyi***

*May occur as annual or perennial

Table 9-4: **New herb additions to treated (cleared) transects, first recorded during the 2015 survey at Canoe Reach, Kinbasket Reservoir.** Perennial species are shown in bolded text.

Species		
Agrostis gigantea	***Eleocharis mamillata***	***Rumex crispus***
Agrostis stolonifera	***Epilobium ciliatum***	***Scirpus microcarpus***
Bidens cernua	***Equisetum hyemale***	***Sium suave***
Callitriche palustris	*Galium trifidum*	***Sparganium emersum***
Carex brunnescens	***Glyceria striata***	***Triglochin palustris***
Carex crawfordii	***Juncus alpinoarticulatus***	***Typha latifolia***
Carex stipata	***Leucanthemum vulgare***	
Cerastium fontanum	*Persicaria maculosa*	
Deschampsia cespitosa	***Potamogeton pusillus***	
Deschampsia danthonioides	*Ranunculus gmelinii*	
Galium trifidum	*Ranunculus pensylvanicus**	

*May occur as annual or perennial

9.5 Bush Arm Physical Works Sites: Plant Species Lists

Table 9-5. Plant species recorded on constructed mounds and adjacent mound footprints at Bush Causeway in July 2018. Species were recorded for three loosely defined elevation zones (bottom, middle, and upper). Species lists pooled across mounds. Exotic species are indicated by *.

Position on constructed mound (elevation zone)		
Bottom	Middle	Upper
*Agrostis gigantea**	*Agrostis gigantea**	*Agrostis gigantea**
Agrostis scabra	*Agrostis scabra*	*Agrostis scabra*
Anaphalis margaritacea	*Anaphalis margaritacea*	*Anaphalis margaritacea*
Betula papyrifera	*Calamagrostis canadensis*	*Calamagrostis canadensis*
Brassicaceae	*Calamagrostis stricta*	*Calamagrostis stricta*
Calamagrostis canadensis	*Carex flava*	*Carex aquatilis*
Calamagrostis stricta	*Carex kelloggii*	*Carex bebbiana*
Carex aquatilis	*Carex lasiocarpa*	*Carex kelloggii*
Carex aurea	*Cirsium vulgare*	*Carex lasiocarpa*
Carex bebbiana	*Comarum palustre*	*Cirsium vulgare**
Carex flava	*Cornus stolonifera*	*Cornus stolonifera*
Carex interior	*Danthonia spicata*	*Danthonia spicata*
Carex lasiocarpa	*Deschampsia cespitosa*	*Deschampsia cespitosa*
Carex saxatilis	*Dryas drummondii*	*Dichanthelium acuminatum*
Carex utriculata	*Elymus repens**	*Elymus repens**
Chamerion angustifolium	*Epilobium ciliatum*	*Epilobium latifolium*
*Cirsium vulgare**	*Equisetum arvense*	*Equisetum arvense*
Comarum palustre	*Equisetum variegatum*	*Erigeron philadelphicus*
Cornus stolonifera	*Erigeron philadelphicus*	*Erucastrum gallicum**
Danthonia spicata	*Erucastrum gallicum**	*Fragaria virginiana*
Deschampsia cespitosa	*Fragaria virginiana*	*Glyceria striata*
Dryas drummondii	*Hierochloe hirta*	*Leucanthemum vulgare**
Elymus sp.	*Leucanthemum vulgare**	*Lobelia kalmii*
*Elymus repens**	*Lysimachia thyrsiflora*	*Lysimachia thyrsiflora*
Epilobium latifolium	*Medicago lupulina**	*Mentha arvensis*
Equisetum arvense	*Mentha arvensis*	*Packera plattensis*
Equisetum variegatum	*Packera plattensis*	*Phalaris arundinacea**
Erigeron philadelphicus	*Phalaris arundinacea**	*Poa compressa**
*Erucastrum gallicum**	*Poa palustris*	*Poa palustris*
Fragaria virginiana	*Poa pratensis*	*Poa pratensis*
*Galeopsis tetrahit**	*Poaceae*	*Populus balsamifera* ssp. *trichocarpa*
Glyceria striata	*Populus balsamifera ssp.*	*Potentilla norvegica**
Lamium sp.	*Potentilla anserina*	*Rosa acicularis*
*Leucanthemum vulgare**	*Potentilla norvegica**	*Rubus idaeus*
Lobelia kalmii	*Primula mistassinica*	*Salix bebbiana*
Lysimachia thyrsiflora	*Rhinanthus minor*	*Salix brachycarpa*
*Medicago lupulina**	*Rosa acicularis*	*Salix lucida* ssp. *lasiandra*

Position on constructed mound (elevation zone)		
Bottom	Middle	Upper
Mentha arvensis	*Rubus pubescens*	*Sisyrinchium montanum*
Packera plattensis	*Rubus idaeus*	*Symphyotrichum ciliolatum*
Parnassia parviflora	*Rubus parviflorus*	*Taraxacum officinale**
Persicaria amphibia	*Salix brachycarpa*	*Trifolium pratense**
*Phalaris arundinacea**	*Salix farriae*	*Verbascum thapsus**
*Plantago major**	*Salix lucida* ssp.*lasiandra*	
Platanthera stricta	*Salix* spp.	
*Poa compressa**	*Scutellaria galericulata*	
Poa palustris	*Shepherdia canadensis*	
Poa pratensis	*Solidago lepida*	
Populus balsamifera ssp. *trichocarpa*	*Symphyotrichum ciliolatum*	
Potentilla anserina	*Taraxacum officinale**	
*Potentilla norvegica**	*Trifolium hybridum**	
*Prunella vulgaris**	*Trifolium pratense**	
Ranunculus sceleratus	*Verbascum thapsus**	
Rhinanthus minor	*Viola macloskeyi*	
Rosa acicularis		
Rubus idaeus		
Rubus parviflorus		
Rubus pubescens		
Salix brachycarpa		
Salix farriae		
Salix lucida ssp. *lasiandra*		
Salix spp.		
Scutellaria galericulata		
Sisyrinchium montanum		
Sium suave		
Solidago lepida		
Symphyotrichum ciliolatum		
*Taraxacum officinale**		
*Trifolium aureum**		
*Trifolium hybridum**		
*Trifolium pratense**		
*Verbascum thapsus**		

Table 9-6. **Baseline list of vascular plant species lists recorded in sample transects at five proposed physical works site in Bush Arm, June/July 2015, prior to physical works treatments.** BAC-N: Bush Arm Causeway-North; BAC-S: Bush Arm Causeway-South; CHT: Chatter Creek; GDF: Goodfellow Creek; Hope: Hope Creek.

Site	Species		
BAC-N	*Agrostis gigantea*	*Equisetum variegatum*	*Salix brachycarpa*
	Agrostis scabra	*Fragaria virginiana*	*Salix farriae*
	Alisma triviale	*Galium trifidum*	*Salix lucida ssp.lasiandra*
	Braya humilis	*Glyceria striata*	*Salix maccalliana*
	Calamagrostis canadensis	*Juncus alpinoarticulatus*	*Salix melanopsis*
	Calamagrostis stricta	*Leucanthemum vulgare*	*Salix prolixa*
	Carex aquatilis	*Lobelia kalmia*	*Salix sp.*
	Carex lasiocarpa	*Lysimachia thyrsiflora*	*Sisyrinchium montanum*
	Carex saxatilis	*Medicago lupulina*	*Solidago lepida*
	Carex utriculata	*Mentha arvensis*	*Symphyotrichum ciliolatum*
	Carex viridula	*Packera plattensis*	*Symphyotrichum subspicatum*
	Coeloglossum viride	*Parnassia parviflora*	*Taraxacum officinale*
	Cornus stolonifera	*Phalaris arundinacea*	*Triantha glutinosa*
	Deschampsia cespitosa	*Poa palustris*	*Trifolium aureum*
	Eleocharis elliptica	*Poa sp.*	*Trifolium hybridum*
	Eleocharis mamillata	*Potentilla anserina*	*Vicia cracca*
	Epilobium latifolium	*Potentilla norvegica*	*Viola macloskeyi*
	Equisetum arvense	*Prunella vulgaris*	*Viola sp.*
	Equisetum fluviatile	*Rhinanthus minor*	*Zigadenus elegans*
	Equisetum palustre	*Rosa acicularis*	
BAC-S	*Agrostis gigantea*	*Galium trifidum*	*Rubus pubescens*
	Calamagrostis canadensis	*Hierochloe hirta*	*Salix bebbiana*
	Calamagrostis stricta	*Leucanthemum vulgare*	*Salix brachycarpa*
	Carex crawfordii	*Lysimachia thyrsiflora*	*Salix commutata*
	Carex lasiocarpa	*Medicago lupulina*	*Salix farriae*
	Carex kelloggii	*Medicago sativa*	*Salix maccalliana*
	Carex viridula	*Packera plattensis*	*Salix prolixa*
	Cornus stolonifera	*Persicaria maculosa*	*Salix sitchensis*
	Deschampsia cespitosa	*Phalaris arundinacea*	*Salix sp.*
	Elymus repens	*Poa compressa*	*Taraxacum officinale*
	Equisetum arvense	*Poa palustris*	*Trifolium hybridum*
	Equisetum pratense	*Populus trichocarpa ssp. balsamifera*	*Trifolium pratense*
	Equisetum variegatum	*Potentilla norvegica*	*Trifolium repens*
	Erucastrum gallicum	*Prunella vulgaris*	*Verbascum thapsus*
	Erysimum cheiranthoides	*Rhinanthus minor*	
	Fragaria virginiana	*Rosa acicularis*	
GDF	*Agrostis gigantea*	*Dryas drummondii*	*Poa palustris*

Site	Species
	Betula occidentalis *Betula papyrifera* *Calamagrostis canadensis* *Calamagrostis stricta* *Carex aquatilis* *Carex lasiocarpa* *Carex kelloggii* *Carex saxatilis* *Cornus stolonifera* *Deschampsia cespitosa* *Elymus repens* *Equisetum arvense* *Equisetum variegatum* *Erucastrum gallicum* *Galeopsis tetrahit* *Leucanthemum vulgare* *Medicago lupulina* *Melilotus alba* *Persicaria maculosa* *Phalaris arundinacea* *Populus trichocarpa ssp. balsamifera* *Potentilla norvegica* *Prunella vulgaris* *Rosa acicularis* *Rubus parviflorus* *Rubus pubescens* *Salix brachycarpa* *Trifolium hybridum* *Trifolium pratense* *Verbascum thapsus*
Hope	*Agrostis gigantea* *Anaphalis margaritacea* *Anemone drummondii* *Braya humilis* *Calamagrostis canadensis* *Calamagrostis stricta* *Carex aperta* *Carex flava* *Carex lasiocarpa* *Carex kelloggii* *Cornus stolonifera* *Danthonia spicata* *Deschampsia cespitosa* *Dichanthelium acuminatum* *Equisetum arvense* *Equisetum variegatum* *Erysimum cheiranthoides* *Fragaria virginiana* *Glyceria striata* *Leucanthemum vulgare* *Medicago lupulina* *Packera pauciflora* *Packera plattensis* *Persicaria maculosa* *Phalaris arundinacea* *Poa palustris* *Populus trichocarpa ssp. balsamifera* *Potentilla norvegica* *Prunella vulgaris* *Rosa acicularis* *Salix brachycarpa* *Salix commutata* *Salix farriae* *Salix lucida ssp. lasiandra* *Salix sp.* *Symphyotrichum ciliolatum* *Taraxacum officinale* *Trifolium hybridum* *Trifolium repens* *Verbascum thapsus*
CHT	*Calamagrostis canadensis* *Cardamine pensylvanica* *Carex aperta* *Carex crawfordii* *Carex lasiocarpa* *Carex kelloggii* *Carex saxatilis* *Collomia linearis* *Elymus repens* *Equisetum arvense* *Equisetum variegatum* *Erysimum cheiranthoides* *Leucanthemum vulgare* *Medicago lupulina* *Melilotus alba* *Persicaria maculosa* *Phalaris arundinacea* *Poa compressa* *Poa palustris* *Populus tremuloides* *Populus trichocarpa ssp.balsamifera* *Potentilla norvegica* *Rorippa palustris* *Rosa acicularis* *Salix commutata* *Salix sitchensis* *Trifolium aureum* *Trifolium hybridum* *Verbascum thapsus*