Columbia River Project Water Use Plan

Kinbasket and Arrow Lakes Revegetation Management Plan

Implementation Year 5

Reference: CLBMON-33

Arrow Lakes Reservoir Inventory of Vegetation Resources

Study Period: 2014

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

October 26, 2015

KINBASKET AND ARROW LAKES RESERVOIRS

Monitoring Program No. CLBMON-33

Arrow Lakes Reservoir Inventory of Vegetation Resources

Implementation Year 5 – 2014

Final Report

Prepared for

BC Hydro Generation

Water Licence Requirements
Burnaby, BC

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Cover photos

From left to right: Gravelly beach (BG), Arrow Lake Narrows; Log zone (LO), Beaton Arm; Horsetail lowland (PE), Edgewood; Reed Canarygrass (PC), Revelstoke Reach. All photos © Michael T. Miller and Judy E. Muir, LGL Limited.

EXECUTIVE SUMMARY

The Arrow Lakes Reservoir Inventory of Vegetation Resources study (CLBMON-33) is a Water License Requirement project initiated in 2007 to assess the impacts of the current reservoir operating regime on existing vegetation in the drawdown zone of the Arrow Lakes Reservoir. The primary objective of this 10-year study is to monitor landscape level changes in the spatial extent, structure, and composition of vegetation communities within the 434-440 m ASL elevation band of the drawdown zone, and to assess if any observed changes are attributable to "soft constraints." Soft constraints are operational targets developed by the Columbia Water Use Planning Consultative Committee (WUP CC) for the benefit of various interests (vegetation, wildlife, fish, culture and heritage, recreation, erosion, and power generation). Each target identifies the ideal/preferred reservoir operations (water level over the year) for a specific interest. The degree to which an individual objective is met varies by water year and the requirements of competing objectives. Results of the current study will help determine if soft constraints are effective at maintaining the spatial limits, structure, and composition of existing vegetation communities in the drawdown zone and, if not, what changes to the operating regime may be required to enhance existing shoreline vegetation and the ecosystems it supports.

As in previous years, the current study design employed aerial imagery of 43 discrete study areas of the Arrow Lakes Reservoir drawdown zone acquired prior to summer inundation to compare vegetation conditions between time periods (in this case between 2007 and 2014, the maximum available time span). For 2014, a sample set of vegetation polygons was selected for field study using a stratified random approach. Community typing (and associated data collection) occurred within 5-m radius randomly located subplots within selected polygons.

No statistically significant differences were found in vegetation community type (VCT) frequencies or polygon composition between 2007 and 2014 within the drawdown zone of Arrow Lakes Reservoir. Although approximately 10 per cent of individual polygons and subplots in the drawdown zone underwent a shift in vegetation character from 2007 to 2014, these localized changes did not translate into significant changes in VCTs at the landscape level. Our overall conclusions are consistent with those reached following previous study years: in terms of its vegetation features, the Arrow Lakes Reservoir drawdown zone is a moderately dynamic system at the local scale but relatively stable at the landscape level. There is currently no compelling evidence to indicate that the soft constraints operating regime of Arrow Lakes Reservoir is failing to maintain vegetation spatial limits, structure, and composition of existing vegetation communities in the drawdown zone.

Some recommendations moving forward include:

- If the operational regime changes in the near future, consider expanding the existing time series dataset of vegetation development in the Arrow Lakes Reservoir drawdown zone by continuing to monitor conditions over time.
- Adopt the use of LIDAR remote sensing technology in addition to digital photography for capturing aerial images of the Arrow Lakes drawdown zone.
- Refine the current community classification system so that it more accurately reflects the full range of plant species associations occurring in the drawdown zone of Arrow Lakes Reservoir. It may not be practicable at this stage of the monitoring program to undertake a retroactive analysis of the data using a revised classification; however, a refinement of the current classification could

help us more fully address management questions around community composition and diversity.

- Consider monitoring vegetation structure (as a proxy for wildlife habitat structure) as a useful addition to the currently defined VCTs. Imagery from previous years could be retrospectively assessed in terms of broad structural attributes (e.g., non-vegetated habitat; sparse or pioneer vegetation; grassland; shrubland; young forest; and mature forest) to determine if structural shifts have occurred over time.
- Keep using effective growing degree units (GDUs) as a potential management tool for fine-tuning soft constraints operating regimes to maximize desired vegetation values in the Arrow Lakes drawdown zone.

The status of CLBMON-33 after Year 8 (2014) with respect to the management questions and management hypotheses is summarized below.

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
1. What are the existing riparian and wetland vegetation communities in Arrow Lakes Reservoir drawdown zone between 434 m and 440 m?	Partially	Enns et al. (2007 and subsequent reports) identified sixteen vegetation community types (VCTs) based on a combination of similar topography, soils, and vegetation features. The LO (woody debris zone), which was dropped as a monitored community type after 2010 due to its ephemeral nature (K. Enns, pers. comm. 2014), was reintroduced to the study in 2014 because wood debris can have substantial influence on vegetation development. VCTs have been mapped within the drawdown zone in each of 2007, 2008, 2010, 2012 and 2014. Improvements with aerial photographs continue to lead to refinements in the vegetation community mapping. Wetland communities have yet to be completely described for the ALR. While the classification yields a number of landscape-scale VCTs that lend themselves fairly well to aerial mapping, these VCTs do not completely capture the diversity of plant associations present in the drawdown zone.	Some refinements to the community typing may be required to fully address management questions. One option is to employ two separate classifications: a first one based primarily on floristics (such as that developed for a similar BC Hydro monitoring project in the Kinbasket Reservoir) that more fully addresses management questions around species composition and diversity; and a second one, for use in aerial photo monitoring, based on coarse structural/seral stages that are more easily identified at the 1:5,000 mapping scale. In the latter instance, it would be relatively simple in subsequent implementation years to construct retroactively a time series of data as for VCTs, based on the ortho-imagery already available	• The observed combination of topo-edaphic conditions and species composition in the field sometimes did not clearly match up with any of the pre-defined VCTs. • Only the 43 study areas selected for sampling in 2007 by BCH can be assessed relative to this management question.
2. What are the spatial extents, structure and composition (i.e., relative distribution and diversity) of these communities within the drawdown zone between 434 m and 440 m?	Yes	Findings in 2014 were generally consistent with those of Enns et al. (2007, 2008, 2010, 2012). The PC (Reed Canarygrass) VCT was the most widespread VCT in the drawdown zone, with others following in descending order as follows: PA – Redtop upland > PE – Horsetail lowland > BE – Sandy beach > CR – Cottonwood riparian >	N/A	• Annual climatic variation • Variable reservoir operations • DEM errors • Only the 43 study areas selected for sampling in 2007 by BCH can be assessed relative to this

Management Question (MQ)	Has MQ been addressed?	Scope		Sources of Uncertainty
		Current supporting results	**Suggested modifications to methods where appropriate**	
		LO – Log zone > BG – Gravelly beach > RR – Reed rill > IN – Industrial/disturbed > SF – Slope failure		management question.
3. How do spatial limits, structure and composition of vegetation communities relate to reservoir elevation and the topo-edaphic site conditions (aspect, slope and soil moisture, etc.)?	Yes	Preliminary findings of Enns (2010, 2012) indicate that soil nutrient regime and moisture availability influence cover within VCTs. Several VCTs show strong correlations with particular elevations. For example CR and PA are found at higher elevations (e.g., 437-440 m ASL); BE, BG, PC and RR occur over a range of elevations (434-438 m ASL) and PE is generally at lower elevations (e.g., 434-435 m ASL). 2014 results show there was a well-defined trend towards increased structural advancement with increased elevation in the drawdown zone. Arrow Lakes had a relatively higher percentage of subplots at the sparse/pioneer stage and a lower percentage of tall shrub subplots, compared to both the reservoir as a whole and to Revelstoke Reach. Findings in 2014 indicate a relationship between the distribution of vegetation communities in the drawdown zone and effective growing degree units (GDUs) that represented the amount of time that ambient air temperatures were suitable for plant growth, corrected for inundation time. Low elevation pioneering and early seral VCTs typically associate with low historical average summer GDUs (<100). Mid-	Because the present community classification is closely predicated on elevation and topo-edaphic site conditions (consistent with the Terrestrial Ecosystem Mapping [TEM] approach), most of these correlates are already contained in the VCT definitions and thus, as it stands, there is an element of circularity associated with this MQ. We thus recommend deferring further analysis of these environmental correlates as potential predictors of observed vegetation zonation until such time as the current community classification can be revised to be more guild or species-centric (see MQ1 above). Plant height was used as a proxy for structure in earlier studies (e.g., Enns et al. 2010). Structural stage was used instead in 2014 because this is less affected by phenology. Changes in structural stage over time could not be assessed because this variable was not sampled in earlier study years. However, it would be relatively simple in subsequent implementation years to construct retroactively a time series of data as for VCTs, based on the ortho-imagery already available. Such a time	• Annual climatic variation • Variable reservoir operations • DEM errors • Subjective decisions regarding VCT assignments occasionally required during aerial photo analysis. • Longer time series of data are required to adequately address this question.

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
		elevation herbaceous VCTs establish in areas with typically higher summer heat loads (GDUs between 50 and 200), while shrublands rarely associate with GDUs <100 and Cottonwood forests typically experience at least 200 GDUs. The VCT-GDU relationships appear to be influenced by month, with stronger relationships noted during June and August. Classification trees were used in 2014 to investigate relationships of elevation, inundation and topo-edaphic site conditions with the probability of change in VCT at subplots between 2007 and 2014. Results were inconclusive as there was no consistent pattern between covariates and community shifts over time. The analysis may have had limited ability to determine relationships given there was no significant change in VCTs over time.	series could yield important alternative insights into vegetation dynamics in the drawdown zone.	
4. Does the soft constraints operating regime of Arrow Lakes Reservoir maintain vegetation spatial limits, structure and composition of existing vegetation communities in the drawdown zone?	Partially	Preliminary findings of Enns (2012) indicate that soft constraints are maintaining existing vegetation at the landscape level. Similarly, no significant differences in VCT spatial extent or composition occurred between 2007 and 2014 within the drawdown zone of Arrow Lakes Reservoir, or when stratified by elevation band or landscape unit. Nevertheless, several polygons and subplots experienced changes in VCTs over this period. These observed changes attest to the region's dynamic nature.	N/A	• Annual climatic variation • Variable reservoir operations • Subjective decisions regarding VCT assignments occasionally required during aerial photo analysis.

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
5. Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?	Partially	The recent operating regime has not resulted in any notable landscape-scale changes in vegetation cover or extent since 2007. Holding reservoir elevations lower than at present (as per the soft constraints goal) would likely result in at least some directional vegetation changes, by (for example) facilitating the advancement of shrubland and/or Reed Canarygrass (depending on location) into upper and mid elevations of the drawdown zone. Such changes may run counter to the soft constraints stated goal of maintaining vegetation status quo above 434 m ASL, although some of these changes (such as greater shrubland development) could result in desirable benefits for vegetation quality, wildlife habitat, and/or social values. Given that the goal is to maintain (rather than enhance) existing vegetation in its current state, we feel this will be more effectively achieved by managing the *duration* of inundation during the growing season as opposed to limiting the absolute *depth* of inundation (as represented by the annual maximum achieved). If inundation is necessary, we recommend that peak flood durations be kept as short as possible, both to allow for seedling establishment and completion of reproductive cycles, and to minimize the physiological impact of flooding on upland perennial and woody species especially at upper elevations of the drawdown zone.	N/A	Lack of examples of low reservoir maximums in recent years prevents proper assessment of the potential effectiveness of holding reservoir elevations lower as a way of maintaining existing vegetation (as per the stated soft constraints goal).

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
6. Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?	Yes	Results in 2014 concur with those by Enns et al. (2012) in that Revelstoke Reach is not representative of the remainder of the reservoir. The two landscape units are influenced by different topography and climatic regimes and thus exhibit some vegetation differences. Revelstoke Reach has a lower diversity of VCTs, more area under PC, and less vegetated beach area than the Arrow Lakes. In addition, 2014 data indicate that communities in Arrow Lakes have a higher local turnover rate than ones in Revelstoke Reach.	N/A	N/A

KEYWORDS: Arrow Lakes Reservoir; soft constraints operating regime; vegetation community; spatial extent; composition; diversity; distribution; monitoring; drawdown zone; landscape level; air photos; reservoir elevation.

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1.0 INTRODUCTION

During development of the Water Use Plan for BC Hydro's mainstem Columbia River facilities, the Columbia River Water Use Plan Consultative Committee identified a set of "soft constraint targets" for Arrow Lakes Reservoir to balance the wildlife, recreation, fisheries, culture and heritage, shoreline conditions, and power generation interests on this reservoir (BC Hydro 2005). The consultation process acknowledged that these objectives may conflict with each other and that in any given hydraulic year it would be unlikely that all objectives would be met simultaneously (BC Hydro 2005).

The soft constraint targets identified for vegetation (BC Hydro 2005) were to:

- 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.
- Target lower reservoir levels in the fall to allow exposure of plants during the latter part of the growing season if vegetation is showing signs of stress as a result of inundation during the early part of the growing season (May to July).
- Preserve current levels of vegetation at and above elevation 434 m (1424 ft).

This study, Arrow Lakes Reservoir Inventory of Vegetation Resources (CLBMON-33), is a Water License Requirement project to assess the impacts of the soft constraints operating regime on existing vegetation in the drawdown zone of the Arrow Lakes Reservoir. This 10-year monitoring project is being conducted as outlined in the Order by the Provincial Comptroller of Water Rights under the Water Act on 26 January 2007. The primary objective of this project, which was initiated in 2007, is to monitor landscape level changes in the spatial extent, structure, and composition of vegetation communities within the 434 to 440 m ASL elevation band of the Arrow Lakes Reservoir drawdown zone, and to assess if any observed changes are attributable to the soft constraints operating regime. Results of this program will help determine whether changes to the reservoir's operating regime may be required to maintain or enhance existing shoreline vegetation and the ecosystems it supports.

The study is designed to span a period of ten years (2007–2016), and to occur in alternating years from 2008 onward. Work completed during the first four implementation years (2007, 2008, 2010, and 2012) used aerial photograph interpretation, field sampling and statistical analyses to monitor changes in the defined vegetation community types (VCTs; Enns 2007, Enns *et al.* 2007, 2008, 2010, 2012). Here, we report results at the project's 8-year mark (2014 study year).

2.0 MANAGEMENT QUESTIONS AND HYPOTHESES

The management questions for this monitoring program, which link back to the objectives above, address the landscape level response of vegetation communities in the drawdown zone of the Arrow Lakes Reservoir to the soft constraints operating regime (BC Hydro 2005):

MQ1: What are the existing riparian and wetland vegetation communities in Arrow Lakes Reservoir drawdown zone between 434 m and 440 m?

MQ2: What are the spatial extents, structure and composition (i.e., relative distribution and diversity) of these communities within the drawdown zone between 434 m and 440 m?

MQ3: How do spatial limits, structure and composition of vegetation communities relate to reservoir elevation and the topo-edaphic site conditions (aspect, slope and soil moisture, etc.)?

MQ4: Does the soft constraints operating regime of Arrow Lakes Reservoir maintain vegetation spatial limits, structure and composition of existing vegetation communities in the drawdown zone?

MQ5: Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?

MQ6: Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?

Monitoring will be designed to test the following null hypothesis and associated sub-hypotheses:

H_0: Under the soft constraints operating regime (or possibly a newly selected alternative after five years), there is no significant change in existing vegetation communities at the landscape scale.

H_{0A}: There is no significant change in the spatial extent (number of hectares) of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir.

H_{0B}: There is no significant change in the structure and composition (i.e., distribution and diversity) of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir.

3.0 DEFINITIONS

The following definitions are provided to clarify the terminology used in this report. Definitions are presented alphabetical order.

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

Experimental units – vegetation polygons or plots, depending on analysis objectives. Both polygons and plots are used in different statistical analyses to address management questions.

Growing Degree Units (GDD) – a measure of seasonal heat accumulation used to predict plant development rates and to estimate the amount of time available in the season for plant growth.

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

Plots – sampling units for obtaining field (or ground-truthing) data within each experimental unit. In 2014, field data were collected within 5-m radius circular plots at randomized locations within sample polygons.

Sample – selection of vegetation polygons or plots representing each community type, elevation band, and landscape unit (i.e., the experimental strata) from which data will be collected to address management questions and hypotheses.

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

Statistical population – total number of vegetation polygons delineated in the drawdown zone of the Arrow Lakes Reservoir between 434 m and 440 m ASL. The polygons delineated in 2007 (Enns *et al.* 2007) and subsequently corrected in 2008 and 2010 (Enns *et al.* 2008, 2010) are considered the baseline population against which comparisons will be made. The baseline population will be modified as new information is made available (i.e., the base condition will be scrutinized each year and any errors to the original delineation corrected).

Terrestrial Ecosystem Mapping [TEM] – a standardized approach to stratifying the landscape into map units according to ecological features using a combination of manual airphoto interpretation and ground sampling.

Vegetation community type (VCT) – a general classification for vegetation communities found in the drawdown zone of the Arrow Lakes Reservoir, consisting of habitats that share similar vegetation, substrates, and topography. Not all VCTs (e.g. BB) are vegetated, and certain VCTs (indicated with an *) are more likely to be influenced by reservoir operations than others (Enns *et al.* 2010). The 16 currently recognized VCTs are listed below; more detailed descriptions are provided in Appendix 10.1.

BB: Boulders, steep
BE*: Sandy beach
BG*: Gravelly beach

CL: Cliffs and rock outcrops
CR*: Cottonwood riparian
IN: Industrial / residential / recreation
LO*: Log zone[1]
PA*: Redtop upland
PC*: Reed Canarygrass mesic
PE*: Horsetail lowland
PO: Pond
RR*: Reed – rill
RS: Willow – Red Osier Dogwood – stream entry
SF: Slope failure
SS: Steep sand
WR: Silverberry river entry

Vegetation polygons – discrete vegetated (or non-vegetated) areas of the drawdown zone that delineate VCTs visible in the aerial photography. Vegetation polygons are sampling and statistical units in various analyses to address management questions.

4.0 STUDY AREA

The Arrow Lakes Reservoir is situated on the Columbia River, between the Revelstoke Dam at Revelstoke in the north, and the Hugh Keenleyside Dam at Castlegar, British Columbia, in the south. The reservoir includes two main sections: Revelstoke Reach in the north and Arrow Lakes in the south. These sections are being monitored within 43 discrete study areas previously selected by BC Hydro (based on access considerations) and representing over half of the total drawdown zone between 434 and 440 m ASL (Enns *et al.* 2010; Figure 5-1). The distance between the southernmost site at Deer Park, north-east of Castlegar, and Revelstoke Dam is ~230 km. Further details on study area climate, physiography, and geology are provided in Enns *et al.* (2007).

5.0 METHODS

5.1 Study Design

Work completed during years 1 to 6 (Enns 2007, Enns *et al.* 2007, 2008, 2010, 2012) used aerial photograph interpretation, field sampling, and statistical analyses to monitor changes in the defined VCTs (Enns *et al.* 2007, 2008). Although the project terms of reference (BC Hydro 2007) placed primary emphasis on the interpretation of spatio-temporal patterns of vegetation

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

community changes via aerial imagery, it was recognized early in the study (Enns *et al.* 2007) that landscape level processes cannot be properly understood in isolation from local scale processes. Consequently, much of the effort to date has been focused on monitoring and assessing site level (i.e. within-community) vegetation characteristics (Enns *et al.* 2007, 2008, 2010, 2012). However, this has led to considerable overlap in methods and reported results between CLBMON-33 and its partner study CLBMON-12, which was explicitly designed to assess vegetation at the site level (Enns *et al.* 2008, 2009, Enns and Enns 2012).

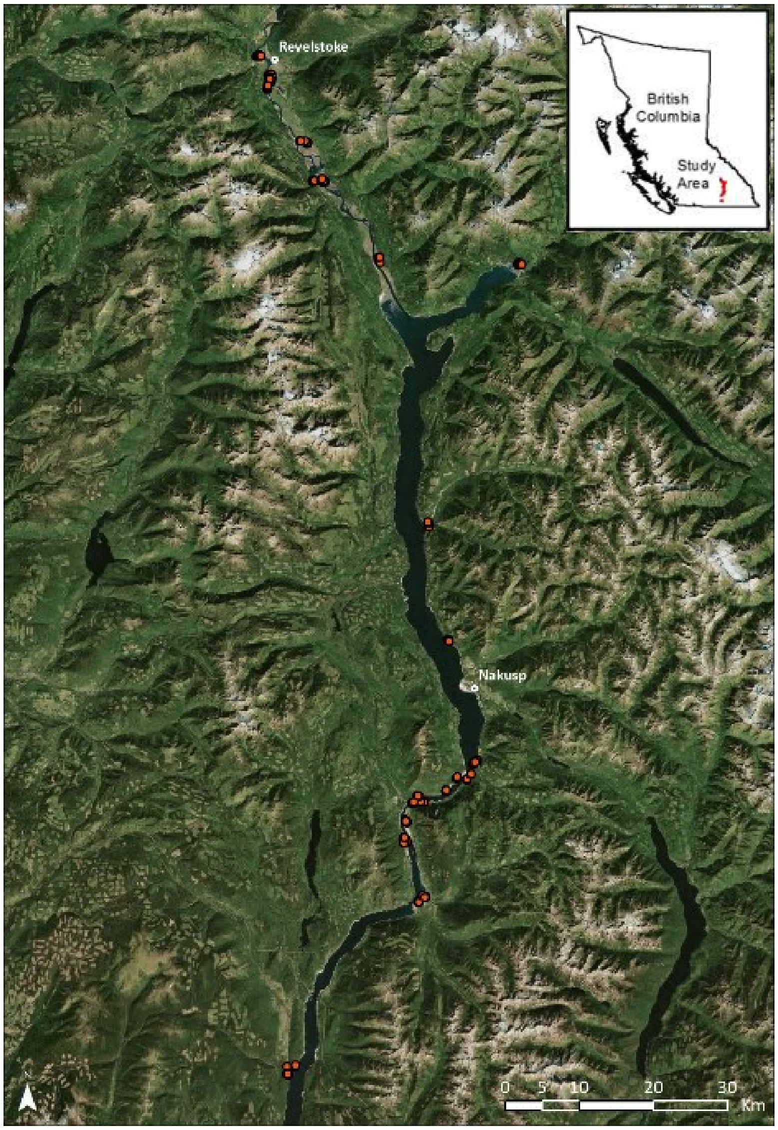

Figure 5-1: Location of the CLBMON-33 project in the drawdown zone of the Arrow Lakes Reservoir, between Revelstoke Dam and Castlegar B.C. Red dots are plot locations

Following consultations with BC Hydro, the decision was taken to follow the same general approach of Enns *et al.* (2007, 2008. 2010, 2012) for the 2014 study year (implementation year 5), but with modifications to reduce perceived redundancies between CLBMON-33 and CLBMON-12 while maintaining the site-level information required for interpreting landscape level findings of CLBMON-33.

The objectives of the 2014 field sampling were: (1) to resample vegetation polygons established in 2007, 2008, or 2010; (2) to verify the delineation of vegetation polygons on the aerial photos obtained in 2014; and (3) to assess whether vegetation community types (VCTs) had changed over time at the landscape level. The following specific questions were addressed:

1. Do the frequency and distribution of vegetation communities within each elevation and geographic stratum in the drawdown zone change over the seven year period of the study to date?
2. If community change is detected, can this be attributed to the recent operating regime of the reservoir? Specifically, can this be attributed to changes in inundation depth, frequency and duration (while controlling for potentially confounding variables such as climate, human and wildlife use, successional advancement and topography)?

As in previous years, the current study design employed aerial imagery of 43 discrete study areas of the Arrow Lakes Reservoir drawdown zone acquired prior to summer inundation to compare vegetation conditions between time periods (in this case between 2007 and 2014, the maximum available time span). The main variables of interest were the relative frequency (ubiquity) and proportional dominance (local composition) of vegetation community types (VCTs) originally identified by Enns *et al.* (2007). VCTs were assessed within polygons originally delineated by Enns *et al.* (2007) and subsequently modified by Enns *et al.* (2010). For 2014, a sample set of vegetation polygons was selected for field study using a stratified random approach. Four polygons were selected at random from the available set of mapped polygons (i.e. the statistical population) within each of 18 previously sampled sub-reaches of the Arrow Lakes Reservoir (e.g. Burton Creek, Beaton Bay, Illecillewaet River, Edgewood; Enns *et al.* 2007) (Figure 5-1). Because time allowed for additional sampling once in the field, 17 extra polygons were selected for sampling on an ad hoc basis within a few of the sub-reaches, resulting in a total of 89 polygons being field assessed.

Polygons ranged in size from <0.1 ha to >30 ha (averaging 1.2 ha). Community typing (and associated data collection) occurred within 5-m radius randomly located subplots. Using a GIS, subplots were located by overlaying a square grid onto the polygon, starting at a random location within the polygon, and creating plot centres at the grid intersections. Each subplot was assigned a unique identifier. The number of subplots created was approximately proportional to the polygon size; larger polygons were subsampled at a higher rate than smaller polygons to ensure comparable proportional coverage of each polygon. The targeted subsample rate was 15 subplots for areas >5 ha, 10 subplots for areas between 0.5 and 5 ha, and 5 subplots for areas <0.5 ha. The spacing between the subsample plots/grid intersections was a function of polygon size and number of subplots to be sampled and was determined by the following formula (after Meidinger 2003):

$$grid\ spacing\ in\ metres = \sqrt{(10\,000\ \times polygon\ area\ in\ ha)/(no.\ of\ subplots)}$$

The field plots served as useful ground-based reference points for the subsequent aerial photo interpretations and also as geo-referenced point samples of drawdown zone biotic and abiotic conditions.

5.2 Aerial Photo Acquisition

Photos were captured digitally in late May 2014 by Terrasaurus Aerial Photography Ltd. Reservoir elevations ranged from 433.27 to 433.82 m ASL during photo acquisition. The northern section (i.e., Revelstoke Reach) was flown on May 27th and the southern areas (remainder of Arrow Lakes Reservoir) on May 31st 2014. Photos were taken in optimum sun angles between 10:30 am–12:30 pm and 1:30–3:00 pm. Additional photo acquisition metadata are included in Appendix 10.2.

5.2.1 Aerial Photo Interpretation

As delineated by Enns *et al.* (2007), each polygon can contain from 1 to 3 distinct VCTs. In previous implementation years, each VCT within a polygon was assigned a decile value (a cover value in 10 per cent increments) representing its estimated total cover in the polygon. However, due to the extensive intermixing of community types at these small scales (often just a few metres), attributing decile values to adjacent VCTs from 1:5,000 air photos is, by nature, a largely subjective exercise that can yield results that are very difficult to replicate among observers and time periods. For this reason, the decile method was dropped beginning with the present implementation year (2014), when aerial photo interpretation was used instead to categorically rank (from 1 to 3) the top three VCTs within polygons based on visual estimates of their proportional covers/extents within the polygon. Polygon compositions were assessed separately for 2014 and 2007, by first overlaying the 2014 orthophoto mosaics onto the designated mapped polygons, then repeating the process using the corresponding 2007 imagery.

The set of polygons used for imagery comparisons (and for the statistical analyses) consisted of all polygons directly sampled in the field in 2014 (n=89), supplemented by an additional 238 polygons from the statistical population (total=327). These latter polygons were a subset of the 398 polygons previously randomly stratified and selected by Enns *et al.* (2010) for comparing 2007 against 2010 imagery. The field sampled subplots were used to support aerial photo interpretation of areas not reached by ground sampling.

We used VCT frequency (number of occurrences) and relative frequency (proportion of samples) to compare community occurrence over space (Arrow Lakes Reservoir and each of the two landscape units of Arrow Lakes and Revelstoke Reach) and time (2007 versus 2014). For each year, frequency and relative frequency were determined for each of the dominant, secondary and tertiary VCTs within polygons. We assumed that a VCT's frequency in an area was generally correlated with its ubiquity on the landscape and, by extrapolation, its spatial extent.

We caveat this assumption by noting that that frequency measures are a function of both the dispersion and density of a population (Greig-Smith 1983); patchiness (non-randomness) in a VCT's distribution will reduce the likelihood of a randomly placed sample "finding" the VCT and therefore reduce the frequency estimate. For this reason, some caution is needed when comparing among different VCTs or study areas. We also note that, in this case, relative frequency was not a truly standardized measure because most mapped polygons (the sample units) varied markedly in size (number of hectares) and shape; due to random chance, larger polygons are more likely to contain a given VCT than smaller polygons. We attempted to partially control for this variability by separately assessing, and reporting, relative VCT frequencies for a set of identically sized point samples (5-m radius subplots) from within each polygon.

For the plot-level analysis, all surveyed points (subplots) with their associated 2014 VCT designations were mapped as a separate GIS layer and overlaid onto the 2007 orthophoto mosaics. Each point was assigned a second VCT designation based on its presentation in the corresponding imagery from 2007, and the field-assessed state of each point in 2014 compared retroactively against its estimated state in 2007.

5.3 Reservoir Operations and Growing Degree Units (GDU)

Historical daily water levels during 2004–2014, measured at the Fauquier elevation gauge within the Arrow Lakes reservoir, were used to examine patterns of seasonal water level heights in the reservoir across years and to determine the proportion of time each 1-m elevation band was above water during each month of April–September of each year. The proportion of time a 1-m elevation band was exposed each month was calculated by determining the total number of days each month that elevation band was above the recorded daily water level, and dividing this total by the number of days for that month.

Plant development rates are strongly influenced by, among other factors, ambient daily air temperatures. However, because temperatures can vary greatly from year to year, it is difficult to predict plant growth based on the calendar alone. “Growing degree units” (GDUs) are a way of assigning a standardized heat value to each day during the growing season based on actual temperatures. Daily GDU values can be added together to give an estimate of the amount of seasonal growth time achieved by plants, and are commonly used in agriculture and natural resources management to predict crop maturation and other lifecycle events (Miller et al. 2001). Although we have elsewhere referred to growing degree units as “growing degree days” (e.g., Hawkes et al. 2013), in keeping with some of the literature, here we employ the former term to better reflect the term’s actual definition.

GDUs were calculated using meteorological data from the Revelstoke A station at the north end of Arrow Lakes Reservoir (latitude: 50.96° N, longitude: 118.18° W, elevation: 444.7 m ASL)[2]. GDUs are given as the average number of celsius degrees within a 24 hour period above a base temperature below which plant growth is assumed to be zero. GDUs were calculated for the drawdown zone for each day during April–September 2004–2014 using the following formula:

$$GDU = \frac{T_{max} + T_{min}}{2} - T_{base}$$

Where T_{max} = maximum daily temperature, T_{min} = minimum daily temperature, and T_{base} = a base temperature, which was arbitrarily set to 10°C (in reality, base temperatures will vary from species to species, but 10°C is a commonly used value; Baskerville and Emin 1969). Any average daily temperature that was less

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[2] Data obtained from the Canadian government historical climate data website: http://climate.weather.gc.ca/index_e.html

than the base temperature was set to the base temperature before performing the GDU calculation, giving a GDU for that day of zero. Likewise, daily GDU was set to zero if a site was inundated on that day—regardless of the ambient atmospheric temperature.

GDUs were calculated for each 1-metre elevation increment between 434 and 440 m, after correcting for inundation time (giving the "effective" GDUs). The corrected daily GDUs were summed (∑DGU) to produce total cumulative GDUs, an estimate of the heat energy that was available for plant growth, for each combination of elevation, month, and year. We used the GDU data to explore how available GDUs might influence VCT distributions in the reservoir, and to assess its importance as a predictor of community changes over time.

5.4 Field Sampling

Field sessions were timed to correspond with sampling in previous study years. Vegetation sampling occurred during two field sessions: May 12–22 and July 2–8, when the reservoir elevation was between 429 and 434 m ASL. A crew of six workers participated in the May field sampling session. The July field sampling session involved three crew members. Site access was via truck and on foot.

Predetermined sample plots were located in the field using a hand held GPS receiver (Garmin GPSMap 60CSx). At each sample point, information required to identify the vegetation community type (plant species covers, site modifiers, and structural stage) was recorded onto modified ground inspection forms (Appendix 10.3) based on standards in the *Field Manual for Describing Terrestrial Ecosystems, 2nd Edition* (B.C. Ministry of Forests and Range and B.C. Ministry of Environment 2010). Data were collected in a 5-m radius plot, and the VCTs and their proportions in each plot were recorded. The attributes collected at each site are listed in Table 5-1.

Table 5-1: Attributes collected for plot samples using field data form

Attribute	Unit / Category
Date	
Surveyor(s)	
Polygon number	
Plot number	
Waypoint and UTM coordinates	easting and northing
Vegetation community type (VCT)	See Section 3.0 for VCT categories
Photo numbers	Photos taken from centre of plot facing north, east, south, west
Aspect	degrees
Slope	degrees

Soil moisture regime	very xeric, xeric, subxeric, submesic, mesic, subhygric, hygric, subhydric, hydric
Primary water source	precipitation, surface seep, stream sub-irrigation, stream surface flooding
General surface topography	concave, convex, straight
Microtopography	smooth, channeled, gullied, mounded, tussocked
Terrain texture	boulders, cobble, gravel, fines, sand, silt, clay, mud, wood, organics
Scouring, erosion, or deposition	Qualitative evidence of scouring, erosion, or deposition – yes or no
Site disturbance	Qualitative evidence of non-operation site disturbance (ATV, wildlife, etc.) – yes or no
Species cover	Per cent cover
Total cover by stratum	Per cent cover (tree layer, shrub layer, herb layer)
Structural stage	sparse/pioneer, herb, low shrub, tall shrub, pole/sapling, young forest, mature forest, old forest

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

5.5 Statistical Analyses

Descriptive summaries and statistical analyses were conducted for sampled polygons and subplots. All statistical analyses were conducted in R version 3.1.2 (R Development Core Team 2007). Polygon analyses used all those directly sampled in the field in 2014 (n=89), supplemented by an additional 238 polygons selected from the remaining population of mapped polygons (total n=327; see Interpretation, Section 5.2.1). As described in Section 5.2.1, each polygon could contain up to three distinct VCTs that were ranked as dominant, secondary and tertiary in terms of their relative cover within the polygon. Descriptive summaries and statistical analyses were conducted separately for dominant, secondary and tertiary VCTs. A total of 506 subplots were field-assessed in 2014. The total number of subplots sampled within each VCT, elevation band, and geographic region is shown in Appendix 10.4. Of these, 405 subplots had corresponding baseline aerial imagery from 2007 (or 2008) and could be used for making temporal comparisons over the maximum seven-year timespan.

5.5.1 Vegetation Communities: Spatial Extent

We used VCT frequency (number of occurrences) and relative frequency (proportion of samples) of polygons and subplots to compare community occurrence over space (Arrow Lakes Reservoir and each of the two landscape units: Arrow Lakes, Revelstoke Reach) and time (2007 versus 2014). Frequency and relative frequency were determined for each of the dominant, secondary and tertiary VCTs within polygons, and for subplots in each year. We assumed that a VCT's frequency in an area was generally correlated with its ubiquity on the landscape and, by extrapolation, its spatial extent. Summary tables and plots were used to describe VCT frequencies and relative frequencies in the area of interest, and changes from 2007 to 2014.

Pearson chi-square statistics ($X^2_{P,}$ Pearson 1900) with Monte-Carlo simulations (n=100,000) were used to test the significance of the differences in VCT frequency. Specifically, chi-square tests were used to assess if the frequency of VCTs within an area changed significantly between 2007 and 2014. Separate analyses were conducted for each of the dominant, secondary and tertiary VCTs within polygons, and for the subplot VCTs. VCTs with less than five occurrences were excluded from polygon tests. Subplot analyses only tested VCTs with greater than five occurrences; this higher cut off was due to the greater sample sizes for subplots. Changes in VCT frequency were tested pooled across the Arrow Lakes Reservoir and stratified by landscape unit. Chi-square tests stratified by elevation were also conducted for subplots.

Tukey's boxplots, a way of visually displaying variation in a variable of interest (further described in Hawkes et al. 2013), were used to explore the relationship of subplot VCTs to growing degree units (GDUs) averaged over June–September, 2004 to 2013 for each 1-m elevation band. An averaged GDU was assigned to a subplot VCT based on that subplot's elevation. Boxplots were created for all yearly and monthly data.

5.5.2 Vegetation Communities: Structure and Composition

For purposes of the 2014 implementation year, "structure" was defined as structural stage (as opposed to plant height, sensu Enns et al. 2008 and subsequent reports). Summary tables were used to describe the distribution of structural stages across the Arrow Lakes Reservoir and by landscape unit. Tukey's boxplots were used to display the vertical distribution of structural stages determined for subplots during 2014 field sampling relative to drawdown zone elevations stratified by landscape unit. As comparable structural stage data were not available for previous years, changes in structure over time were not assessed.

"Composition" at the landscape level was assessed in terms of the relative distribution and abundance of vegetation community types in the drawdown zone of Arrow Lake Reservoir and in each landscape unit. VCT species compositions themselves were not investigated for this report (as these are being addressed for an associated BC Hydro project, CLBMON-12: Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis).

Compositional changes were also assessed at the local scale by examining changes between 2007 and 2014 in each of the dominant, secondary and tertiary VCTs within each of the 327 polygons, and in the VCT associated with each point sample (subplot). Kappa tests (Sim and Wright 2005) were conducted to assess if observed changes in VCT frequencies between 2007 and 2014 within polygons or plots were statistically significant. The Kappa tests assessed whether the number of times that a plot or polygon had the same vegetation community in 2007 and 2014 was different than that expected from chance alone.

The kappa statistic is defined as:

$$\frac{\text{proportion of observed agreement - proportion of chance agreement}}{\text{1-proportion of chance agreement}}$$

A value of 1 indicated perfect agreement in a vegetation community between 2007 and 2014, i.e., that each of polygons or plots had the same community in the two years. A value of 0 meant that the agreement between the two years was not different than that expected by chance alone. Negative kappa values are possible but rare, and would indicate less agreement than expected by chance alone. The magnitude of the positive kappa statistic indicated the degree of agreement between the two years; values between 0.61 and 0.80 suggested substantial agreement, while values above 0.80 suggested almost perfect agreement (Landis and Koch 1977). The kappa (K) statistics were statistically tested using a null hypothesis of K=0, and 95% confidence intervals were computed. Therefore, significant results meant the K statistics were statistically different than 0, thus the agreement in vegetation communities between 2007 and 2014 was not due to chance alone.

5.5.3 Classification Trees

Classification trees (De'ath and Fabricius 2000, Moisen 2008) were used to explore the possible influence of topo-edaphic variables on vegetation community stability between 2007 and 2014. This approach is detailed in Appendix 10.5.

6.0 RESULTS

6.1 Reservoir Operations and GDU

Water levels in the Arrow Lakes reservoir between 2004 and 2014 (Figure 6-1) show considerable variability in elevation across years. In general, water levels typically rise quickly from approximately the beginning of May each year, and peak during mid-late July before gradually subsiding throughout the remainder of the summer and fall. The 10 to 90 percentile range indicates daily differences in water levels of up to ~ 8 m across years. The reservoir exceeded the normal operating maximum during July 2012. Water levels during 2014 appeared to be lower compared to most years in 2004–2013.

The proportion of time each 1-m elevation band between 434 and 440 m was above water during each month of April to September 2004 to 2014 is shown in Table 6-1. All elevations were exposed for most of or all of April and May each year. Exposure time began to decrease in June each year with most of the lowest six elevation bands completely inundated in July. Receding water levels after this time result in increased exposure time during August and again in September. Lower water levels in 2004 and 2005 resulted in most elevation bands being above water during the entire growing season.

The effect of inundation on the number of GDUs that are effectively available for vegetation growth each month for each 1-m elevation band in each year is shown in Table 6-2. GDUs during most of April and May are consistent across all elevation bands each year because reservoir water levels were typically below 434 m during these times. Effects of inundation on GDUs become apparent during June–September; the combination of average temperature combined with inundation results in considerable variability in monthly GDUs per 1-m elevation band across each year of 2004–2014. For example, 2004/2005 had notably higher GDUs in June and July than subsequent years, especially as compared to 2012, whereas 2013/2014 showed relatively high GDUs in August (Table 6-2).

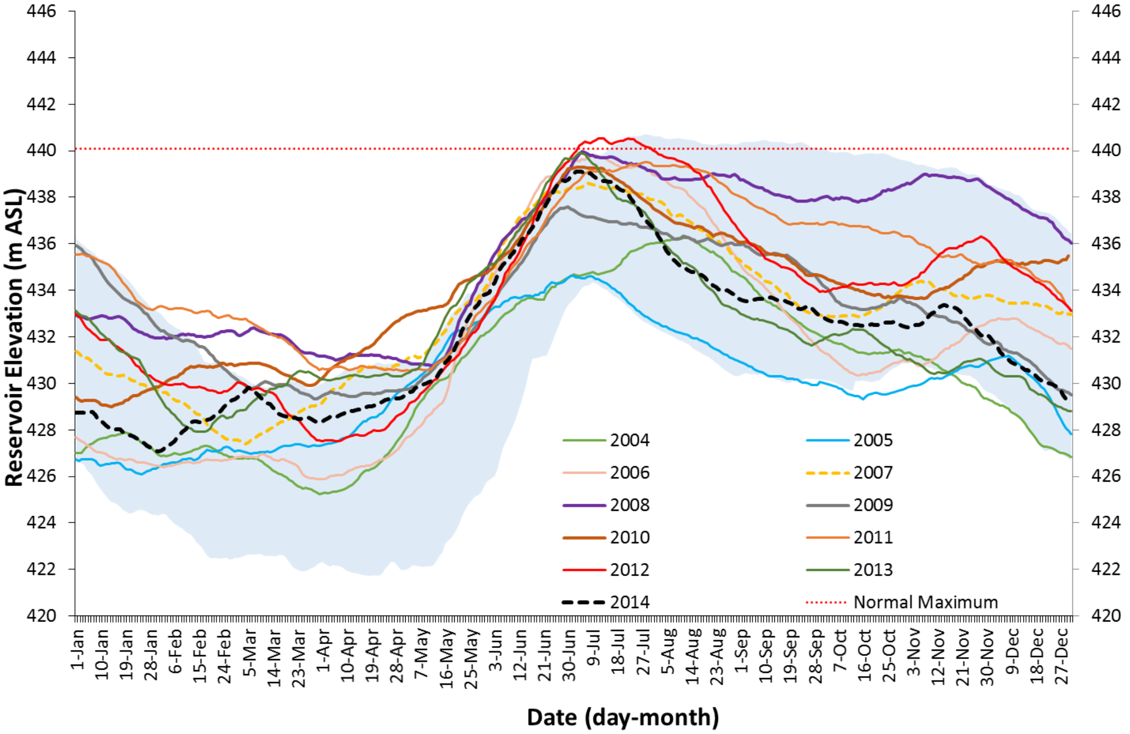


Figure 6-1: Daily water levels in Arrow Lakes Reservoir shown by year for 2004–2014. . Shaded area illustrates the range of the daily 10th and 90th percentile of water levels across all years. The dotted red line indicates the normal maximum operating level of the reservoir (440.1 m ASL)

Table 6-1: **Proportion of monthly days that each 1-m elevation band from 434–440 m ASL in Arrow Lakes Reservoir was above water for the months of April to September, 2004–2014.** Cells are colour-coded by proportion: red: < 0.1 or ~0-3 days; yellow: 0.1–0.9 or ~3-27 days; green: > 0.9 or ~27-31 days.

		Year										
Month	**Elevation (m ASL)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
April	**434**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	435	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	436	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	437	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	438	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	**434**	1.00	1.00	0.97	0.94	0.87	1.00	0.61	1.00	1.00	0.71	1.00
	435	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	436	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	437	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	438	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	**434**	0.77	0.70	0.00	0.00	0.00	0.13	0.00	0.13	0.13	0.00	0.03
	435	1.00	1.00	0.13	0.10	0.00	0.37	0.07	0.30	0.27	0.00	0.17
	436	1.00	1.00	0.27	0.20	0.17	0.57	0.33	0.50	0.43	0.27	0.40
	437	1.00	1.00	0.43	0.37	0.40	0.73	0.53	0.70	0.57	0.47	0.60
	438	1.00	1.00	0.57	0.67	0.73	1.00	0.73	0.90	0.70	0.63	0.77
	439	1.00	1.00	0.83	1.00	0.97	1.00	0.93	1.00	0.83	0.80	1.00
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	**434**	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	435	0.55	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	436	0.94	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	437	1.00	1.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.03	0.10
	438	1.00	1.00	0.00	0.10	0.00	1.00	0.16	0.00	0.00	0.45	0.29
	439	1.00	1.00	0.03	1.00	0.00	1.00	0.55	0.16	0.00	0.61	0.77
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.10	1.00	1.00
August	**434**	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.23
	435	0.13	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.68
	436	0.48	1.00	0.16	0.23	0.00	0.19	0.00	0.00	0.00	0.90	0.90
	437	1.00	1.00	0.32	0.61	0.00	1.00	0.81	0.00	0.10	1.00	1.00
	438	1.00	1.00	0.58	1.00	0.00	1.00	1.00	0.00	0.26	1.00	1.00
	439	1.00	1.00	1.00	1.00	0.94	1.00	1.00	0.32	0.45	1.00	1.00
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	**434**	0.80	1.00	0.67	0.50	0.00	0.00	0.00	0.00	0.03	1.00	1.00
	435	1.00	1.00	0.97	0.90	0.00	0.23	0.27	0.00	0.47	1.00	1.00
	436	1.00	1.00	1.00	1.00	0.00	1.00	0.87	0.00	0.87	1.00	1.00
	437	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.47	1.00	1.00	1.00
	438	1.00	1.00	1.00	1.00	0.40	1.00	1.00	0.97	1.00	1.00	1.00
	439	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	440	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6-2: Available monthly GDUs during each year within each 1-m elevation band from 434–440 m ASL in Arrow Lakes Reservoir. The total calculated GDUs for an elevation band based on daily mean temperatures for each month were multiplied by the proportion of time that elevation band was above water that month

		Year										
Month	**Elevation (m ASL)**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
April	**434**	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	435	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	436	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	437	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	438	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	439	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
	440	89.9	96.0	74.9	50.0	24.0	47.6	79.4	21.9	45.7	43.8	39.4
May	**434**	135.7	188.4	157.4	161.6	128.8	146.9	80.2	139.6	131.5	117.5	137.6
	435	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
	436	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
	437	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
	438	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
	439	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
	440	135.7	188.4	162.7	172.8	147.9	146.9	130.9	139.6	131.5	165.6	137.6
June	**434**	188.4	129.4	0.0	0.0	0.0	31.6	0.0	23.7	19.0	0.0	6.3
	435	245.8	184.8	30.8	19.5	0.0	86.8	12.6	53.3	38.1	0.0	31.5
	436	245.8	184.8	61.5	39.0	31.7	134.2	63.1	88.8	61.8	45.7	75.6
	437	245.8	184.8	100.0	71.4	76.1	173.7	101.0	124.3	80.9	80.0	113.5
	438	245.8	184.8	130.7	129.9	139.6	236.8	138.9	159.8	99.9	108.5	145.0
	439	245.8	184.8	192.3	194.8	184.0	236.8	176.8	177.6	118.9	137.1	189.1
	440	245.8	184.8	230.7	194.8	190.3	236.8	189.4	177.6	142.7	171.4	189.1
July	**434**	0.0	119.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	435	174.2	264.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	436	297.1	264.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	437	317.6	264.2	0.0	0.0	0.0	204.7	0.0	0.0	0.0	10.3	31.1
	438	317.6	264.2	0.0	34.9	0.0	352.6	47.1	0.0	0.0	144.7	93.3
	439	317.6	264.2	11.1	360.4	0.0	352.6	160.3	35.6	0.0	196.3	248.9
	440	317.6	264.2	343.6	360.4	267.4	352.6	292.3	220.8	26.7	320.3	321.5
August	**434**	0.0	292.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.7	64.7
	435	39.3	292.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	157.6	194.0
	436	147.3	292.0	41.6	55.3	0.0	59.5	0.0	0.0	0.0	259.5	258.7
	437	304.5	292.0	83.2	150.2	0.0	307.6	201.4	0.0	26.4	287.3	286.5
	438	304.5	292.0	149.8	245.0	0.0	307.6	249.8	0.0	70.3	287.3	286.5
	439	304.5	292.0	258.1	245.0	219.4	307.6	249.8	79.0	123.0	287.3	286.5
	440	304.5	292.0	258.1	245.0	234.5	307.6	249.8	245.0	272.4	287.3	286.5
September	**434**	84.6	120.8	114.7	70.7	0.0	0.0	0.0	0.0	4.6	162.5	142.9
	435	105.8	120.8	166.3	127.2	0.0	40.7	29.7	0.0	64.9	162.5	142.9
	436	105.8	120.8	172.0	141.4	0.0	174.4	96.4	0.0	120.6	162.5	142.9
	437	105.8	120.8	172.0	141.4	0.0	174.4	111.3	79.4	139.2	162.5	142.9
	438	105.8	120.8	172.0	141.4	46.1	174.4	111.3	164.5	139.2	162.5	142.9
	439	105.8	120.8	172.0	141.4	115.3	174.4	111.3	170.2	139.2	162.5	142.9
	440	105.8	120.8	172.0	141.4	115.3	174.4	111.3	170.2	139.2	162.5	142.9

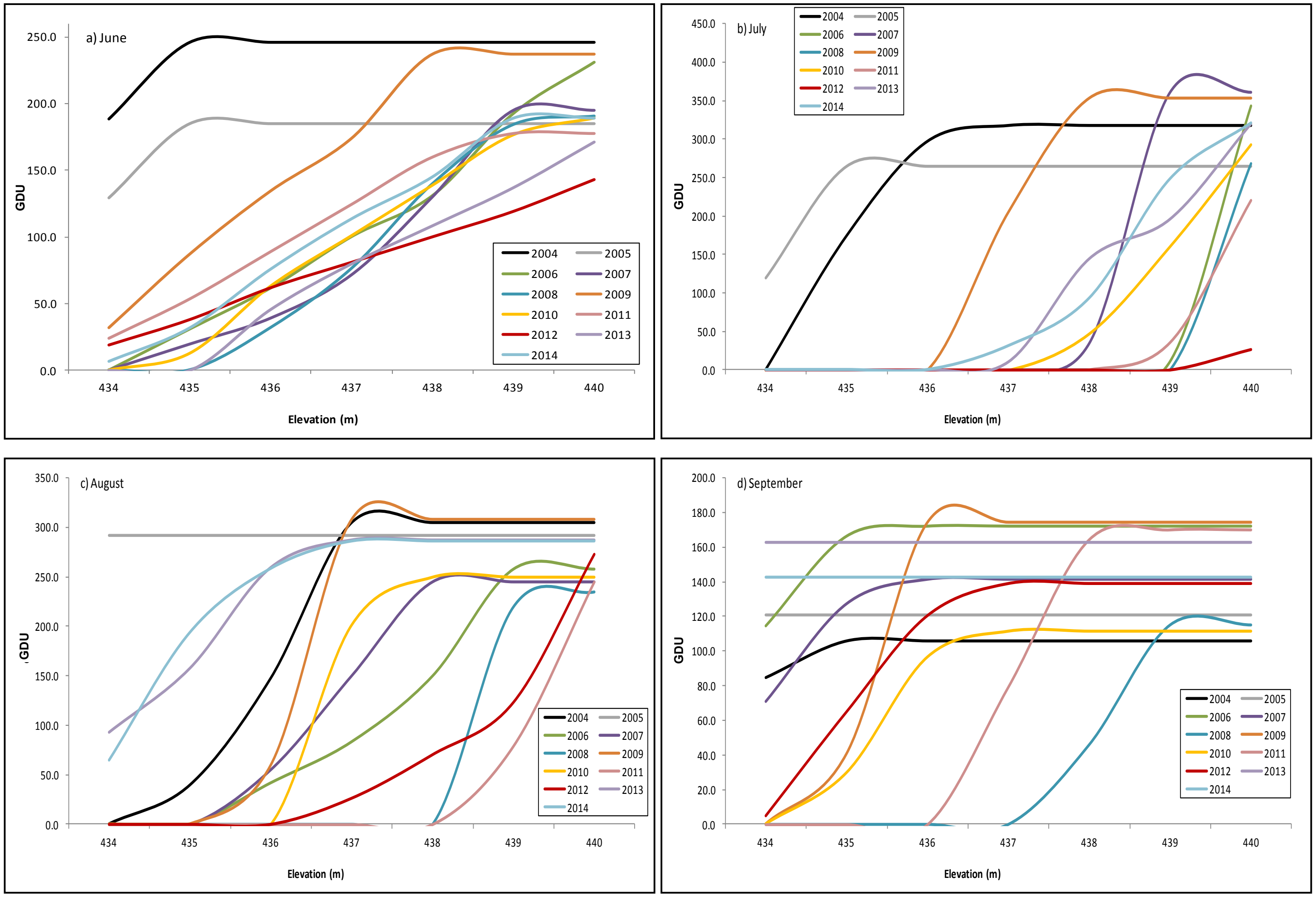


Figure 6-2: **Average 2004 to 2014 growing degree units (GDU) in June (panel a), July (panel b), August (panel c) and September (panel d) per 1-m elevation band. Flat lines indicate inundation during which no accumulation of GDUs occurred.**

6.2 Vegetation Communities

6.2.1 Frequency

6.2.1.1 Polygons

The community composition of the drawdown zone, as represented by the distribution of vegetation community types (VCTs) within sample polygons, showed few changes between 2007 and 2014 (Figure 6-3). The most frequent dominant VCTs in both years were PC—Reed Canarygrass mesic and CR—Cottonwood riparian. SF—slope failure, SS—steep sand, and WR—Silverberry river entry communities were rare; each occurred only once as a dominant VCT in each study year. CL—cliffs and rock outcrops and PO—ponds did not occur as the dominant VCT in any of the sampled polygons. The PC type decreased the most in frequency between the 2007 and 2014 sample periods, while BE—sandy beach) showed the largest increase (Figure 6-3).

Comparing geographic regions (Arrow Lakes versus Revelstoke Reach), it is apparent that most of the observed minor changes were in the southern portion of the reservoir (Arrow Lakes); there were relatively few changes with respect to dominant VCTs over time in Revelstoke Reach (Figure 6-4).

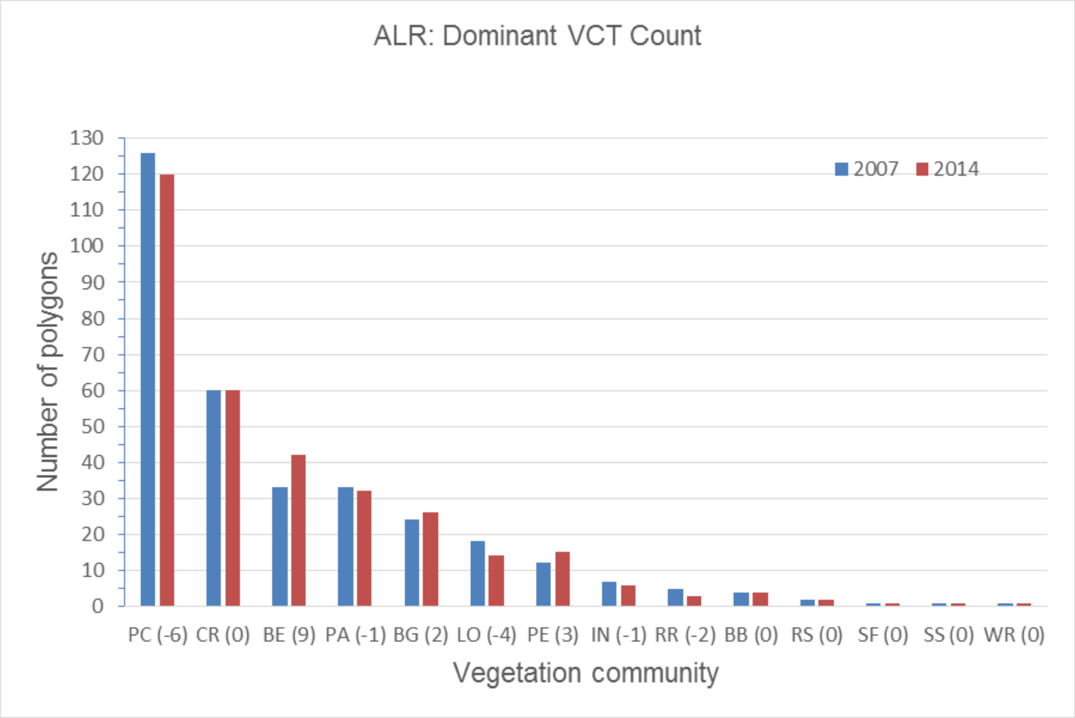
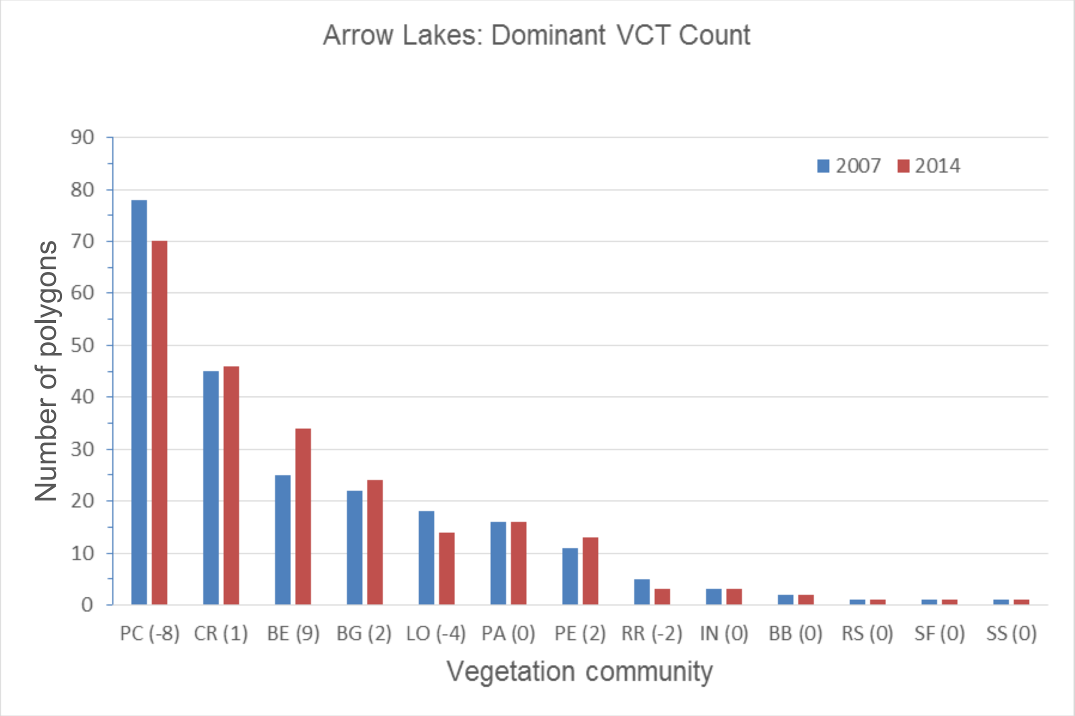


Figure 6-3: Frequencies of VCTs recorded as the dominant community type within 327 randomly sampled polygons in Arrow Lakes Reservoir (ALR) in 2007 and 2014. The directional change in counts over time is shown for each VCT in parentheses next to the VCT label (top panel). VCTs are shown from left to right in descending order of frequency in 2007



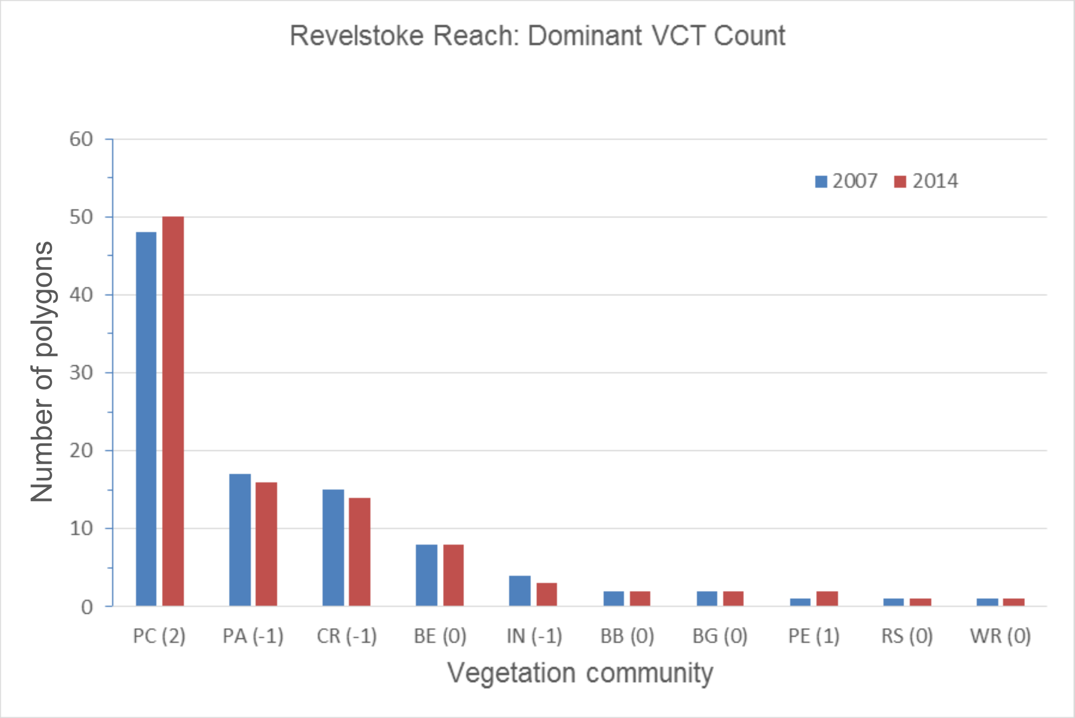


Figure 6-4: Counts of the dominant VCT in the 228 randomly sampled polygons within the Arrow Lakes (top) and 99 polygons sampled in Revelstoke Reach (bottom) landscape units during 2007 and 2014. The directional change in counts over time is shown for each VCT in parentheses next to the VCT label. VCTs are shown from left to right in descending order of frequency for the dominant community in 2007 for each landscape unit

At the scale of the whole reservoir, there were no differences between 2007 and 2014 VCT frequencies (a proxy for VCT spatial extent). This held for both dominant (X^2_p=2.73, p=0.977), as well as secondary (X^2_p=2.27, p=0.998) and tertiary (X^2_p=3.64, p=0.932) VCTs. Similarly, frequencies of dominant, second and tertiary vegetation communities were independent of sampling year when samples were stratified by landscape unit (Pearson chi-square statistics not shown).

6.2.1.2 Subplots

Among sampled subplots (n=405), as among polygons, the PC—Reed Canarygrass mesic community type showed the greatest relative decrease in frequency from 2007 to 2014, with corresponding increases in frequency in PE—Horsetail lowland and BE—sandy beach (Figure 6-5). From aerial photo comparison, localized losses (or contractions) of PC could be ascribed at several locations to beach encroachment within the 434-436 elevation band. In other locations, beach habitat was beginning to succeed to the more vegetated PE. Such community shifts appear to reflect the dynamic nature of sediment deposition (and removal) within the lower reaches of the drawdown zone in response to wave and scouring action. These shifts, which may be ephemeral in nature, did not manifest as significant community changes at the landscape scale (below).

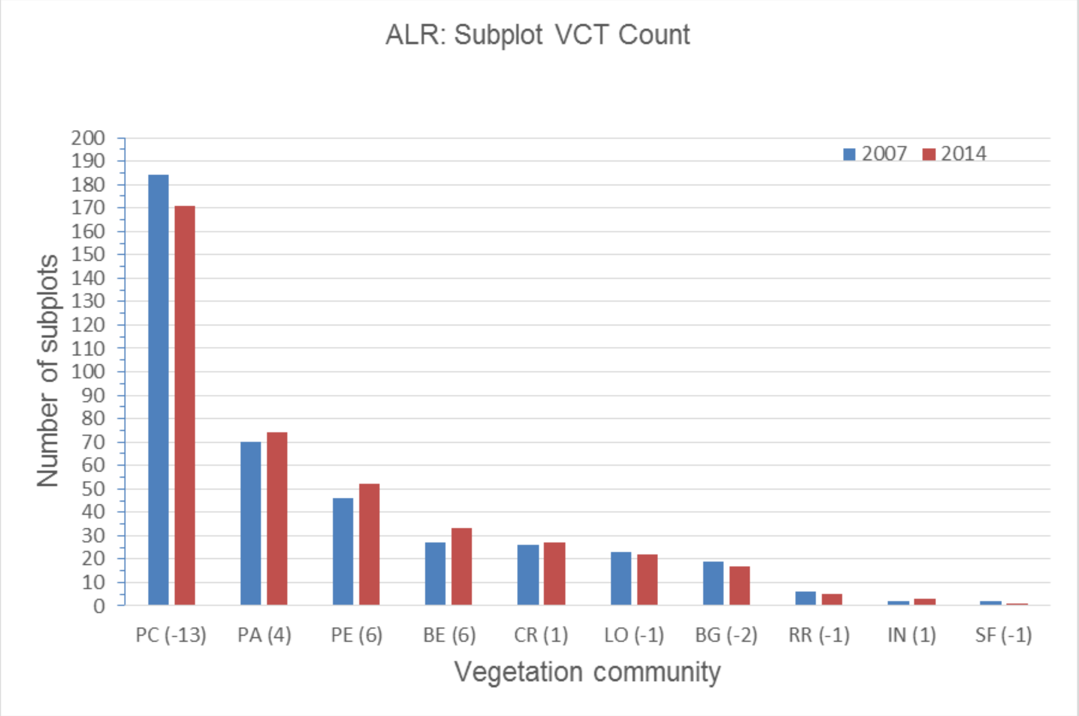
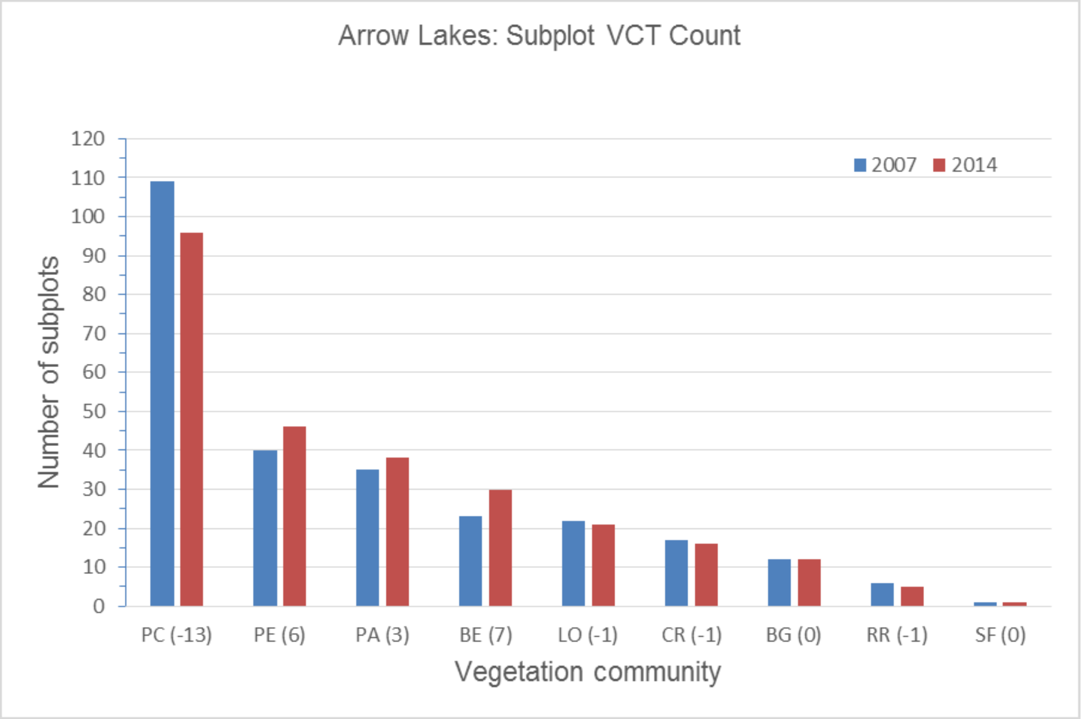


Figure 6-5: Counts (top) and relative frequencies (bottom) for VCTs in 405 randomly sampled subplots within Arrow Lakes Reservoir (ALR) during 2007 and 2014. The directional change in counts over time is shown for each VCT in parentheses next to the VCT label (top panel). VCTs are shown from left to right in descending order of frequency in 2007



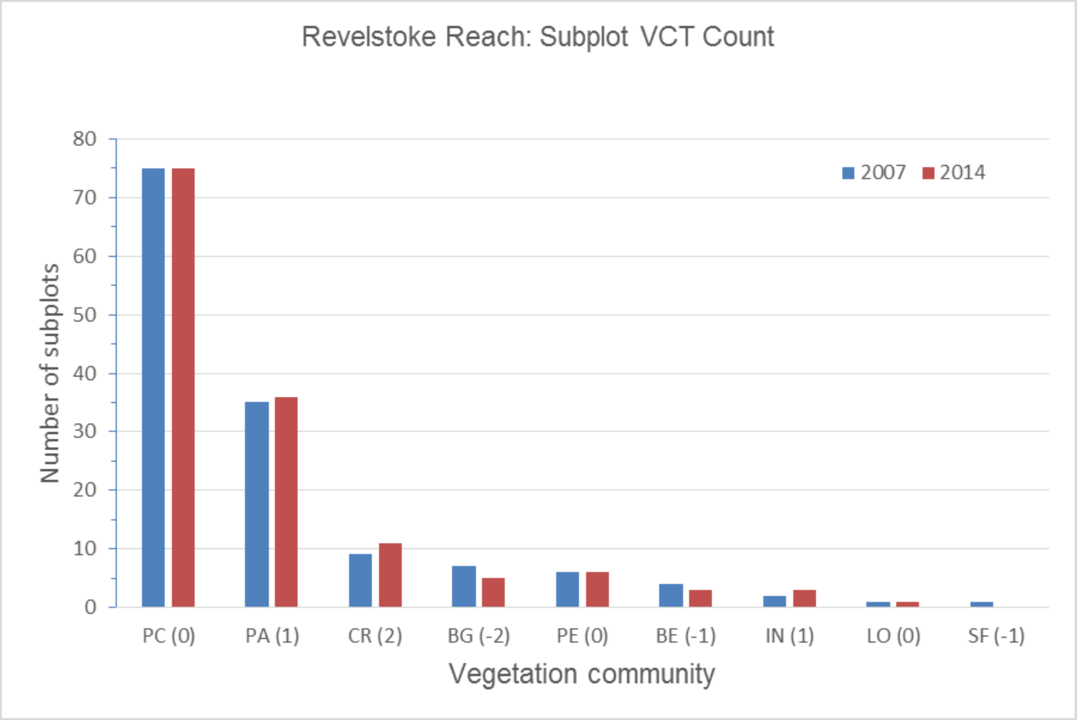


Figure 6-6: **Count of VCTs in 265 randomly sampled subplots within the Arrow Lakes (top) and the 140 subplots sampled in Revelstoke Reach (bottom) landscape units during 2007 and 2014.** The directional change in counts over time is shown for each VCT in parentheses next to the VCT label. VCTs are shown from left to right in descending order of frequency in 2007 for each landscape unit

Compared to Arrow Lakes, Revelstoke Reach had a lower incidence of VCT turnover between the two study years, suggestive of greater community stability in the more northerly landscape unit (Figure 6-6). The relatively more stable conditions in Revelstoke Reach can no doubt be ascribed in part to the greater preponderance of seeded Reed Canarygrass, an aggressive, introduced, thatch-forming grass species that is effective both at stabilizing the soil and pre-empting habitat for other species and community types.

As with polygons, the changes between 2007 and 2014 were not statistically significant, either when tested for the entire Arrow Lakes Reservoir (X^2_p=1.71, p=0.947), the Arrow Lakes region (X^2_p=2.435, p=0.968) or Revelstoke Reach (X^2_p=0.887, p=0.9915). Similarly, no significant difference was found in frequency of VCTs within the entire Arrow Lakes Reservoir when stratified by elevation band (Pearson chi-square statistics not shown).

6.2.1.3 Hypothesis H_{0A}: no change in VCTs in Arrow Lakes Reservoir

Based on these findings, we conclude that there has been no significant change in the spatial extent of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir over the time frame of this study.

6.2.2 Structure and Composition

6.2.2.1 Structure

Most subplots sampled in the reservoir (56.5 per cent) were categorized within the herb structural stage. Percentage values for this structural stage were similar for both Arrow Lakes and Revelstoke Reach landscape units (Table 6-3). Arrow Lakes had a relatively higher percentage of subplots at the sparse/pioneer SS, and a lower percentage of tall shrub subplots, compared to both the reservoir as a whole and to Revelstoke Reach.

Not unexpectedly, there was a clear trend toward increased structural advancement (from pioneering, to herb, to woody vegetation) from low (434-436 m) to high (438-440 m) elevation bands in the drawdown zone, presumably reflecting reservoir constraints on vegetation development (Figure 6-7). Thus, sparse and/or pioneering herbaceous phases were most frequently sampled in the 434-436 m elevation band, whereas forested phases were mostly restricted to elevations above 439 m. The relationship between structural stage and elevation was fairly consistent between landscape units, although for as yet undetermined reasons, shrub stages tended to appear in samples at slightly lower elevations in Revelstoke Reach compared to Arrow Lakes (Figure 6-7).

Table 6-3: Distribution of structural stages in subplots sampled throughout Arrow Lakes Reservoir (ALR) in 2014, and for Arrow Lakes (AL) and Revelstoke Reach (RR) landscape units (LU)

	Count			Percent		
Structural Stage	ALR	AL LU	RR LU	ALR	AL LU	RR LU
Sparse/pioneer	54	48	6	13.3%	18.1%	4.3%
Herb	229	151	78	56.5%	57.0%	55.7%
Low shrub	23	14	9	5.7%	5.3%	6.4%
Tall shrub	76	38	38	18.7%	14.3%	27.0%
Pole/sapling	2	2	0	0.5%	0.8%	0.0%
Young forest	8	3	5	2.0%	1.1%	3.6%
Mature forest	13	9	4	3.2%	3.4%	2.9%

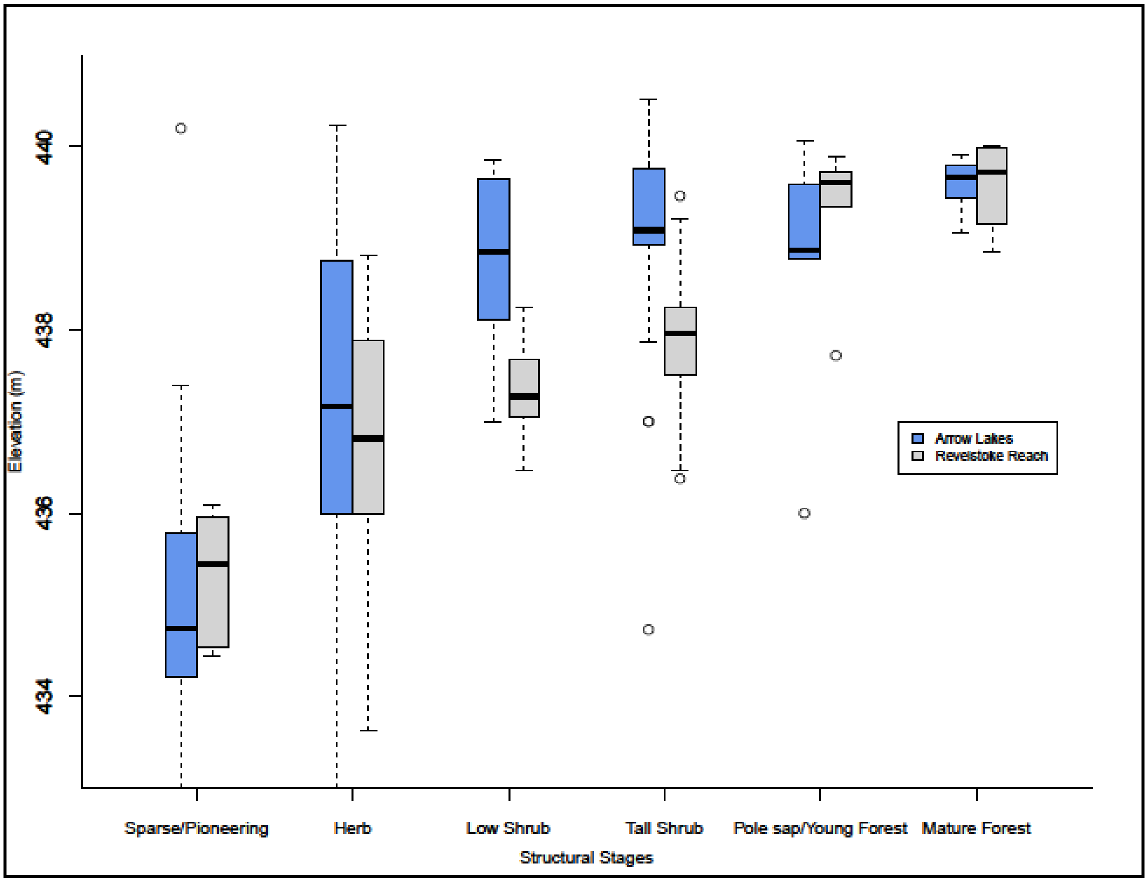


Figure 6-7: Variation in the elevation at which plots from various structural stages were mapped in 2014 in the Arrow Lakes reservoir. Colours refer to the two areas of the reservoir sampled. Structural stages are ordered from early to late seral stages

6.2.2.2 Composition

6.2.2.2.1 Polygons

A total of 31 polygons (~10 per cent) underwent a change in dominant VCT from 2007 to 2014 (Table 6-4). Most of these changes involved the PC—Reed Canarygrass mesic type, followed by PA—Redtop upland and LO—log zone. Proportionally, LO, PE—Horsetail lowland, and RR—reed-rill communities had the highest likelihood of changing between 2007 and 2014, although the sample size for RR was small and this result should be treated with caution. Over 85 per cent of the polygons sampled in BE—sandy beach, BG—gravelly beach, PC, PA and CR—Cottonwood riparian vegetation communities were stable over time with respect to the dominant VCT.

In Arrow Lakes, changes to the dominant VCT affected ~11 per cent of polygons, whereas only ~6 per cent of polygons in Revelstoke Reach experienced such a change. The changes primarily affected PC—Reed Canarygrass mesic, LO—log zone and PE—Horsetail lowland dominated polygons in Arrow Lakes and PA polygons within Revelstoke Reach. In Arrow Lakes, most changes involving PC VCTs were to PE and BE—sandy beach types (Figure 6-8). Changes in LO dominated polygons were mainly to PC types and changes in PE dominated polygons were to either BG—gravelly beach or BE types. In Revelstoke Reach, one IN—industrial/disturbed type in 2007 became a PA—Redtop upland, one PC type became a PE, three PA types transitioned into PC, and one CR—Cottonwood riparian type was reclassified as PA.

Despite local changes, at the scale of the entire reservoir vegetation polygons were statistically stable over time (Kappa test; Appendix 10.6). This stability was most pronounced in Revelstoke Reach (Kappa test; Appendix 10.6), possibly due to the prevalence of Reed Canarygrass-dominated habitat, as noted above (6.2.1.2).

6.2.2.2.2 Subplots

Thirty seven of the 405 sampled subplots (~9 per cent) within the Arrow Lakes Reservoir underwent a change in VCT between 2007 and 2014, with most subplots switching to PE—Horsetail lowland, BE—sandy beach, and PA—Redtop upland types (Table 6-5). The highest number of changes were recorded for PC—Reed Canarygrass mesic subplots (N=19, 10 per cent of all PC subplots). Proportionally, the SF—slope failure, LO—log zone, and RR—reed-rill subplots changed most. However, note that for SF and RR the results are likely spurious due to the small sample sizes for these VCTs.

More Arrow Lakes subplots than Revelstoke Reach subplots experienced a VCT change between 2007 and 2014, both in absolute numbers (30 vs. 7, respectively) and proportionally (11 vs. 5 percent, respectively). In Arrow Lakes, most subplot changes involved the PC type, followed by LO, PE, and PA. Changes were recorded for PC, BG, LO, BE, and SF—slope failure types in Revelstoke Reach (Figure 6-9).

Most of the PC subplots and all of the PE subplots that changed were located at low elevation in the Arrow Lakes landscape unit. Overall, mid-and upper-elevation sites were more stable than low elevation sites, presumably reflecting the more extreme conditions encountered at low elevations with respect to water energetics, sediment deposition, and inundation depth and duration (Table 6-6).

At the scale of the entire reservoir, subplots, like polygons, did not undergo any significant compositional change between 2007 and 2014 (Kappa test; Appendix 10.6).

6.2.2.3 Hypothesis H0$_B$: no change in structure/composition of VCTs in Arrow Lakes Reservoir

Based on these findings, we conclude that there has been no significant change in the composition of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir over the time frame of this study. We could not test the corresponding null hypothesis of no change in the structure of vegetation communities, as we did not have matching data on stage structure for 2007.

Table 6-4: Number of polygons that changed dominant vegetation community types (VCTs) or remained stable between 2007 and 2014, in Arrow Lakes Reservoir

VCT	Number of polygons		Per cent changed
	Changed	stable	
IN—industrial/disturbed	1	6	14.3
SF—slope failure	0	1	0.0
BB—boulders, steep	0	4	0.0
SS—steep sand	0	1	0.0
BG—gravelly beach	0	24	0.0
LO—log zone	5	13	27.8
BE—sandy beach	0	33	0.0
PE—Horsetail lowland	3	9	25.0
RR—reed-rill	2	3	40.0
RS—stream entry	0	2	0.0
PC—Reed Canarygrass	14	112	11.1
PA—Redtop upland	5	28	15.2
WR—river entry	0	1	0.0
CR—Cottonwood riparian	1	59	1.7
Total	**31**	**296**	9.5

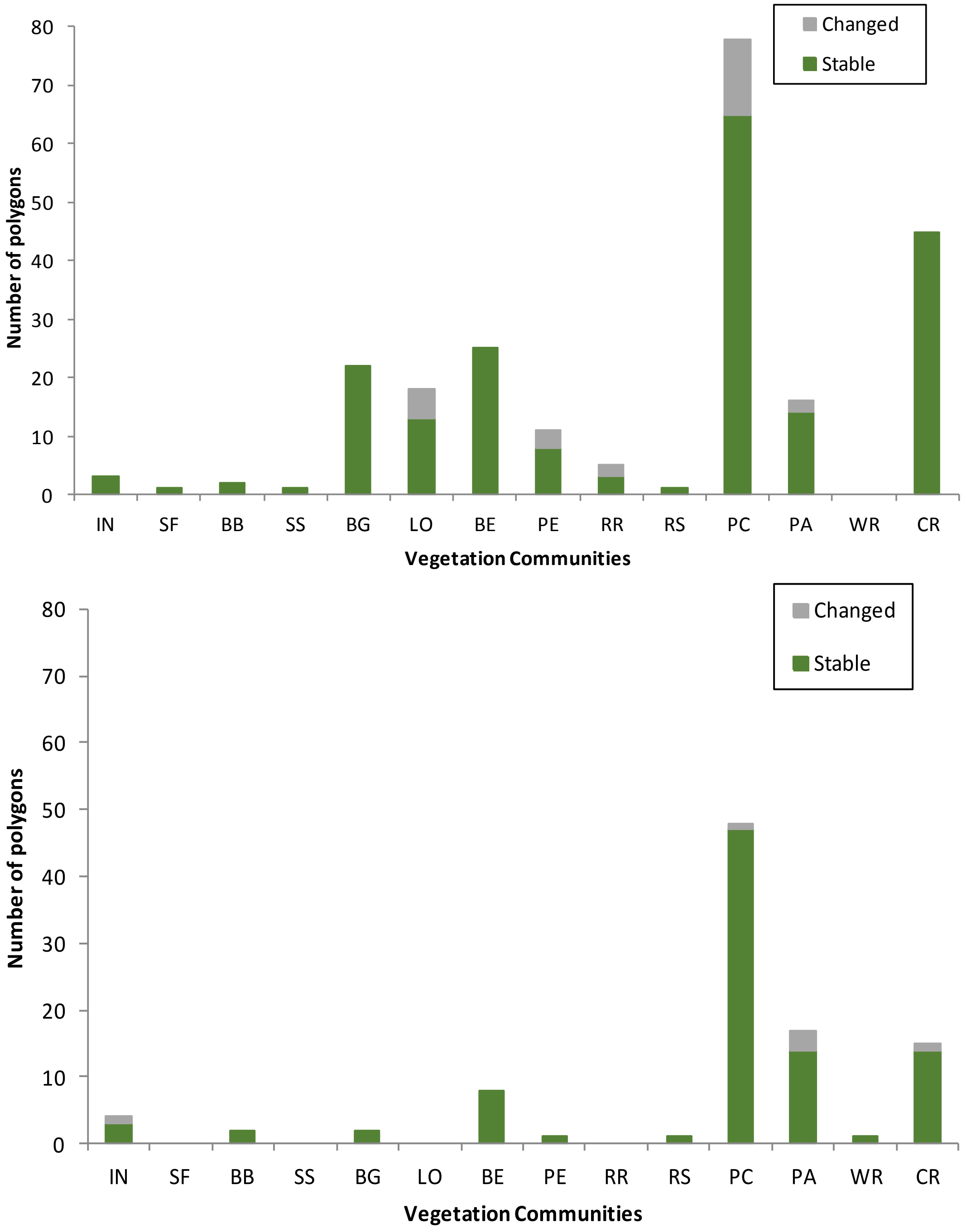


Figure 6-8: **Number of polygons that changed dominant VCT from 2007 to 2014 are shown for Arrow Lakes (top) and Revelstoke Reach (bottom) landscape units.** The height of each bar indicates the number of occurrences of the indicated VCT in 2007

Table 6-5: Number of subplots that changed dominant vegetation community types (VCTs) or remained stable between 2007 and 2014, along with the VCT to which the subplots changed, in Arrow Lakes Reservoir

VCT	Number of subplots		Per cent changed	Changed to:
	Changed	Stable		
IN—industrial/disturbed	0	2	0.0	--
SF—slope failure	1	1	50.0	PC
BG—gravelly beach	2	17	10.5	PA(2)
LO—log zone	6	17	26.1	PA(2), PC(4)
BE—sandy beach	1	26	3.7	PC
PE—Horsetail lowland	3	43	6.5	BE(3)
RR—reed-rill	1	5	16.7	BE
PC—Reed Canarygrass	19	165	10.3	BE(3), CR(2), LO(2), PA(3), PE(9)
PA—Redtop upland	3	67	4.3	IN, LO(2),
CR—Cottonwood riparian	1	25	3.8	LO
Total	**37**	**368**	**9.1**	

6.2.3 Growing degree units (GDUs)

Different elevations within the Arrow Lakes drawdown zone experience different levels of inundation (both between and within years), and this influences how plant communities are distributed across the elevation gradient (Enns *et al.* 2010). We explored the relationship between inundation timing and duration and current vegetation structuring further, using growing degree units (GDUs) over the past decade to estimate the amount of heat energy available for plant growth during the primary growing season at different elevations ("effective" GDUs). For a given elevation stratum and time frame, effective GDUs indicate the amount of time that ambient air temperatures were suitable for plant growth, corrected for inundation time (i.e., the time that the elevation was under water and hence not experiencing conditions favourable to plant growth, even if the ambient temperatures were favourable).

We found that there was a trend among the "primary" vegetated VCTs (BG—gravelly beach, BE—sandy beach, PE—Horsetail lowland, RR—reed-rill, PC—Reed Canarygrass mesic, PA—Redtop upland, and CR—Cottonwood riparian) from lower to higher GDUs that appears related to seral stage (with early seral stages characterized by low GDU and later seral stages by high GDU).

Thus, low elevation pioneering and early seral VCTs such as PE and BE typically associate with low historical average summer GDUs (<100). Mid-elevation herbaceous VCTs such as PC establish in areas with typically higher summer heat loads (GDUs between 50 and 200), while shrublands rarely associate with GDUs <100 and Cottonwood forests typically experience at least 200 GDUs. Moreover, the relationship between monthly GDUs and seral stage appears to be stronger for some months (e.g. June) than others (e.g. September), implying that not just the total time inundated, but also the timing of inundation within the growing season, can play a role in structuring drawdown zone vegetation. Further details are provided in Appendix 10.7.

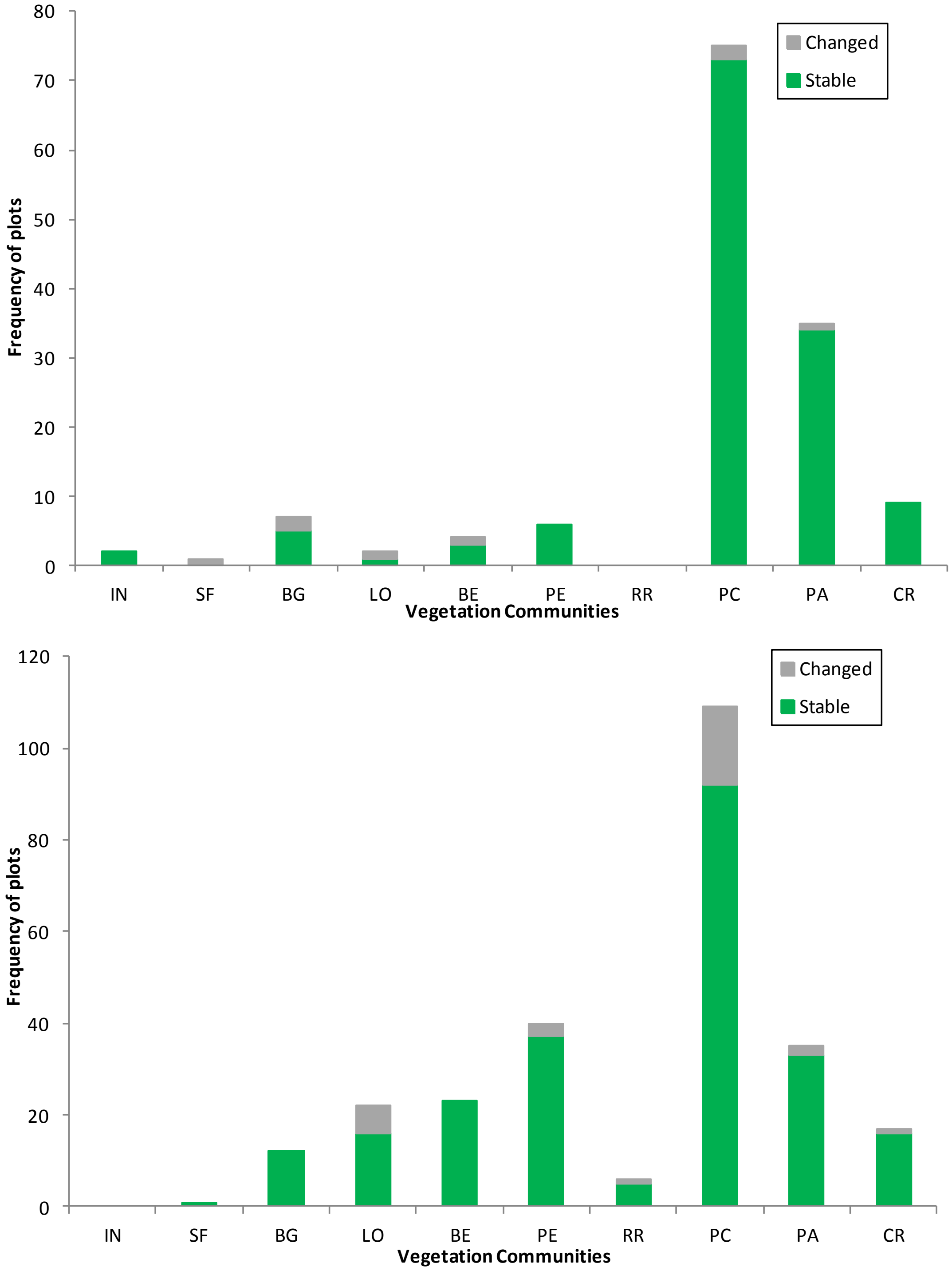


Figure 6-9: **Number of recorded VCT changes within subplots between 2007 and 2014 per VCT as mapped in 2007, in Arrow Lakes (top) and Revelstoke Reach (bottom).** The height of each bar indicates the number of occurrences of the indicated VCT in 2007

Table 6-6: Number of subplots in which the vegetation community type (VCT) was stable or changed between 2007 and 2014, for the three monitored elevation bands of the Arrow Lakes and Revelstoke Reach landscape units

Elevation band	VCT	Arrow Lakes		Revelstoke Reach	
		Stable	Changed	Stable	Changed
434-436	SF—slope failure	1	0	--	--
	BG—gravelly beach	7	0	4	0
	BE—sandy beach	17	0	3	0
	PE—Horsetail lowland	28	3	3	0
	RR—Reed-rill	2	0	--	--
	PC—Reed Canarygrass	9	11	15	0
436-438	BG—gravelly beach	4	0	1	2
	BE—sandy beach	6	0	0	1
	PE—Horsetail lowland	6	0	3	0
	RR—reed-rill	1	1	--	--
	PC—Reed Canarygrass	53	1	42	2
	PA—Redtop upland	2	0	16	1
	CR—Cottonwood riparian	--	--	0	1
438-440	IN—industrial/disturbed	--	--	2	0
	SF—slope failure	--	--	0	1
	BG—gravelly beach	1	0	--	--
	LO—log zone	16	6	1	0
	PE—Horsetail lowland	3	0	--	--
	RR—Reed-rill	2	0	--	--
	PC—Reed Canarygrass	30	5	16	0
	PA—Redtop upland	31	2	18	0
	CR—Cottonwood riparian	16	1	8	0

7.0 DISCUSSION

Drawdown zones of large hydroelectric reservoirs in British Columbia present a notably challenging environment for plant establishment and growth. Nevertheless, many of these zones support vegetation assemblages seemingly adapted to (or at least at equilibrium with) the alternating regimes of prolonged inundation and extreme exposure. The influence of fluctuating water levels and inundation duration (i.e., reservoir operations) in structuring, maintaining, and modifying drawdown zone vegetation communities has been studied in the Arrow Lakes Reservoir, an impoundment of the Columbia River in southern British Columbia, since 2007. As part of this study, aerial photographic images of selected regions of the drawdown zone have been captured in alternating years (2007, 2008, 2010, 2012, and 2014) to provide a time series record of landscape-scale vegetation changes since 2007.

Previously, aerial imagery from 2010 was compared with that of 2007 (Enns *et al.* 2010), and 2012 imagery was compared with 2010 imagery (Enns *et al.* 2012) to assess whether BC Hydro's reservoir operations, and specifically its "soft constraints" program, had been effective in maintaining the existing drawdown zone vegetation over these time periods. For the present report, the fifth reporting year of the monitoring program, aerial imagery from 2014 was compared with 2007 imagery, thus representing a seven-year increment and the maximum timespan available to date.

The 2014 results for CLBMON-33 are discussed below in relation to the specific management questions (Section 2.0), which have been addressed to a varying degree in previous reports (Enns *et al.* 2007, 2008, 2010 and 2012). The objective here is not to re-summarize these earlier results, but rather to highlight any new relevant findings from the most recent investigations.

7.1 MQ1: What are the existing riparian and wetland vegetation communities in Arrow Lakes Reservoir drawdown zone between 434 m and 440 m?

This MQ was addressed by Enns *et al.* (2007; 2008; and 2010), who defined seven primary and nine secondary vegetation community types (VCTs) based on a combination of similar topography, soils, and vegetation features (Section 3.0, Appendix 10.1). The 2014 field verifications suggest that further refinements to this classification may be required before this management question can be fully addressed, as described in Appendix 10.1.2.

7.2 MQ2: What are the spatial extents, structure and composition (i.e., relative distribution and diversity) of these communities within the drawdown zone between 434 m and 440 m?

Previous annual reports have addressed this MQ at length with respect to the defined vegetation community types or VCTs (Enns *et al.* 2007, 2008, 2009, 2010, 2010, 2012). Results in 2014 confirmed earlier findings that the Reed Canarygrass mesic VCT was the most widespread community in the drawdown zone, being recorded as the dominant VCT in over 35 per cent of polygons sampled.

However, whereas earlier reports indicated that the Cottonwood riparian VCT had one of the lowest total area coverages of identified VCTs (Enns *et al.* 2010), this VCT was the locally dominant type in 18 per cent of polygons sampled in 2014 (second only to PC), suggesting it may be a more common component of the uppermost elevation band than previously reported. With a 10 per cent probability of being recorded as a dominant VCT, the PA—Redtop upland type exhibited an intermediate level of local dominance, below CR—Cottonwood riparian and PC—Reed Canarygrass, but above that of the BG—gravelly beach, LO—log zone, and PE—Horsetail lowland VCTs. However, as noted in Appendix 10.1.2, the PA type is likely overestimated due to the occasional erroneous lumping together of PA with unclassified, mid-elevation shrublands. Future monitoring will likely show that this VCT, as originally defined, is a less widespread component of the drawdown zone than current observations suggest.

While VCTs such as BE—sandy beach, PA, BG, and LO were far less likely than PC to be recorded as a dominant community type (in terms of local coverage), the disparities were less marked for subdominant (secondary) VCTs; PA was just as likely as PC to be recorded as a subdominant community, while PE and BE were nearly as likely to be recorded as such. In terms of tertiary-ranked contributions to vegetation composition, the distinction was even less marked; most primary VCTs had a more or less similar likelihood of appearing as a minor vegetation component of the overall community. Disregarding VCT ranks within polygons and considering only overall VCT frequencies as determined through the subplot samples, the PC VCT continued to rank as the most ubiquitous vegetation type in the study area, with others following in descending order as follows: PA > PE > BE > CR > LO > BG > RR—reed-rill > IN—industrial/disturbed > SF—slope failure.

There were numerous similarities but also some notable differences in the VCT frequencies for Arrow Lakes versus Revelstoke Reach, consistent with the previous conclusion of Enns *et al.* (2010) that these two landscape units differ in terms of their vegetation composition. For example, while PC—Reed Canarygrass was the most frequent dominant type within polygons of both landscape units, these polygons were proportionally more common in Revelstoke Reach. Polygons dominated by CR were recorded more often in Arrow Lakes, as were PE and BE. In contrast, willow shrublands (as represented by PA) were the second most ubiquitous dominant vegetation type in Revelstoke Reach after PC, whereas PE- and BE-dominated polygons were both relatively uncommon components of this landscape unit (Figure 6-4).

In earlier studies (e.g., Enns *et al.* 2010), “structure” was typically equated with plant height. However, plant height, particularly for herbaceous species, is a phenological trait that is likely to be strongly influenced in any given year by snowmelt dates, spring weather, and/or the date of sampling (not to mention plant growth form). For this reason, we do not feel that plant height is a particularly informative metric for assessing reservoir effects on vegetation, except perhaps in specific applications. For 2014 we chose to characterize an alternative aspect of vegetation structure that is less insensitive to phenology, namely, structural stage. We used basic structural stage classes (e.g., pioneer, herb, low/tall shrub, young/mature/old forest) to characterize the successional phase and dominant physiognomy of sample plots at different elevations in the drawdown zone, stratified by geographic region. As noted in Appendix 10.1.2 structural stage has the potential to serve as a useful proxy for more complex community mapping during aerial photo monitoring.

Most subplots sampled (56.5 per cent) in the reservoir were categorized within the herb structural stage. Percentage values for this structural stage were similar for both Arrow Lakes and Revelstoke Reach landscape units. Arrow Lakes had a relatively higher percentage of subplots at the sparse/pioneer SS, and a lower percentage of tall shrub subplots, compared to both the reservoir as a whole and to Revelstoke Reach. Not unexpectedly, early seral sites with sparse and/or pioneering herbaceous phases were most frequently sampled in the low elevation bands, where inundation depths and durations are greatest. The more advanced seral, forested phases were generally restricted to elevations above 439 m, with shrub structural stages occupying mid and upper elevations—presumably reflecting the differing physiological tolerances of these structural guilds toward prolonged inundation. The relationship between structural stage and elevation was more or less consistent between north and south reservoir regions, although for as yet undetermined reasons shrub communities tended to appear in samples at slightly lower elevations in Revelstoke Reach than in Arrow Lakes.

7.3 MQ3: How do spatial limits, structure and composition of vegetation communities relate to reservoir elevation and the topo-edaphic site conditions (aspect, slope and soil moisture, etc.)?

This management question, which overlaps somewhat with MQ2 above, has also been addressed at length in previous reports (Enns *et al.* 2007, 2008, 2009, 2010, 2010, 2012). Based on the lack of significant change observed in community frequency and composition between 2007 and 2014 (see MQ4), it appears that the general elevation-VCT relationships have not changed from those reported earlier. These include the following patterns, after Enns *et al.* (2010, 2012):

- CR—Cottonwood riparian occurs between 436 and 440 m ASL and is most common between 439 to 440 m ASL.
- PA—Redtop upland occurs between 435 and 439 m ASL and is very strongly aligned with the 439 m ASL elevation.
- BE—sandy beach, BG—gravelly beach, PC—Reed Canarygrass mesic, and RR—reed-rill all occur in a wider range of elevations, from 434 to 438 m ASL.
- PE—Horsetail lowland is centred between 434 and 435 m ASL, but occasionally occurs at higher elevation if adequate moisture is available.
- PC dominates in Revelstoke Reach but is less widespread to the south in Lower Arrow Lakes, whereas BE and BG increase in frequency in the southern half of the reservoir.
- The upper elevation band (438-440 m) in Revelstoke Reach supports the greatest average total vegetation cover, followed by the upper band in Arrow Lakes. Arrow Lakes Reservoir supports higher total vegetation cover than Revelstoke Reach in the mid elevation band (436-438 m). Vegetation cover is sparsest in the lowest monitored elevation band (434-436 m), where the mean covers are similar between the two landscape units.

When we considered the VCT-GDU relationship by individual month (June, July, August, and September), we found the connection to be stronger for some months (June and August) than others (July and September), for which we suggest a possible explanation. In June, while the reservoir is still in the process of filling, lower elevations are becoming inundated while upper elevations remain exposed. During this month, which represents a critical time for vegetation development, the strong disparities in growing conditions that prevail among different portions of the drawdown zone help facilitate the differentiation in vegetation structuring at different elevation bands.

By August, reservoir elevations have usually begun to recede (in most years; Figure 6-1), again leaving some areas exposed and others inundated. The result is a late summer growing advantage for upper elevation sites, furthering the differentiation process. However, in July when the reservoir is at or near full pool, most habitats are inundated irrespective of their location in the drawdown zone. At this time there is relatively little distinction among VCTs with respect to effective growing days, with the exception of the highest located VCTs (LO and CR). By September, reservoir elevations have receded to roughly June levels (in most years; Figure 6-1) but in this instance cooler ambient fall temperatures may largely act to negate the impact of local disparities in exposure. Consequently, we find that most VCTs are associated with similar September GDUs, with the possible exception of the low elevation BE and PE types, which are still often inundated at this time of year. The logical implication, if these assumptions are correct, is that the vegetation spatial structuring and limits we presently observe are in large part determined by reservoir water levels during June and, to a lesser extent, August.

7.4 MQ4: Does the soft constraints operating regime of Arrow Lakes Reservoir maintain vegetation spatial limits, structure and composition of existing vegetation communities in the drawdown zone?

For 2014, we assessed if significant changes in VCT composition occurred between 2007 and 2014 at the landscape scale. Several polygons and subplots were observed to undergo a shift in vegetation character over this period, attesting to the region's dynamic nature. However, these changes did not translate into a significant net change in VCT frequency (at the landscape scale) or composition (at the local level). Based on these results, combined with those of Enns *et al.* (2010, 2012), we conclude that the soft constraints operating regime of the Arrow Lakes Reservoir is more or less maintaining vegetation spatial limits, structure and composition over the time span of the study.

7.5 MQ5: Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?

The goal of the soft constraints operating regime for vegetation is to "maintain the current (2004) level of vegetation in the drawdown zone by maintaining lower reservoir water levels during the growing season." Over the past decade, reservoir levels have been maintained at higher, not lower, levels on average than in 2004/2005, so from this perspective the soft constraints goal has not been met.

Despite this, the recent operating regime has not resulted in any notable landscape-scale changes in vegetation cover or extent since 2007. Where changes have been observed, these have generally been localized. It is possible that the evident lack of change merely reflects the short time span of the study relative to the generation times of many of the plant species occurring in the drawdown zone; communities composed of long-lived perennials such as graminoids and willows can have slow response times that may not become manifest at the landscape level for several years. However, in this case we feel it is more likely that operation conditions post-2007 (in terms of annual hydroperiod) have not differed substantially enough from those prevailing prior to the introduction of soft constraints to effect a significant shift in vegetation characteristics.

On this basis, there is no *a priori* reason to suspect that targeting consistently lower reservoir levels would be more effective at maintaining existing vegetation at the landscape scale. On the contrary, such a strategy would likely result in at least some directional vegetation changes, by (for example) facilitating the advancement of shrubland and/or Reed Canarygrass (depending on location) into upper and mid elevations of the drawdown zone. Such changes may run counter to the soft constraints stated goal of maintaining the existing status quo above 434 m ASL. It is possible that some of these changes (such as greater shrubland development) would result in desirable benefits for vegetation quality, wildlife habitat, and/or social values, but any such benefits remain purely hypothetical until a reduced flooding regime is actually tested in practice. The low reservoir maximum reached in 2015 (435.48 m), which is well below the recent average, could help to shed light on the potential impacts (either positive or negative) of holding reservoir levels relatively low for an entire growing season; these impacts will be assessed, and associated recommendations made, in the final (2016) report.

It should be noted that the vast majority of plant species found in the drawdown zone of Arrow Lakes Reservoir are adapted to, and may even depend on, a certain amount of seasonal flooding as part of their annual moisture requirements. Stem losses and dieback tend to occur when the duration of inundation exceeds a species' physiological tolerance to anoxia. Given that the goal is to maintain (rather than enhance) existing vegetation in its current state, we feel this will be more effectively achieved by managing the *duration* of inundation during the growing season as opposed to limiting the absolute *depth* of inundation (as represented by the annual maximum achieved). If inundation is necessary, we recommend that peak flood durations be kept as short as possible, both to allow for seedling establishment and completion of reproductive cycles, and to minimize the physiological impact of flooding on upland perennial and woody species especially at upper elevations of the drawdown zone.

7.6 MQ6: Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?

This question has largely been addressed by Enns et al. (2010). The two geographic areas, which are influenced by different climatic regimes, differ substantially with respect to vegetation; Revelstoke Reach is shrubbier and has a lower diversity of VCTs, more area under Reed Canarygrass, and less vegetated beach area than the Arrow Lakes.

Temporally, VCTs in the Arrow Lakes landscape units showed a higher local turnover rate than ones in Revelstoke Reach, possibly due to the greater preponderance of gently sloped low elevation beach and pioneering habitats (which appear to be more heavily influenced by factors such as sediment deposition, scouring, and erosion). In addition, Reed Canarygrass, which was seeded widely in Revelstoke Reach, continues to be the dominant structuring force at mid to upper elevations in this portion of the reservoir. We thus anticipate that, at the landscape scale, Arrow Lakes vegetation will prove more sensitive to changes in the operating regime over time than the vegetation of Revelstoke Reach.

8.0 CONCLUSIONS AND RECOMMENDATIONS

In this annual summary data report for CLBMON-33 we convey some of the incremental gains in understanding that have been made with respect to the vegetation resources of the Arrow Lakes reservoir since the last implementation year (2012), particularly as these relate to the soft constraints operating regime. Our overall conclusions are consistent with those reached following previous study years: in terms of its vegetation features, the Arrow Lakes Reservoir drawdown zone is a moderately dynamic system at the local scale but relatively stable at the landscape level. Local shifts in community composition and frequency occur from year to year, but these have not generally translated into net gains or losses to vegetation at larger scales over the time frame of the present investigation (2007 to 2014). There is currently no compelling evidence to indicate that the soft constraints operating regime of Arrow Lakes Reservoir is failing to maintain vegetation spatial limits, structure, and composition of existing vegetation communities in the drawdown zone.

The status of CLBMON-33 after Year 8 (2014) with respect to the management questions and management hypotheses is summarized below (Table 8-1).

To help strengthen and improve this monitoring program moving forward, we make the following recommendations:

1. If the operational regime changes in the near future, consider expanding the existing time series dataset of vegetation development in the Arrow Lakes Reservoir drawdown zone by continuing to monitor conditions over time.
2. Beginning with the next implementation year, employ LIDAR remote sensing technology in place of digital photos for capturing aerial images of the Arrow Lakes drawdown zone, in keeping with the approach recently taken for the associated Kinbasket Reservoir monitoring project, CLBMON-10.
3. Consider refining the current community classification system so that it more fully addresses management questions around species composition and diversity. This could take the form of a floristics approach (such as that developed for a similar BC Hydro monitoring project in the Kinbasket Reservoir; Hawkes *et al.* 2007) that is less closely tied to topoedaphic features and more closely tied to the specific plant species associations found in the drawdown zone. It may not be practicable at this stage of the monitoring program to undertake a retroactive analysis of the data using a revised classification; however, a refinement of the current classification could help us more fully addresses management questions around community composition and diversity.
4. At the same time, consider ways to make the classification more precise as a field tool to increase the consistency and replicability of community typing. This might involve developing dichotomous identification keys for use during field surveys.
5. Vegetation community types (VCTs) as currently defined are difficult to distinguish reliably from 1:5000 air photos. For purposes of aerial photo monitoring, we recommend switching to a simplified classification system based on vegetation structural stages or functional guilds (e.g., non-vegetated habitat; sparse or pioneer vegetation; grassland; shrubland; young forest; and mature forest) more easily identifiable from the air. A simplified system based on coarse habitat structure would likely result in greater transparency with respect to orthophoto interpretations while bearing more direct relevance to wildlife values of management interest. Imagery from previous years could be retrospectively assessed in terms of these attributes to determine if structural shifts have occurred over time.
6. Keep using effective growing degree units (GDUs) as a potential management tool for fine-tuning soft constraints operating regimes to maximize desired vegetation values in the Arrow Lakes drawdown zone.

Table 8-1: Status of CLBMON-33 management questions after Year 5 (2014)

Management Question (MQ)	Has MQ been addressed?	Scope		Sources of Uncertainty
		Current supporting results	Suggested modifications to methods where appropriate	
1. What are the existing riparian and wetland vegetation communities in Arrow Lakes Reservoir drawdown zone between 434 m and 440 m?	Partially	Enns et al. (2007 and subsequent reports) identified sixteen vegetation community types (VCTs) based on a combination of similar topography, soils, and vegetation features. The LO (woody debris zone), which was dropped as a monitored community type after 2010 due to its ephemeral nature (K. Enns, pers. comm. 2014), was reintroduced to the study in 2014 because wood debris can have substantial influence on vegetation development. VCTs have been mapped within the drawdown zone in each of 2007, 2008, 2010, 2012 and 2014. Improvements with aerial photographs continue to lead to refinements in the vegetation community mapping. Wetland communities have yet to be described for the ALR. While the classification yields a number of landscape-scale VCTs that lend themselves fairly well to aerial mapping, these VCTs do not completely capture the diversity of plant associations present in the drawdown zone.	Some refinements to the community typing may be required to fully address management questions. One option is to employ two separate classifications: a first one based primarily on floristics (such as that developed for a similar BC Hydro monitoring project in the Kinbasket Reservoir) that more fully addresses management questions around species composition and diversity; and a second one, for use in aerial photo interpretation, based on coarse structural/seral stages that are more easily identified at the 1:5000 mapping scale.	• The observed combination of topo-edaphic conditions and species composition in the field sometimes did not clearly match up with any of the pre-defined VCTs. • Only the 43 study areas selected for sampling in 2007 by BCH can be assessed relative to this management question.
2. What are the spatial extents, structure and composition (i.e., relative distribution and diversity) of these communities within the drawdown zone between 434 m and 440 m?	Partially	Findings in 2014 were generally consistent with those of Enns et al. (2007, 2008, 2010, 2012). The PC (Reed Canarygrass) VCT was the most widespread VCT in the drawdown zone, with others following in descending order as follows: PA – Redtop upland > PE – Horsetail lowland > BE – Sandy beach > CR – Cottonwood riparian > LO – Log zone > BG – Gravelly beach > RR – Reed rill > IN – Industrial/disturbed > SF – Slope failure	N/A	• Annual climatic variation • Variable reservoir operations • DEM errors • Only the 43 study areas selected for sampling in 2007 by BCH can be assessed relative to this management question.

Management Question (MQ)	Has MQ been addressed?	Scope		Sources of Uncertainty
		Current supporting results	Suggested modifications to methods where appropriate	
3. How do spatial limits, structure and composition of vegetation communities relate to reservoir elevation and the topo-edaphic site conditions (aspect, slope and soil moisture, etc.)?	Partially	Preliminary findings of Enns (2010, 2012) indicate that soil nutrient regime and moisture availability influence cover within VCTs. Several VCTs show strong correlations with particular elevations. For example CR and PA are found at higher elevations (e.g., 437-440 m ASL); BE, BG, PC and RR occur over a range of elevations (434-438 m ASL) and PE is generally at lower elevations (e.g., 434-435 m ASL). 2014 results show there was a well-defined trend toward increased structural advancement with increased elevation in the drawdown zone. Arrow Lakes had a relatively higher percentage of subplots at the sparse/pioneer SS, and a lower percentage of tall shrub subplots, compared to both the reservoir as a whole and to Revelstoke Reach. Findings in 2014 indicate a relationship between the distribution of vegetation communities in the drawdown zone and effective growing degree units (GDUs) that represented the amount of time that ambient air temperatures were suitable for plant growth, corrected for inundation time. Low elevation pioneering and early seral VCTs typically associate with low historical average summer GDUs (<100). Mid-elevation herbaceous VCTs establish in areas with typically higher summer heat loads (GDUs	Because the present community classification is closely predicated on elevation and topo-edaphic site conditions (consistent with a TEM mapping approach), most of these correlates are already contained in the VCT definitions and thus, as it stands, there is an element of circularity associated with this MQ. We thus recommend deferring further analysis of these environmental correlates as potential predictors of observed vegetation zonation until such time as the current community classification can be revised to be more guild or species-centric (see MQ1 above). Plant height was used as a proxy for structure in earlier studies (e.g., Enns et al. 2010). Structural stage was used instead in 2014 because this is less affected by phenology. Changes in structural stage over time could not be assessed because this variable was not sampled in earlier study years. However, it would be relatively simple in subsequent implementation years to construct retroactively a time series of data as for VCTs, based on the ortho-imagery already available. Such a time series could yield important alternative insights into vegetation dynamics in the drawdown zone.	• Annual climatic variation • Variable reservoir operations • DEM errors • Subjective decisions regarding VCT assignments occasionally required during aerial photo analysis. • A longer time series of data are required to adequately address this question.

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
		between 50 and 200), while shrublands rarely associate with GDUs <100 and Cottonwood forests typically experience at least 200 GDUs. The VCT-GDU relationship appear to be influenced by month, with stronger relationships noted during June and August.		
4. Does the soft constraints operating regime of Arrow Lakes Reservoir maintain vegetation spatial limits, structure and composition of existing vegetation communities in the drawdown zone?	Partially	Preliminary findings of Enns (2012) indicate that soft constraints are maintaining existing vegetation at the landscape level. Similarly, no significant differences in VCT spatial extent or composition occurred between 2007 and 2014 within the drawdown zone of Arrow Lakes Reservoir, or when stratified by elevation band or landscape unit. Nevertheless, several polygons and subplots experienced changes in VCTs over this period. These observed changes attest to the region's dynamic nature even if they did not result in significant differences when testing hypotheses.	N/A	• Annual climatic variation • Variable reservoir operations • Subjective decisions regarding VCT assignments occasionally required during aerial photo analysis.
5. Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?	Partially	The recent operating regime has not resulted in any notable landscape-scale changes in vegetation cover or extent since 2007. Holding reservoir elevations lower than at present (as per the soft constraints goal) would likely result in at least some directional vegetation changes, by (for example) facilitating the advancement of shrubland and/or Reed Canarygrass (depending on location) into upper and mid elevations of the drawdown zone. Such changes may run counter to the soft constraints stated goal of maintaining vegetation status quo above 434 m ASL, although some of these changes (such as greater shrubland development) could result in desirable benefits for vegetation quality, wildlife habitat, and/or social values.	N/A	Lack of examples of low reservoir maximums in recent years prevents proper assessment of the potential effectiveness of holding reservoir elevations lower as a way of maintaining existing vegetation (as per the stated soft constraints goal).

Management Question (MQ)	**Has MQ been addressed?**	**Scope**		**Sources of Uncertainty**
		Current supporting results	**Suggested modifications to methods where appropriate**	
		Given that the goal is to maintain (rather than enhance) existing vegetation in its current state, we feel this will be more effectively achieved by managing the *duration* of inundation during the growing season as opposed to limiting the absolute *depth* of inundation (as represented by the annual maximum achieved). If inundation is necessary, we recommend that peak flood durations be kept as short as possible, both to allow for seedling establishment and completion of reproductive cycles, and to minimize the physiological impact of flooding on upland perennial and woody species especially at upper elevations of the drawdown zone.		
6. Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?	Yes	Results in 2014 concur with those by Enns et al. (2012) in that Revelstoke Reach is not representative of the remainder of the reservoir. The two landscape units are influenced by different topography and climatic regimes and thus exhibit some vegetation differences. Revelstoke Reach has a lower diversity of VCTs, more area under PC, and less vegetated beach area than the Arrow Lakes. In addition, 2014 data indicate that communities in Arrow Lakes have a higher local turnover rate than ones in Revelstoke Reach.	N/A	N/A

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10.0 APPENDICES

10.1 Vegetation Community Types (VCTs)

10.1.1 Summary descriptions of Vegetation Community Types (VCTs) identified for the Arrow Lakes Reservoir (ALR). Adapted from Enns *et al.* (2007; 2012)

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

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

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

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

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

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

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

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

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

PC (Reed Canarygrass mesic)**:** The Reed Canarygrass vegetation type is the mesic vegetation in the ALR and is both very common and widespread, occurring in all the map areas. It is relatively variable, and can be influenced by drainage, moisture regime, and slope position. Materials vary somewhat, but usually consist of gently sloping to flat anoxic, compacted sandy-silty to silty-sandy materials, often with quite coarse sand. Gravel depositional areas can have openings, which result in a few more species than the usual species composition for this VCT. The PC covers large parts of individual polygons and is dominated by Reed Canarygrass with minor amounts of Lenticular Sedge, Common Horsetail, and Pennsylvania Bitter-cress. Reed Canarygrass can be monospecific and form very dense, mostly pure stands of 1 ha or larger in size, especially in

Revelstoke Reach. This type has been heavily grazed by geese in the Arrow Lakes, and in this this condition it can be invaded by several species of sedges, grasses, cranesbill, bedstraw, and other inundation-tolerant or requiring plants.

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

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

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

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

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

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

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

10.1.2 VCT Recommendations

The existing community classification, which is strongly weighted toward topo-edaphic conditions but quite coarse-grained with respect to species composition, yields a number of coarsely-defined VCTs (e.g., PC) that lend themselves reasonably well to aerial mapping but do not completely capture the diversity of plant associations present in the drawdown zone. For example, the classification does not distinguish various common, and potentially diagnostic, vegetation features such as the willow-dominated shrublands occurring in flat or depressional topography at mid elevations, usually in conjunction with PC. By default, previous surveys typically (and apparently incorrectly based on the VCT definitions) assigned this vegetation type to the “PA – Redtop upland” VCT. For consistency, this convention was also followed in 2014. As a result, the abundance and extent of Redtop upland proper has generally been subject to overestimation, while lower elevation shrublands have generally gone unrecognized. Other example of vegetation features apparently underrepresented in the classification are the numerous Lenticular Sedge (*Carex lenticularis*)-Columbia Sedge (*C. aperta*) dominated stands found at mid elevation, and various low elevation floodplain associations (which by default have usually been lumped with the “PE – Horsetail lowland” type despite not strictly meeting the definitions for that type).

During field verification sessions, surveyors sometimes found that the observed combination of topo-edaphic conditions and species composition did not clearly match up with any of the pre-defined VCTs, or with previous aerial mapping. Transitional zones (such as often occur between PC – Reed Canarygrass mesic, BE – Beach, and PE – Horsetail lowland) that are not explicitly accounted for in the classification were difficult to type consistently, and surveyors had to rely on subjective judgment when assigning field plots to specific VCTs in these situations. Similar issues were encountered during the aerial photo interpretation phase because any uncertainties in ground-truthing tended to become amplified when the terrain was viewed as a 1:5000 photo image, with potential implications for the study's replicability both within and among years. To limit the incidence of observer bias across time periods, we retroactively assessed all 2007 imagery used in this report's time series comparisons, making adjustments to the earlier mapping where necessary.

For purposes of reservoir-wide aerial photo monitoring, there would be clear benefits to focusing on a selection of easily identifiable vegetation features that can be reliably detected at the scale of the aerial photo. The terms of reference for CLBMON-33 call a community classification that accurately represents the diversity of plant communities while being coarse-scale enough to be monitored using air photos—but no single classification scheme is likely going to be able to meet both objectives simultaneously.

One alternative is to employ two separate classifications: a first one based primarily on floristics (such as that developed for a similar BC Hydro monitoring project in the Kinbasket Reservoir; Hawkes *et al.* 2007) that more fully addresses management questions around species composition and diversity; and a second one, for use in aerial photo interpretation, based on coarse structural/seral stages that are more easily identified at the 1:5000 mapping scale. This might include distinguishing between such simple categories as "unvegetated" and "vegetated" and, for vegetated sites, between "pioneering herb," "established herb," "shrub," and "forest." Vegetation structure, which in some regards is a more intuitive concept than "vegetation community type," may also be more closely correlated with certain wildlife habitat values of importance to reservoir managers.

For example, Wiens and Rotenberry (1981) noted that vegetation structure was the key factor structuring avian assemblages across habitats at coarse regional scales, while floristics (plant species composition) increases in importance within structurally homogeneous habitats at the local scale. The observation that plant physiognomy outranks floristics in bird–habitat relationships at large scale, and vice versa at local scales, is also consistent with hierarchical models of habitat selection in animal communities (Saab 1999, Harvey and Weatherhead 2006). With this in mind, we undertook preliminary characterizations of vegetation structural stage in 2014, which we discuss further under other MQ subheadings.

Another alternative would be to retain the current community typing in its general form but introduce refinements that allow for improved replicability in future implementation years. For example, the current set of VCT definitions could be revised to more closely reflect the range of vegetation and terrain conditions they were designed to represent, and a set of clearly defined plant cover and terrain thresholds developed for distinguishing different VCTs under ambiguous situations in combination with simple dichotomous classification keys to assist surveyors with field identifications and help ensure consistency among observers. Some example field guides used provincially that could serve as useful models for such an approach include MacKenzie and Moran (2004) and Mackenzie (2012).

10.2 Aerial Photography MetaData[3]

Flight & Camera Details

- Vertically mounted aerial digital camera on gimballed mount.
- Most western shore sites were flown in the morning hours so that tree shadow was not obscuring foreshore; most eastern shore sites flown in afternoon.
- All sites were flown at 15 cm pixel size and subsequently reprocessed to 20 cm, resulting in high quality 20 cm imagery.
- Area photographed is outlined in shapefile (Arrow_areas.shp).
- GPS moving map display used for survey flight guidance.
- Pilot: Chuck Rebstein. Photographer: Jamie Heath.

Camera Details & Calibration

- Alpha Metric FPS medium format digital camera
- Focal length = 99.8 mm
- Principal point offset: x= 0.0 y= -0.0
- Chip Size = 53.904 x 40.4 mm, 60 megapixel
- Radial Distortion: K0= 0.000898734, K1= 2.54638e-007, K2= 3.30237e-012, and K3= -7.78417e-014.
- All photos taken as 16 bit raw imagery, reprocessed to the optimum 8 bit tiffs.

Aerial Triangulation / Ortho Details

- Aerial triangulation completed by COWI and Terrasaurus.
- The existing 2008 and 2011 orthophotos were used as ground control.
- Airborne GPS (ABDGPS) and IMU data were also used in the AT process.
- All colour balancing was completed by Terrasaurus using their proprietary colour program.
- Orthorectifying and mosaicking completed by Terrasaurus.
- A high resolution DEM was used for all sites. The main (northern) area used the DEM that was created in 2011 by 4DGIS, and the southern areas used DEMs created in 2008 by 4DGIS. Terrasaurus created a new DEM for the area between the 2011 northern DEM and Crawford area DEM. The elevation was deliberately kept the same as the Crawford and northern DEM elevation to ensure a contiguous DEM. For the southern sites, Terrasaurus resampled the TRIM DEM and appended it to areas outside of the existing foreshore DEM for more complete DEM coverage.
- Map projection is UTM11, Nad83.
- All mosaics delivered in both Geotiff and ECW formats.
- Individual photos delivered also. All photos are delivered with the exterior orientation data supplied.

Additional Notes

- The Broadwater site was captured as a new site (in southern section of lakeshore, near Castlegar).

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[3] Contributed by Terrasaurus Aerial Photography Ltd.

10.3 Example of data form used to record vegetation and associated site-specific information in plots sampled in 2014

Project ID CLBMON-33: Arrow Lakes Reservoir Inventory of Vegetation Resources **Sheet No.______/______**

Date: **Surveyors:** **Garmin #:** **VCT:**

Poly #: **Plot #** **Wpt. #:** **UTM:**

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

Aspect: ° **Slope:** %

Poly Photo #, wpt #, UTM

Gen. Surface topography: concave convex straight

Microtopraphy: smooth channelled gullied mounded tussocked

Prim. Water Source:

precip. seep stream_sub-irrigation stream_flooding mineral_spring

Soil Moisture:

very_xeric xeric submesic mesic subhygric hygric subhydric hydric

Terrain texture (rank 1-3):

boulders____ cobble____ gravel____ fines____ sand ____ silt____ clay____ mud____ wood____ organics____

Recent evidence of scouring, erosion, or deposition:

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

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

Vegetaion Cover	%	TREE LAYER (A)				
Tree Layer (A)		Species	A1	A2	A3	Tot
Shrub Layer (B)						
Herb Layer						
Seedlings (D)						
Moss (E)						

Shrub Layer (B)						
Species	B1%	B2%	Tot%	B1%	B2%	Tot%

HERB LAYER (C)		
Species	%	Notes

Notes

VCT codes	
BE	Sand beach
BG	Gravelly beach
CR	Cottonwood riparian
PA	Shrub/grasss upland
PC	Reed canarygrass/sedge
PE	Horsetail lowland
RR	Rill - seepage
LO	Woody debris
PO	Pond
RS	Willow stream entry
WR	River entry
BB	Boulders, steep
CL	Cliffs/outcrops
SF	Slumping bank
SS	Steep sand
IN	Indust./recreational disturb.

10.4 Numbers of sample subplots completed in each vegetation community type (VCT) by reservoir region (Arrow and Revelstoke Reach) and elevation band

	Arrow			**Arrow Total**	**Revelstoke Reach**			**Revelstoke Total**	**Grand Total**
VCT	**434 to 436 m**	**436 to 438 m**	**438 to 440 m**		**434 to 436 m**	**436 to 438 m**	**438 to 440 m**		
BB						1		1	1
BE	24	7		31	18	1		19	50
BG	10	4	1	15	4	1		5	20
CR			16	16		3	12	15	31
IN	1			1	2	2	2	6	7
LO			21	21			1	1	22
PA		2	36	38		18	25	43	81
PC	15	58	34	107	54	47	17	118	225
PE	44	7	3	54	4	3		7	61
RR	2	3	2	7					7
SF	1			1					1
Total	97	81	113	291	82	76	57	215	506

10.5 Classification Trees

Classification trees were used to explore the relationships of topo-edaphic variables on vegetation community stability between 2007 and 2014 within subplots. Multivariate classification trees deal well with continuous or discrete variables, nonlinear relationships, complex interactions, missing values, and outliers (De'ath and Fabricius 2000, Moisen 2008), and are useful methods to explore relationships and patterns between response variable(s) of interest and a series of independent variables. A classification tree is built by partitioning the independent variables (e.g., elevation, GDUs) into a series of boxes (the leaves) that contain the most homogeneous groups of objects (in our case, of subplot changes in VCT). Splits are created by seeking the threshold levels of independent variables that produce groups with highest percentage of the same value of the categorical response variable (e.g., "yes" or "no"). Trees can be "pruned" using a similar method to cross validation (Ripley 2014). Classification trees return a misclassification error rate statistic referring to the percentage of objects returned to incorrect leafs after pruning (Ripley 2014).

The response variable was whether or not each of the 405 subplots changed vegetation communities between 2007 and 2014 ("Yes" or "No"). The independent variables included elevation, heatload (aspect weighted by solar exposure and latitude; McCune and Keon 2002), slope, landscape unit, surface and microtopography, primary water source, soil moisture regime, terrain texture, and wave action effects (e.g., erosion and deposition).

Results: Classification trees were useful in highlighting several topo-edaphic variables that could be associated with VCT change in sampled subplots between 2007 and 2014 (e.g., elevation, surface topography, aspect). However, we found the trees to be highly sensitive to the initial input conditions (i.e., the specific combination of covariates used), which tended to result in highly variable predictive threshold values for the different topo-edaphic variables modeled. Misclassification errors were also often high depending on the initial input conditions. Thus, although they provide some heuristic value, the trees are not displayed here to avoid conveying potentially misleading information.

10.6 Kappa test results

Polygons

Kappa values were > 0.8 for all three cases of polygon ranking (dominant, secondary, and tertiary VCTs; Table 10-1), indicating strong similarity between the years. The k-values were significantly different from 0, suggesting that similarities between 2007 and 2014 were not due to chance alone (dominant: k=0.88, 95% CI:0.84-0.92, z=35.3, p<0.0001; secondary: k=0.83, 95% CI:0.78-0.87, z=42.5, p<0.0001; tertiary: k=0.83, 95% CI:0.78-0.87, z=36, p<0.0001). All VCTs exhibited stability over time, especially those rated as the dominant type in a given polygon.

Similar results were obtained after stratifying by the two landscape units, Arrow Lakes and Revelstoke Reach (Table 10-2 and Table 10-3). For Arrow Lakes, kappa was >0.8 for dominant VCTs (k=0.87, 95% CI:0.82-0.92, z=29.8, p<0.0001), and approximately 0.8 for secondary (k=0.80, 95% CI:0.74-0.85, z=34.3, p<0.0001) and tertiary VCTs (k=0.78, 95% CI:0.72-0.84, z=28.7, p<0.0001). Kappa was higher for Revelstoke Reach, suggesting greater stability in vegetation communities within polygons of this region (dominant; k=0.91, CI:0.82-0.96, z=17.2, p<0.0001; secondary: k=0.90, 95% CI:0.81-0.95, z=23.0, p<0.0001; tertiary: k=0.93, 95% CI:0.85-0.97, z=21.1, p<0.0001).

Subplots

The kappa statistic for VCT changes involving sampled subplots was >0.8 (k=0.88, 95% CI:0.84-0.91, z=36.2, p=0), indicating (as for polygons) strong similarity between 2007 and 2014. Kappa was significantly different from 0, suggesting that VCT similarities between 2007 and 2014 were not due to chance alone. All VCTs at the subplot level exhibited stability over time, particularly BG, CR, PA, and RR (Table 10-4).

Similar indications of community stability were obtained when subplots were assessed separately by landscape unit (Arrow Lakes: k=0.855, 95% CI= 0.80-0.90 z=30, p<0001; Revelstoke Reach: k=0.922, 95% CI:0.85-0.97, z=18, p<0001; Table 10-5). As with polygons, community stability was greater in Revelstoke Reach. Lower stability tended to be associated with the most prevalent VCTs in Arrow Lakes: (PC, PE, PA), whereas the most frequent VCTs in Revelstoke Reach (PC, PA) exhibited high stability. Although the net frequency of the LO community within the Arrow Lake region only changed by 1 from 2007 to 2014 (Figure 6-6), this community type had the lowest kappa statistic, possibly reflecting local scale fluctuation.

Table 10-1: Kappa statistics (k) for the polygon dominant, secondary, and tertiary VCTs in the Arrow Lakes Reservoir compared between 2007 and 2014. A k value of 1 indicates complete concordance in VCT relative rankings between 2007 and 2014

Vegetation Community	Dominant			Second dominant			Third dominant		
	k	z	p value	k	z	p value	k	z	p value
IN	0.922	16.66	< 0.0001	0.748	13.50	< 0.0001	0.809	14.62	< 0.0001
SF	1	18.08	< 0.0001	--	--	--	0.497	8.99	< 0.0001
BB	1	18.08	< 0.0001	0.665	12.01	< 0.0001	1	18.08	< 0.0001
SS	1	18.08	< 0.0001	0.856	15.45	< 0.0001	1	18.08	< 0.0001
BG	0.957	17.30	< 0.0001	0.881	15.90	< 0.0001	0.626	11.31	< 0.0001
LO	0.803	14.52	< 0.0001	0.799	14.43	< 0.0001	0.831	15.02	< 0.0001
BE	0.864	15.63	< 0.0001	0.844	15.24	< 0.0001	0.695	12.56	< 0.0001
PE	0.652	11.80	< 0.0001	0.789	14.24	< 0.0001	0.883	15.96	< 0.0001
RR	0.747	13.51	< 0.0001	0.698	12.60	< 0.0001	0.909	16.45	< 0.0001
RS	1	18.08	< 0.0001	1	18.06	< 0.0001	1	18.08	< 0.0001
PC	0.857	15.49	< 0.0001	0.803	14.50	< 0.0001	0.608	10.99	< 0.0001
PA	0.846	15.30	< 0.0001	0.781	14.10	< 0.0001	0.815	14.74	< 0.0001
WR	1	18.08	< 0.0001	--	--	--	0.497	8.99	< 0.0001
CR	0.980	17.71	< 0.0001	0.930	16.79	< 0.0001	1	18.08	< 0.0001
CL	--	--	--	1	18.06	< 0.0001	--	--	--
PO	--	--	--	--	--	--	1	18.08	< 0.0001
No vegetation	--	--	--	0.918	16.58	<0.0001	0.888	16.05	<0.0001

Table 10-2: Kappa statistics (k) for the polygon dominant, secondary, and tertiary VCTs in the Arrow Lakes landscape unit compared between 2007 and 2014. A k value of 1 indicates the VCT was ranked in the same position within the polygons in 2007 and 2014

	Dominant			Secondary			Tertiary		
VCT	k	z	p value	k	z	p value	k	z	p value
BB	1	15.10	<0.0001	0.664	10.03	<0.0001	1	15.10	<0.0001
BE	0.825	12.45	<0.0001	0.832	12.56	<0.0001	0.595	8.98	<0.0001
BG	0.952	14.37	<0.0001	0.879	13.28	<0.0001	0.618	9.33	<0.0001
CR	0.986	14.89	<0.0001	0.904	13.66	<0.0001	1	15.10	<0.0001
IN	1	15.10	<0.0001	0.380	5.73	<0.0001	0.742	11.21	<0.0001
LO	0.798	12.06	<0.0001	0.783	11.83	<0.0001	0.803	12.13	<0.0001
PA	0.866	13.07	<0.0001	0.750	11.32	<0.0001	0.748	11.29	<0.0001
PC	0.820	12.38	<0.0001	0.774	11.69	<0.0001	0.488	7.37	<0.0001
PE	0.648	9.79	<0.0001	0.740	11.17	<0.0001	0.828	12.50	<0.0001
RR	0.746	11.26	<0.0001	0.655	9.90	<0.0001	0.882	13.32	<0.0001
RS	1	15.10	<0.0001	1	15.10	<0.0001	1	15.10	<0.0001
SF	1	15.10	<0.0001	--	--	--	1	15.10	<0.0001
SS	1	15.10	<0.0001	0.855	12.91	<0.0001	--	--	--
WR	--	--	--	--	--	--	0.664	10.03	<0.0001
No vegetation	--	--	--	0.925	13.97	<0.0001	0.865	13.06	<0.0001

Table 10-3: **Kappa statistics (k) for the polygon dominant, secondary, and tertiary VCTs in the Revelstoke Reach landscape unit compared between 2007 and 2014.** A k value of 1 indicates the VCT was ranked in the same position within the polygons in 2007 and 2014

	Dominant			Secondary			Tertiary		
VCT	k	z	p value	k	z	p value	k	z	p value
BB	1	9.95	<0.0001	--	--	--	--	--	--
BE	1	9.95	<0.0001	0.878	8.73	<0.0001	0.918	9.13	<0.0001
BG	1	9.95	<0.0001	0.884	8.79	<0.0001	0.662	6.58	<0.0001
CL	--	--	--	1	9.95	<0.0001	--	--	--
CR	0.960	9.55	<0.0001	1	9.95	<0.0001	1	9.95	<0.0001
IN	0.852	8.48	<0.0001	0.925	9.21	<0.0001	0.898	8.93	<0.0001
LO	--	--	--	1	9.95	<0.0001	1	9.95	<0.0001
PA	0.818	8.14	<0.0001	0.851	8.47	<0.0001	1	9.95	<0.0001
PC	0.919	9.15	<0.0001	0.870	8.65	<0.0001	1	9.95	<0.0001
PE	0.662	6.58	<0.0001	0.879	8.74	<0.0001	1	9.95	<0.0001
PO	--	--	--	--	--	--	1	9.95	<0.0001
RR	--	--	--	1	9.95	<0.0001	1	9.95	<0.0001
RS	1	9.95	<0.0001	1	9.95	<0.0001	1	9.95	<0.0001
SS	--	--	--	--	--	--	1	9.95	<0.0001
WR	1	9.95	<0.0001	--	--	--	--	--	--
No vegetation	--	--	--	0.898	8.93	<0.0001	0.939	9.34	<0.0001

Table 10-4: **Kappa statistics (k) for each VCT sampled by subplots at the landscape level in the Arrow Lakes Reservoir in 2007 and 2014.** VCTs are ordered from non-vegetated to early pioneering to late seral stages

Vegetation Community	k	z	p value
IN	0.799	16.08	<0.0001
SF	0.665	13.39	<0.0001
BG	0.942	18.96	<0.0001
LO	0.741	14.92	<0.0001
BE	0.856	17.23	<0.0001
PE	0.861	17.32	<0.0001
RR	0.908	18.27	<0.0001
PC	0.875	17.60	<0.0001
PA	0.916	18.43	<0.0001
CR	0.939	18.91	<0.0001

Table 10-5: Kappa statistics (k) for each VCT sampled by subplots, stratified by landscape unit (Arrow Lakes and Revelstoke Reach) in 2007 and 2014. A k value of 1 indicates no VCT changes within subplots of that community type between 2007 and 2014. VCTs are ordered from non-vegetated to early pioneering to late seral stages

Arrow Lakes

Vegetation Community	k	z	p value
BE	0.853	13.89	<0.0001
BG	1	16.28	<0.0001
CR	0.968	15.75	<0.0001
LO	0.722	11.75	<0.0001
PA	0.889	14.47	<0.0001
PC	0.833	13.56	<0.0001
PE	0.833	13.57	<0.0001
RR	0.907	14.77	<0.0001
SF	1	16.28	<0.0001

Revelstoke Reach

Vegetation Community	k	z	p value
BE	0.853	10.099	<0.0001
BG	0.826	9.772	<0.0002
CR	0.892	10.558	<0.0003
IN	0.796	9.423	<0.0004
LO	1	11.832	<0.0005
PA	0.943	11.162	<0.0006
PC	0.943	11.153	<0.0007
PE	1	11.832	<0.0008

10.7 Growing degree days (GDUs)

The first GDU boxplot (Figure 10-1) shows the range of GDU levels that each VCT experienced (on average) between 2004 and 2014 across its occupied elevation strata. Not unexpectedly, non-vegetated terrain types such as BB and SF tend to occupy the lower GDU bands suggestive of extended inundation periods. Also not surprisingly, the LO (woody debris) type occupies the upper end of the GDU spectrum, consistent with a typical position near the reservoir's upper waterline at full pool. There is a notable trend from lower to higher GDUs among the "primary" vegetated VCTs (BG, BE, PE, RR, PC, PA, and CR) that appears related to seral stage (with early seral stages characterized by low GDU and later seral stages by high GDU). The second GDU boxplot (Figure 10-2) displays the same information but with average annual GDUs calculated separately for each month from June to September. In this case, a similar patterning with respect to primary VCT distributions is evident though the relationship between GDUs and seral stage appears stronger for some months (June and August) than others (July and September).

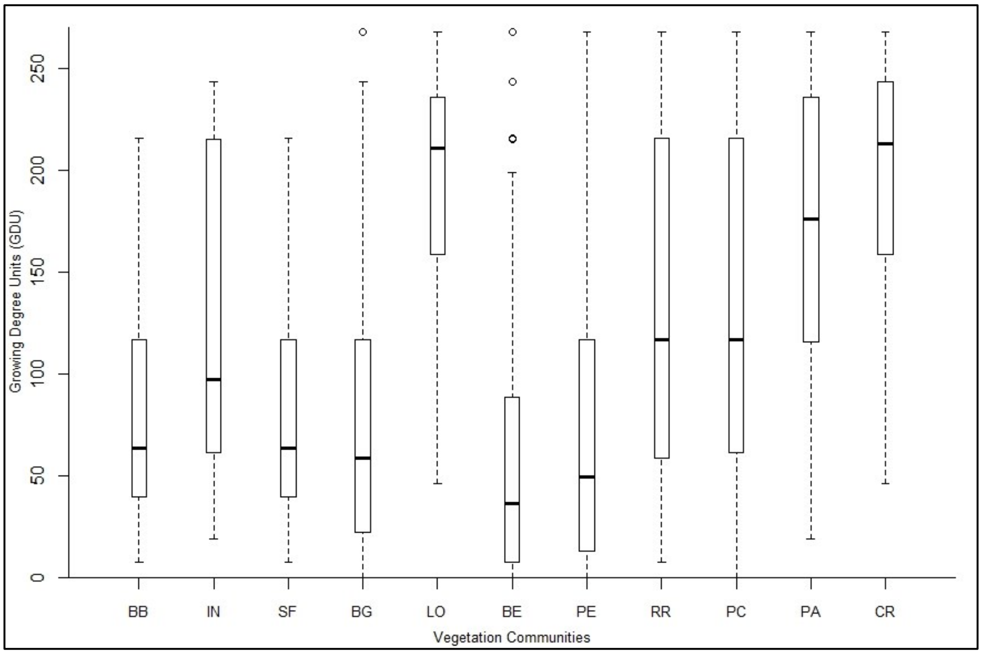

Figure 10-1: Variation in growing degree units (GDUs) in relation to 2014 subplot vegetation communities in the Arrow Lakes Reservoir. GDUs for each VCT were averaged over June to September for each year. The length of the boxes illustrates the extent of variation in GDUs among years and subplots for a given vegetation community.

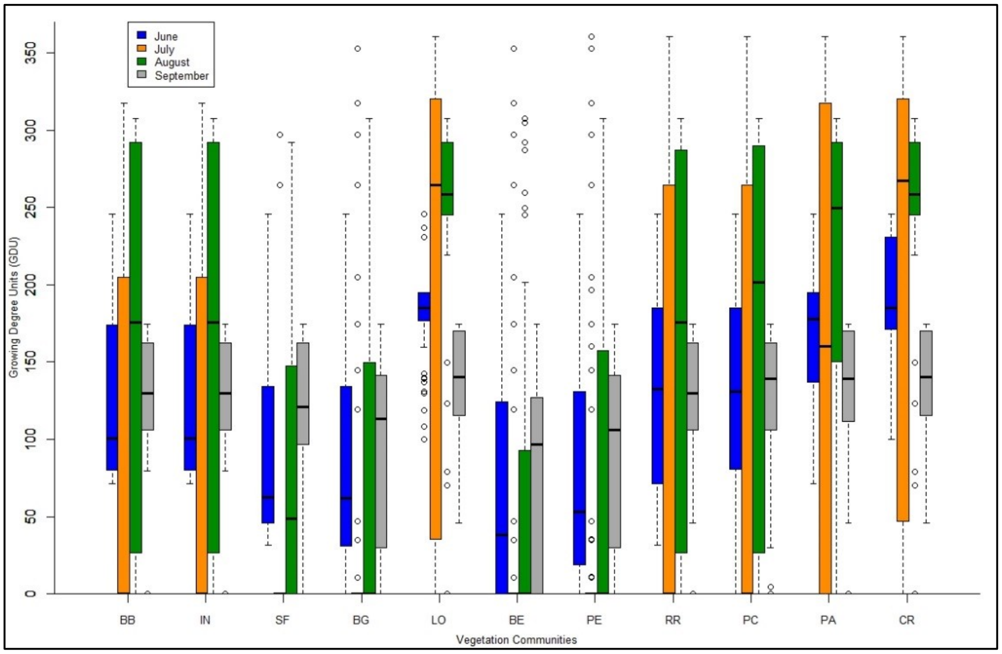

Figure 10-2: **Variation in growing degree units (GDUs) in relation to 2014 subplot vegetation communities in the Arrow Lakes Reservoir.** The length of the boxes illustrates the extent of variation in GDUs among and within years and among subplots for a given vegetation community.