Columbia River Project Water Use Plan
Kinbasket and Arrow Lakes Revegetation Management Plan

Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

Implementation Year 4

Reference: CLBMON-12

Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

Study Period: 2013

Delphinium Holdings Inc.
Castlegar, B.C.

November 2013

Original Report Cover

CLBMON-12
ARROW LAKES RESERVOIR MONITORING OF REVEGETATION EFFORTS AND VEGETATION COMPOSITION ANALYSIS
2013 DRAFT REPORT

Cottonwood Stakes at Inonoaklin, May 23 2013

Submitted to:

BC Hydro
Water Licence Requirements
Castlegar, B.C.

by:

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Cover photo: 2013 Cottonwood stake plantings at middle elevation; situated at Inonoaklin, north of Edgewood, B.C.; Arrow Lakes Reservoir.

EXECUTIVE SUMMARY

This is the seventh report in a series of studies on the effects of reservoir operations on revegetated and non-revegetated areas in the drawdown zone of the Arrow Lakes Reservoir. Two vegetation monitoring studies, which ran during alternate years and used similar field methodologies, were undertaken. The present study, CLBMON-12, addressed site-level changes in vegetation in response to various influences, including revegetation treatments. CLBMON-33 addressed landscape-level changes in vegetation and used aerial photography and field measurements to evaluate effects of reservoir operations on existing vegetation communities. Both studies have used field measurements to assess effects. CLBMON-12 attempted to distinguish between the influence of reservoir operations on both native and managed vegetation, as well as accounting for how ‘background” influences, including climate, topography and parent materials influence vegetation.

Twelve Management Questions were posed by BC Hydro for this project. The answers to many of the Management Questions have been provided in a multiyear review by Enns and Overholt (2013) as well as in previous documents (see below for summaries in the Results Section). CLBMON-12 was initiated in 2009, and ran every odd year between 2009 and 2013. A comparison between 2011 (the previous CLBMON-12 assessment) and 2013 is the main focus of this year’s final report, with some long term trends identified and discussed. Data from CLBMON-33 was used to provide continuity from year to year in the two studies.

A specific goal of this study has been to assess the effectiveness of the CLBWORKS-2 Arrow Lakes Reservoir Revegetation program. The physical works program (CLBWORKS-2) had the objectives of maximizing vegetation growth in the Arrow Lakes Reservoir drawdown zone, increasing plant diversity, and improving shoreline stability (BC Hydro 2008). Treatments, including spring planting and fertilizing, began in 2008. Spring and fall planting, live-staking, and re-fertilizing took place in 2009, and planting and live-staking in 2010 and 2011. The revegetation program is now complete.

Monitoring of CLBWORKS-2 was initiated in 2008 as an evaluation of pre-treatment baseline conditions. Post-treatment measurements at the site level were taken in 2009, 2011 and 2013. Records for fertilization treatments were incomplete, therefore no evaluation of the efficacy of fertilization was possible.

Existing Vegetation

The vegetation of the Arrow Lakes Reservoir has been adapting to reservoir conditions since the mid-1960’s, and has developed distinct vegetation communities with a high tolerance for inundation at low elevation, and drought tolerance at high elevation (Leyer 2005; Kozlowski 1984). Since 2007/2008, each vegetation community type has shown the same within-type trends in species composition, cover, abundance, heights, and vigour in relation to differences in elevation. Most of the common species of the Arrow Lakes Reservoir have not changed in their dominance over time, although some annual variation has occurred. The lack of dynamic change in vegetation since 2007 has possibly been due to the fact that few changes in the operating regime have taken place. An exception to this trend has been the high-water winter of 2008-2009. Some species declined in the number of plots in which they occurred following this period of high water from midsummer to the following early spring (2009 measurement), but subsequently recovered in 2010, 2011 and 2013.

The low-elevation vegetation communities are somewhat negatively influenced by prolonged inundation in the midsummer to fall period. Some of the low-elevation vegetation has been reduced in cover or height. However, many of the species in the drought-tolerant vegetation community types at higher elevations apparently benefit from brief inundation if they are not scoured by too much wave activity in the winter. In the past three years a general trend of increasing cover of dominant vegetation has occurred, however some of this result is due to the objective of monitoring treated vegetation.

Some species are lost annually from communities. These are mostly opportunistic, somewhat weedy species with high natural rates of change. Introductions to the reservoir from upslope are common, and such species are often lost, whereas the drought- and inundation-tolerant species that make up the largest proportion of the vegetation communities have persisted over most measurement periods. The highest rates of loss have occurred in low- to mid-elevation communities exposed to scouring.

Treated vegetation

Vegetation treatments consisted of *Carex* and seedling plug planting, and cottonwood stake planting[1]. Based on a comparison with 2009, there was a slight increase in vegetation cover, height, richness and diversity, and distribution became more even in both revegetated and control plots between 2009 and 2013. It was not possible to attribute any of the changes to the effects of the treatments, with the exception of total cover and height which increased in some treated plots due to the presence and expansion of crowns of cottonwood stakes. The number of days of inundation and the depth of inundation (based on elevation of the plant measurement plot), and the sand, silt and gravel substrate percentages accounted for most of the variation in plant cover. Duration of inundation exceeding 100 days negatively influenced plant height in both treated and control plots. Vegetation heights were influenced by planting of live stakes, which were usually taller than the pre-existing vegetation.

It is not certain that the treatments in previously non-vegetated areas will persist over the long term. Middle elevation sedge plug planting was generally very successful, except in high energy areas where scouring of materials was common. Sedge plugs may have been more successful in these areas if they had been anchored. Cottonwood stake mortality continued to occur between 2011 and 2013, typically in plantings undertaken below 437 m; cottonwood seldom occurs naturally below 437 m in the reservoir. Cottonwood stake plantings did very well in gravels above 437 m where a moisture supply was available

[1] Other treatments occurred, such as fertilization and willow stake planting, but they did not have sufficient record keeping or number of treatment areas to include in the monitoring study.

Revegetation treatments were "operational" - that is, they were aimed at improving exposed soils and conducting infill planting on sites that had a potential to respond to treatment. It will remain to be seen in subsequent years if the treated vegetation begins to resemble the native vegetation in cover, abundance, diversity, vigour, and distribution.

Our assessment of benefits and costs of the treatment is qualitative, and is not based on the actual monetary cost of the treatments. The largest benefit is the increase in vegetated areas, where no vegetation previously existed. The largest "cost" or disadvantage is the potential for cottonwood stakes to introduce disease to new areas of the reservoir. The stake plantings have a somewhat artificial appearance. Natural thinning will likely reduce this over time.

The sedge plug planting was very successful in many areas. These plants are now almost undistinguishable from natively occurring sedges.

Summary of the Recommendations

We recommend that a period of low water be permitted to occur in early to late fall to allow vegetation to accumulate biomass before winter.

We have provided some advice for the continuation of the projects if BC Hydro still wishes to monitor the effects of the operating regime on the vegetation. It should be possible to amalgamate and simplify the two CLBMON 12 and 33 projects. A combination of aerial photographic interpretation and field documentation of the species compositional changes in permanent repeated plots should more accurately show the response of the vegetation to changes in the operating regime. The design is most suited to the use of parametric statistics based on approximately even sample sizes and repeated measures, with the use of redundancy analysis to identify the factors controlling vegetation cover and height. A large database of over 500 permanent plots exists for the purposes of long term comparisons of change in the vegetation over time.

Management Objectives and Management Questions

Results to date for the CLBMON-12 management questions are summarized in the discussion section of this report (Sections 6.1 and 6.2). A summary of the statistics and outcomes in response to the management questions, objectives and hypothesis is provided in Appendix A (a separate document). The first seven management questions pertain to existing, untreated vegetation, and the remaining management questions pertain to the effects of vegetation treatments. Tables A shows the status of the Management Objectives and Table B addresses the Management Questions.

T*able A. Status of Management Objectives for CLBMON-12*

Management Objectives	**Methods used to address this Objective**	**Results Summary**
MO1: Determine the species composition (i.e. distribution, diversity and vigour) of existing vegetation communities to identify species that have been successfully surviving long-term inundation;	Distribution, diversity and vigour of species have been measured every odd year spanning a period of 7 years in a series of fixed, repeated plots. These measures do not show changes in survival however. We tracked which species were lost from plots and if they re-occurred in subsequent years, including data from the CLBMON-33 project.	Survival of the most widespread and common species over 7 years has been continuous. Distribution patterns of continuously occurring species have tended to increase from sparsely distributed to more continuous cover between 2009 and 2013. Some species thought to be invading from upslope or upstream appear to reoccur and some occur only once, and then are lost. Their loss from plots was often attributed to timing of the measurement . Diversity is variable but appears to be maintained at similar overall species richness over time. Vigour of species is variable and is not an indication of survival. Survival / mortality of species attempting to colonize lower elevation sites has occurred. Willows that may have established during the reconstruction of the Hugh Keenleyside dam have been lost from elevations below 437 m.
MO2**:** Evaluate the cover, abundance and biomass of existing vegetation communities in relation to elevation in the drawdown zone	Cover was measured every year for seven years, and abundance and biomass were measured every odd year spanning a period of seven years in a series of fixed, repeated plots.	Cover of vegetation was lower in some plots following a year of long duration inundation from June of 2008 to March of 2009, and then subsequently increased in most plots from 2009 to 2013. Height and biomass tended to be lowest in plots with the highest number of days of inundation. Presence of a very common, low elevation inundation requiring species, *Carex lenticularis* impacted the biomass measurements and made many biomass measurements heavier at low elevation. In general heights of all vegetation increases with elevation, consistently on an annual basis.
MO3: Monitor the response of existing vegetation communities at the local site level to the continued implementation of the soft constraints operating regime for the Arrow Lakes Reservoir and other environmental variables.	Vegetation response variables, duration and depth of inundation and environmental variables (climate, soils, slope, aspect, etc) were examined statistically	Environmental variables such as soil texture and physical scouring along with the number of days of inundation accounted for variation in vegetation cover and height. However the annual duration and depths of inundation have followed a similar pattern each year with the exception of a longer duration of inundation than usual, in 2008-2009. This period was followed by a decline in cover and heights in vegetation, which is since recovered.

MO4: Assess the long-term effectiveness of the revegetation program at restoring and expanding the quality (as measured by diversity, distribution and vigour) and quantity (as measured by cover, abundance and biomass) of vegetation in the drawdown zone for ecological and social benefits	Comparisons of vegetation data on an annual basis with previous winter's operational data.	Allow a period of low water in late summer to early fall.
MO5: Assess the costs and benefits of the recommended revegetation prescriptions applied under CLBWORKS-2 (Mid-Columbia and Arrow Lakes Reservoir Revegetation Program physical works) by monitoring the response of revegetated communities to different treatments in the drawdown zone of the reservoir	Cottonwood stem counts in treatment areas in 2009, 2011 and 2013, comparison of species assemblages, cover, height, distribution, vigor and biomass between treated and nontreated areas in 2009 – 2013 (the 2009 data had some limitations). Soil sampling in treated and untreated areas. Casual observations on bird habitat utilization in treatment areas (data not shown).	**Benefits** include the addition of biomass and stability to low elevation sites by introducing more Carex plants, as well as the addition of shade, and perching and gleaning habitats for songbirds by introducing cottonwoods above 437 m. The planting holes have created moist microsites which have increased diversity slightly. **Costs** include compaction and disturbance to soils and vegetation by machines, increased disease in cottonwood and unsightly dead stems of cottonwood in some locations.

T*able B.* ***Status of Management Questions for CLBMON-12,*** **Supporting Data and Results Summary. MQs 1 and 2 are combined.**

Management Questions	**Field data**	**Results**
Existing Vegetation		
MQ 1 and MQ 2 (combined): What are the cover, distribution, vigour, species diversity, abundance and biomass of existing vegetation communities in relation to elevation in the drawdown zone?	Species cover, distribution, vigour, diversity, richness, evenness, abundance and biomass assessments in repeated plots within community types over their range of elevations in the reservoir. The most common and abundant VCTs that span elevation zones could be used to examine the effects of the operating regime. Depth and duration of inundation is a function of elevation. The number	Fourteen distinct Vegetation Community Types (VCTs) were defined. They have characteristics species and biophysical features aligned with elevation zones and water behavior. Vegetation cover declined in the low elevation communities between fall of 2008 and spring of 2009 in both the Arrow and Reach portions of the Arrow Lakes Reservoir and subsequently recovered. Cover varies with elevation and can be very patchy and dependant on substrate and exposure. Distribution varies and also depends on substrate and exposure. Vegetation heights consistently increase with

	of days a permanent plot was inundated was also a function of the elevation. Height measurements were included in the CLBMON-12 project.	increasing elevation. Vigour overall has not shown any strong trends in relation to elevation, in comparison to mortality (see vegetation response to treatment, below). Species diversity increases with elevation. Plant species abundance can be high at both very low and at high elevations. When shrubs and trees are excluded, plant biomass is highest at mid elevation in the reservoir due to the high cover of the very dense and heavy *Carex lenticularis* plants. When shrubs are included in the biomass estimates, the highest overall biomass is at 438 – 440 m in the shrub and riparian forest communities where plants are taller, more completely developed and more abundant.
MQ3: How does the current operating regime affect the within-community quality and quantity of existing vegetation?	Species cover, abundance, biomass, diversity, distribution and height (added variable) in relation to the plot's operating regime: water level duration and depth of inundation.	Height and biomass tended to be lowest at the highest number of days of inundation. Plots that have been inundated for longer than 100 days tended to have lower vegetation cover, height, distribution, biomass and abundance than plots that have a longer exposure period. However drought and drought-prone coarse textured soils at high elevation (with long exposure periods above water each year) can also have very low vegetation cover, heights, abundance, biomass and etc. Some communities appear to benefit from some inundation, but not from scouring or from wave action on exposed high energy sites.
MQ4: Is there a shift in community structure (species dominance) or a potential loss of existing vegetation communities that is attributable to environmental conditions, including the current operating regime?	Changes in the proportions of the dominant species in repeated plots over time. Ranked frequency of occurrence of species within communities over time. Comparisons with known ecological requirements.	Dominant species occurrence has not changed much from 2008 to 2013, although there was a measureable decline in total cover and heights following one high water period from June 2008 to March 2009. Some annual, opportunistic species increased dramatically each year.
MQ5: What are the species-specific survival rates under soft	Species losses (individual records) from	Losses of weedy annuals, seedlings and perennials were

constraints operating regime (i.e., what are the tolerances of existing plant species to inundation?)	repeated plots, and comparisons with ecological data.	common, but replacement also took place. Invasions from upslope occurred and were lost. Willows declined in Revelstoke Reach at middle elevation as a result of populations expanding into low elevations, and subsequently being inundated for longer than their usual tolerance would allow.
MQ6. What recommendations can be made to more effectively maintain existing vegetation at the site level in the future?	Comparisons of vegetation data on an annual basis with previous winter's operational data.	Allow a period of low water in late summer to early fall. This will allow plants to gain weight and photosynthate so they can over-winter successfully and set viable seed.
Revegetated Areas		
MQ7. What is the quality and quantity of vegetation in revegetated areas between 434 m and 440 m compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?	Species compositions, distribution codes, vigour assessments, cover, abundance and biomass estimates in treated versus control stands.	Most vegetation measurements were higher in control plots than treatment plots across all elevations, as a result of operational planting in very poor areas up their boundaries, and adjacent controls having slightly better growing conditions. The pre-treatment condition of controls and treatments were judged to be similar enough to make comparisons over time, however. Carex plantings were relatively successful unless scouring of fine textures occurred. Cottonwood live stakes had higher average heights than controls, and did best in moist sands and gravels, and had low survival below 437 meters.
MQ8. 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)?	Comparison of species composition over time in treated plots.	Losses of species per plot over time were slightly higher than gains. This was similar to other losses vs. gains comparisons over time. Common species tended to persist and somewhat ephemeral invasive species, often outside their usual growing conditions tended to be lost. Survival of the treatment species showed some strong patterns. Losses of planted Carex have been severe in scoured sandy locations. The losses of cottonwood stakes are greatest below 437 meters.

MQ9. 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?	RDA of independent variables, including depth and duration of inundation, and all biophysical variables (slope, aspect, terrain texture, sheltering effects), accounting for the variation in existing and treated plant cover.	Existing plant cover tended to align closely with silt and clay in terrain or soil textures, and treatment vegetation tended to align closely with sands and gravels. Inundation and duration did not account for a lot of the variation in plant cover, indicating several other factors were important.
MQ10. What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-2, at increasing the quality and quantity of vegetation in the drawdown zone?	Cover, diversity, abundance, distribution and vigour of treated versus control vegetation. Height was an added variable.	There was no difference in any of the measured variables, except height, which was higher in the treated vegetation. Survival of live-stakes was poor below 437 meters.
MQ11. 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?	Area estimates, qualitative assessment.	Some areas of vegetation have expanded to where there was previously no vegetation. Cottonwoods have added shade, food and vertical structure to bird habitats. Some disadvantages include increased pathogens from cottonwood stakes.
MQ12. Is there an opportunity to modify operations to more effectively maintain revegetated communities at the landscape and site level in the future?	The evidence is inferential: visual comparison of the changes in the water level over time, annually vs. any trends in vegetation response.	Allow a period of low water in late summer to early fall. Use analysis of covariance and a change in the soft constraints operating regime from its current pattern.

KEYWORDS

Arrow Lakes Reservoir, vegetation, vegetation community type, revegetation, existing vegetation, management questions, cover, height, vigour, diversity, biomass, distribution, abundance, frequency of occurrence, survival, recommendations.

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1.0 INTRODUCTION

The Arrow Lakes Reservoir is located in southeastern British Columbia, between the Revelstoke Dam at Revelstoke, B.C., in the north, and the Hugh Keenleyside Dam at Castlegar B.C., in the south. The Arrow Lakes Reservoir is 230 km long and is typically quite shallow in the northern Revelstoke Reach portion and variable, but often deep, in the Arrow Lakes portion. The Hugh Keenleyside Dam was completed on October 10th, 1968 (BC Hydro 2004[2]), and was originally intended to control the floodwaters of the Columbia River, including a drainage area of 3,650,000 hectares. In 2004, the Columbia Power Corporation completed the construction of a 185 MW power plant adjacent to the Hugh Keenleyside Dam. During the period prior to the construction of the power plant, water levels were lower than the current levels. This could have resulted in an invasion of drought tolerant species in the draw down zone that would not normally have established and may still be adjusting to the current operating regime (Auble et al. 2007). Current water levels can vary by as much as 20 metres annually, and tend to be lowest during the fall and winter months and highest in the late spring to summer months (BC Hydro[3]).

The Columbia River Water Use Plan Consultative Committee (WUP CC) developed a series of soft operating constraints for the Arrow Lakes Reservoir. The interests included Vegetation, Wildlife, Fish, Recreation, Culture and Heritage, Erosion Control and Power Generation (BC Hydro 2010). The constraints, which related to each of the stated interests, were a series of targets with inherent flexibility and some potential conflicts. The WUP CC recognized the value of riparian and wetland vegetation for enhancing littoral productivity; providing physical, structural and biological character for wildlife habitat; protecting cultural heritage sites; and providing aesthetic benefits, including dust control (BC Hydro 2010). The WUP CC therefore supported a revegetation program for the Arrow Lakes in which the approach consisted of repeated treatments over multiple years to facilitate the growth of vegetative cover in those areas that had good potential to become self-sustaining. The key environmental and social objective of the revegetation program was to maximize vegetation growth in the drawdown zones. The revegetation was to benefit littoral productivity and wildlife habitat, while preventing shoreline erosion and controlling dust.

To evaluate the success of the revegetation program and assess the effectiveness of the soft constraints to maintain existing vegetation and allow for its expansion through the revegetation program, BC Hydro implemented two 10-year vegetation monitoring programs in the Arrow Lakes Reservoir. The programs were partially intended to assess the impacts of the soft constraints operating regime on existing and treated vegetation communities, as well as the long-term outcome(s) of the physical works CLBWORKS-2 Arrow Lakes Reservoir Revegetation Program. The CLBMON-12 project was initiated in 2008, to provide a site-level evaluation of the success of the CLBWORKS-2 program. Part of the evaluation included distinguishing the effects of the operating regime on untreated vegetation from the effects of other environmental constraints. The CLBMON-33 project was initiated in 2007 to provide a landscape-level evaluation of the effects of the operating regime and environmental influences on existing vegetation of the

[2] http://web.archive.org/web/20080221200617/http://www.bchydro.com/recreation/southern/southern1202.html Accessed February 2012.

[3] http://www.bchydro.com/community/recreation_areas/arrow_lakes_reservoir.html#Water_levels accessed February 2012.

drawdown zone. CLBMON-12 and CLBMON-33 are carried out in alternate years, with similar field measures and slightly different overall objectives.

The revegetation project, CLBWORKS-2, was undertaken by Keefer Ecological Services Ltd (KESL) and was completed in 2011. Draft mapping of the treatment locations was provided annually. The current year represents the third post-treatment assessment of the revegetation of specific areas in the Arrow Lakes Reservoir. The timelines for the three projects are provided in Figure 1 for comparison.

PROJECT	YEAR						
	2007	2008	2009	2010	2011	2012	2013
CLBMON-33	Landscape level monitoring						
CLBMON-12		Site level re-vegetation monitoring					
CLBWORKS-2		Annual plug and stake plantings in spring and fall					

Figure 1. Timelines for CLBMON-12 and CLBMON-33 (monitoring projects) and CLBWORKS-2 (treatment project)

Planning for assessment of the revegetation treatments of CLBWORKS-2 began in 2007. Many of the initial plantings in 2008 failed due to early inundation of juvenile seedlings (BC Hydro 2010). Although some monitoring plots were established in 2008, it was not always clear whether the plots were treated or not, due to incomplete records. Usually, treated vegetation appears more uniform in distribution with fixed distances between plants in rows, but that characteristic has been fading with time. Some of the plots from CLBMON-33 in 2010 were located in treatment areas, and they provided some continuity of monitoring through the 2010 monitoring year. Control plots were also established and paired with the new treatment plots. Although monitoring was initiated in 2009, by 2011, the largest number of monitoring plots was established to ensure that BC Hydro would have permanent records for the main treatment areas throughout the reservoir. In 2013 only native non-treated vegetation and paired treatment and control plots that had been previously sampled in 2009 and or 2011 were resampled. The non-treated native vegetation plots were sampled to address Management Questions concerning the effect of the reservoir behaviour on native vegetation and the treatment. The control paired plots were sampled to address the Management Questions concerning the effect of treatments.

2.0 SCOPE, OBJECTIVES, MANAGEMENT QUESTIONS AND MANAGEMENT HYPOTHESIS

The Columbia River Water Use Planning Consultative Committee (WUP CC) recognized the value of vegetation in improving aesthetic quality, controlling dust, protecting cultural heritage sites, and enhancing wildlife habitat and littoral productivity for fish. They recognized that the most significant opportunity for accomplishing these objectives lay in restoring and expanding riparian and wetland vegetation in the reservoir drawdown zone, as this zone is the only area that can be substantially affected by changes in BC Hydro's operation of the reservoir (BC Hydro 2008).

The WUP CC supported implementation of a revegetation program that was compatible with the current operating regime to enhance and expand vegetation communities within the drawdown zone. The program was proposed as a multi-year project to facilitate long-term self-sustaining vegetation cover. The associated monitoring programs were recommended to assess selected treatment techniques, and to evaluate the effectiveness of planting and fertilization efforts over the long term. During the evaluations undertaken to define potential areas for revegetation, considerable pre-existing vegetation was found in target areas of the reservoir (BC Hydro 2008). The areas that were not vegetated, and were therefore potential targets for revegetation, were designated as "problem sites", where wind or water erosion and unfavourable substrates presented challenges to vegetation establishment.

As a result of the planting done in 2008 to 2011, a total of 89.15 hectares[4] were treated and mapped by KESL using a variety of techniques (KESL 2011). The goals and objectives of CLBMON-12 are focused on the monitoring of existing and revegetated communities at the site level to document change in species composition, which the Terms of Reference define as vegetation diversity, distribution, vigour, abundance and biomass. The monitoring program addresses uncertainties regarding the relative importance of timing, frequency, duration and depth of inundation, as well as multi-year stresses, on trends in community maintenance (BC Hydro 2008).

2.1 Scope

The scope of the CLBMON-12 project is to identify and evaluate changes in vegetation communities within the areas mapped in the CLBMON-33 project in response to revegetation treatment, to the soft constraints operating regime, and to other environmental factors.

2.2 Objectives

The goals of the CLBMON-12 monitoring program (BC Hydro 2008) are to:

1) determine the species composition (i.e. distribution, diversity and vigour) of existing vegetation communities to identify species that have been surviving long-term inundation;
2) evaluate the cover, abundance and biomass of existing vegetation communities in relation to elevation in the drawdown zone;
3) monitor the response of existing vegetation communities at the local site level to the continued implementation of the soft constraints operating regime for the Arrow Lakes Reservoir and other environmental variables;
4) assess the long-term effectiveness of the revegetation program at restoring and expanding the quality (as measured by diversity, distribution and vigour) and quantity (as measured by cover, abundance and biomass) of vegetation in the drawdown zone for ecological and social benefits; and
5) assess the costs and benefits of the recommended revegetation prescriptions applied under CLBWORKS-2 (Mid-Columbia and Arrow Lakes Reservoir

[4] The number of hectares treated is based on a GIS analysis of the mapped areas provided in Keefer (2011)..

Revegetation Program physical works) by monitoring the response of revegetated communities to different treatments in the drawdown zone of the reservoir.

2.3 Management Questions

The study focus of CLBMON-12 is two-fold: monitor naturally occurring vegetation change in response to the soft constraints operating regime (also a focus of CLBMON-33), and monitor the response of revegetated areas to treatments.

The management questions for the project are as follows:

Existing Vegetation

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

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

3. 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?

4. 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)?

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

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

Revegetated Areas

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

2. What are the 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 restoration and expansion of vegetation communities in the drawdown zone?

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

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?

These management questions have been reiterated each year, with similar annual results and interpretations, occasionally supplemented with increasing evidence or new trends to support the answers. In order to abbreviate the report this year, previously reported answers are only summarized and the appropriate references are provided. The analysis of 2013 data required to answer the management questions is provided in an appendix to this report.

2.4 Management Hypotheses

A series of management hypotheses and sub-hypotheses were proposed (BC Hydro 2008) with the option to address the management questions. The management hypotheses and sub-hypotheses are included in Appendix 1 of the 2011 report (Enns and Enns 2012), as this report will focus on the management questions.

3.0 STUDY AREA

The Arrow Lakes Reservoir includes the Revelstoke Reach, Beaton Arm and the Arrow Lake sections of the Columbia River drainage between Revelstoke, B.C. and the Hugh Keenleyside Dam west of Castlegar, B.C. (Figure 2). The reservoir is 230 km long. The vegetation of the drawdown zone of the Arrow Lakes Reservoir has been influenced by the timing, frequency, duration and depth of inundation of water since the construction of the Hugh Keenleyside Dam in 1968.

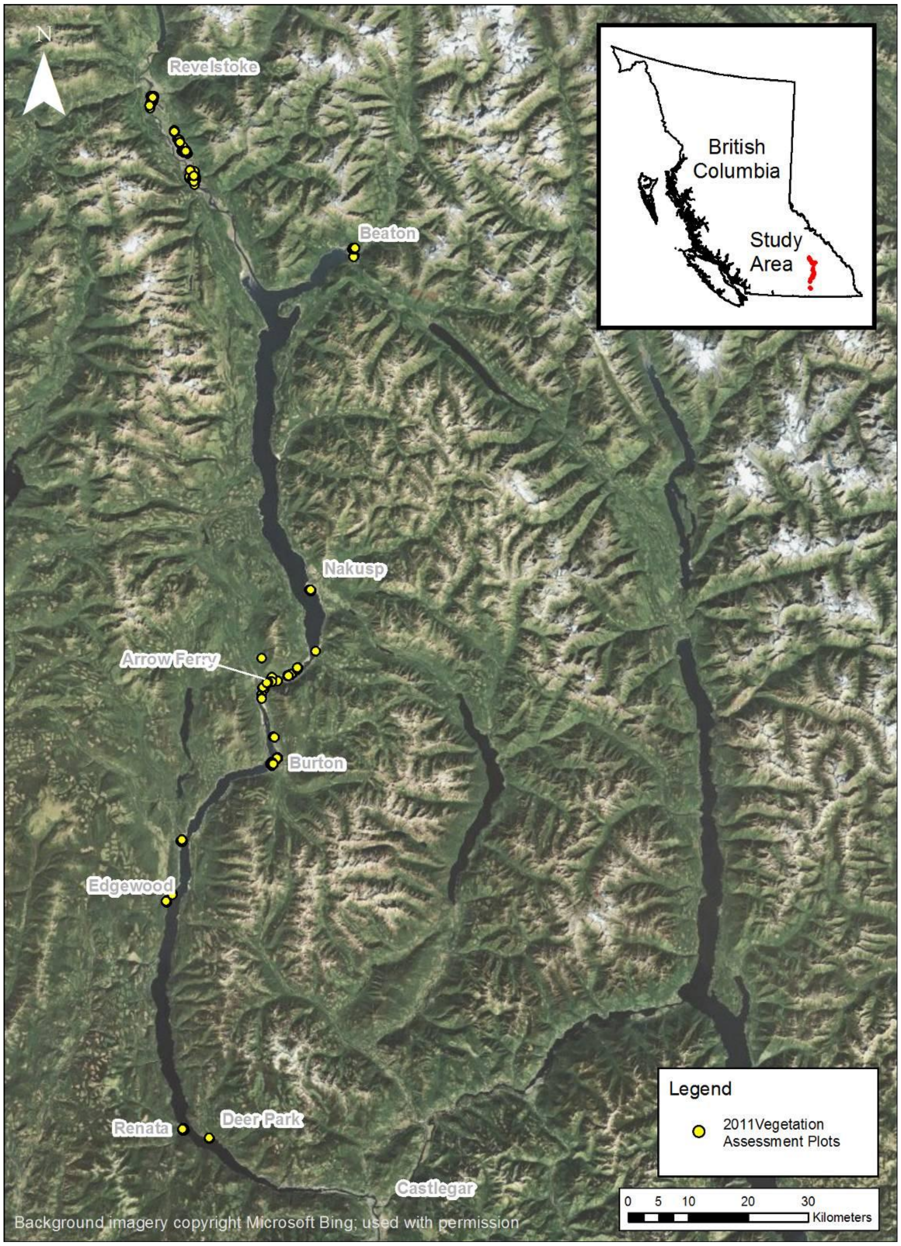

Figure 2. General locations of field plots completed in 2013 for the CLBMON-12 project within the Arrow Lakes Reservoir. Yellow dots denote groups of plot locations. Individual plot locations are not discernable at this scale. Enns and Enns (2012) contains maps showing the individual plot locations repeated in the 2013 field study

The range in climate and physiography of the Arrow Lakes Reservoir varies from north to south, and accounts for considerable variation in the vegetation. The plant species assemblages, landforms, climate and biogeoclimatic classification of the reservoir were described in previous reports (Enns 2007, Enns *et al.* 2011). The vegetation community types (VCTs) occurring between 434 m and 440 m within the drawdown zone of the reservoir were defined in the field and were sampled repeatedly between 2007 and 2013. The VCT classifications were based on a combination of local topography, parent materials (or true soils), and characteristic vegetation features. The VCTs used in this project are described in Table 1.

Table 1. Vegetation community types (VCTs) of the Arrow Lakes Reservoir

Vegetation Community Type	Description
BE: Sandy Beach	Very sparsely vegetated finely sandy areas dominated by drought-tolerant herbaceous plants, seedlings, grasses. Very common. Occurs at all elevations.
BG: Gravelly Beach	Sparsely vegetated gravels and sands with grasses and herbaceous plants. Infrequent. Occurs at all elevations.
PA: Redtop Upland	Upper-elevation coarse sands with shrubs and grasses, drought-tolerant herbs and several species of weeds. Common.
PC: Reed Canary Grass Mesic	Mostly mid-elevation silty sandy materials dominated by reed canary grass (*Phalaris arundinacea*). Very common.
PE: Horsetail Lowland	Low to mid elevation, fine textured silts dominated by lenticular sedge (*Carex lenticularis)* horsetails, rushes, reeds, and mosses. Common.
BB: Boulders, Steep	Bouldery steep slopes over all elevations, very sparsely vegetated. Infrequent.
CL: Cliffs, Rock Outcrops and Steep Rocky Shores:	Exposed rocks, outcrops and cliffs, very sparsely vegetated, almost always at high elevation. Common outside study areas, very infrequent inside study areas.
CR: Cottonwood Riparian Forests	Upland forest edges, restricted to high elevation. Common.
IN: Industrial	Anthropogenic land uses; roads, developments, and areas disturbed by recreational use, occurs at all elevations. Common.
PO: Ponds, Standing Water	Standing open water, in channels and depressional areas, the edges of these are at middle to high elevations. Very infrequent.
RS: Willow Stream Entry	Stream entries often dominated by willows and alder. Relatively frequent, but small in area at all elevations. Infrequent.
SS: Steep Sand	Steep sands, all elevations, mostly very sparsely vegetated. Infrequent.
RR: Reed Rill	Upwelling of underground streams, middle elevation, diverse; with horsetails, reeds, rushes, sedges and ditch weeds. Common, but small in area.
SF: Slope Failure	Peeling and slumping sands and silts, very sparsely vegetated. At low and high elevation, usually depending on slope. Infrequent.

Figure 3 shows a typical pattern of the some of the vegetation community types in the Arrow Lakes Reservoir.

Figure 3. Typical configuration of Vegetation Community Types in Arrow Lakes Reservoir: Larger photograph: BG = Gravelly Beach, BE = Sandy Beach, PC = Reed Canary Grass Mesic, PE = Horsetail Lowland, SS = Steep Sand, BB = Boulders, Steep. Smaller photographs; lower left: BE, mid-left: BG, mid-right; PA: Redtop Upland, lower right: Cottonwood Riparian (CR)

CLBMON-12 examined the effects of the reservoir on all the VCTs listed in the table above; however, some VCTs are either non-vegetated (SS, BB) or heavily influenced by factors other than the reservoir, such as stream and river entries (RS). Some vegetation types, such as cliffs (CL), ponds (PO), and slope failures (SF), are very uncommon; they cover less than one per cent of the study area, and have little or no representation across the elevation classes. The responses of plants to the water regime in communities such as these could not be interpreted clearly. For this reason our reports have focused on the VCTs that have been primarily influenced by the reservoir water behaviour and were at least partly vegetated. The treatments undertaken by CLBWORKS-2 took place primarily in the IN, BE, BG, PA, PC and PE community types.

4.0 METHODS

The methods used in the CLBMON-12 project have been described in detail in previous reports (Enns *et al.* 2009, Enns and Enns 2012). Abbreviated summaries of the methods are provided below.

4.1 Background: Existing Vegetation Community Types

The field data collected for CLBMON-12 in 2013 were classified into vegetation community types as defined in the CLBMON-33 project (Table 1). Each VCT has a unique combination of topographic and parent material (soil or other substrate) features together with characteristic vegetation associated with those features. Data collected in untreated (control) areas and in areas with plots representing existing, untreated vegetation were used to assess the influence of the water regime on the quality and quantity of naturally occurring vegetation in the drawdown zone. Untreated, control areas were matched to treatment areas as closely as possible in terms of elevation range, slope and aspect, soil types and vegetation cover. The influences of environmental variables on treatments and controls, such as soil texture, on existing native vegetation were examined in previous reports (Enns *et al.* 2010; Enns and Enns 2012).

4.2 Background: Treated Vegetation

Data collected in paired treated (revegetated) and untreated (control) areas were used to assess the influence of the water regime, and the effectiveness of the revegetation program in remediating and expanding the quality and quantity of vegetation in the drawdown zone. In 2013 we sampled only the control and treatment plots that had been previously sampled in 2009 and 2011, so that a direct comparison of change over time could be made.

4.3 Field Procedures

The GPS locations and field data for previously sampled plots were relocated using a GPS unit (Nomad 800L with SX Blue Differential). Table 2 shows the dates of activities prior to, during and after the fieldwork for the CLBMON-12 project in 2013.

Table 2. Dates worked to complete CLBMON-12 in 2013

Action	Date
Pre-fieldwork planning, including map preparation	April, 2013
Field assessment of vegetation plots in existing and treated vegetation	May, 2013
Plant I.D.; reviewing and editing field forms. Updating and editing the plant species database based on unknown plant I.D. Field data archiving; cleaning and data entry	June – July, 2013
Data analysis and Interim Report for all years	August – September, 2013
Reporting	August – November, 2013

Calibration and standardization of vegetation cover estimates and height measurements were done throughout the field session. The field data collected for plots in previous years, including collected plant specimens, were available for reference in the field.

As in previous years, the timing and location of fieldwork had to be prioritized to assess the low-elevation sites before they were inundated. Fieldwork at low-elevation (434 m to 436 m) sites was completed in the first weeks of the sampling period. Middle- to high-elevation (436 m to 440 m) field sampling was completed in the last week of May, 2013.

4.4 Vegetation Sampling Methods

Vegetation sample methods were described in Enns and Enns (2012) and have not been changed. The VCTs within polygons were sampled using 5 m x 10 m (50 m^2) vegetation plots.[5] For each species in the plot, the Latin name was recorded and per

[5] In 2008 and 2009, plots consisted of three 0.5 m^2 subplots within a larger 5m X 10 m plot. A list of all species was made for each subplot and for the larger plot. In 2010, field sampling procedures were changed so that only the larger plots were sampled. This change was adopted because sampling of the smaller subplots did not add new species to the total for a site, but it did add considerably to the amount of time required to complete a plot. Also, data collected for the three subplots were amalgamated during the analysis to represent the larger plot in all of the past reports, so the use of three subplots was judged as redundant and unnecessary.

cent cover, abundance class, vigour class, distribution code, and average height were either estimated or measured. Percent cover was considered to be additive due to overlapping crowns and final tallies for all species could (uncommonly) exceed 100% cover. An overview of the plot locations is shown in Figure 2, and detailed mapped plot locations are included in Folio 1 of the 2011 report (Enns and Enns 2012). The number of existing vegetation monitoring plots sampled in 2013 is shown in Table 3, and the number of paired control-treatment plots sampled is reported in Table 4.

Table 3. Number of existing vegetation plots within VCTs in the Arrow Lakes Reservoir sampled in 2013

	Elevation Band (m)			
VCT	**434 - 436**	**436 - 438**	**438 - 440**	**Total**
BB	1	3	4	**8**
BE	27	20	12	**59**
BG	13	18	8	**39**
CR	0	1	17	**18**
IN	8	8	5	**21**
PA	0	15	19	**34**
PC	32	31	35	**98**
PE	20	10	1	**31**
RR	4	6	5	**15**
RS	3	2	0	**5**
SF	1	1	1	**3**
SS	1	1	0	**2**
WR	0	1	0	**1**
WS	0	1	0	**1**
Total	**110**	**118**	**107**	**335**

Table 4. Number of revegetation treatment plots sampled in 2013 for the three main treatment types: cottonwood seedlings, cottonwood stakes, and *Carex* plugs

Treatment Type	Control plots	Treatment plots	Total
Cottonwood seedlings	15	15	**30**
Cottonwood stakes	28	28	**56**
***Carex* plugs**	44	44	**88**

On the advice of Dr. C. Schwarz (SFU, pers. comm. 2012), we aimed for an even distribution of plots among the three elevation classes (434 m to 436 m, 436 m to 438 m, and 438 m to 440 m) for each VCT. The plot midpoint elevation was used to calculate both the depth and duration of inundation of the vegetation in each plot. An even number of samples for each vegetation community type across the elevation range of the reservoir provided us with greater statistical power to detect changes in vegetation that are attributable to the effects of the operating regime.

We tried to include as many of the 43 study areas as possible, but some could not be sampled because of access constraints. Representation across all elevations is not possible for some vegetation communities. The CR (cottonwood riparian) VCT, for example, is limited to the high-elevation range of the drawdown zone between 438 and 440 metres.

Photographs of the completed plot forms were taken in the field. The vegetation in the plot and surroundings was photographed as well.

4.5 Field data collection in treatment plots

The revegetation program was carried out by Keefer Ecological Services Ltd. (KESL 2011). We attempted to assess every area that had been treated, both in 2011 and earlier, according the interim mapping that was supplied by KESL. Treatments selected for revegetation assessments included planted sedge plugs, planted willow plugs and stakes, cottonwood cuttings/stakes, applied seed mixes and fertilizer treatments. In 2011, KESL planted approximately 266,580 sedge plugs and 18,680 black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), willow (*Salix* spp.), and red-osier dogwood (*Cornus stolonifera*) seedlings, as well as 4,347 live black cottonwood stakes. We established and assessed plots within treatment areas using the same process described for existing vegetation (Section 4.4).

Plugs and seedlings were designated as such in the database, if mature enough to be distinguishable. The numbers of live and dead individuals were counted and recorded on the plot forms.

Live-staked areas were difficult to characterize because they varied in size. In some areas we established 5 m x 10 m vegetation plots as usual, and counted the number of live and dead stakes within the plot. This procedure provided information about the diversity and condition of the untreated vegetation, but did not adequately sample the survival of the stakes in areas that had been extensively treated. Therefore, at sites where stakes had been planted in large numbers over large areas, we either increased the area of the sample to include the entire stake-treated area or we established a larger fixed-size permanent sample plot in the centre of the large treatment area. We collected GPS locations around the perimeter of the smaller stake treatment areas and then counted the number of live and dead stakes within the treatment polygons. Within very large treatment areas, we selected a representative area of approximately 100 m x 50 m in size and conducted the live/dead counts of planted stakes. In the larger treated areas we also established vegetation plots, to describe the untreated vegetation within the overall treated area. The shape files describing the perimeter of all the mid-sized to larger treatment assessment polygons have been recorded in the database.

Within a survey area, the numbers of live stakes, dead stakes, and the total number of planted stakes by species were tallied and recorded on field data forms along with the assessment area identification number and the assessment area location. Stakes were recorded as dead if they had no leaves or shoots with living buds. Stakes had to have some living leaf tissue or live buds to be classified as “live”. Because cottonwood live stakes may sometimes appear dead for long periods but eventually produce new shoots, future live/dead counts may show recovery of plants previously counted as “dead”.

The information collected at stake plot locations included general location, area number, number of live and dead stems by species, and particle size of the substrate. Photographs of the stake count areas and forms were also taken.

4.6 Biomass Sampling and Estimation

Biomass sampling was replicated in a number of the paired treatment and control plots in order to compare productivity between treated and control (untreated) areas within the target VCTs. Methods were described in Enns and Enns (2012). The weights of all plants of each species inside the frame were first estimated, and then the plants were clipped with scissors to ground level and weighed to obtain the wet weight. Species that occurred in very small amounts within the biomass subplots were assigned a weight of < 1 g. Several samples of each species were dried and used to calculate a dry weight correction factor, which was applied to the remaining samples. These values were then used to estimate the final grams per hectare productivity of each plot.

4.7 Photography

Photographs were taken of each plot to provide a record of species composition and vegetation characteristics, as well as the surrounding vegetation and soil characteristics. Photographs were taken while standing at the south end of the plot. A photograph of the plot itself was taken, then a series of landscape photographs were taken of each cardinal direction (east, west, and south), and finally closeup shots were taken of plot vegetation. Significant features of the photographs were noted on the plot forms. After the plot documentation was completed, plot location flags were removed from the corners, and a labelled wooden stake was installed at the downstream, uphill corner of the plot, if a new plot marker was required.

4.8 Field Quality Control

Field forms were reviewed and corrected daily, and were ready for data entry during each day of the fieldwork. Each completed field form was photographed on the same day as data collection to provide backup copies of the plot data. The field data were downloaded weekly into a GIS database. Checks of the GIS accuracy were run each week, and plots were recorded on new versions of the maps for further use in the field. Hard copies of the field data, digital photographs, and photographic backup records were stored both on and off site.

4.9 Plant Identification

Many of the plants in the CLBMON-12 field study were immature when the field assessments were conducted. Collected specimens were identified daily, using standard plant field guides and taxonomic keys. Some specimens that were difficult to identify were sent to private contracting botanists for verification or identification. Names of the identified specimens were used to complete the field records and to update the species list in the database. A plant collection for this project has been maintained since 2007. The complete species list, with seven letter codes and common names, and a table of autecological characteristics is included in Appendix A.

4.10 Data Entry, Analyses, and Interpretation

The field data were entered into a spreadsheet using the same methodology as in all previous reports. Species name codes were checked for spelling errors, and redundant names and missing data were reconciled. Any changes in soils, for example, deposition of sand over vegetation, were made in the environmental database for each plot. Plot midpoint elevation was used to calculate both the depth and duration of inundation of the vegetation in each plot.

The results pertaining to previously answered management questions are summarized in this report. Management questions were addressed individually in the analysis by identifying the dependent and independent variables applicable to each question, and examining trends in data distributions, primarily with the use of boxplots and scatterplots in the 2013 version 10 of JMP[6]. Where appropriate, ANOVA, regression, and canonical analysis were used to assess trends in the data or compare sampling distributions for significant changes over time or differences between levels (such as treatment types or elevation bands). The complete results of these are presented in Appendix A. Details surrounding the analytical methods were described in Enns and Enns (2012), including transformations used (where necessary), multidimensional scaling, use of boxplots and bar graphs with 95% confidence limits, species diversity index calculations, species richness calculations, Analysis of Variance, Redundancy Analysis, Repeated Measures Analysis and Regression.

5.0 RESULTS

Water behaviour is considered to be a main factor influencing the vegetation of the Arrow Lakes Reservoir drawdown zone. Figure 4 shows the timing, frequency, duration and depth of inundation from January 2006 to July 2013.

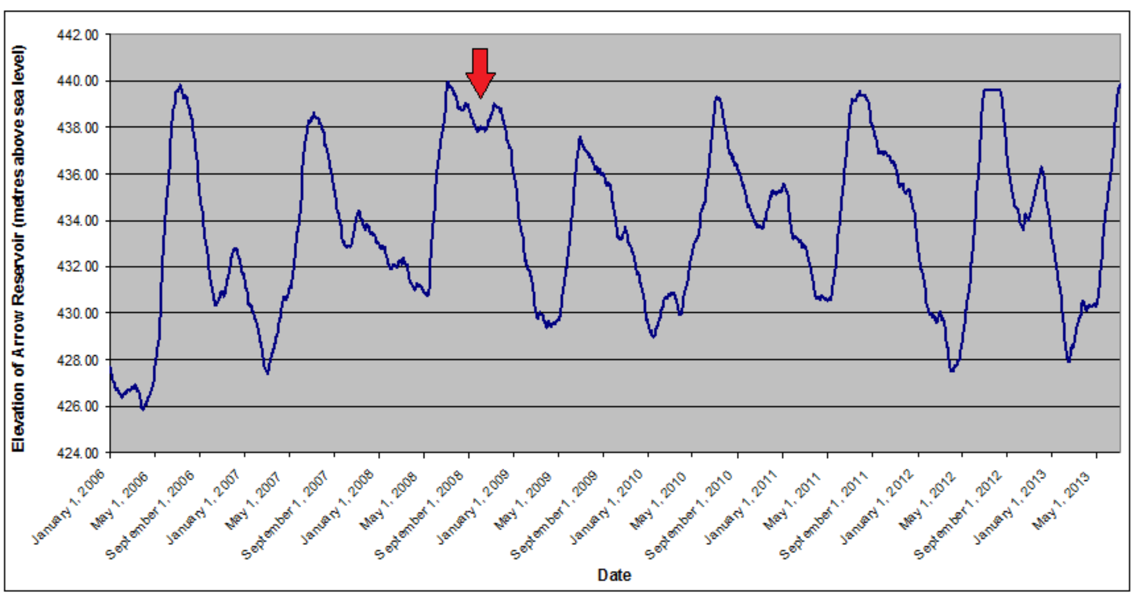

Figure 4. Water levels in the Arrow Lakes Reservoir from January 2006 to July 2013. A one-time period of prolonged inundation in 2008 is indicated with a red arrow.

[6] JMP ® Version 10. SAS Institute Inc., Cary NC. 1989-2007.

The patterns of inundation have followed a similar trend since 2006; there was a comparatively precipitous rise in water levels starting in June to September then a more gradual decline over the fall and winter months, with the exception of the 2008 high level long duration period under the red arrow shown in Figure 4. During the one period of different water behaviour (illustrated with a red arrow above), a prolonged period of inundation above 438 m occurred from May 2008 to December 2009. This differs from other years in that a low water period has usually occurred during the fall. This difference in the water management regime was followed by a measurable difference in the vegetation in the spring of 2009, with reduced cover and some reduction in vegetation heights, especially at low elevations (Enns *et al.* 2010). Over the duration of the CLBMON-12 and CLBMON-33 projects, vegetation cover has generally increased each year (Enns and Overholt 2013). Therefore, the changes in the operating regime may not have been sufficiently dramatic enough to be reflected in vegetation change (Enns and Overholt 2013).

5.1 Existing Vegetation

Management Question 1 and 2: What are the species cover, distribution, vigour, diversity, abundance and biomass of existing vegetation communities in relation to elevation in the drawdown zone?

Cover

Vegetation cover is plotted by elevation in Figure 5 and by vegetation community type in Figure 6. Some VCTs, such as the CR and PA types, do not occur in all three elevation bands. Figure 6 includes data collected in 2009, 2011 and 2013 combined.

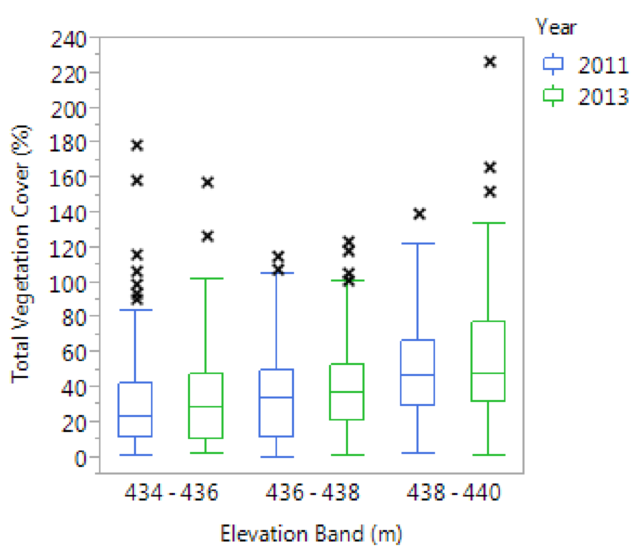

Figure 5. Total vegetation cover by elevation band as measured in 2011 and 2013 in the combined Arrow Lakes and Revelstoke Reach portions of the reservoir (n = 197 for 2011 and n = 144 for 2013)

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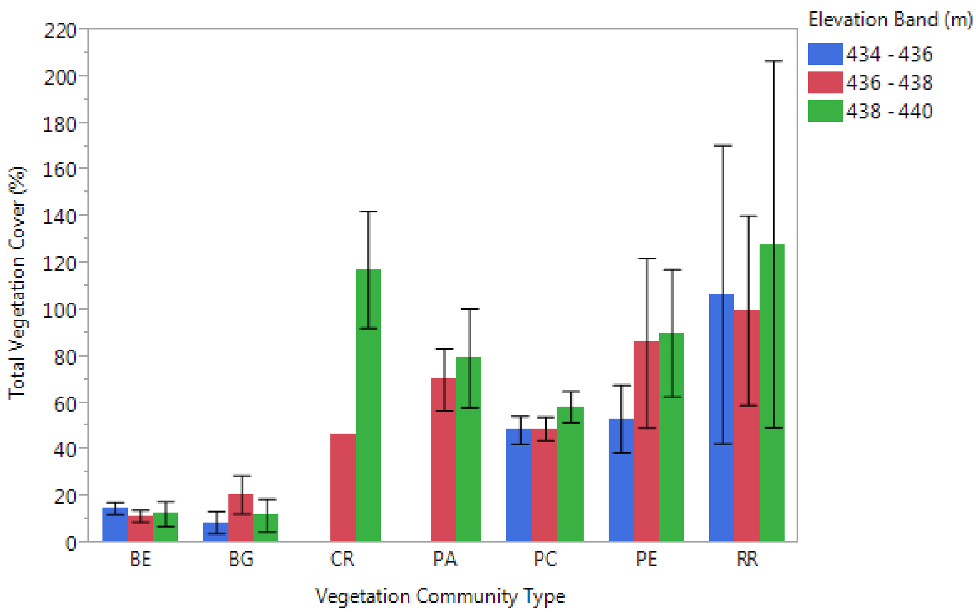

Figure 6. **Total vegetation cover by VCT and elevation band (n = 271 for the 434 – 436 m band, n = 258 for the 436 – 438 m band, n = 211 for the 438 – 440 m band). Error bars represent 95% confidence intervals of the mean. This figure includes data collected in 2009, 2011 and 2013**

Average vegetation cover has been lowest in the BE and BG communities. Cover tended to be greatest in the high-elevation band (438 – 440 metres), but the relationship between cover and elevation varied substantially among community types. In order to examine within-type changes over elevation, we considered types that span the range of elevations in the reservoir; such as the PC type. There was evidence that total cover was greater in the high-elevation band than in the mid-elevation band within the PC VCT (one-way ANOVA, alpha = 0.05, p = 0.0388). There was no evidence of differences in cover among elevation bands within any of the other VCTs (detailed ANOVA results are provided in Appendix A). There was a general trend toward lower vegetation covers from 2011 to 2013, but no statistically significant differences were detected.

Distribution

Distribution is a descriptive coded value describing the spatial pattern of species, ranging from a single individual or a few scattered individuals to clumps of individuals to evenly distributed continuous distributions of individuals (Figure 7). Distribution is influenced by disturbance, including surficial erosion (Von Holle *et al*. 2007).

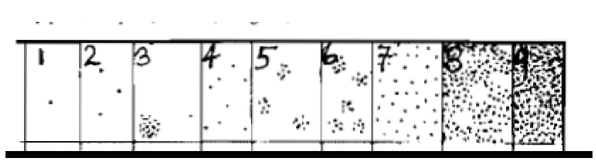

Figure 7. **Distribution Classes 1 through 9, used in the measurement of vegetation in the Arrow Lakes Reservoir. Adapted from Luttmerding *et al.* (1990)**

Figure 8 shows the range in species distribution values for the seven most common VCTs in the reservoir, grouped by elevation band. Average distribution for all types combined is plotted by elevation band and sampling year in Figure 9. Some VCTs are restricted to certain elevation zones so that between-elevation comparisons for these were not possible. Figure 8 includes data collected in 2009, 2011 and 2013 combined.

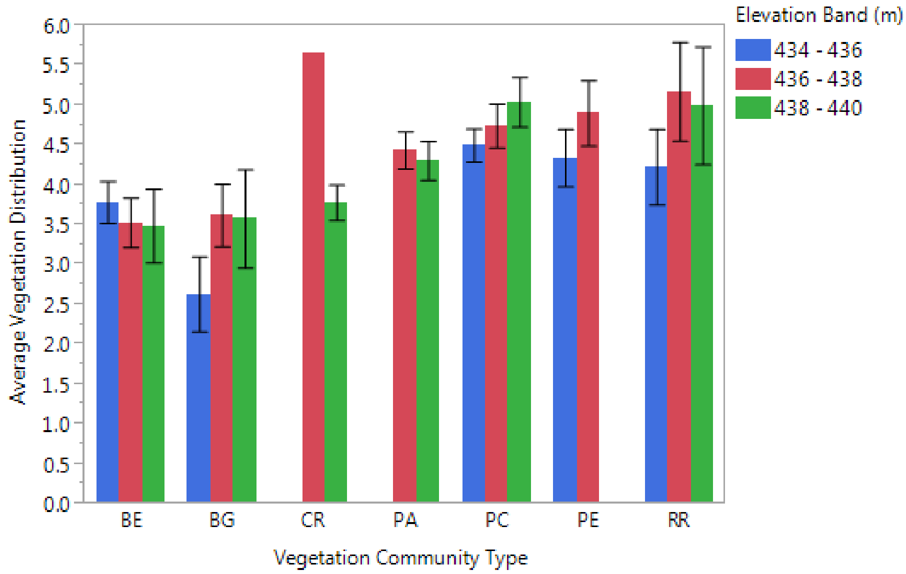

Figure 8. **Average coded vegetation distribution by VCT and elevation band. Combined data from 2009, 2011 and 2013 were used in this figure (n = 271 for the 434 – 436 m band, n = 258 for the 436 – 438 m band, n = 211 for the 438 – 440 m band). Error bars represent 95% confidence intervals of the mean**

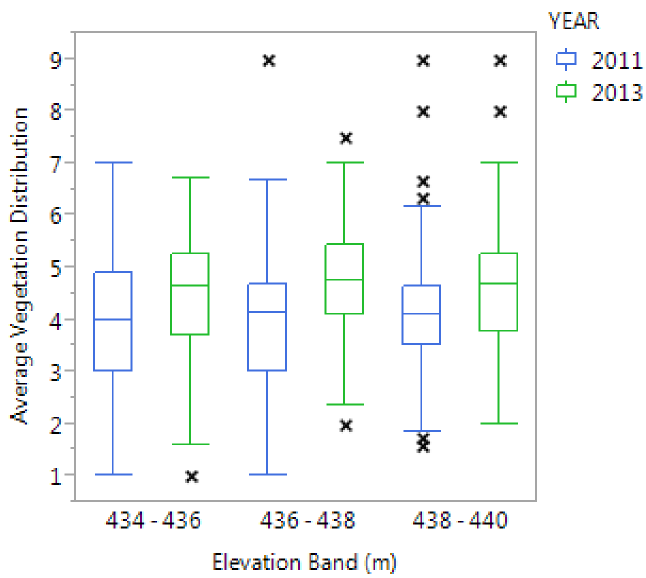

Figure 9. **Average coded vegetation distribution by elevation band as measured in 2011 and 2013 in the combined Arrow Lakes and Revelstoke Reach portions of the reservoir (n = 197 for 2011 and n = 144 for 2013)**

When all vegetation records for those vegetation communities occurring over all elevations were grouped together, there was a trend toward lower vegetation distribution codes in 2011, but the observed differences were not statistically significant for any of the elevation bands.

There was evidence that average vegetation distribution within the BG VCT was lower in the 434 – 436 m elevation band than in either the 436 – 438 m elevation band (one-way ANOVA, alpha = 0.05, p = 0.0166) and in the 438 – 440 m elevation band (one-way ANOVA, alpha = 0.05, p = 0.0430). There was also evidence that average vegetation distribution within the RR community was greater in the 436 – 438 m band than within the 434 – 436 m band (one-way ANOVA, alpha = 0.05, p = 0.0458). No other differences among elevation bands were detected.

Vigour

Species vigour was measured as a coded variable with four levels, ranging from dead (1) to moderate necrosis and other, multiple symptoms or conditions (2) to slight necrosis (3) to vigorous natural growth (4). Figures 10 and 11 show the ranges in vegetation vigour across elevation bands within each community type, and comparing 2011 to 2013.

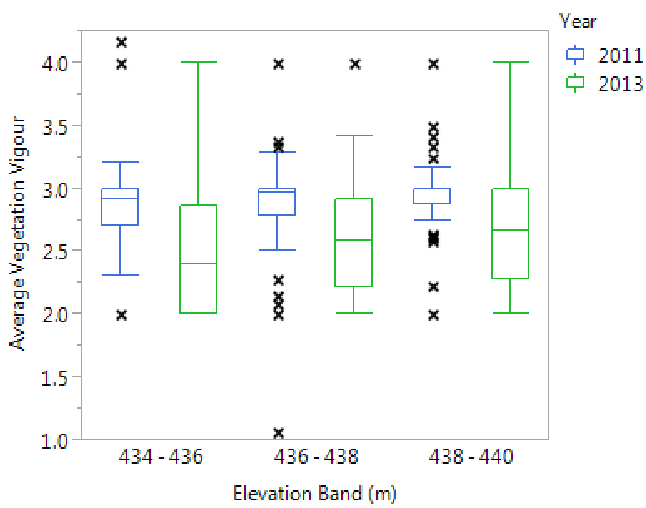

Figure 10. Average vegetation vigour by elevation band as measured in 2011 and 2013 in the combined Arrow Lakes and the Revelstoke Reach portion of the reservoir (n = 197 for 2011 and n = 144 for 2013)

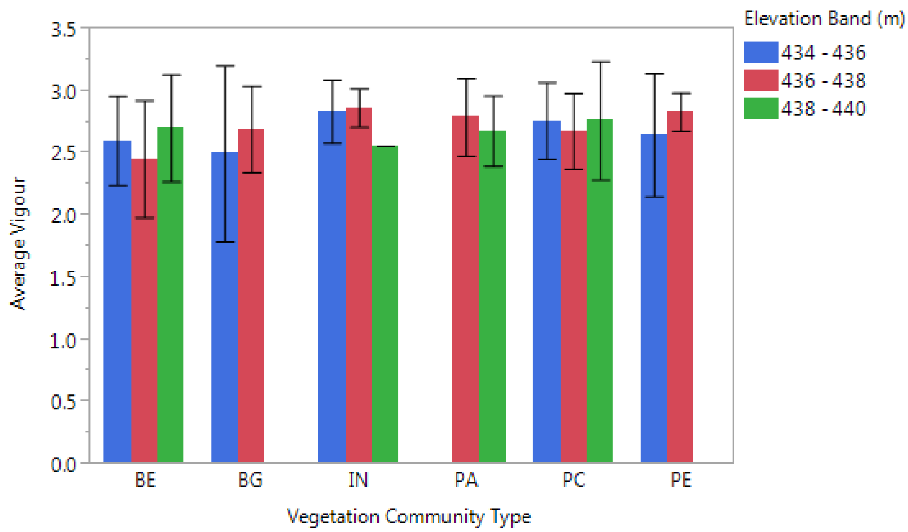

Figure 11. Average vegetation vigour by VCT and elevation band, combined for 2011 and 2013 in the Arrow Lakes and the Revelstoke Reach portion of the reservoir (n = 197 for 2011 and n = 144 for 2013)

The vegetation in 2013 shows somewhat lower average vigour than measured in 2011 in all three elevation bands, but the 2013 vigour data were more variable and the differences between years were not statistically significant. There were no clear trends between vegetation vigour and elevation in the Arrow Lakes Reservoir, with vigour increasing with elevation in some VCTs, decreasing with elevation in others, and showing no change in the remainder. There was no evidence to support the hypothesis of differences in vigour among elevation bands within any of the VCTs.

Abundance

Four classes of vegetation abundance were assessed in 2011 and 2013, based on groupings of number of individuals in each species. Figure 12 shows abundance in relation to elevation class in 2011 and 2013. (Some VCTs do not occur in all elevation bands). Figure 13 shows the abundance classes of vegetation within the VCTs of the Arrow Lakes and Revelstoke Reach portions of the Arrow Lakes Reservoir, as measured in 2011 and 2013.

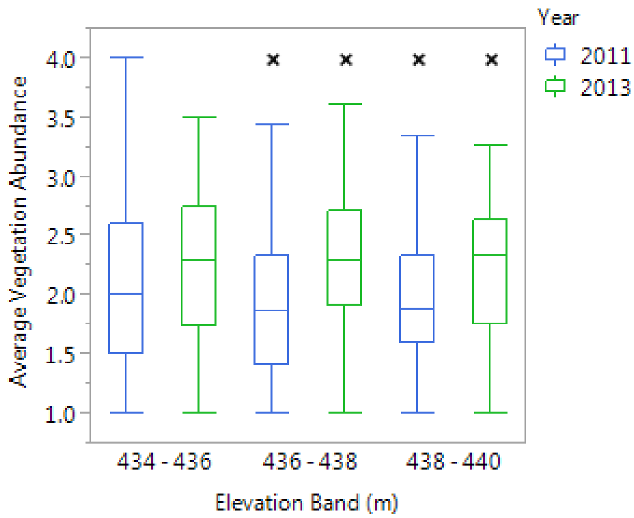

Figure 12. Average vegetation abundance by elevation band for all VCTs combined as measured in 2011 and 2013 (n = 197 for 2011 and n = 144 for 2013). (1= 1- 20 individuals of a species; 2=21-50; 3=51-100; 4=>50)

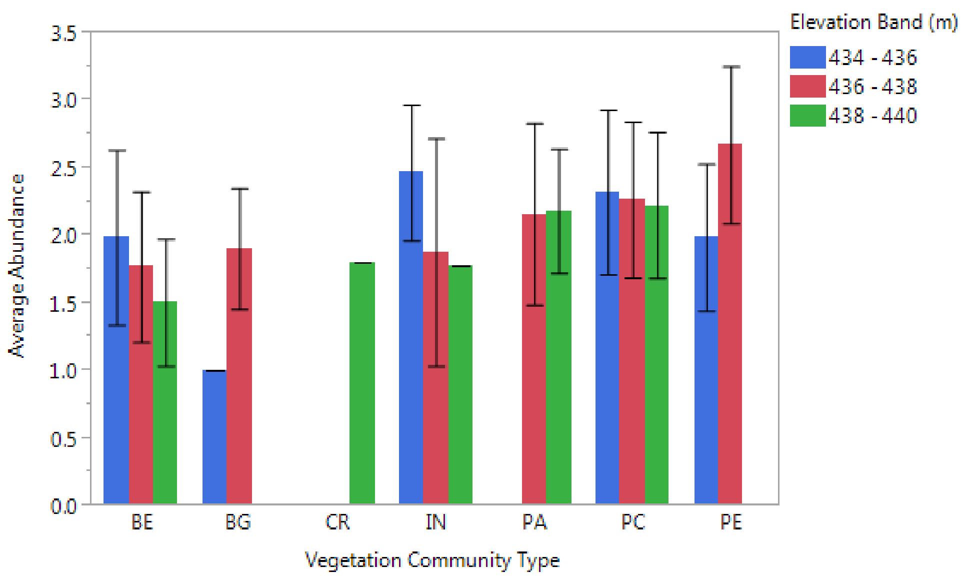

Figure 13. Average vegetation abundance by VCT and elevation band as measured in 2011 and 2013 (n = 197 for 2011 and n = 144 for 2013). (1= 1- 20 individuals of a species; 2=21-50; 3=51-100; 4=>50)

Within the BE VCT there was evidence that average vegetation abundance was greater in the 434 – 436 m elevation band than in the 438 – 440 m band (one-way ANOVA, alpha = 0.05, p = 0.0215). No other significant differences between elevation bands were detected. The lowest elevation band had, in general, the highest species abundance, although vegetation abundance was more uniform among elevation bands in 2013 than in 2011. The lowest elevation bands tended to receive moisture from the reservoir and from downslope drainage; therefore, seedlings tended to be more abundant at lower elevations in sandy and silty substrates. The mesic Reed Canary Grass VCT (PC) had uniform plant abundance over all three elevation classes, and the Sandy Beach VCT

(BE) tended to have declining plant abundance with increasing elevation class. The high-elevation sites tended to have fewer individual plants, of a larger size.

Biomass

Data for biomass were collected from 0.5 x 0.5 m adjacent subplots that were paired with the main vegetation plots, in 2008, 2011 and 2013. Figure 14 shows the range of biomass measurements in each elevation band for the most common VCTs. Figure 15 compares biomass measurements among elevation bands for each year. Biomass was sampled only in commonly occurring VCTs.

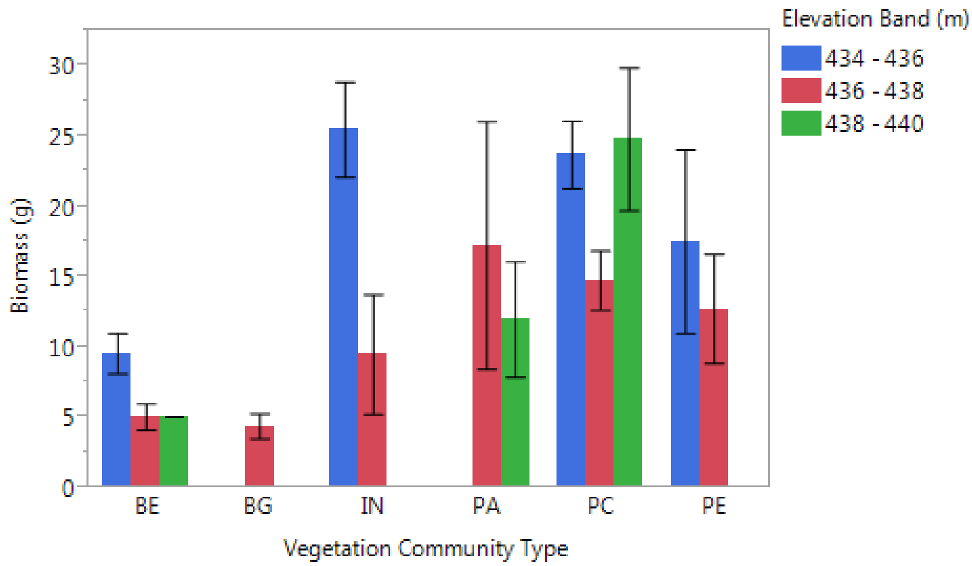

Figure 14. Average vegetation biomass by VCT and elevation band, as measured in 2011 and 2013 (n = 197 for 2011 and n = 144 for 2013)

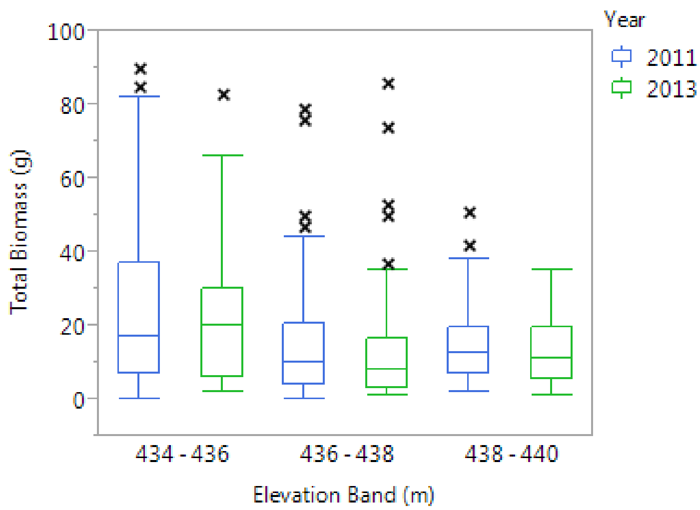

Figure 15. Average vegetation biomass by elevation band as measured in 2011 and 2013, for all VCTs combined (n = 197 for 2011 and n = 144 for 2013)

Biomass measurements tended to follow the same pattern as the cover and abundance estimates for each VCT. Biomass in the IN, BB, BE and BG tended to be very low and did not change between 2008 and 2011 (data not shown). The PC, PE and PA VCTs had higher biomass and greater variation, but also have not shown much change over time. There was no evidence that average biomass differed significantly among elevation bands within any of the VCTs included in this analysis. However, within the BE VCT, biomass in the 434 – 436 m elevation band was somewhat greater than in the 436 – 438 m band (one-way ANOVA, alpha = 0.05, p = 0.0501). There appeared to be a general trend toward decreasing biomass with increasing elevation (Figure 15). This may be a function of sampling methodology, however.

Species Diversity, Richness and Evenness

Species richness by elevation band of each of the main vegetation community types in the reservoir, as measured in 2011 and 2013, is shown in Figure 16. Figure 17 compares the range in species diversity, evenness and richness of each of the main vegetation community types in the reservoir, as measured in 2011 and 2013.

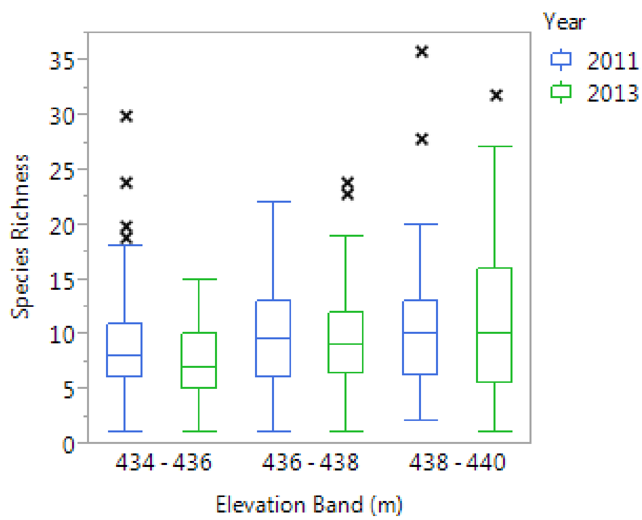

Figure 16. Species richness by elevation band as measured in 2011 and 2013 (n = 289 for 2011 and n = 293 for 2013)

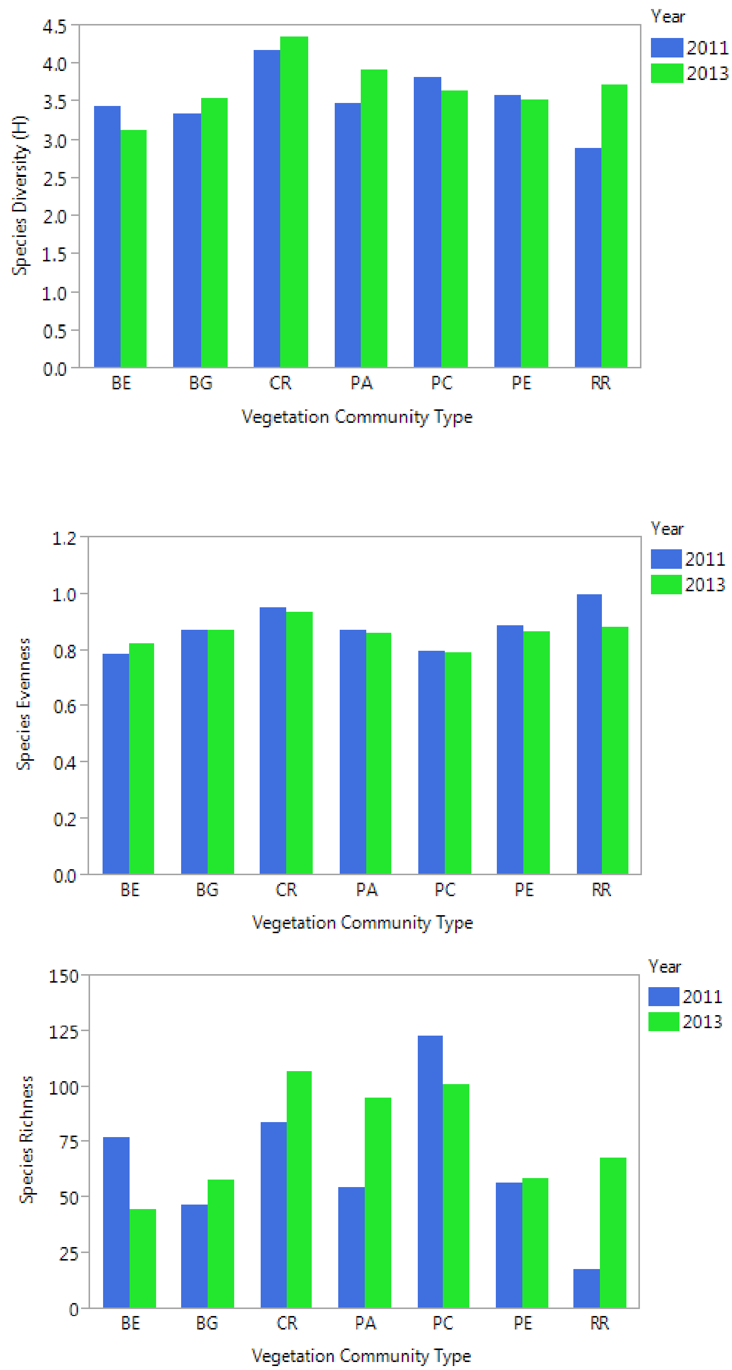

Figure 17. **Species Diversity (top), Pielou's species evenness (middle) and total species richness (bottom) of the seven most dominant VCTs in the reservoir, as measured in 2011 and 2013 (n = 289 for 2011 and n = 293 for 2013). Data for 2009 was considered insufficient for measures of species diversity, richness and eveness.**

Between 2011 and 2013, average species diversity appears to have increased within the BG, CR, PA and most dramatically in the RR VCTs, and decreased within the BE, PC and PE communities (see the Appendix accompanying this report). Average species evenness decreased slightly in all of the VCTs included except for the BE type. Species richness decreased in the PC and BE communities, but increased in all other VCTs, most dramatically in the RR VCT.

When the data for all VCTs were combined, no increase in species richness between 2011 and 2013 was detected within any of the three elevation bands. There was, however, a general trend toward a decrease in species richness within the 434 – 436 m elevation band and the 436 – 438 m band, and an increase in species richness within the 438 – 440 m elevation band. Total species richness generally increased with elevation; this trend was especially apparent in the 2013 data.

Management Question 3: How does the current operating regime affect the within-community quality and quantity (i.e., species cover, abundance, biomass, and distribution within existing communities) of existing vegetation?

In order to assess the impact of the current operating regime on reservoir vegetation, scatterplots were used to illustrate how average plant cover, abundance, biomass, diversity, distribution and height were influenced by inundation. In Figures 18 to 22 the average values of vegetation variables, as measured in 2011 and 2013, were plotted against the number of days each plot was inundated between June 2010 and April 2011 (2011 field data) and between June 2012 and April 2013 (2013 field data). These figures include only those VCTs that occur across multiple elevation bands. RR was not included due to a low sample size.

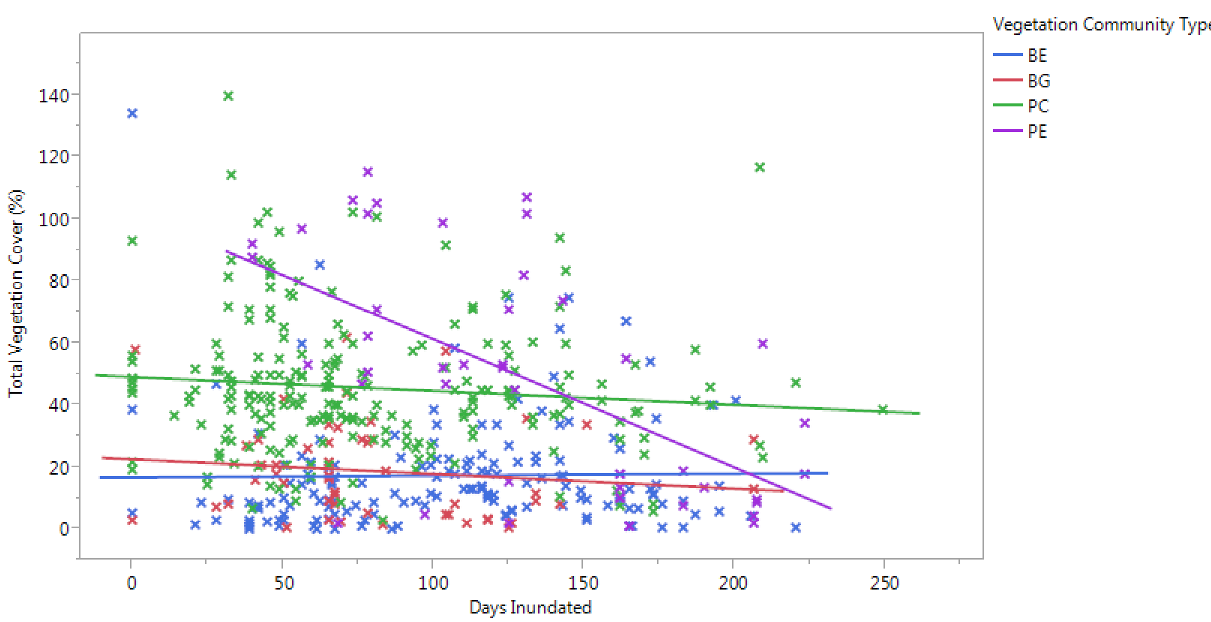

Figure 18. Average vegetation cover of plots in the BE: Sandy Beach; BG: Gravelly Beach; PC: Reed Canary Grass Mesic; PA: Redtop Upland; and PE: Horsetail Lowland VCTs in relation to the number of days vegetation was inundated.

The regression lines are based on the best fit least-squares linear model (see Appendix A)

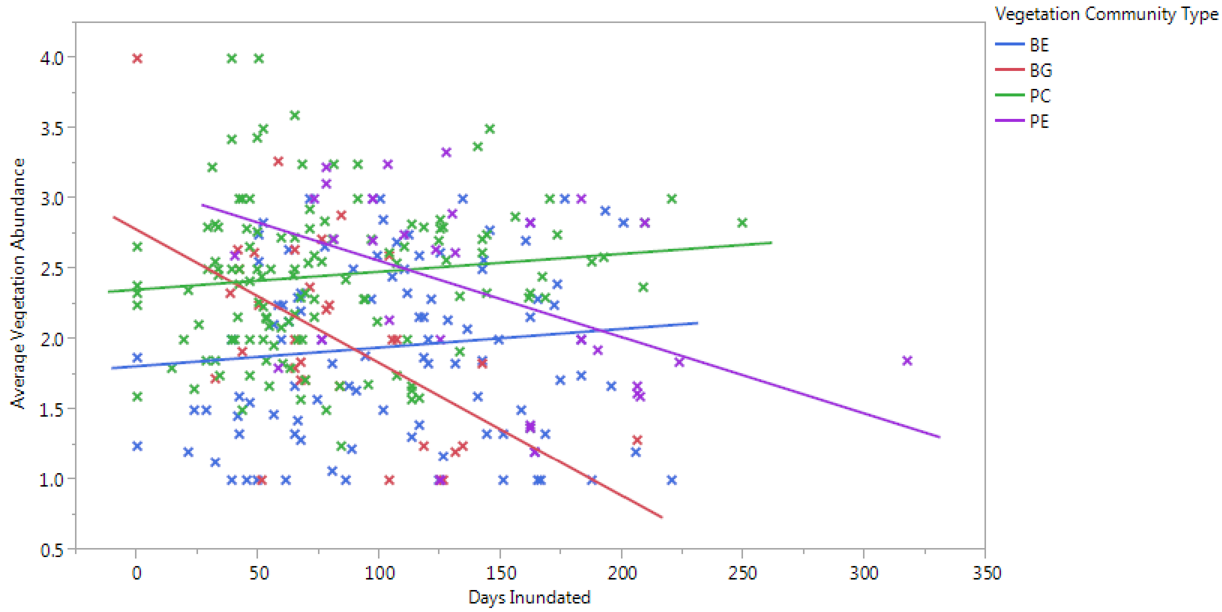

Figure 19. Average vegetation abundance of plots in the BE: Sandy Beach; BG: Gravelly Beach; PC: Reed Canary Grass Mesic; PA: Redtop Upland; and PE: Horsetail Lowland VCTs in relation to the number of days vegetation was inundated. The regression lines are based on the best fit least-squares linear model (see Appendix A)

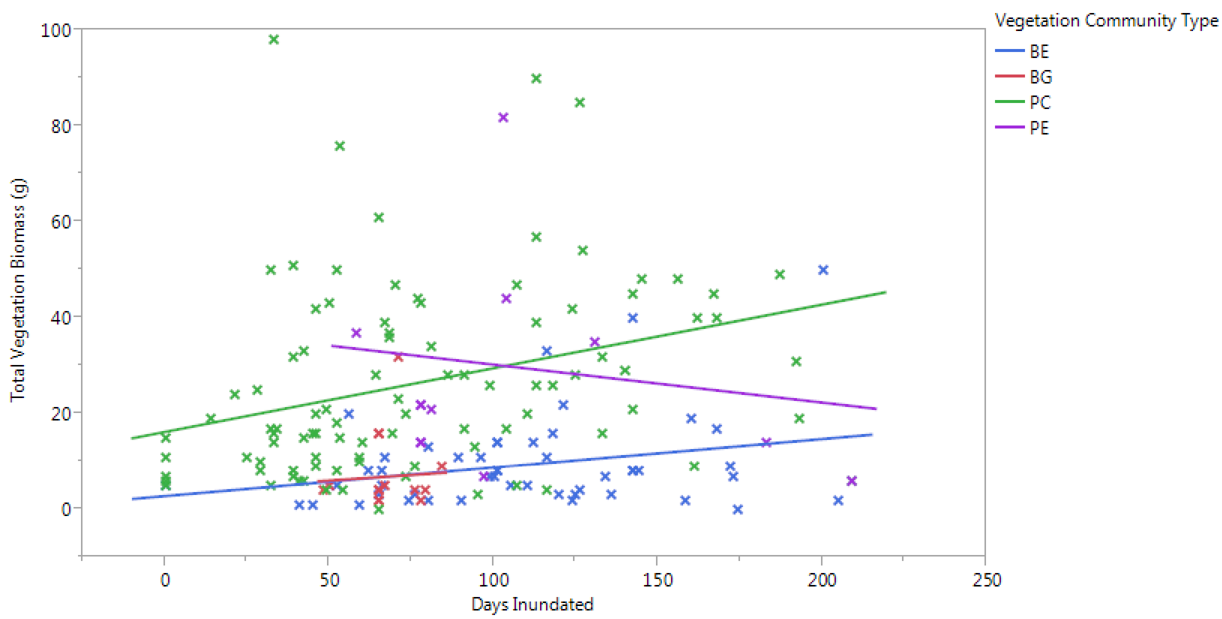

Figure 20. Average vegetation biomass of plots in the BE: Sandy Beach; BG: Gravelly Beach; PC: Reed Canary Grass Mesic; PA: Redtop Upland; and PE: Horsetail Lowland VCTs in relation to the number of days vegetation was inundated. The regression lines are based on the best fit least-squares linear model (see Appendix A)

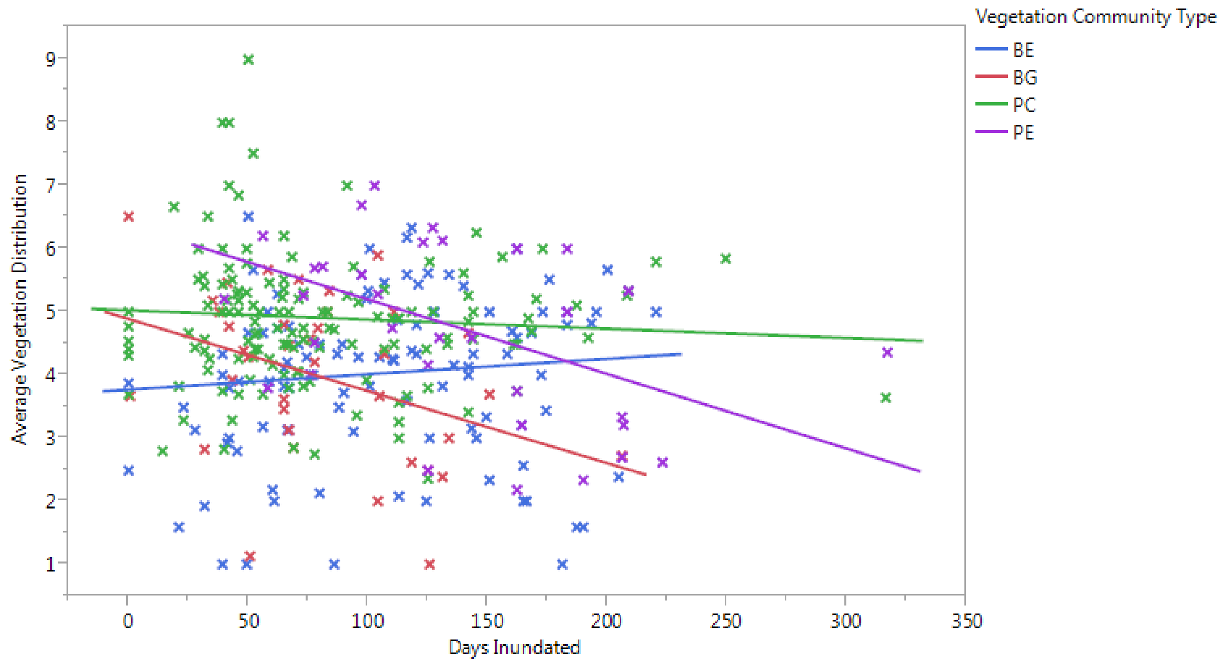

Figure 21. **Average vegetation distribution of plots in the BE: Sandy Beach; BG: Gravelly Beach; PC: Reed Canary Grass Mesic; PA: Redtop Upland; and PE: Horsetail Lowland VCTs in relation to the number of days vegetation was inundated. The regression lines are based on the best fit least-squares linear model (see Appendix A)**

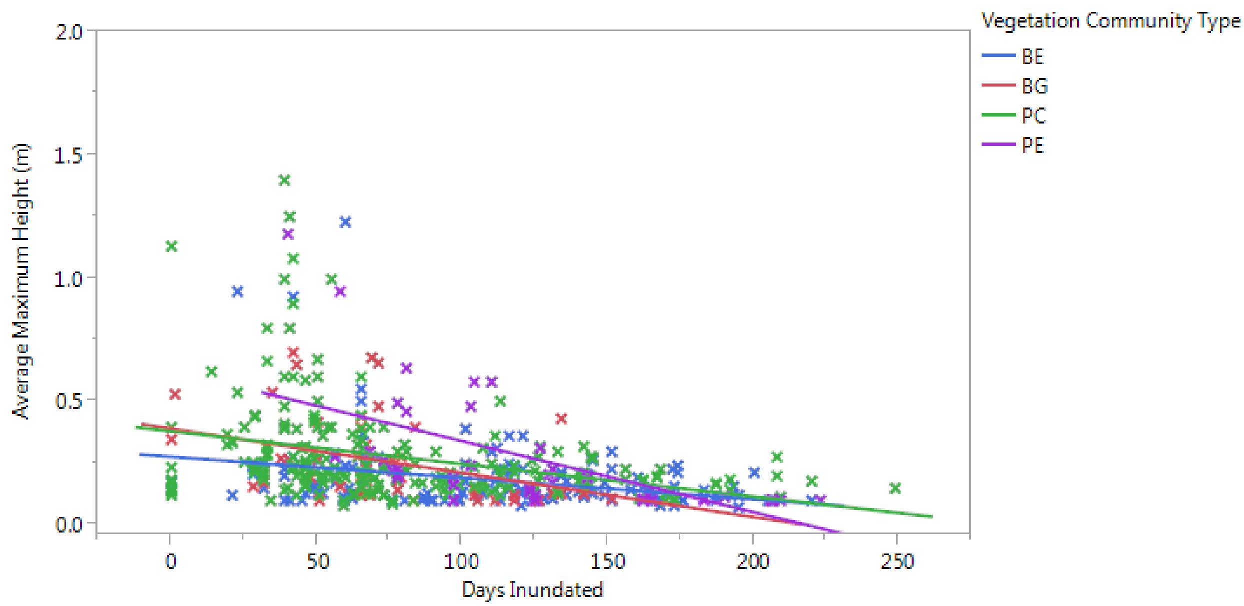

Figure 22. **Average vegetation maximum height of plots in the BE: Sandy Beach; BG: Gravelly Beach; PC: Reed Canary Grass Mesic; PA: Redtop Upland; and PE: Horsetail Lowland VCTs in relation to the number of days vegetation was inundated. The regression lines are based on the best fit least-squares linear model (see Appendix A)**

With the exception of vegetation height, there were no strong associations between the number of days a plot was inundated and any of the vegetation variables measured. For VCTs ranging over all of the elevation bands of the reservoir, both high and low biomass and high and low maximum vegetation heights were found in plots that were inundated for a relatively short period. When inundation exceeded 100 days, average maximum vegetation height tended to decrease compared to plots with a shorter duration of inundation (Figure 22). This indicates that prolonged inundation may negatively impact plant growth and development, and is similar to trends discussed in previous reports (Enns *et al.* 2012, Enns and Enns 2012; Enns *et al.* 2012; Enns *et al.* 2010, etc.).

The PE (Horsetail Lowland) VCT was affected more strongly by inundation than were the other types. The PE type tends to occur mainly at lower elevations (< 436 m), so the response of this VCT may be due to its tolerance for low elevations within the reservoir. Very few PE plots occurred at a high-enough elevation to be inundated for fewer than 100 days. Where PE occurs at high elevation it usually associated with a perched depressional area with poor drainage to the slope below it, or with former forested wetlands. An example of the latter occurs at McDonald Creek Park, 15 km south of Nakusp.

Management Question 4: Is there a shift in community structure (e.g., species dominance) or a potential loss of existing vegetation communities that is attributable to environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation)?

This management question was addressed in annual reports from 2008 through 2013. These findings are summarized below. The most dominant species remained relatively constant over time, while some of the less frequently occurring species shifted slightly in dominance. The two most commonly occurring species (lenticular sedge and reed canary grass) have not changed dramatically in their constancy (dominance), although there is some evidence that reed canary grass has decreased in dominance since 2008 in selected areas impacted by scouring. The aggressive perennial, Canada bluegrass (*Poa compressa*), has increased in the past three years, and Columbia sedge (*Carex aperta*) has also increased in the past two years.

The patterns in vegetation succession have been dynamic; however there has been a clear trend of previously minor species becoming more prominent in some plots, usually within a single season, followed by a decline and replacement by some other species the following year. Species that have shown dramatic increases include common stork's bill (*Erodium cicutarium*) and hare's-foot clover (*Trifolium arvense*) in 2008 (compared to the previous or following year), tufted vetch (*Vicia cracca*) in 2009, and little meadow-foxtail (*Alopecurus aequalis*), which increased in 2008, declined in 2009, then steadily increased between 2009 and 2013.

To examine shifts in species dominance *within* vegetation community types and to identify losses of existing vegetation, we compared species losses over time. The 15 species that occurred most frequently in 2011 were identified and their frequency of occurrence within the BE, BG, PA, PC, and PE VCTs was ranked for each year, 2007 - 2011 (see Table 2 in Appendix A, presented in a separate document). These VCTs were selected because they are common throughout the reservoir and occur across a range of elevation bands. Thus, the comparison of frequency of occurrence reflects the survival over time of the most frequently occurring species in the dominant VCTs.

Another obvious pattern has been that very similar dominant species occurred in each VCT, while some subdominant species or combinations of species were unique to a given VCT. This is very common in vegetation studies, and is why diagnostic or change-sensitive species are more often used than dominant species to show change over time[7] (Mueller-Dombois and Ellenberg 1974). Many of the dominant species, such as reed canary grass, rushes, willows, and sedges, are aggressive and disturbance-tolerant perennials, whereas others, such as marsh yellow cress (*Rorippa palustris*), the knotweeds (*Polygonum* spp.), montia (*Montia* spp.), popcorn flower (*Plagiobothrys scouleri*), and speedwell (*Veronica* spp.) are opportunistic and aggressive weeds. Some of the dominant species appeared to be more aggressive under reservoir conditions than would be expected from the information found in the literature (Enns *et al.* 2012). Therefore, in order to continue to address MQ 4, fluctuations in species dominance should continue to be observed and explained using permanent repeated plots as these provide the clearest indication of a negative trend in vegetation status in the reservoir.

Management Question 5: What are the species–specific survival rates under the soft constraints operating regime (i.e., what are the tolerances of existing plant species to inundation)? [8]

Species-specific survival rates between 2007 and 2013 showed a pattern of similar numbers of losses of species from repeated plots each year, with slightly higher numbers of losses during treatment monitoring years than during landscape level objective years (CLBMON-12 vs. CLBMON-33) as shown in Enns and Overholt (2013). This was due to monitoring treatment plots being naturally species poor (and therefore needing treatment). In general, losses from repeated plots declined over time. The following trends in survival rates were described in detail in Enns and Enns (2012).

Trees and shrubs have established in the reservoir and most of them are observed in the same plots every year. However, few have been observed below 437 m. Most persisted, but individual trees and shrubs have been killed and removed, mostly from 436 to 438 m possibly as much from drought as from scouring and physical removal by coarse woody debris (Figure 23). High elevation vegetation communities may require inundation and benefit from it. The assumption that inundation has an overall negative effect on vegetation is incorrect for many species and community types in the reservoir.

[7] One of the first steps in community analysis and interpretation is to remove the dominant species from consideration.

[8] **Vegetation (Soft Constraints)**

- Maintain current level of vegetation in the drawdown zone by maintaining lower reservoir water levels during the growing season. No specific operating targets were identified to meet this general objective.
- If vegetation is showing signs of stress as a result of inundation during the early part of the growing season (May to July), target lower reservoir levels in the fall to allow exposure of plants during the latter part of the growing season.
- Preservation of current levels of vegetation at and above elevation 434 m (1424 ft) is considered a priority.

Figure 23. Persistence and losses of PA vegetation in the winter wave zone at Edgewood North. Plot 08-12-152 (438 m) in fall of 2007 (left) and again in spring of 2013 (right). Small shrubs and grasses were removed but cottonwood and common horsetail (*Equisetum arvense*) persisted

Since the start of the project, inundation has seldom exceeded 438 m for long periods each winter, so it is difficult to define the effect of inundation on trees and shrubs at this elevation. Few changes have been observed in the highest-elevation CR: Cottonwood Riparian forest type. Shrubs and trees below 439 m in the PA type that appeared to have failed to survive inundation included naturally occurring cottonwood, wild cherries, Sitka and Pacific willow (*Salix sitchensis* and *S. lucida* ssp. *lasiandra*), and blue elderberry (*Sambucus cerulea*), as well as herbaceous plants, mosses and lichens. Some of these losses may have been mostly from drought, or by inundation and scouring which removed the plants. Limiting factors at the highest elevations in the reservoir are very likely availability of soil moisture, shade and sources of propagules from upslope, and from moisture retention beneath woody debris that allows trees and shrubs to survive in this relatively soil-less, coarse textured zone (Jackson *et al.* 1995; Skeesick 1991; Wendt and Allen 2001). The long period of exposure following the re-construction of the Hugh Keenleyside dam may have been important in allowing some of the more drought-tolerant species to invade low elevation sites. Losses from some plots over the long term may still be an adjustment to invasion during the low water period (Auble *et al.* 2007).

Ponderosa pine (*Pinus ponderosa*) seedlings were lost following the 2009 season from the lowest portion of the high elevation sites, suggesting that inundation caused the removal of this drought-tolerant species. The decline of the *Salix* species complex at low-elevation sites was thought to be due to a combination of inundation injury to plants that invaded the low- to middle-elevation sites during low-water years, and to gall insect infestations (Enns *et al*. 2009). Recovery was not seen in 2011 or 2013, but new seedlings were noted.

Herbaceous annual and perennial species were often seedlings of the current year or established adults. There was a group of small, inundation-tolerant herbs, including members of the genera *Veronica*, *Cardamine*, *Cerastium* and *Plagiobothrys,* that were common and persistent at low elevation. A second group of more drought-tolerant herbs persisted at high elevation (Figure 24). If these two groups the lower elevation species are more influenced by the soft constraints. Most of herbaceous species that were lost were annuals that failed to re-establish in repeated plots, due to the washing away of seedlings, seeds, root fragments, or rhizome fragments from sites (Jackson et al. 1995).

Losses could also be attributed to drought or physical disturbance if they occurred above the water line the following winter. This relates to the soft constraints in that short periods of high elevation inundation may have a positive outcome for many plants.

Figure 24. Herbaceous plants at higher elevation were almost all very drought resistant

Grasses were prolific and abundant in the drawdown zone of the Arrow Lakes Reservoir (Figure 25) and survival has been better in this group than in all other groups of plants. In 2013, several sites had losses of the dominant and aggressive reed canary grass in excess of 50% cover compared to previous years. The loss of reed canary grass from several locations between 2010 and 2013 is thought to be an important species decline in the Arrow Lakes Reservoir because its loss may allow other species to establish. No evidence of this was found, however, because the lack of survival has been most common in scoured sites, where the substrates were stripped to bare mineral soil and no new species were recorded. However, measurements have always been taken in May before the vegetation matured to full potential cover, so this may present an incomplete picture of invasion and survival in the reservoir.

Figure 25. Grasses persisted in non-treated plots at all elevations in the Arrow Lakes Reservoir, with a relatively high diversity

Inundation-tolerant plants The most important inundation-tolerant species, lenticular sedge, has not declined in most plots over the long term, although some losses due to scouring were noted in 2013. Losses from one year to the next could be a result of the water regime exceeding or failing to meet their inundation thresholds for survival. Some inundation-tolerant plants are mobile and able to relocate to new downstream sites in the reservoir every year. Others, such as thread rush (*Juncus filiformis),* require and benefit from inundation, and tolerate being completely immersed in winter months (Figure 26).

Figure 26. Inundation-requiring *Juncus filiformis* (centre) at Derbyshire beach, north of Nakusp at 437 m

Mosses, **lichens and ferns** often had a high rate of survival in repeated plots in pre-existing, non-treated plots over the long term. Mosses occasionally formed a very high proportion of the total plant cover, and in many cases have persisted over several years in repeated plots, especially at low elevation on sands. Mosses are thought to be important in maintaining soil stability in the drawdown zone (Odland and Del Moral 2002). Lichens, especially species of *Peltigera*, *Cladonia*, and *Cladina* were common in the 438 m to 440 m elevation band, and many have appeared to have withstood inundation. Ferns, however, were rare in the drawdown zone of the Arrow Lakes Reservoir, and where they have occurred, they tended to be absent from repeated plots the following year. Liverworts, hornworts, and clubmosses were incidental species with few records available to show trends in response to the soft constraints operating regime.

Figure 27. Mosses persisted at all elevations, were somewhat resistent to scouring but formed densest mats from 436 to 440

Weeds include several species of B.C. listed weeds[9], common wasteland weeds, roadside and ditch weeds. There was a decline in weed species survival following the prolonged high-elevation inundation in the winter of 2008 – 2009. Drought-tolerant weeds have established in the highest-elevation areas and along roadsides within the IN: Industrial VCT. Access roads in the drawdown zone are likely a major source of weed propagules to the rest of the drawdown zone.

Overall, the total number of identified species present in 2013, including mosses, lichens and liverworts was 240, in 335 vegetation plots. Excluding those species that could only identified to genera (e.g. Veronica sp.), for both treated and nontreated plots, the number of species that increased in frequency of occurrence from previous years was 60, those that decreased in frequency was 42 and the number of constant species, that did not change was 24. Fourteen species cannot be assessed for frequency because they were immature at the time of assessment or otherwise could not be confirmed as to specific epithet. The complete species list for all years is shown in Appendix A (separate document). There were no new species for 2013, although some previous records for prairie rose (*Rosa woodsii* subsp. *ultramontana*) may be a hybrid with an introduced species sweetbrier (R. *eglanteria).* The *r*ecords for the project have kept up with changes in taxonomy in Asteracea and other groups.

[9] http://www.weedsbc.ca/

Management Question 6: What recommendations can be made to more effectively maintain existing vegetation at the site level in the future?

Vegetation cover declined in 2009 following a one-time prolonged high-water period during the winter of 2008 - 2009 (Figure 28).

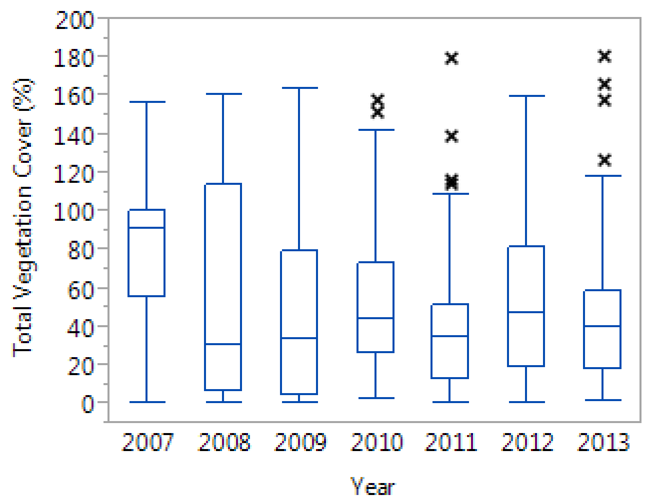

Figure 28. **Total average cover of vegetation (from all non-treatment plots) in the Arrow Lakes Reservoir for all sampling years (n = 150 for 2007, n = 72 for 2008, n = 135 for 2009, n = 507 for 2010, n = 289 for 2011, n = 340 for 2012, n = 293 for 2013)**

Vegetation cover was measured in October for the 2007 field season, and had the benefit of an entire field season to grow. In all other years vegetation cover was measured in May and was stunted and possibly not yet emergent compared to 2007. Therefore, the high vegetation cover observed in 2007 cannot be reliably compared to the cover values measured in the other years. For this reason the 2007 data were not included in the ANOVA analysis for 2013. A slight, but significant decline in total cover occurred in 2013 (one-way ANOVA, alpha = 0.05, $p < 0.0004$).

The pattern of alternate years (2011 and 2013 having lower cover than 2010 and 2012) was a function of the inclusion of treated vs. untreated control plots in the database (Enns and Overholt 2013). The plots measured to compare to treatments had to be paired to be as similar ecologically as possible. Vegetation cover was generally lower in 2011 and 2013, when the paired treatment plots were measured for CLBMON-12, than in 2010 and 2012, when landscape-level vegetation cover was monitored for CLBMON-33.

In general, winters with a long duration of high water levels, such as 2008 – 2009, and, to a lesser extent, 2012 – 2013, were followed by a decline in average vegetation cover. The winter of 2008 – 2009 was the only winter period so far in which inundation covered plants from June to March of the following spring. This relationship is inferential, however, and there may have been additional factors, such as a cold or particularly dry spring climate, influencing the observed decline in vegetation cover.

5.2 Revegetated Areas

Management Question 7: What is the quality and quantity of vegetation in revegetated areas between elevations 434 to 440 compared to untreated areas based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover?

There were three main revegetation treatments in the Arrow Lakes Reservoir that had sufficient numbers of treated areas to monitor. These were the *Carex* plugs, cottonwood seedlings, and cottonwood stakes[10]. Species distributions, diversity, vigour, abundance, biomass and cover in the revegetated areas have been described in previous reports (Enns *et al.* 2009; Enns and Enns 2012, Enns *et al.* 2012). To compare 2011 to 2013, boxplots were used to identify differences in the quality and quantity of vegetation in treated plots versus control plots, followed by ANOVA where the boxplots indicated a difference may have occurred. The results for each treatment are presented below.

Carex plugs: quality and quantity of vegetation, by elevation band

The quality and quantity of vegetation, measured as average cover, height, biomass, abundance, distribution and vigour, in *Carex* plug-treated plots versus control plots is shown in Figure 29.

Control plots were chosen to represent pre-treatment conditions of vegetation in the treated area, and we attempted to match as many environmental variables (e.g. elevation, substrate, pre-existing species, and slope) as possible. While there are some differences between cover and plant distribution in the control and treated paired plots and assessment areas (Figure 33), the differences were not significant (i.e. not enough separation between control vs. treatment boxplots), and species assemblages, pre-treatment heights, elevations, soil features, slopes and aspects were close enough to serve as comparisons over time.

[10] According to the most recent KESL mapping available (accessed February, 2012) two fertilization trials were located in co-located areas at Burton, although more areas may have been treated (KESL, 2011). The method of fertilizer application is uncertain (e.g.,. “side banding” was used but not defined (p. 31-32; KESL, 2011). No plots were established in the two trial areas at Burton as the mapping for fertilizer treatments was not available at the time of the field work. Therefore, an evaluation of fertilization treatment effects was compiled by comparing the appearance of the vegetation in the two fertilized areas vs. the unfertilized areas at Burton using the 2010 aerial photography. No difference was observed between the cover, color expression or heights of the vegetation in the fertilized vs. non fertilized areas (data not shown). Pre-treatment soil fertility data are available for comparison with post treatment data, from the CLBMON-33 project.

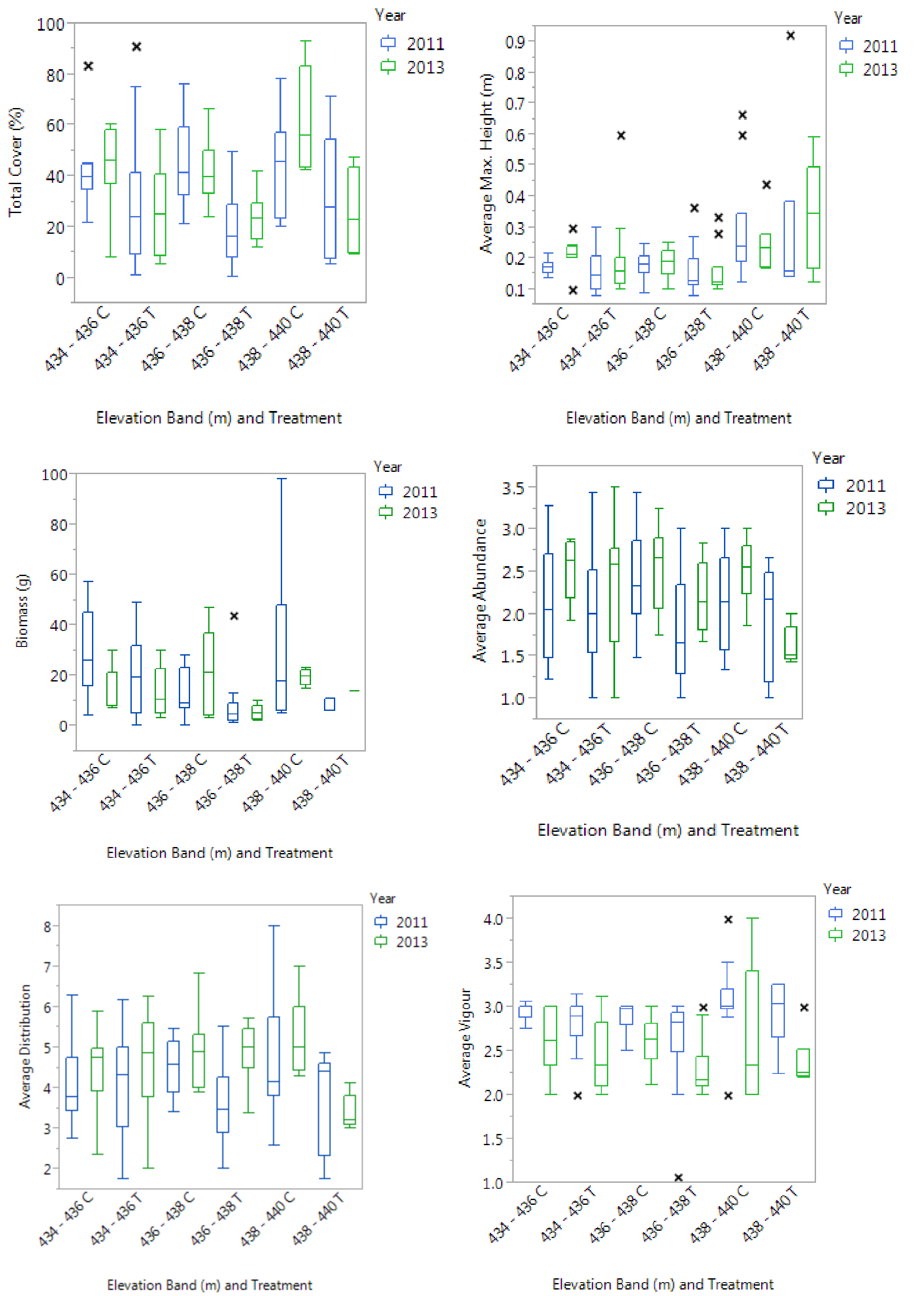

Figure 29. **Average vegetation biomass (top left), average abundance (top right), average distribution (centre left), average vigour (centre right), average total cover (lower left), and average maximum height (lower right) of vegetation in control plots (C) and plots treated with *Carex* plugs (T), over three elevation bands in the Arrow Lakes Reservoir (n = 197 for 2011 and n = 144 for 2013)**

Boxplots (not shown) and ANOV were used to determine if a difference between control and treatment plots occurred between 2011 and 2013. Most of the measured variables increased between 2011 and 2013, with the exception of average vegetation vigour, which decreased in both control and treatment plots within all three elevation bands. ANOVAs were performed comparing the control plots to plots treated with *Carex* plugs within the three elevation bands of the reservoir. The results of the analysis are summarized in Table 5.

Table 5. Results of analysis of variance for control *vs. Carex* plug-treated plots within the three elevation bands of the Arrow Lakes Reservoir between 2011 and 2013. Only statistically significant results are shown in this table

***Carex* Plugs vs. Controls**			
Dependent Variable	**Elevation Band (m)**	***p*-value**	**Significance**
Average Total Vegetation Cover	434 - 436	0.0012	There was evidence that average total cover was higher in control plots than in treatment plots within all three elevation bands.
	436 - 438	0.0001	
	438 - 440	0.0095	
Average Vegetation Vigour	434 - 436	0.0544	There was evidence that average vigour was higher in control plots than in treated plots within the 436 - 438 m elevation band.
	436 - 438	0.0304	
	438 - 440	0.2256	
Average Vegetation Abundance	434 - 436	0.3314	There was evidence that average abundance was higher in control plots than in treated plots within the 436 - 438 m and 438 - 440 m elevation bands.
	436 - 438	0.0013	
	438 - 440	0.0088	
Average Vegetation Distribution	434 - 436	0.9563	There was evidence that average distribution was higher in control plots than in treated plots within the 436 - 438 m and 438 - 440 m elevation bands.
	436 - 438	0.0190	
	438 - 440	0.0035	
Average Vegetation Biomass	434 - 436	0.1571	There was evidence that average biomass was higher in control plots than in treatment plots within the 436 - 438 m elevation band.
	436 - 438	0.0136	
	438 - 440	0.0525	

The results indicate that control plots have slightly better growing conditions than treatment plots, but there may have been insufficient time between these assessments to know for sure that treatments have not been as successful as controls. There was evidence that average total vegetation cover, average abundance, average distribution, average vigour, and average biomass were greater in control plots than in plots treated with *Carex* plugs in the higher elevation bands. There was no evidence that adding *Carex* or other species of plugs to the reservoir increased the diversity of existing vegetation. Height of the treatments in the 438 m to 440 m band was influenced by the presence of shrubs, commonly pre-existing at that elevation. Monitoring changes in species diversity and abundance over time will be necessary in order to more completely answer this Management Question.

Cottonwood seedlings: quality and quantity of vegetation, by elevation band

The quality and quantity of vegetation in cottonwood seedling-treated stands versus control plots is shown in Figure 30.

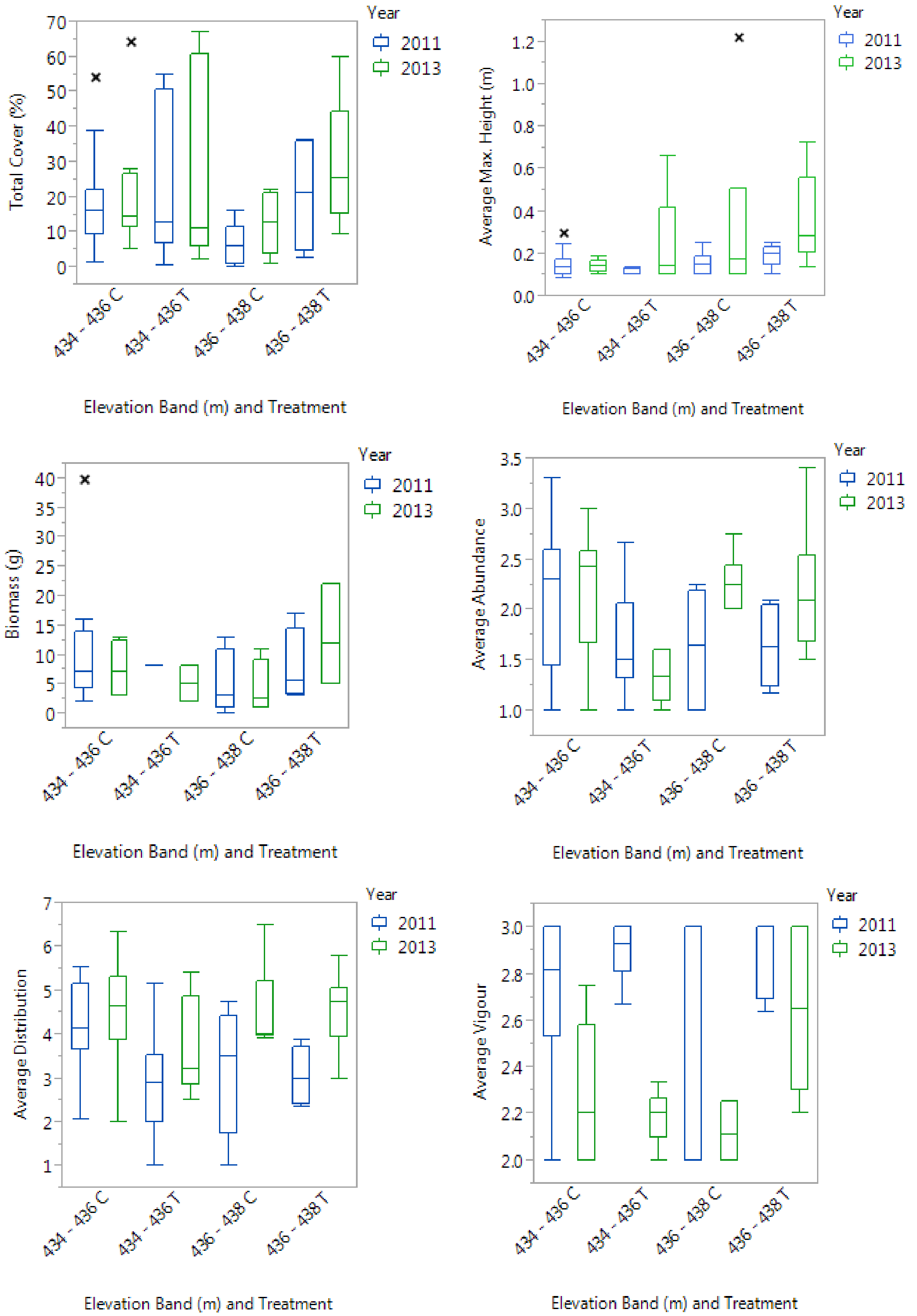

Figure 30. **Average vegetation biomass (upper left), average abundance (upper right), average distribution (lower left), and average vigour (lower right) of plots treated with cottonwood seedlings (T) versus control plots (C), over two elevation bands in the Arrow Lakes Reservoir (n = 197 for 2011 and n = 144 for 2013)**

The figure includes data collected in 2011 and 2013. Treatment and control pairs with insufficient numbers of replicates (fewer than five) were removed from the data set for this comparison. There has been a general increase in most of the measured variables between 2011 and 2013, with the exception of average vegetation vigour which decreased in both control and treatment plots within all three elevation bands.

To determine if there was a difference in the quality or quantity of vegetation, ANOVAs were performed comparing control plots and plots treated with cottonwood seedlings within the three elevation bands of the reservoir. The results of the analysis are summarized in Table 6. Detailed ANOVA results are presented in Appendix A.

Table 6. Results of analysis of variance for control *vs.* cottonwood seedling treated plots within the three elevation bands of the Arrow Lakes Reservoir. Only statistically significant results are shown in this table

Cottonwood Seedlings vs. Controls			
Dependent Variable	**Elevation Band (m)**	**p-value**	**Significance**
Average Total Vegetation Cover	434 - 436	0.4323	Average total cover was higher in treated plots than control plots within the 436 - 438 m elevation band.
	436 - 438	0.0091	
	438 - 440	NA	
Average Vegetation Abundance	434 - 436	0.0029	Average abundance was higher in control plots than in treatment plots within the 434 - 436 m elevation band.
	436 - 438	0.8122	
	438 - 440	NA	
Average Vegetation Distribution	434 - 436	0.0327	Average distribution was higher in control plots than in treated plots within the 434 - 436 m elevation band.
	436 - 438	0.6208	
	438 - 440	NA	

There was evidence that average vegetation cover was greater in plots treated with cottonwood seedlings than in control plots within the 436 – 438 m elevation band, and that average vegetation abundance and distribution were greater in control plots than in treated plots within the 434 – 436 m elevation band. It should be noted that cottonwood seedlings were often planted in sandy, sparsely vegetated areas. The corresponding control plots were also established in sandy, sparsely vegetated areas nearby, so that the observed increases in vegetation abundance and cover often reflected the comparison of a treated plot with almost no vegetation in it but seedlings, to a control plot with almost no vegetation in it at all.

Cottonwood stakes: quality and quantity of vegetation, by elevation band

The quality and quantity of vegetation in stands treated with cottonwood stakes was compared to the vegetation measurements from control plots in Figure 31 below. The figure includes data collected in 2011 and 2013. Treatment and control pairs with insufficient numbers of replicates (fewer than five) were removed from the data set for this comparison.

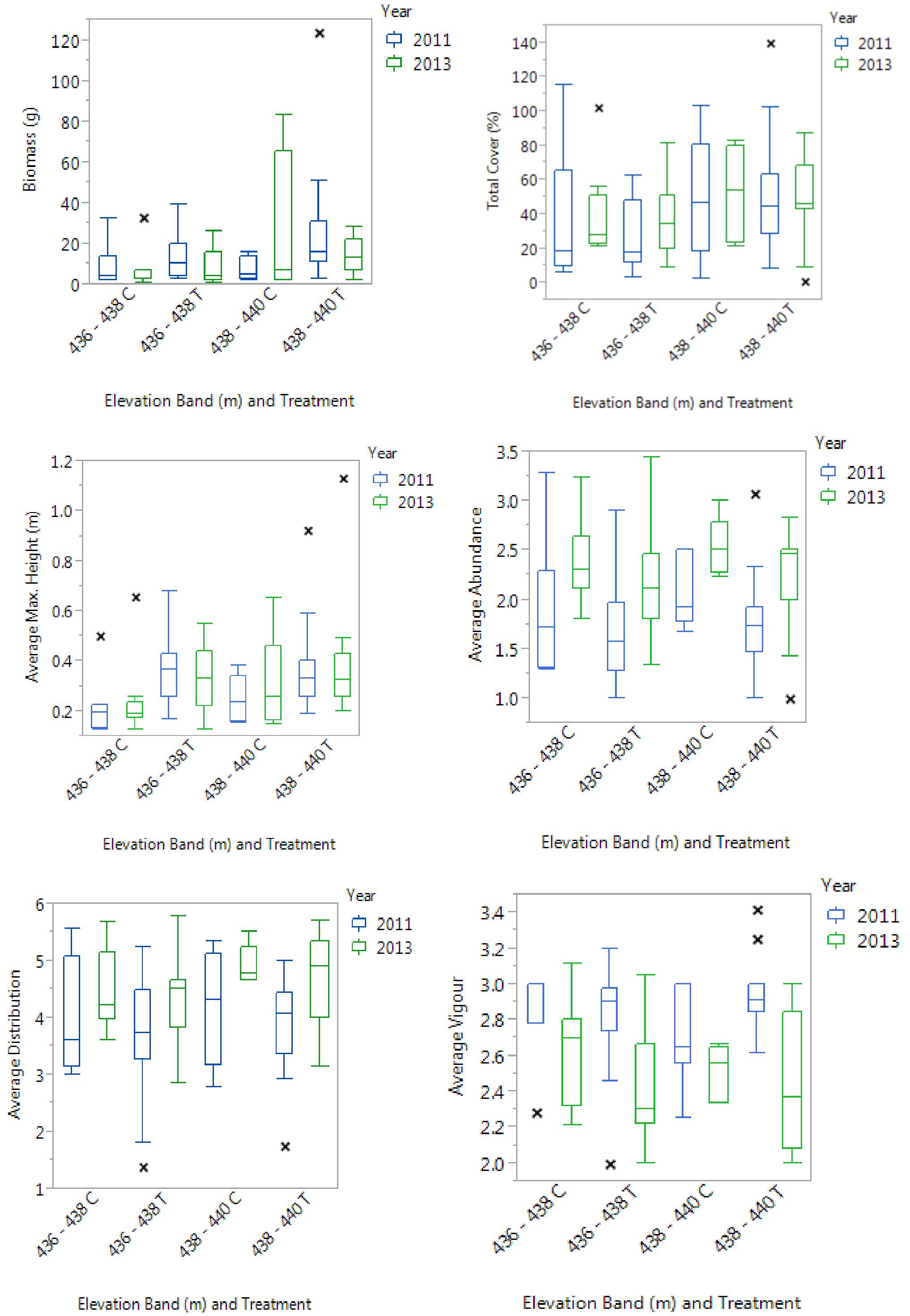

Figure 31. **Average vegetation biomass (top left), average total cover (top right), average maximum height (centre left), average abundance (centre right), average distribution (bottom left) and average vigour (bottom right) of plots treated with cottonwood stakes (T) versus controls (C), over two elevation bands in the Arrow Lakes Reservoir (n = 197 for 2011 and n = 144 for 2013)**

There was an increase in most of the measured variables between 2011 and 2013, with the exception of average vegetation vigour and average vegetation biomass, which decreased in both the control and treated plots within the 436 – 438 m and 438 – 440 m elevation bands. ANOVAs were performed on these data to detect differences in the measured variables between control and treatment plots within the three elevation bands of the reservoir. Significant results are summarized in Table 7. Detailed ANOVA results are presented in Appendix A.

Table 7. Results of analysis of variance for control *vs.* cottonwood stake treated plots within the three elevation bands of the Arrow Lakes Reservoir. Only statistically significant results are shown in this table

Cottonwood Stakes vs. Controls			
Dependent Variable	**Elevation Band (m)**	**p-value**	**Significance**
Average Vegetation Height	434 - 436	0.0032	Average height was greater in treated plots than control plots within all three elevation bands.
	436 - 438	0.0129	
	438 - 440	0.0481	

Only average vegetation heights were significantly greater in plots treated with cottonwood live stakes; none of the other variables representing quality and quantity of vegetation differed between control and treated plots.

In general, the revegetation treated plots tended to vary slightly from control plots. Although efforts were made to pair controls with treatments in terms of elevation, vegetation species composition, materials, aspect and slope, there were differences between treated and control plots. Many of the treatment areas covered entire locations that were influenced by scouring, with no untreated scoured area available for a paired control plot. Consequently, the treatment plots were often in poorer condition than the control plots. The differences in vigour were greater at middle elevation than at low elevation. Heights in both treatment and controls were lower at low elevation, which is consistent with other measures taken in the reservoir, not related to treatments (Enns and Enns 2012; Enns *et al.* 2012). There was also a tendency for existing vegetation to be sparser in plots treated with cottonwood seedlings. As filling in of vegetation in sparse areas is an objective of the treatment program, it is not surprising that the data should reflect this difference. The data do not show dramatic trends with respect to elevation, although vegetation is sparser in treated plots in the middle-elevation band.

Management Question 8: What are the 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)?

Survival rates were assessed by determining if species have been lost over time from repeated plots. Monitoring plots sampled in both 2011 and 2013 were compared for species losses and gains over time (Table 8).

Table 8. Species losses and gains from repeatedly monitored treatment plots 2008–2011

No. of plots compared	No. of plots in each elevation band	No. of plots that lost species over time	No. of plots that gained species over time	Average no. of species per plot lost over time	Average no. of species gains per plot over time
Plots treated with *Carex* plugs					
66	434–436 m = 37 436–438 m = 20 438–440 m = 9	39 (55%)	21 (32%)	3.36	2.33
Plots treated with Cottonwood Seedlings					
27	434–436 m = 15 436–438 m = 10 438–440 m = 2	20 (74%)	5 (19%)	2.85	2.60
Plots treated with Cottonwood Stakes					
45	434–436 m = 6 436–438 m = 20 438–440 m = 19	25 (56%)	16 (36%)	4.56	2.75

Most species that remained in the repeated treatment plots were emergent to semi-aquatic perennials or rapidly spreading annuals, such as lenticular sedge, reed canary grass, common horsetail, little meadow-foxtail, and Canada bluegrass. These species were not removed from any of the plots in which they originally occurred. Most species that were lost were relatively aggressive semi-amphibious ditch weeds, such as needle spike-rush (*Eleocharis acicularis*), purslane speedwell (Veronica peregrina), nodding chickweed *(Cerastium nutans)*, small bedstraw (*Galium trifidum*), narrow-leaved montia, (*Montia linearis*) common knotweed (*Polygonum aviculare*), marsh yellow cress, lady's thumb (*Persicaria maculata*), and yellow clover (*Trifolium aureum*). The development of tolerance of plant species to drawdown zone conditions is common, but it is usually accompanied by high variation of species occurrence over time (Van der Valk and Davis 1976, Andersson *et al.* 2000).

Management Question 9: What environmental conditions, including the current operating regime (i.e., timing, frequency, duration and depth of inundation) may limit or improve the restoration and expansion of vegetated communities in the drawdown zone?

This management question was addressed in 2009 and 2011 for this project, as well as for non-treatment plots in 2010 and 2012 as part of the CLBMON-33 project. In 2009 RDA was used to determine if a linear combination of the environmental variables explained the variation found in species cover in treated, control, and background vegetation plots. The independent variables included exposure, topography, terrain texture (sand, silt, clay, gravels, and cobble percentages), aspect, latitude (representing climate), as well as plot elevation and days of inundation (the variables associated with the current operating regime). This was repeated in 2011. A total of 295 plots were included in the analysis after deleting any plots that had zero to one species. Eleven environmental variables, corresponding to the eleven canonical axes, were used in the forward selection (see Table 3 in Appendix A). The resulting biplot is provided in Appendix A (see Figure A3).

In total, the eleven environmental variables explained 12 per cent of the observed variation in vegetation cover. Duration of inundation (the number of days that each plot was inundated) and plot elevation accounted for the highest proportion of the variation in cover, followed by substrate composition (per cent sand, silt and gravels; Figure 32).

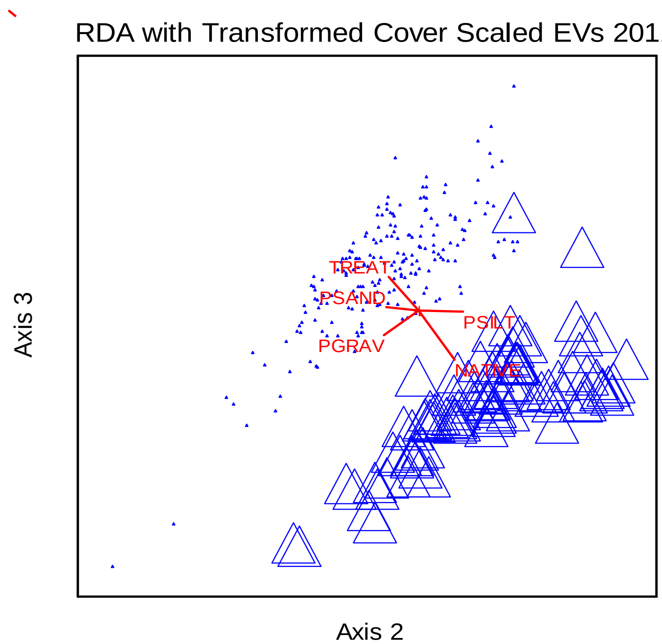

Figure 32. Redundancy analysis with transformed cover and scaled environmental variables from 2011 field measurements and estimates from the Arrow Lakes Reservoir. Large triangles represent existing vegetation plot ordination scores, very small triangles are the treatment and control plot ordination scores. Psand = per cent sand, Pgrav = Per cent gravels, Psilt = per cent silt. Red lines = environmental variables, blue triangles = species cover values. From Enns and Enns, 2012.

The paired control and treatment plots (small triangles in Figure 32) are grouped together and visibly separate from the pre-existing vegetation plots (large triangles in Figure 33), indicating that the paired control and treatment plots are more similar to each other than to the pre-existing vegetation plots, which is an indication that the environmental conditions influencing pre-existing vegetation are possibly different from those influencing treated vegetation. We would expect scouring and soil texture to be even more important in treated vegetation than in pre-existing vegetation, as a whole.

Figure A3 in Appendix 2 shows an RDA biplot prepared as part of the 2012 CLBMON-33 report. This report contains additional environmental variables as well as more plot data than the 2011 biplot. Based on the 2012 analysis, total vegetation cover was positively associated with soils containing a high percentage of sand and silt, and negatively associated with scouring, abundance of gravels and boulders, and locations with high wave action. Average vegetation height was positively associated with high average daily temperatures, total annual precipitation, high elevation, and with fewer days of inundation. Vegetation height was weakly associated with sheltered locations. These results are consistent with the findings of the RDAs previously performed for the CLBMON-33 and CLBMON-12 projects (Enns *et. al* 2009, 2010).

In both 2011 and 2012 the pre-existing vegetation was more closely aligned with silty substrates, while treated and control vegetation was more closely aligned with sands and gravels (see Figure A3 and Figure A4). This association was commonly observed in the field, as well. There was a tendency for treatments to be placed in sandy or gravel-dominated soils, as an ameliorative action to enhance the vegetation cover. Cottonwood stakes were often planted in gravels and sedge plugs in sands, whereas existing native vegetation not subjected to treatments often occurred on substrates that had noticeably higher silt fractions. Fine-textured materials, including silt, clay, and very fine sand, were identified this year and in previous years as being important for vegetation development in the drawdown zone. They are associated with greater cover, abundance, biodiversity, and higher dispersal of individual plants for a variety of reasons.

It is very clear from seven years of monitoring that plant heights increase with elevation in the reservoir. Average maximum vegetation height was negatively correlated with prolonged inundation (Linear correlation, Rsquare = 0.2194, P = 0.0079). Plant heights were lower, on average, in plots with longer periods of inundation. In particular, plots that were inundated for more than 100 days showed a marked decrease in average vegetation height. This result suggests that current reservoir operations, in particular the number of days that low-elevation plots are inundated, may be having a negative impact on vegetation growth, however it is also likely that plants occurring at low elevation tend to have a short stature and are adapted to longer term inundation. No significant correlations were detected between total vegetation covers and inundation duration. Both vegetation cover and height increased with elevation in the drawdown zone (Figure 5), but this may be due to the natural distribution of vegetation communities within the reservoir and a function of the somewhat steady state of the current operating regime. The timing and frequency of inundation may also have significant impacts on reservoir vegetation, but these variables have not varied enough between sampling years for their impact on vegetation to be assessed.

Some variation remains to be explained, including aspects of the water regime that are not related to inundation and elevation alone, such as the influence of debris, sorting of materials and non-reservoir sources of moisture.

Management Question 10: What is the relative effectiveness of the different revegetation treatments, as applied through CLBWORKS-2, at increasing the quality and quantity of vegetation in the drawdown zone?

Data from paired control and treatment plots were used to compare the three revegetation treatments: *Carex* plug plantings, cottonwood seedling plantings, and cottonwood stake plantings (Figures 33). These figures were prepared using data collected in 2011 and 2013 combined.

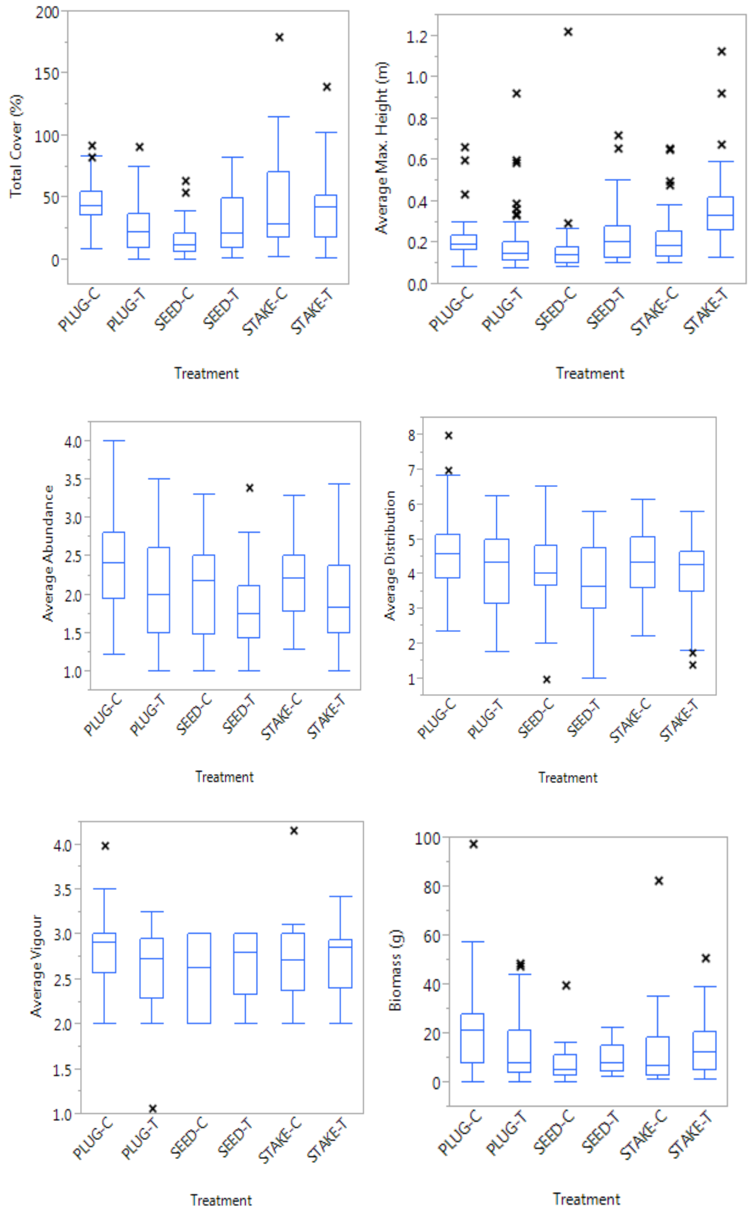

Figure 33. **Total vegetation cover (upper left) and average maximum vegetation height (upper right), average vegetation abundance (middle left), average distribution (middle right), average vigour (lower left) and average biomass (lower right) in revegetation plots versus controls: *Carex* plug control (PLUG-C), *Carex* plug treatment (PLUG-T), cottonwood seedling control (SEED-C), cottonwood seedling treatment (SEED-T), cottonwood stake control (STAKE-C), cottonwood stake treatment (STAKE-T). Figures are based on data collected in 2011 and 2013 (n = 197 for 2011 and n = 144 for 2013)**

ANOVAs were performed comparing vegetation quality and quantity, as measured by average vegetation cover, height, abundance, biomass, distribution and vigour, among treatment types. Data collected in repeated plots in 2011 and 2013 were combined for this analysis. Figure 34 shows how controls compare to treatments for all measured variables.

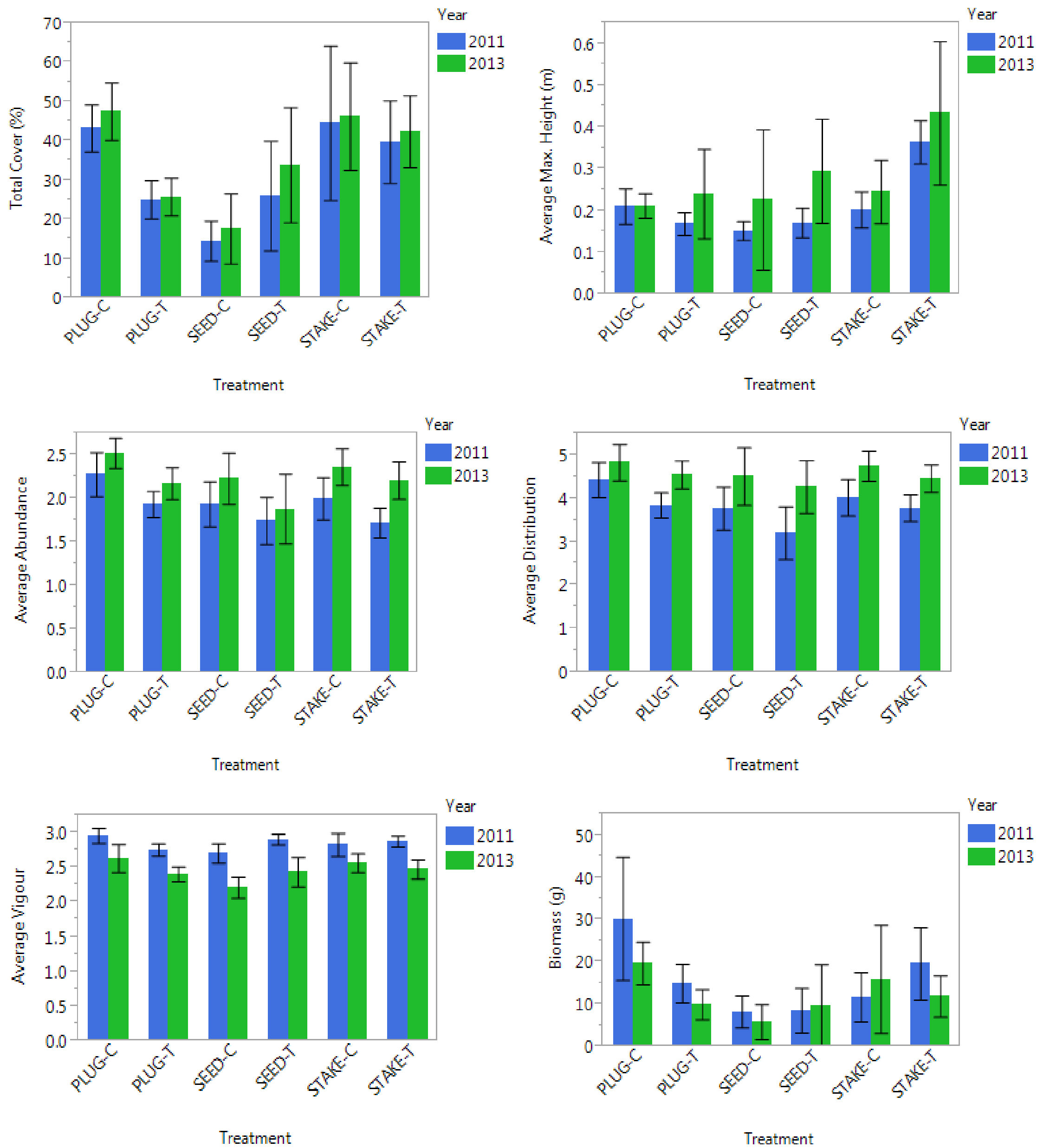

Figure 34. Vegetation cover (top left), average maximum vegetation height (top right), average abundance (middle left), average distribution (middle right), average vigour (bottom left) and average biomass (bottom right) in controls and treatment plots as measured in 2011 (blue) and 2013 (green) (n = 197 for 2011 and n = 144 for 2013)

Average total vegetation cover was greater in the cottonwood stake-treated plots than in the *Carex* plug-treated plots (one-way ANOVA; alpha = 0.05; F ratio = 9.83; p = <0.0001), likely due to the higher amount of cover projection from large cottonwood crowns. Average maximum vegetation height was also greater in the stake-treated plots than in either the cottonwood seedling- (one-way ANOVA; alpha = 0.05; F ratio = 12.15; p = <0.016) or *Carex* plug-treated plots (one-way ANOVA; alpha = 0.05; F ratio = 12.15; p = <0.0001). (Note: average maximum height is measured by taking the height measurement from the most common height range of the crowns for each species). No significant differences between treatments were detected in average vegetation abundance, biomass, distribution or vigour.

Vegetation cover, distribution, height, abundance, vigour and biomass in control and treated plots, as measured in 2011 and 2013, are compared in Figure 34.

ANOVAs were also performed to compare the measured vegetation variables, as observed in 2011 and 2013, for changes over time. Table 9 provides a summary of the results of this analysis; differences between years were found for all three of the main treatment types.

Table 9. Summary of ANOVA results: comparing vegetation variables between 2011 and 2013 for the three main (grouped) revegetation treatments (*Carex* plugs, cottonwood seedlings and cottonwood stakes)

Variable	F-ratio	*p*-value	Significance
***Carex* Plugs**			
Cover	0.69	0.4077	No change
Height	2.30	0.1316	2013 > 2011
Distribution	11.80	0.0007	No change
Abundance	6.56	0.0113	No change
Vigour	31.89	0.0001	2011 > 2013
Biomass	2.26	0.1357	No change
Cottonwood Seedlings			
Cover	2.10	0.1523	No change
Height	6.15	0.0157	2013 > 2011
Distribution	8.20	0.0056	2013 > 2011
Abundance	1.64	0.2045	No change
Vigour	33.99	0.0001	2011 > 2013
Biomass	0.15	0.6979	No change
Cottonwood Stakes			
Cover	0.14	0.7083	No change
Height	1.08	0.3004	No change
Distribution	17.34	0.0001	2013 > 2011
Abundance	18.53	0.0001	2013 > 2011
Vigour	31.79	0.0001	2011 > 2013
Biomass	0.49	0.4852	No change

Within the *Carex* plug-treated plots average height increased in 2013, but average vigour decreased. In the cottonwood seedling group both average height and distribution increased from 2011 to 2013, but average vigour decreased. Average distribution and abundance increased in 2013 within the cottonwood stake-treated plots, but, once again, average vigour had decreased compared to 2011. This observed decrease in vigour may be largely attributable to the pre-treatment vigour of the plant stock. This is also illustrated by the observed decrease in stake survival between 2011 and 2013 (see Figure 36, below). Stakes may continue to decline in the Arrow Lakes Reservoir.

Species Diversity, Richness and Evenness

Species diversity, richness and evenness in 2011 and 2013 are compared among the three main treatment groups in Figure 35. Data collected in 2009 were not included in these figures due to small sample sizes.

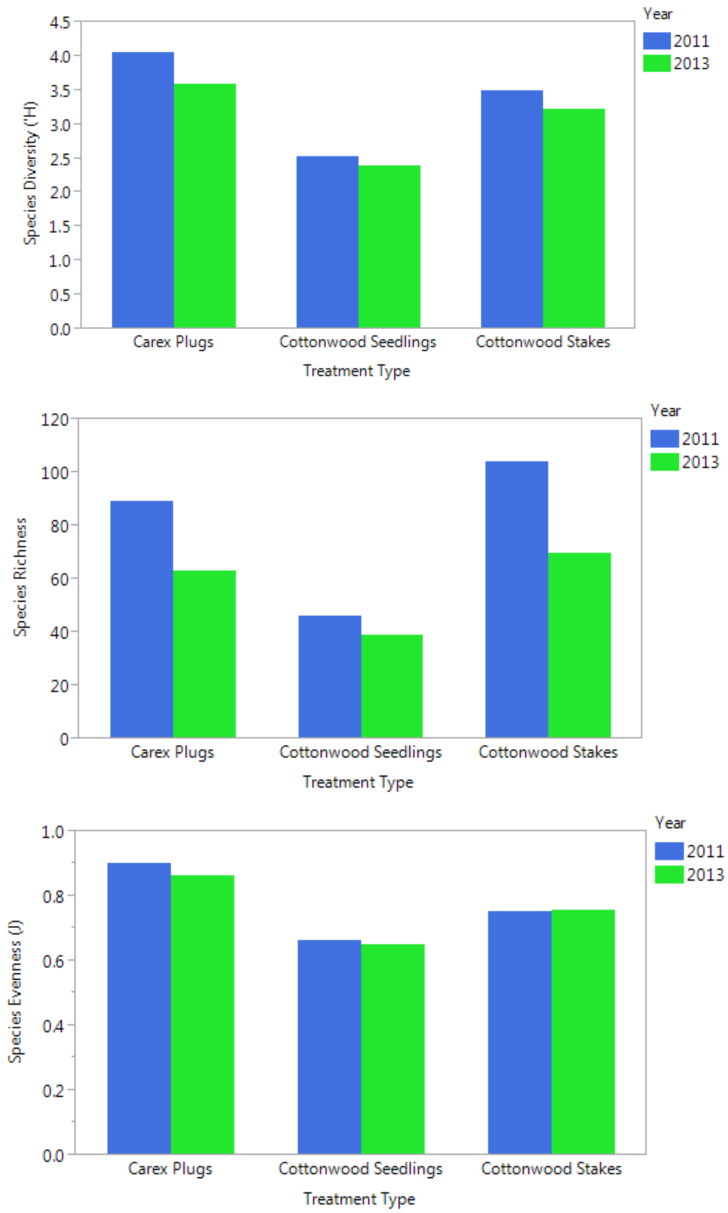

Figure 35. Species diversity (top), richness (centre), and evenness (bottom) in plots treated with *Carex* plugs, cottonwood seedlings and cottonwood stakes as measured in 2011 (blue) and 2013 (green) (n = 197 for 2011 and n = 144 for 2013)

In all three treatment types species diversity, richness, and evenness decreased between 2011 and 2013. Species richness had the largest decrease between monitoring years of 2011 and 2013. All three variables were lowest in the cottonwood seedlings treatment (not to be confused with stake treatments, below). However, this treatment also showed the least change between years. *Carex* plug treatment areas supported the greatest species diversity, but also had the greatest decrease in diversity between sampling years. Conversely, species richness was highest in the cottonwood stake treatments, but species richness also decreased in stake treated areas between 2011 and 2013.

Mortality of Treatments

We evaluated the success of *Carex* plug treatments by tallying the number of obviously planted individuals (determined by their spatial layout) in an area compared to the number of native *Carex* plants, but due to the lack of field identification markings, there was a high degree of uncertainty associated with the plug counts. We were more confident of our assessments of cottonwood stake treatments, which were marked with flagging tape and readily discernible from pre-existing vegetation. The percentages of live cottonwood stakes in relation to elevation, sampling year, and community type are shown in Figure 36.

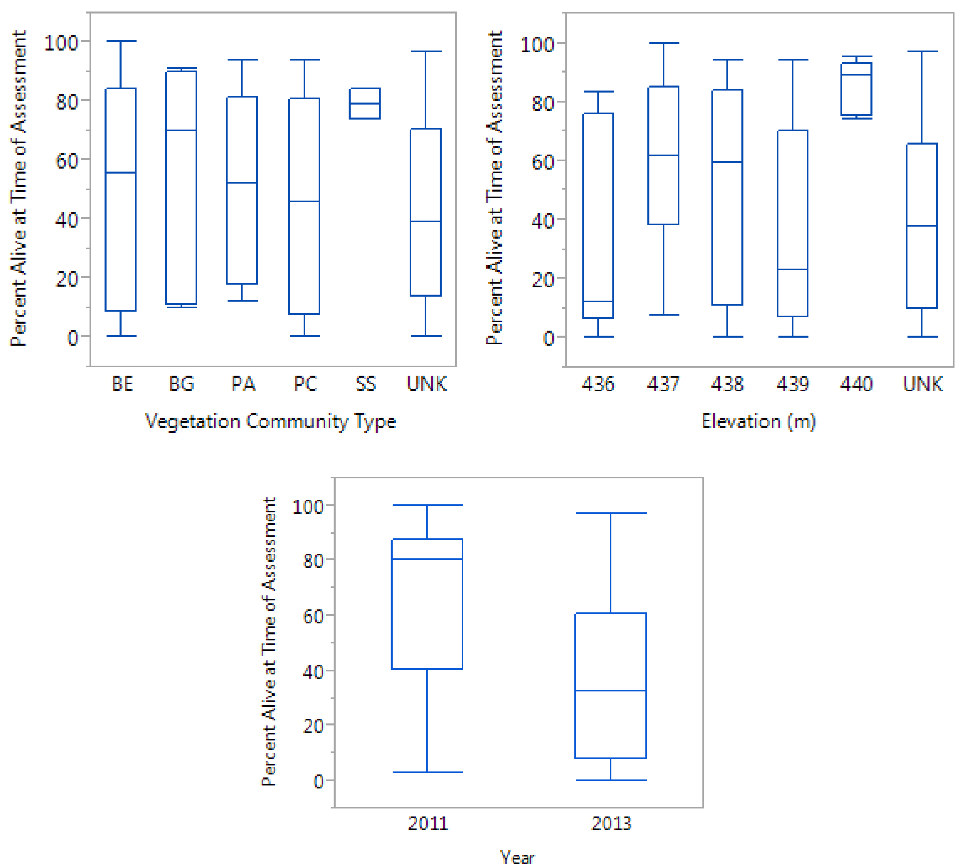

Figure 36. Percentage survival of cottonwood stakes *vs.* vegetation community type (top left), by elevation in metres (top right) and in 2011 *vs.* 2013 (bottom). BE = Sandy Beach, BG = Gravelly Beach, IN = Industrial, PA = Redtop Upland, PC = Reed Canary Grass Mesic, SS = Steep Sand, Unk = unknown + areas outside the CLBMON-33 map area. Figures are based on data collected in 2011 and 2013 (n = 36 areas for 2011. n = 39 areas for 2013)

Cottonwood stakes continued to decline from levels of mortality seen in 2011 (two-sided t-test, t-ratio = -4.28, DF = 72.28, p = 0.0001). No statistically significant differences in stake mortality were detected among VCTs or elevation groupings (one-way ANOVA, p > 0.05 for all levels). However, cottonwood stake survival was noticeably higher in the mid-elevation zone of the reservoir, specifically between 437 and 438 metres. Survival of cottonwood stakes appears to have been greatest in well drained materials at 437 m that were receiving some moisture. Survival was also found to be higher at 440 metres, but the sample size at this elevation (n = 5) makes this finding less reliable. Stake survival was highest in the BG and SS VCTs, but, again, the small sample size in the SS VCT (n = 2) makes the results for this VCT unreliable.

Management Question 11: 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?

Montana Slough, Edgewood, Inonoaklin Rd. and Arrow Narrows were planted with cottonwood stakes, in areas with few or no cottonwood trees present before the treatments (cover illustration). These areas have been successfully planted and all are above 437 m elevation. Other areas, such as Edgewood River and Burton have had dramatic failures of cottonwood stakes. Most of the failures have occurred below 437 m, but some failures are in dry gravelly soils.

In contrast to the cottonwood stakes, *Carex* plug treatments have naturalized in most planted areas and are almost indistinguishable from native vegetation. In general, based on observations made in the field, most of the *Carex* treatments are incorporated into areas with pre-existing vegetation, and therefore are not larger in area, but they do show an increase in overall vegetation cover and abundance.

Management Question 12: Is there an opportunity to modify operations to more effectively maintain revegetated communities at the landscape and site level in the future?

To maintain vegetation in the reservoir, BC Hydro should allow for an annual low water period in the fall to allow vegetation time to develop.

6.0 DISCUSSION

6.1 Summary: Existing vegetation

MQ 1: What are the cover, distribution, vigour, species diversity, abundance and biomass of existing vegetation communities in relation to elevation in the drawdown zone?

Average vegetation cover, height and biomass increased with elevation for almost all VCTs that occur in multiple elevation bands. No relationship between elevation and average vegetation vigour was detected. Average vegetation distribution increased with elevation in the PC, PA and PE community types, but no relationship was detected for the other VCTs. Average vegetation abundance increased with elevation only in the BG

VCT. Species diversity increased with elevation in the PC and BE community types. The results to date for Management Questions One are summarized in Appendix A.

MQ 2: How does the current operating regime affect the within-community quality and quantity of existing vegetation?

Very few dramatic changes have taken place and most of the larger changes in vegetation are detected in the aerial photographic comparisons undertaken in CLBMON 33 (Enns and Enns 2012). There was a widespread measureable decline in average vegetation cover and heights following a prolonged high water period in the winter of 2008 - 2009. In this project, both average vegetation height and biomass tended to be lowest for the plots with the longest duration of inundation. Some communities, such as PA (upland shrubs) and CR (riparian cottonwood), were not inundated for long, and may actually benefit from short-term annual inundation. In the absence of changes in the operating regime, these data represent a baseline to which future changes can be compared.

MQ 3: Is there a shift in community structure (species dominance) or a potential loss of existing vegetation communities that is attributable to environmental conditions, including the current operating regime?

Community structure has not changed much from 2007 to 2013 in any of the communities sampled. In many low- to mid-elevation VCTs annual, opportunistic species establish each year (often from upslope), but these do not establish in large numbers and often do not survive inundation. Species gains and losses between years have been documented, but there has been no significant change in species dominance.

MQ 4: What are the species-specific survival rates under the soft constraints operating regime (i.e., what are the tolerances of existing plant species to inundation?)

The total number of identified species present in 2013, including mosses, lichens and liverworts was 240, in a 342 vegetation plots. There were few new species for 2013. Losses of weedy annuals, seedlings and perennials are common, but replacement also takes place. Invasions from upslope occur but the new vegetation is often removed by the next sampling year. Willows declined in Revelstoke Reach at middle elevation as a result of expansion into lower elevations and subsequent prolonged inundation.

MQ 5: What recommendations can be made to more effectively maintain existing vegetation at the site level in the future?

The provision of a late summer to early fall low water period has been recommended. This recommendation was based on observations of decreased vegetation quality (as measured by decreased vegetation cover, height and vigour) following a one-time period of prolonged inundation in the winter of 2008 - 2009. As yet the soft constraints operating regime has not actually been tested to the greatest extent that water levels could be manipulated (BC Hydro 2013). Prolonged high level inundation will likely have a negative impact on overall vegetation quality, as measured by average cover, vigour, diversity, etc. (Odland and del Moral 2002). Some of the highest-elevation communities such as PA and CR could be very strongly impacted, whereas some of the inundation-tolerant low-elevation communities such as PE may remain unchanged.

6.2 Summary: Revegetation Treatments

MQ 6: What is the quality and quantity of vegetation in revegetated areas between 434 m and 440 m compared to untreated areas, based on an assessment of species distribution, diversity, vigour, abundance, biomass and cover? (only significant results reported)

Cottonwood seedlings: treated plots had higher average vigour than control plots. Average vegetation cover and abundance tended to be higher at higher elevations, although there were no significant differences among elevation bands.

Cottonwood stakes: average vegetation abundance and height were greater in treated plots than in control plots. Species diversity tended to be highest at middle elevations, but this may be due to the fact that more stake treatments were planted, and sampled, in the mid elevation bands than in either the high- or low-elevation bands

Carex plugs: average vegetation cover, biomass, vigour, abundance and distribution were greater in control plots than in treatment plots. Average vigour was poorer at middle elevation than at low elevation. As lenticular sedge is essentially a low-elevation species in Arrow Lakes Reservoir, this result may be an indication that this species should not be planted above 436 meters. Total cover and height were also highest in the low-elevation band.

MQ 7: What are the species-specific survival rates under the current operating conditions (i.e., what are the tolerances of revegetated plant communities to inundation timing, frequency, duration and depth)?

Cottonwood seedlings: high mortality was observed in areas where seedlings were exposed to scouring. Mortality also increased above 436 m.

Cottonwood stakes: mortality was greatest below 437 meters. Mortality in cottonwood stakes is difficult to ascertain as they may appear dead but can recover and sprout again in a subsequent year.

Carex plugs: losses were severe in some locations such as sites < 436 m at Burton and Fairhurst. These losses were most likely due to scouring. Plugs could also experience increased mortality in dry, high-elevation sites. *Carex* plugs were most successful in low-elevation areas with a silty substrate.

MQ 8: 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?

Vegetation cover was found to be negatively associated with duration of inundation, however, inundation did not account for much of the observed variation in plant cover, suggesting either that local environmental factors may be more important, or that variation in the operating regime has not been dramatic enough to result in a marked changed in the vegetation. Certainly, a dramatic change in the water behaviour from the patterns exhibited from 2007 to 2013 would likely provide more definite responses. Silts and clays were found to be more common in the soils of pre-existing vegetation communities and coarser textured sands and gravels were more common in the treated vegetation areas. This difference in substrate texture represents sediment conditions before treatment, and may influence the success of treatments over the long term. It is premature, however, to isolate any particular feature of the operating regime as important for restoration and expansion of treated vegetation, when the operating regime has not substantially changed since 2007.

MQ 9: What is the relative effectiveness of the different revegetation treatments (as applied through CLBWORKS-2) at increasing the quality and quantity of vegetation in the drawdown zone?

In general, cottonwood stakes did not have a high survival below 437 m, and some Carex plugs were washed away in high energy areas of the reservoir. Planted cottonwood seedlings also showed very low vigour and experienced high mortality where they were exposed to heavy scouring. There was no detectable difference among treatment types for any of the variables measured except average cover and average maximum height, which was higher in cottonwood stakes than in the other treatments, for obvious reasons (Figure 37). *Carex* plugs tended to have higher average vigour than the other treatments, but the difference was not significant. Most of the variables used to measure the effectiveness of the treatments did not adequately show how effective treatments have been. Crown closure, crown widths, structural complexity and other measures might have been better for showing effectiveness (Figure 37).

Figure 37. Cottonwood stake treatments of similar age at a sheltered site at 438 m at Inonoaklin in gravels (2013) (left), versus 436 m at Edgewood River flats in silts and sands (2013) (right). Other than cover, the variables assigned to the study do not show the differences adequately between these two stands. The Inonoaklin site had more mortality but much greater success overall than the Edgewood site. Note that silts and sands at Edgewood support a higher biodiversity

MQ 10: 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?

In some areas treatment vegetation has expanded to previously non-vegetated sites. Cover has increased in some areas due to treatment, and, where stake plantings have been successful, they have provided stability to the local substrate. These trees are not likely to have occurred in the reservoir at these locations without being planted. Disadvantages include the possible introduction of pathogens from cottonwood stakes and the introduction of non-native species in areas where stakes were planted using excavators.

MQ 11: Is there an opportunity to modify operations to more effectively maintain revegetated communities at the landscape and site level in the future?

The recommendation for maintaining vegetation provided in Management Question 5 applies: allow a late summer to early fall low water period. If more planting is planned for Arrow Lakes Reservoir, planters should plant above 437 m for cottonwood stakes and between 437 and 434 for *Carex lenticularis*. They should select areas with good management potential, such as some pre-existing vegetation, presence of stable silts and fine sands, and sheltered areas. A design for dust control using vegetation should include anchoring devices for *Carex* plantings. Netted plugs were used; these were pulled from the ground in high energy locations due to net mobilization. This group of species is very tolerant of smothering, scouring and wave action (Figure 38), and could have effectively started to control dust in the lower elevations of the drawdown zone if proper anchorings were used.

Figure 38. "Friar Tuck" growth form in naturally occurring sedge in a heavily scoured fine sand flat, at low elevation. Note seedlings and rhizomatous growth emanating from the parent clump

7.0 CONCLUSIONS

7.1 Existing Vegetation

Most of the species with a high frequency of occurrence in the Arrow Lakes Reservoir have not changed in their dominance over time. Variation in the records from year to year have been attributed to slight differences in phenology at the time of the measurement, losses or gains of opportunistic plants as seedlings or juveniles, measurement errors (GPS-caused shifts in plot boundaries) and natural variation. The high water winter of 2008 - 2009 influenced the frequency of occurrence of some dominant species. Some species declined in frequency of occurrence following the period of high water, but subsequently recovered in 2010. There has generally been an increase in cover, abundance and distribution of plants between 2010 and 2013, probably due to consistency in the operating regime and favorable climatic conditions of occasionally wet, warm summers, dry fall periods and mild winters. Unless disturbance is debilitating, plants tend to grow!

There have been a few examples of extirpation from the drawdown zone, and it is not possible to know for certain if the loss of a species was due to the operating regime or to other factors. Many of the losses have taken place within the high-elevation sites (above 437 m), and many of these losses were of upland plants that had invaded the reservoir, persisted for a period of time, then died.

Given the level of variation described for these main communities, it will be difficult to detect differences in vegetation that can be attributed to the effect of the operating regime unless the operating regime changes dramatically.

When response of the vegetation was examined in repeated plots, the elevation, and therefore depth and duration of the water levels, had a negative influence on both the cover and height of vegetation in the low-elevation plots in the reservoir. This impact was especially apparent after one winter (2008 – 2009) in which the water level remained high over the fall and early winter. In subsequent years, the use of aerial photography, simple graphics and repeated measures analysis has shown that environmental variables (substrate composition, precipitation, etc.) explain a higher portion of the variation in species diversity, cover, and heights than variables linked to reservoir operation (depth, duration of inundation, etc.) (Enns *et al.* 2010). Drought-prone substrates (soils or parent materials) and disturbance by scouring and wave action may be more important in their effects on vegetation than the operating regime, until such time as the soft constraints operating regime changes from its current pattern.

7.2 Treatment Vegetation

The trends seen in the native vegetation are not the same as those observed in the observation of control versus treated vegetation. The monitoring of the native vegetation in even years compared to treated and nontreated vegetation in odd years shows the influence of the treatment monitoring management objective: i.e. lower covers in treatment monitoring years.

In some plots of cottonwood stakes the total cover was increased due to the expansion of cottonwood crowns. Heights of the vegetation were influenced by planting live stakes, and some areas that were previously non-vegetated now have some vegetation cover. Additional mortality of lower-elevation cottonwood stakes occurred between 2011 and 2013, even though the stakes may have appeared to be vigourous in previous years. Vigour of some of the middle-elevation lenticular sedge treatments was lower than control vegetation, indicating planting of this species should occur below 436 m, but in general planting of sedges was successful.

8.0 RECOMMENDATIONS

A summary of recommendations are as follows

- Capture the aerial photography for CLBMON 33 annually
- Monitor changes in the vegetation in the plots every second or third year
- Combine CLBMON-12 with CLBMON-33 and remove the redundant variables, management questions and management objectives from the project, and
- Drop some of the sites.

The CLBMON-33 and CLBMON-12 projects are similar and rely on the same database and field data collection methodology. The management questions for the two projects overlap and could therefore be combined and refined without losing resolution (Enns and Overholt 2013). Monitoring of change in vegetation in response to the operating regime versus environmental constraints could be the focus of a combined project that uses both the aerial photographic data and field survey data to directly address the objectives of the two projects. Dramatic changes in vegetation are not expected until subsequent changes in the water behaviour takes place, however.

A new project design could have elements of identification of change in annually flown aerial photography, field truthing of changed areas to document the changes, and repeated examination of long-term plots in vulnerable substrates that would likely be impacted by changes in the soft constraints operating regime. These would include repeated plots with a long history of monitoring change, across all elevations, in exposed areas with a range of past evidence of losses of vegetation.

Some of the 43 original study areas are redundant or are dramatically influenced by sources of change other than the reservoir, such as some of the beaches on the west side of the Arrow Narrows, Halfway River, Nakusp and others. These could be eliminated from the new study.

The frequency of monitoring could be changed to once every 2 to 3 years without loss in resolution. Two levels of intensity of sampling could be adopted, such as quick visual estimates versus detailed plots. The variables species cover, height, distribution and biomass are useful for showing change, whereas vigour and abundance are too vague or difficult to assign in the field. The inclusion of soil and structural variables such as bare mineral soil cover may be helpful. The design is most suited to the use of parametric statistics based on approximately even sample sizes and repeated measures, with the use of redundancy analysis to identify the factors controlling vegetation cover and height.

At the present time the projects are separate, but in reality data from all the measurement years have been used to show change in vegetation over time. The value of considering the landscape level and site level changes in vegetation does not have to be lost; the two scales of resolution can complement each other. For example, the clarity of the aerial photographic coverage can be used to show losses and gains in individual plant communities. Aerial photographic interpretation is the most accurate way to characterize and interpret the effects of scouring and the importance of terrain texture to vegetation, but to quantify the change in the vegetation, fieldwork in permanent plots is required.

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