Columbia River Project Water Use Plan

Kinbasket and Arrow Revegetation Management Plan

Implementation Year 6

Reference: CLBMON-33

Arrow Lakes Reservoir Inventory of Vegetation Resources

Study Period: 2016

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

May 2018

KINBASKET AND ARROW LAKES RESERVOIRS

Monitoring Program No. CLBMON-33

Arrow Lakes Reservoir Inventory of Vegetation Resources




Implementation Year 6 – 2016

Final Report

Prepared for

BC Hydro Generation

Water Licence Requirements
Burnaby, BC

Prepared by

Michael T. Miller[1], Ph.D.

Pascale Gibeau[2], M.Sc., R.P.Bio.

and

Virgil C. Hawkes[1] M.Sc., R.P.Bio.

[1]LGL Limited
environmental research associates
9768 Second Street
Sidney, British Columbia, V8L 3Y8

[2]Ripple Environmental
Vancouver, BC

Suggested Citation

Miller, M.T., P. Gibeau, and V.C. Hawkes. 2018. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources. Final Report–2016. LGL Report EA3545B. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 74 pp + Appendices.

Cover photos

From left to right: BG community type, Arrow Park; LO community type, Beaton Arm; PE community type, Edgewood; PC community type, 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 and map the distribution of existing vegetation in the drawdown zone of the Arrow Lakes Reservoir. The primary objectives of this 10-year study are: (i) to monitor trends in the spatial extent, structure, and composition of vegetation communities within the 434-440 m ASL elevation band in relation to inundation cycles; and (ii) to assess if implementation of the Water Use Plan operating regime (2007-2017), including soft constraints,[1] is effective at maintaining vegetation communities at the local and landscape scales.

This summary report synthesizes results at the project's 10-year mark (2016), representing the 6th and final study year. As in previous years, the study design used field sampling of repeat monitoring plots in combination with aerial photos 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, 2010, 2012, 2014, and 2016). For 2016, orthophoto interpretation was applied to a subsample of the 2,287 vegetation polygons previously mapped by Enns *et al.* (2007, 2010) and representing ~2,067 ha of mapped vegetation in the drawdown zone.

Operation of the reservoir has resulted in identifiable vegetation zonation patterns within the drawdown zone between 434 m and 440 m that are correlated to varying degree with reservoir inundation cycles, substrate conditions, and topography. To date, 21 vegetation community types (VCTs) have been delineated based on commonalities in species composition, elevation, soil moisture regime, soil texture, and slope position. When tracking vegetation trends at the landscape and site levels, we also found it useful to discuss vegetation pattern and process in terms of two other organizational levels: (i) structural stage (e.g., early pioneering, herbaceous, shrubland, forest); and (ii) plant functional groups or "guilds" (e.g., herbs, grasses, sedges, shrubs). Compared to VCT delineations, changes in coarse structure or functional composition may have more direct bearing on wildlife values of management interest.

Multivariate models (e.g., multivariate regression trees [MRT]) that included as variates total plant cover, species richness, cover by species, or cover by guild were used to explore vegetation relationships with different abiotic factors such as time, elevation, daily reservoir levels, inundation timing and duration, ambient air temperatures, and topo-edaphic site conditions (e.g., soil moisture, water source, substrate texture, slope, and micro-topography). Data collected over multiple years on inundation timing/ duration and air temperatures were combined into a single integrative metric: effective growing degree days (GDDs).

Since 2007, there has been a moderate degree of inter-annual fluctuation, but little net (directional) long-term change in the spatial configuration, frequency, and composition of

[1] Soft Constraints are operational targets developed by the Columbia Water Use Planning Consultative Committee (WUP CC) for the benefit of various interests (vegetation, wildlife, fish, culture and heritage, recreation, erosion, and power generation). Each target identifies the ideal/preferred reservoir operations (water level over the year) for a specific interest. While the reservoir was not operated to target specific soft constraints, the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2017, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 48% of the time.

VCTs at the landscape scale. In terms of vegetation structure, the extent of herbaceous and sparse/pioneer structural stages fluctuated somewhat over time, with the former decreasing and the latter increasing toward the middle years of the monitoring period. Shrublands showed a slight increasing trend over time. However, none of the structural stages showed a large net change between 2007 and 2016.

At the local, intra-community level, there have been small but statistically significant declines since 2010 in overall plant cover at all elevations, and in the cover of certain plant groups (forbs, sedges and sedge allies, horsetails) but not others (grasses, shrubs). This decrease was accompanied by a small increase in species richness over time. Diversity (Shannon's H) has not changed significantly over time. It is unknown if the local declines in cover reflects a longer-term trend or merely an inflection point in a continuously fluctuating vegetation cycle. There is currently no compelling evidence to indicate that the operating regime of Arrow Lakes Reservoir during implementation of the Water Use Plan (2007-2016) is failing to maintain overall spatial limits, structure, and composition of existing vegetation communities in the drawdown zone.

The drawdown zone of Arrow Lakes Reservoir supports a vegetation assemblage that is adapted to, and may even depend on, a variable regime of seasonal flooding as part of annual moisture requirements. We predict that the Water Use Plan operating regime can continue to maintain existing vegetation in its present state so long as the historical pattern of variability in hydroperiod is maintained. However, if the objective is to enhance existing vegetation types, our models suggest that both cover and structural diversity at all elevations can be maximized in the following way: (i) by delaying inundation for as long as possible in the spring (preferably until after June), to allow time for germination, establishment, and the completion of reproductive cycles; (ii) by allowing for sufficient June/July inundation at low and mid elevations (434-438 m ASL) to reduce summer drought stress for inundation-adapted species; and (iii) by minimizing (but not eliminating) the depth and duration of inundation at high elevations (>438 m ASL), to maintain herbaceous cover while facilitating woody shrub establishment and growth.

The status of CLBMON-33 in 2016 (final implementation year) with respect to the management questions and management hypotheses is summarized below in tabular form.

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

<table>
<tr><th>Management Question (MQ)</th><th>Summary of Key Results</th></tr>
<tr><td>1. What are the existing riparian and wetland vegetation communities in Arrow Lakes Reservoir drawdown zone between 434 m and 440 m?</td><td>
<u>Summary Findings</u>
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.
While the original classification yielded a number of landscape-scale VCTs that lend themselves fairly well to aerial mapping, these VCTs did not completely capture the diversity of plant associations present in the drawdown zone. To help address some of the identified gaps, in 2016 we characterized seven additional VCTs that emphasized floristic attributes of sub-associations not recognized by the existing classification. The list of identified VCTs is as follows:

Boulders, steep
Sandy beach
Gravelly beach
Saskatoon–cliffs and rock outcrops
Cottonwood riparian
Shrub riparian
Industrial/ residential/ recreational
Log zone
Redtop upland
PC–Willow
PC–Reed canarygrass
PC–Foxtail/horsetail
PC–Sedge
PE–Foxtail
PE–Sedge
Pond
Reed–rill
Willow stream entry
Failing slope
Steep sand
River entry

<u>Sources of Uncertainty/ Limitations</u>

VCT typing has proved difficult to apply consistently across years and observers, because observed combinations of site conditions and species composition do not always correspond well with the existing VCT classification.
Only the 43 study areas selected for sampling in 2007 by BCH have been formally assessed, meaning some wetland types (e.g., marshes) have been under-represented in the mapping.

<u>Comments</u>
The original community classification of Enns et al. (2007) has undergone periodic revisions to make it align more closely with conditions on the ground. Nevertheless, the division of drawdown zone vegetation into separate “community types” is by nature a somewhat arbitrary exercise aimed at introducing order to what is essentially a rather fluid environment for the purpose of addressing the MQs. It may be more accurate to regard the vegetation of the drawdown zone as single complex community composed of an affiliation of numerous intergrading species associations, with certain associations being more clearly demarcated on floristic grounds than others.
</td></tr>
</table>

Management Question (MQ)	Summary of Key Results
	Given the practical challenges around community typing, we found it useful to cast vegetation pattern and process in terms of two other organizational levels, in addition to VCTs: (i) vegetation structure; and (ii) plant species functional groups, or "guilds." Compared to VCT delineations, data on structure and guild composition may have more direct bearing on wildlife values of management interest.
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?	**Summary Findings** Findings in 2016 were generally consistent with those of Enns *et al.* (2007, 2008, 2010, 2012). Operation of the reservoir has resulted in identifiable vegetation zonation patterns within the drawdown zone between 434 m and 440 m that are correlated to varying degree with elevation, reservoir operations, and topo-edaphic features. The PC – Reed canarygrass VCT is the most widespread VCT in the drawdown zone, accounting for over 35 per cent of vegetated cover in 2016. After PC, BE–Sandy beach, BE–Gravelly beach, and PE–Horsetail lowland associations are the next most extensive VCTs, with each accounting for between 10 and 15 per cent of cover at the landscape scale. Relative frequency of other VCTs follows in roughly descending order as: CR–Cottonwood riparian > Shrub riparian = PC–Willow > LO–Log zone = RR–Reed-rill > SS–Steep Sand > RS–Willow stream entry = BB–Boulders, steep = WR–River entry > SF–Slope failure. **Sources of Uncertainty/ Limitations** • Only the 43 study areas selected for sampling in 2007 by BCH have been formally mapped and can be assessed relative to this management question. • Resolution and colour quality of available aerial imagery is often insufficient for estimating vegetation spatial limits or distinguishing between vegetation community types except at a coarse scale. • The relative spatial extents of VCTs are now well established, but as yet there have been no precise estimates made of total VCT coverages (in hectares). • Possible errors associated with the current digital elevation model (DEM) Only the 43 study areas selected for sampling in 2007 by BCH can be assessed relative to this management question. **Comments** No further vegetation mapping is recommended under CLBMON-33 program. However, for future mapping that might be associated with revegetation efforts, consider employing alternative remote sensing technologies (e.g. infrared, LiDAR) that will allow aerial images to be divided into patches of different tone, texture and pattern that correspond to different vegetation states and that allow for rapid and precise landscape-level vegetation measurements using computer digitizers or GIS-based image analysis systems.
3. Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?	**Summary Findings** The two geographic areas, which are influenced by different climatic regimes and land use histories, differ substantially with respect to vegetation structure and composition; Revelstoke Reach is shrubbier and has a lower diversity of species, more area under reed canarygrass (which was intentionally seeded here), and less vegetated beach area than the Arrow Lakes. Arrow Lakes VCTs are less temporally stable, and potentially more sensitive to changes in the operating regime over time, than the vegetation of Revelstoke Reach.
4. 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.)?	**Summary Findings** Several VCTs show strong correlations with particular elevations. For example, CR and PA are found at higher elevations (e.g., 437-440 m ASL); BG, PC, and RR occur over a range of elevations (434-438 m ASL) and PE and BE are generally at low elevations (e.g., 434-435 m ASL). Within VCTs, soil drainage and moisture availability affect cover and species composition. These relationships will be more fully catalogued under CLBMON-35 (program in progress).

Management Question (MQ)	Summary of Key Results
	There is a well-defined trend toward increased structural advancement with increased elevation in the drawdown zone (i.e. higher sites have more woody structure). Arrow Lakes has a relatively higher percentage of area at the sparse/pioneer stage, and a lower percentage of shrubland, compared to Revelstoke Reach. Species richness in Arrow Lakes Reservoir does not appear to be strongly correlated with elevation. The highest recorded species numbers were obtained in 2017 samples of the low-elevation Kellogg's sedge community (PE–Sedge), while the mid-and high-elevation PC–Reed canarygrass VCT was consistently the least speciose. Models distinguished several plant guild and species clusters on the basis of growing degree days (GDDs), latitude, soil moisture regime, elevation, and primary water source. For example, sites receiving minimal July inundation were more likely to be associated with high relative shrub cover than sites with more regular July inundation, which were more strongly correlated with high relative herb high cover. Cover of reed canarygrass was associated with latitudes north of Nakusp, moist to wet sites, and elevations < 437.5 m ASL. Cover of Kellogg's sedge was correlated with southerly latitudes, low elevations (< 435.5 m ASL), and uneven microtopography. **<u>Sources of Uncertainty/ Limitations</u>** • Site history: vegetation in specific locations may reflect past events (e.g. anthropogenic disturbance) more than, or as much as, current conditions. • Variable reservoir operations • Possible DEM errors • Lack of a formal study (experimental) control, which is necessary to separate operational effects from other environmental effects **<u>Comments</u>** Findings from CLBMON-35 (Arrow Lakes and Kinbasket Reservoirs Plant Response to Inundation) can be used to inform on whether obtaining quantitative data on soil moisture, soil structure, and soil organic content would improve our understanding of how spatial extent, structure and composition of vegetation communities relate to topo-edaphic site conditions (such as substrate, drainage, aspect, and slope). The MRT models provide a useful way of predicting species composition at sites for which only environmental data are available. They could also be useful for identifying suitable receptor sites for revegetation or other physical works aimed at habitat enhancement, and for ensuring that the species chosen for out-planting are an appropriate match for existing habitat conditions at receptor sites. This will be further explored in CLBMON-35.
5. 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?	**<u>Summary Findings</u>** Since 2007, there has been a moderate degree of inter-annual fluctuation, but little net (directional) long-term change in the spatial configuration, frequency, and composition of vegetation community types or VCTs at the landscape scale. There is currently no compelling evidence to indicate that the Water Use Plan operating regime of Arrow Lakes Reservoir is failing to maintain overall spatial limits, structure, and composition of existing vegetation communities in the drawdown zone. We predict that the operating regime can continue to maintain existing vegetation in its present state so long as the historical pattern of variability in hydroperiod is maintained. **<u>Sources of Uncertainty/ Limitations</u>** • Variable reservoir operations from year to year. • Lack of a formal study (experimental) control, which is necessary to separate operational effects from other environmental effects • Lack of historical baseline information on the conditions that pertained prior to introduction of soft constraints • The duration of this monitoring program may not have been long enough to fully assess the long-term effects of the operating regime on the spatial extent of existing vegetation communities.

Management Question (MQ)	Summary of Key Results
	<u>Comments</u> This MQ cannot be directly addressed because the reservoir was not operated to target specific soft constraints. Soft constraints were operational targets; the general operation under the WUP allowed for variation where the soft constraint for vegetation was partially met. From 2008 to 2016, the soft constraint target for vegetation (≤ 434 m ASL between April and October) was met 48% of the time. Decisions regarding the location and frequency of future vegetation work should be informed by gap analysis results coming out of the related program CLBMON-35 (Arrow Lakes and Kinbasket Reservoirs Plant Response to Inundation).
6. Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?	**<u>Summary Findings</u>** In theory, opportunities exist for modifying operations to maintain communities at the landscape scale more effectively, but this idea has not been adequately tested. The drawdown zone of Arrow Lakes Reservoir supports a vegetation assemblage that is adapted to, and may even depend on, a variable regime of seasonal flooding as part of annual moisture requirements. Without the opportunity to directly test alternative operating scenarios, it appears that the best way to ensure that the operating regime continues to maintain the existing vegetation status quo is to maintain a similar level of variability in hydroperiod to that which has prevailed historically. if the objective is to enhance existing vegetation types, our models suggest that both cover and structural diversity at all elevations can be maximized in the following way: (i) by delaying inundation for as long as possible in the spring (preferably until after June), to allow time for germination, establishment, and the completion of reproductive cycles; (ii) by allowing for sufficient June/July inundation at low and mid elevations (434-438 m ASL) to reduce summer drought stress for inundation-adapted species; and (iii) by minimizing (but not eliminating) the depth and duration of inundation at high elevations (>438 m ASL), to maintain herbaceous cover while facilitating woody shrub establishment and growth. **<u>Sources of Uncertainty/ Limitations</u>** • The variable annual reservoir operations that have prevailed since the start of the study in 2007, combined with insufficient replication of alternative operational regimes, limits our ability to make specific predictions around vegetation impacts stemming from alterations to the frequency, timing, depth, and duration of inundation. • The comment above (MQ5) regarding duration of the monitoring program also applies to this MQ. **<u>Comments</u>** This MQ cannot be directly addressed under the current reservoir operating constraints. At present we can only suggest hypotheses, based on the best available data, regarding the potential long-term outcomes of different hydroperiod scenarios.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the following individuals for their assistance in coordinating and conducting this study. Mark Sherrington administered the project for BC Hydro. Guy Martel and Kat Enns (DHI) provided information and data pertaining to earlier fieldwork and reports. Alexis Friesen (ONA), Kayla Williams (ONA), Autumn Solomon (ONA), Evan McKenzie, and Jamie Fenneman assisted in the field. Autumn Solomon assisted with data entry and data summaries. ONA participation was overseen and coordinated by Alan Peatt (ONA). Julio Novoa assisted with GIS analysis and Yury Bychkov developed the Access database. Mark Sherrington, Dave Polster, Carrie Nadeau, and Stacey Boczulak provided helpful comments on an earlier draft.

List of contributors

Okanagan Nation Alliance (ONA)

Alan Peatt, B.Sc., Dipl.T., R.P.Bio.

Alexis Friesen, B.Sc., B.B.A.

Kayla Williams, B.Sc.

Autumn Solomon, B.Sc.

LGL Limited environmental research associates

Michael T. Miller, Ph.D.

Virgil C. Hawkes, M.Sc., R.P.Bio.

Julio Novoa, M.Sc.

Yury Bychkov, M.Sc.

Contractors

Evan McKenzie, B.Sc.

Jamie Fenneman, Ph.D (cand.), R.P.Bio.

Pascale Gibeau, Ph.D (cand.), R.P.Bio.

Terrasaurus Aerial Photography Ltd.

Chuck Rebstein

Jamie Heath

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The shorelines of reservoirs managed for power production can undergo seasonal and diurnal water level changes that far surpass those associated with natural flood regimes. Usually measured in tens of vertical metres, reservoir drawdown zones (the area between low and high water lines) tend to be highly dynamic, ruderal environments whose vegetation bears little similarity to that which existed prior to river impoundment (Abrahams 2005, Lu *et al.* 2010). The submergence of the original shoreline requires that new shoreline vegetation develop at higher elevations on often poorer soils that lack a riparian seed bank. The cycle of winter drawdown, followed by rising water levels through the spring, summer, and fall months, runs counter to the natural flood regime (spring/summer freshet) and results in an abbreviated growing window. Prolonged inundation during the growing season produces a repeating cycle of succession consisting of establishment, growth, and disturbance that can serve to retain vegetation in an early (often depauperate or weedy) seral state. Steep and unstable banks, long fetches and associated wave action, loss of organic matter, low soil nutrients, accumulations of woody debris and associated mechanical scouring, and erosion and sediment deposition provide additional challenges to vegetation establishment in the drawdown zone (Johnson 2002, Abrahams 2005).

In Arrow Lakes Reservoir, an impoundment of the Columbia River in British Columbia, water level elevations are managed by BC Hydro under a regime that permits a normal annual minimum of 418.64 metres above sea level (m ASL) and a normal maximum of 440.1 m ASL—a difference of 21.46 m. Between this annual allowance, water levels change daily throughout the growing season. Primary drawdown occurs during the winter, with reservoir elevations reaching their minimum in April. With the arrival of warmer spring temperatures comes snow melt and the freshet along with a reduced need to produce power, which results in the refilling of the reservoir until the maximum elevation for the year is achieved in later summer or early fall, at which time power production increases and the drawdown recommences. While the overall pattern is predictable, the timing, depth, and duration of inundation experienced by each elevation band varies markedly from year to year. The resulting stress on vegetation establishing within those elevation bands is exacerbated by processes of wave action, sediment deposition, and erosion. Because of these difficult growing conditions, much of the foreshore is barren or only lightly vegetated. Where conditions do support plant growth, hydrological gradients or topographic relief can produce strong patterns of plant community zonation, resulting in a mosaic of vegetation types that includes wetland complexes, pioneering annual forb, perennial sedge and graminoid associations, shrub and treed communities, and driftwood zones.

The cumulative impacts on reservoir shoreline vegetation communities, and associated impacts on ecosystem functioning, wildlife values, and aesthetics, were not addressed until 2001 when BC Hydro entered into the Water Use planning process (WUP) for its mainstem Columbia River facilities. During this process, the WUP Consultative Committee (WUP CC) recognized the value of vegetation in improving aesthetic quality, controlling dust storms, protecting cultural heritage sites from erosion and human access, and enhancing littoral productivity and wildlife habitat (BC Hydro 2005). The WUP 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 because 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 (WLR) project to assess the impacts of the Water Use Plan operating regime, including soft constraints, 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 the 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 was designed to span a period of ten years (2007–2016), and to occur in alternating years from 2008 onward. Work completed during the first five implementation years (2007, 2008, 2010, 2012, and 2014) 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, Miller *et al.* 2015). Here, we report results at the project's 10-year mark (2016), representing the 6th and final implementation year.

2.0 MANAGEMENT QUESTIONS AND HYPOTHESES

The general objectives of CLBMON-33 are to a) identify and delineate existing vegetation communities by elevation, and b) evaluate how the current operating regime of Arrow Lakes Reservoir affects vegetation communities at the landscape scale. Management questions for the monitoring program specifically address these objectives as follows (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: Is the current distribution of vegetation communities in Revelstoke Reach representative of conditions in the remainder of the reservoir?

MQ4: 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.)?

MQ5: 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?

MQ6: Are there operational changes that can be implemented to maintain existing vegetation communities at the landscape scale more effectively?

Monitoring was 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 438-440 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 Days (GDDs) – 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. Also referred to as Growing Degree Units (GDU).

Geographic region – one of two broad areas within the Arrow Lakes Reservoir: Revelstoke Reach (northern section) and Arrow Lakes (southern section, including Beaton Arm and Lower Arrow Lakes). Two biogeoclimatic zones are represented in the study area: interior Cedar Hemlock (ICH) and Interior Douglas-fir (IDF). The majority of the study area falls within the ICH, with IDF being restricted to the southernmost portion.

Plots – sampling units for obtaining field (or ground-truthing) data within each experimental unit. In 2016, field data were collected within 10 m x 5 m (50-m^2) rectangular plots at randomized locations within sample polygons.

Sample – selection of 100-m^2 circular orthophoto points and 50-m^2 rectangular ground plots located within different community types, elevation bands, and geographic regions (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.

Vegetation community type (VCT) – a general classification for vegetation communities found in the drawdown zone of Arrow Lakes Reservoir, consisting of habitats that share similar vegetation, soil moisture regimes, substrate, and topography. Not all VCTs are typically vegetated, and certain VCTs are more diagnostic of reservoir effects than others. Summary descriptions of individual VCTs are provided in Appendix 11.1

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 were monitored within 43 discrete mapping areas previously selected by BC Hydro (based partly on access considerations) and covering 2,037 hectares (Enns *et al.* 2010; Figure 4-1). The distance between the southernmost site at Deer Park, northeast of Castlegar, and Revelstoke Dam is ~230 km.

Although the 43 study units represent over half the total drawdown zone between 434 and 440 m ASL, they are large, relatively flat, and more vegetated compared to other sections of the reservoir. Therefore, they may not represent a true proportion of the habitat types in the entire drawdown zone. However, the vegetation monitored within these units is believed to be characteristic of the reservoir vegetation as a whole (Enns *et al.* 2010).

Further details on study area climate, physiography, and geology are provided in Enns *et al.* (2007).

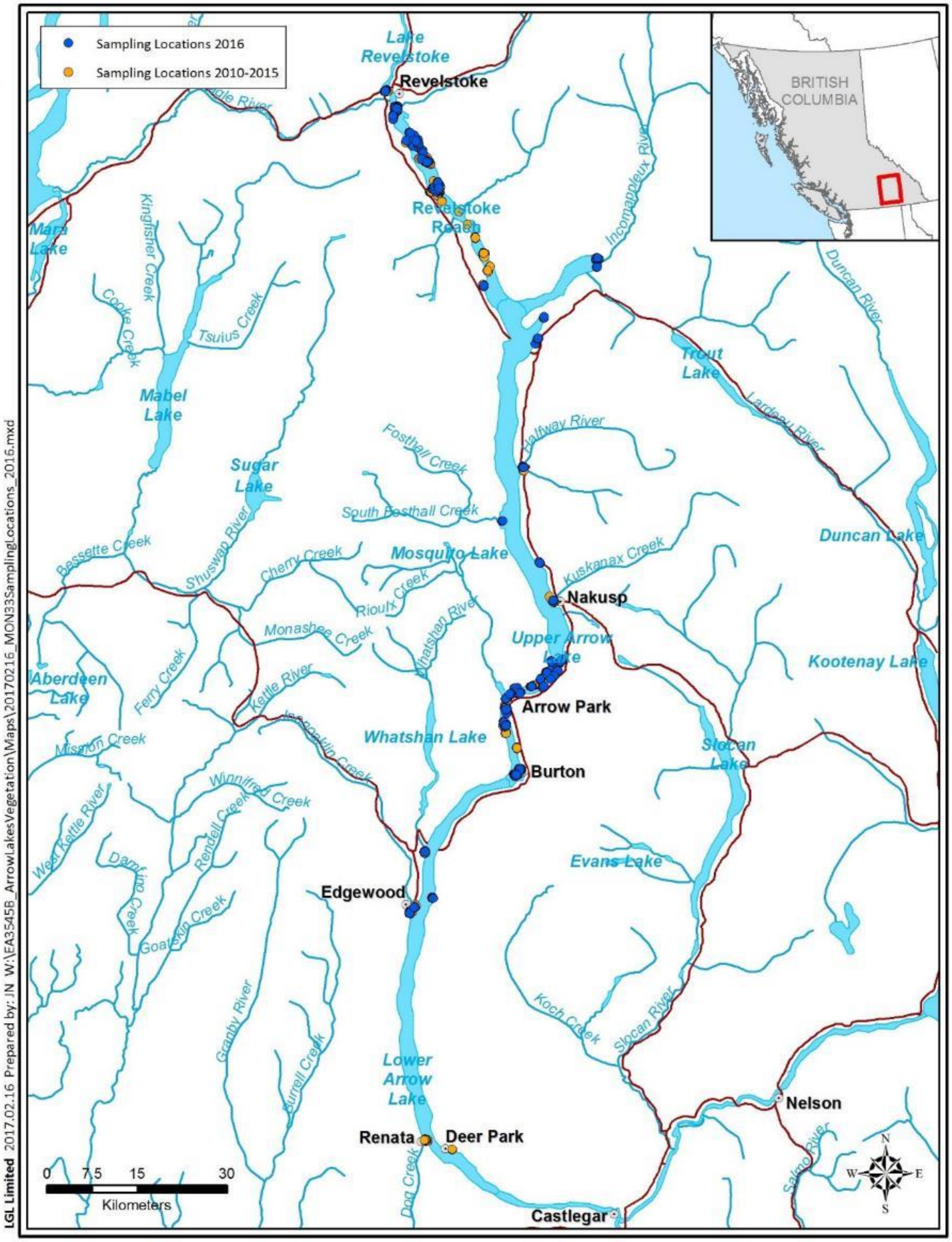


Figure 4-1: Location of the CLBMON-33 project in the drawdown zone of the Arrow Lakes Reservoir, between Revelstoke Dam and Castlegar B.C. 2016 plot locations (blue dots) are overlaid on top of plot locations from 2010-2015 (gold dots), obscuring some of these from view.

5.0 METHODS

5.1 Study Design Overview

5.1.1 2007-2014 Study Years

The project was designed in 2007 (Enns 2007, Enns *et al.* 2007), with minor revisions to the study design occurring at subsequent study intervals (e.g., Enns *et al.* 2008, 2010, 2012). Generally, work completed between 2007 and 2014 used a combination of aerial photo interpretation and repeat sampling of permanent field plots to monitor changes in a defined set of Vegetation Community Types or VCTs first described by Enns *et al.* (2007). The VCTs were based on combinations of similar topography, parent materials or soils, and vegetation features (Appendix 11.1). Base mapping was created in 2007 (and revised in 2008 and 2010) by drawing vegetation polygons onto aerial photographic mosaics at a scale of approximately 1: 20,000 for the 43 mapping areas. Polygons were delineated so as to capture similar groupings of physiographic features and vegetation (e.g. a headland). Approximately 2,000 polygons were mapped. The relative covers of VCTs within polygons were expressed as deciles, i.e., in 10 per cent increments. Each polygon could include up to three VCTs (Enns *et al.* 2007).

For purposes of ground-truthing and monitoring of local trends, polygons were stratified by geographic area (reservoir reach), elevation band, and VCT. Field measurements were carried out within a subsample of smaller (500-m^2 to 400-m^2) biomonitoring plots haphazardly located (via blind stick toss) within each selected polygon. Some of these field plots were shared with—and similarly sampled as part of—the concurrent project CLBMON-12 (Enns *et al.* 2009, Enns and Enns 2012), which operated in alternate (odd years) to CLBMON-33. Thus, some field plots were sampled in successive years (as opposed to alternate years). Other plots were dropped from the study as new ones were added in response to sampling design adjustments (Enns *et al.* 2010, 2012). The high plot turnover between 2007 and 2012 resulted in a set of monitoring plots with highly variable annual sampling histories.

Although the project terms of reference (BC Hydro 2007) placed primary emphasis on the interpretation of spatiotemporal patterns of vegetation 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 early effort was focused on tracking site-level (i.e. within-community) trends (Enns *et al.* 2007, 2008, 2010, 2012). This approach led to some overlaps in methods and results between CLBMON-33 and CLBMON-12, which was explicitly designed to assess vegetation at the site level (BC Hydro 2008). Consequently, for implementation year 5 (2014) the focus was limited to an analysis of landscape-level trends (Miller *et al.* 2015). In that year, vegetation polygons were field-sampled as part of the aerial ground-truthing but the original field plots established by Enns *et al.* (2010) were not resampled (Miller *et al.* 2015).

5.1.2 2016 Landscape-level Assessment

As in previous years, the 2016 study design relied on aerial imagery of Arrow Lakes Reservoir drawdown zone acquired prior to summer inundation to assess landscape-level trends in vegetation condition over time. The photo time series consisted of imagery from 2007, 2010, 2012, 2014, and 2016 (aerial photos were also captured in 2008 but only after the drawdown zone had already been partly inundated, limiting their utility). Orthophoto interpretation was applied to a subsample of the 2,287 vegetation polygons previously mapped by Enns *et al.* (2007, 2010) and representing ~2,067 ha of mapped vegetation in the drawdown zone.

In previous time series comparisons, the main dependant variable was the VCT composition of polygons, and specifically the magnitude and direction of decile change in VCT coverage within polygons (Enns *et al.* 2012, Miller *et al.* 2015). However, Miller *et al.* (2015) identified two problems with the current approach. First, the VCTs as originally defined were closely predicated on elevation and topo-edaphic features and relatively coarse-grained with respect to species composition. Because these physical parameters tend to be fixed in space, the VCTs based upon them can also be expected, by definition, to be spatially static. Consequently, their potential sensitivity as landscape-level indicators of soft constraints impacts is unclear. Second, it was found that the combinations of site conditions and species compositions observed in the field often failed to match up with the pre-defined VCTs. This also meant that VCTs as currently defined were difficult to distinguish reliably from the 1:5000 air photos.

Therefore, for purposes of aerial photo monitoring, Miller *et al.* (2015) recommended switching to a simplified classification system based on vegetation structural stages or functional guilds more readily identifiable from the air. It was considered that a simplified system based on coarse habitat structure would yield 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 (Miller *et al.* 2015).

This recommendation was partially adopted for the 2016 iteration of CLBMON-33. We retained the VCT-based assessment (in modified form; see below, Section 5.1.40), and included an assessment of vegetation structural stage. Using aerial imagery, VCT and structural attributes were assigned to a set of random points in the drawdown zone. Each point was assigned a unique identifier, then resampled through time by sequentially overlaying the bi-annual orthophoto mosaics obtained from 2007 to 2016. This point sample approach, which replaced the "decile" approach of previous implementation years, yielded a spatially explicit time series of vegetation conditions that was used to model observed community shifts against year, elevation band, and geographic region.

5.1.3 2016 Site-level Assessment

For the 2016 (and final) implementation year, ground sampling was geared toward restoring, as far as possible, the data time series established in previous study years. Because of substantial study design changes introduced after 2009 (Enns *et al.* 2010), pre-2010 field data were considered incompatible with a repeated measures design[2]. Instead, the sample population in 2016 consisted of field plots visited at a minimum either in 2010 or 2012. Some of these plots were also

[2] Prior to 2010, field plots consisted of three 0.5-m^2 quadrats nested within a larger 50-m^2 plot. Since 2010, only the larger plot dimension was sampled, resulting in a different data structure and cover estimates.

sampled in 2011 and/or 2013. Extending this (limited) time series through 2016 allowed us to address several CLBMON-12 management questions relating to local-scale dynamics that, for practical reasons, were deferred during the previous implementation of CLBMON-12 (Miller *et al.* 2016).

A total of 427 field plots were resampled in 2016 (Figure 5-1, Appendix 11.17). As in previous years, sampling was stratified geographically between the two major landscape units, Revelstoke Reach and Arrow Lakes, and encompassed study sites on both sides of the reservoir between Edgewood in the south and Big Eddy, north of Highway 1 at Revelstoke (Figure 4-1). Specific reservoir locations visited in 2016 included (from south to north): Edgewood (north and south), Applegrove, Lower Inonoaklin Rd., Burton Creek, Dixon Creek, Fairhurst Creek, Arrow Park (east and west shores), Saddle Bay, McDonald Park, Nakusp, Turner Creek, Fosthall Creek, Halfway River, Galena Bay, Beaton Arm, Cranberry Creek, Drimmie Creek (12 Mile), Duncan Flats (8 Mile and 9 Mile), Cartier Bay, West Revelstoke, Illecillewaet River, and Big Eddy.

Figure 5-1: Examples of repeated 50-m^2 field plots monitored in 2016, illustrating different vegetation community types (VCTs) in the Arrow Lake Reservoir drawdown zone. Top left: BE–Sandy beach; top right: PC- Reed canarygrass; bottom left: PE–Sedge; bottom right: PA–Redtop upland. Photos taken in May 2016 by M. Miller.

5.1.4 Vegetation Community Types (VCTs)

For the current study year, we retained the overall community classification system developed by Enns *et al.* (2007, 2010), but introduced some refinements to the community coding so that it aligned more closely with conditions observed on the ground (following recommendations by Miller *et al.* 2015). The original community codes are listed in Table 5-1 and are further detailed in Appendix 11.1. Newly-recognized VCTs are as follows:

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

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

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

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

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

VI. **PE–Foxtail** (formerly included with PE–Horsetail lowland). Various low elevation floodplain and seepage associations have by default been lumped with the "PE–Horsetail lowland" type despite not strictly meeting the definitions for that type (Appendix 11.1). These are typically moist to wet, sloping sites with predominantly mineral soils, supporting a ruderal mix of annual herbs and low-statured grasses and rushes. Presence of the tufted grass, little meadow-foxtail, is a common diagnostic feature. Other frequent species include marsh yellow cress (*Rorippa palustris*), purslane speedwell (*Veronica peregrina*), nodding chickweed (*Cerastium nutans*), narrow-leaved montia (*Montia linearis*), and Canada bluegrass (*Poa compressa*). The nationally rare species moss grass (*Coleanthus subtilis*) comprises a notable element on some flat and depressional sites.

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

Table 5-1: Vegetation community types (VCTs) of Arrow Lakes Reservoir. Original names (from Enns *et al.* 2010) are shown along with recently introduced revisions to the classification (in bold). Not all VCTs (e.g., BB, SF, SS) are typically vegetated.

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

5.2 Reservoir Operations

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

5.3 Growing Degree Days

Exposure time on its own may not provide an accurate indication of the "growing time" available to plants at a given drawdown zone elevation. This is because plant development rates are strongly influenced by, among other factors, ambient daily air temperatures. Because temperatures can vary greatly from year to year, it is difficult to predict plant growth based on the calendar alone. To control for ambient air temperatures when assessing vegetation response to inundation, we computed growing degree days (GDDs). The GDD calculation assigns a standardized heat value to each day during the growing season based on daily mean temperature. Daily GDD 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 days as "growing degree units" (Miller *et al.* 2015), here we employ the former term in keeping with common convention.

GDDs 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)[3]. GDDs 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. GDDs were calculated for the drawdown zone for each day during April–September 2004–2014 using the following formula:

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

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 1968). Any average daily temperature that was less than the base temperature was set to the base temperature before performing the GDD calculation, giving a GDD for that day of zero. Likewise, daily GDD was set to zero if a site was inundated on that day—regardless of the ambient atmospheric temperature.

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

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

5.4 Aerial Photo Acquisition

Aerial photos of the Arrow Lake Reservoir foreshore were captured with a vertically mounted aerial digital camera on May 7th, 2017 under sunny conditions by Terrasaurus Aerial Photography Ltd. A few of the southern area beaches were flown on May 10th, 2016. Flight dates were earlier than the 2014 flights (late May) to accommodate the earlier rise in water levels. Reservoir elevations ranged from 432.6 to 433.2 m ASL during photo acquisition. Photos were taken in optimum sun angles (shadows facing away from the beach). The west side of the reservoir was captured in the late morning, the east side in early afternoon. The imagery was captured at a 15-cm scale, and subsequently reprocessed as 20-cm orthophotos. Additional photo acquisition metadata are included in Appendix 10.2.

5.5 Orthophoto Interpretation

A total of 936 points, representing 220 mapped vegetation polygons, were sampled during the imagery comparisons. Sample polygons were drawn from a subset of 398 vegetation polygons previously randomly stratified and selected by Omule and Enns (2010) for comparing 2007 against 2010 imagery, supplemented by a few additional polygons haphazardly chosen to compensate for gaps in habitat representation, or as replacements for polygons deemed unsuitable for on-screen sampling. Polygons were rejected for sampling if they were obscured by shadows, or if the image was murky or the resolution too low to make a reasonable comparison between years. Polygons ranged in size from <0.1 ha to >30 ha (averaging 1.2 ha). The distribution of sampled polygons was such that all the photo-monitored study areas were included in the comparison. For each polygon, a set of one to five random UTM coordinates was generated in GIS and pinned onto the ortho-mosaics (from different years) displaying that polygon. An approximately 5-m radius circle around the point was examined on-screen to arrive at a vegetation classification for each time step.

Five measures were taken at each of the point samples during the polygon review: (i) vegetation structural stage, (ii) VCT, (iii) elevation, (iv) sub-reach and reach, and (v) UTM coordinates. Structural stages were recorded in categories readily identifiable at the 20 cm scale of the orthophotos. Following structural categories identified in B.C. Ministry of Environment, Lands, and Parks and B.C. Ministry of Forests (2010), these were defined as: (1a) sparse or pioneer vegetation; (2) herb-dominated habitat; (3) shrubland; and (5) young forest. Similarly, not all the VCT refinements described in Section 5.1.4 were distinguishable on the aerial imagery. Thus, VCT assignments generally followed the original classification, but included the following two new types: PC–Willow, and Shrub riparian.

An attribute table by year was created for the individual points. For each sample year, the relative frequency of each structural stage and VCT was calculated based on the proportion of samples in which they were recorded. This value was used to approximate the ubiquity on the landscape and, by extrapolation, the relative spatial extent of each structural stage or community type for a given year (e.g., 2016) or geographic area (e.g., Revelstoke Reach). Relative frequency was treated as a dependent variable in spatial comparisons and time series analyses conducted in support of the management questions.

5.6 Field Sampling

Field sessions were timed to correspond with sampling in previous study years. Vegetation sampling occurred during two field sessions: May 10–22 and May 27–June 5, when the reservoir elevation was between 433 and 437 m ASL. A crew of four workers participated in each of the two field sessions. Site access was via truck and on foot. Permanent monitoring plots were relocated in the field using a hand-held GPS receiver (Garmin GPSMap 60CSx).

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

Per cent cover, measured as the percentage of the ground surface covered when the crowns are projected vertically, was visually estimated and rounded as follows: <1% - traces; 1-10% - rounded to nearest 1%; 11-30% - rounded to nearest 5%; 31-100% - rounded to nearest 10%. Percent covers were considered additive due to overlapping crowns and final tallies for species and layers could exceed 100% cover. Other attributes recorded at each sample location are listed in Table 5-2. Information on slope aspect was subsequently used to compute "heatload," which is aspect weighted by solar exposure and latitude (McCune and Keon 2002). The 2010 digital elevation model (DEM) supplied by BC Hydro was used to determine plot elevations.

5.6.1 Plot Resampling Histories

Because of changes that occurred over time with respect to sampling design (Enns *et al.* 2010, Miller *et al.* 2015), site access, and inundation timing, the subset of field-sampled plots varied substantially in composition from year to year. Relatively few plots were resampled every year between 2010 and 2016 (the period chosen for this assessment; Section 5.1.3). Beginning from 2010, most plots were resampled two to three times; a total of 33 were resampled the maximum possible six times (Table 5-3). However, out of the more than 400 plots visited in 2016, 319 could be paired with comparable data from 2010: 126 at low elevation, 98 at mid elevation, and 95 at high elevation, providing strong data support for conducting repeated-measures analyses over this time frame.

Table 5-2: Attributes collected for plot samples using field data form.

Attribute	Unit / Category
Date	
Surveyor(s)	
Location	Site descriptor and reservoir reach
Plot number	
Waypoint and UTM coordinates	easting and northing
Vegetation community type (VCT)	See Section 3.0 for original VCT categories and Section 0 for modified VCTs
Photo numbers	Photos taken from centre of plot facing north, east, south, west
Slope aspect	Compass 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
Wave action effects	Qualitative evidence of scouring, erosion, or deposition – yes or no
Recent 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

Table 5-3: Number of field plots that were resampled a given number of times (years) over the six yearly sampling periods, by elevation band. Years were 2010, 2011, 2012, 2013, 2015, and 2016. Because 2014 plots were not repeated (either before or after), they are not included in the counts.

Elevation Band (m ASL)	No. Times Resampled					
	2	**3**	**4**	**5**	**6**	Total
434-436	90	59	17	34	14	214
436-438	64	38	26	30	14	172
438-440	81	48	22	23	5	179
Total	235	145	65	87	33	565

5.7 Statistical Analyses

5.7.1 Landscape-level Assessment

The orthophoto analyses yielded annual point count data for VCTs and structural stages spanning the years 2007, 2010, 2012, 2014, and 2016. The data were organized into frequency distribution tables stratified by year, elevation, and reservoir region. We assumed that the frequency of a VCT or structural stage in an area was generally correlated with its ubiquity on the landscape and, by extrapolation, its spatial extent (Miller *et al.* 2015).

Pearson chi-square statistics with Monte-Carlo simulations (n=100,000) were used to test the significance of changes in attribute (VCT and structural stage) frequency across time, stratified by elevation. Specifically, we tested the hypothesis that the relative proportions of VCTs and structural stages were independent of year. Separate analyses were conducted for the two reservoir regions (Arrow Lakes and Revelstoke Reach).

To maintain consistency with earlier reports (Enns *et al.* 2010, 2012), Kappa tests (Sim and Wright 2005) were also conducted to characterize the degree of consistency in VCT and structural stage attributes over time. The Kappa tests assessed whether the number of times that a point on the ground exhibited the same attribute over the monitored time period was different than that expected from chance alone.

The Kappa statistic is defined as:

$$K = \frac{P_o - P_c}{1 - P_c}$$

Where P_o is the proportion of observed agreements and P_c is the proportion of agreements expected by chance (Sim and Wright 2005). A value of 1 indicates perfect agreement in VCT or stage structure among years, i.e., that each point sample showed the same attribute in all years. A value of 0 would mean that the agreement among 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 indicates the degree of agreement among years; values between 0.61 and 0.80 suggest substantial agreement, while values above 0.80 suggest almost perfect agreement (Landis and Koch 1977). The kappa (K) statistics were statistically tested using a null hypothesis of K=0. Significant results indicated K was statistically different than 0, meaning the agreement in vegetation communities between years was not due to chance alone.

5.7.2 Site-level Assessment

As in previous implementation years (e.g., Enns *et al.* 2012), field data from sampled 50-m^2 monitoring plots were used to assess within-community trends in plant cover, species richness, and species diversity over time. All statistical analyses were performed in R version 3.3.1 (R Development Core Team 2007).

We used line graphs and Tukey's boxplots (described in Hawkes *et al.* 2013) to display variation in these attributes among elevation bands, geographic regions, and years for three organizational levels: total vegetation (all species combined); plant guilds (herbs, grasses, shrubs, etc.); and VCTs (vegetation community types). Differences between 2010 and 2016 (repeated plots) were tested statistically with repeated-measures ANOVAs using a generalized linear mixed model (GLMM, Zuur *et al.* 2007). Use of GLMMs allowed for an explicit consideration of the repeated nature of the data by including plots as a random effect.

GLMMs were then used to assess variation in total cover and richness over time (all years from 2010 to 2016, including both repeated and non-repeated plots) against a backdrop of operational and non-operational variables (Table 5-2). Operational variables were: inundation timing/duration (represented by the standardized metric of growing degree days, or GDDs) for April-September; and average monthly water depth for June-September. Non-operational variables included elevation; geographic location; surface topography; soil moisture and texture; and evidence of water energetics effects (scouring, erosion, and/or deposition).

Two series of models were built: one that included elevation as an explanatory variable, and one that included GDDs and average depth of inundation per month. Because GDDs and inundation depth are derived from elevation, they could not be included in same model. Continuous explanatory variables, which varied with respect to units and dimensions, were standardized prior to inclusion (Legendre and Legendre 2012). Cover and richness were log-transformed to ensure that models were fitted to a positive scale. To allow for a presumed 1-yr lag in vegetation response to inundation, GDDs and inundation depths were set to time *t*-1 (i.e., they were correlated with vegetation attributes in the following year).

During model selection, diagnostic plots were reviewed to determine how the data aligned with fitting assumptions. Models with the lowest AIC (Akaike information criterion) were selected. Results were displayed as separate coefficient plots showing the value of the regression coefficients (effect size) for each explanatory variable, along with a measure of their variation (± 2 SE with confidence interval). The width of the confidence intervals gives an indication of the confidence in both the magnitude and sign (positive or negative) of the coefficient. Intervals that cross the 0 line indicate lack of confidence in the effect described by the coefficient. The significance of the GLMMs was tested via a wald test, which approximates the likelihood ratio test that tests each coefficient against the full model containing all coefficients. GLMMs were performed using the R package 'nlme' (vers. 3.1-129).

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

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

For guilds, two MRTs were generated: one based just on cumulative monthly (April-Sept.) GDDs for 2010-2016; and one based on a wider array of environmental variables including GDDs, average monthly water depth, UTM-X, UTM-Y, slope, heat load, surface topography, soil moisture, and substrate texture.

For the species MRTs, we first modeled 2016 cover and frequency data relative to elevation and other environmental variables (UTM-X, UTM-Y, slope, heat load, surface topography, primary water source, soil moisture, soil texture, disturbance, and evidence of water energetics effects (scouring, erosion, and/or deposition). Species included were those present in at least 10 plots (out of the 372 possible), for a total of 66 species. A second model included 2010 plant cover data, GDDs, and inundation depths (while excluding elevation as a variable). This model included all species present in at least 15 plot-year samples (out of 674 possible samples), for a total of 70 species.

As with the GLMMs (above), GDDs and inundation depths were set to time *t*-1 to allow for a presumed 1-yr lag in vegetation response to inundation.

6.0 RESULTS

6.1 Reservoir Operations and GDDs

Water levels in the Arrow Lakes reservoir between 2008 and 2016 (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 2015 and 2016, but particularly during 2015, were low compared to years prior. In 2015, water levels peaked on 13 June at 435.48 m, remaining at or above 435.4 m for a total of six days before receding (Figure 6-1).

The proportion of time each 1-m elevation band between 434 and 440 m was above water during each month from May to September is shown in Table 6-1. In most years, exposure time began to decrease in June each year with most of the lowest six elevation bands (434-439 m) completely inundated in July. Receding water levels after this time result in increased exposure time during August and again in September. In 2015, in contrast, all but the lowest elevations (434-435 m) were fully exposed for the entire growing season (Table 6-1).

Effective growing degree days (GDDs) indicate the number of accumulated heat units available for plant growth each month, once time underwater has been accounted for (Table 6-2). GDDs during April and May are consistent across most elevation bands each year, since reservoir water levels are typically below 434 m during these periods. Effects of inundation on GDDs at the lower elevations become apparent during late May (e.g., 2008, 2010, 2013, 2016) and June, with effects becoming pronounced across most elevations by July. Nevertheless, the combination of variable monthly temperatures combined with a variable hydroperiod results in considerable variability in cumulative monthly GDDs per 1-m elevation band across years. For example, July GDDs were notably higher in 2015 and 2016 than in previous years, especially as compared to 2012, whereas 2008 and 2011 both had relatively low August GDDs. June GDDs were higher at low elevations, but reduced at upper elevations, in 2009 compared to 2015, a reflection of the earlier onset of inundation, but warmer June temperatures, that prevailed in 2015. In 2016, April GDDs were substantially higher than at any time in the previous decade, due solely to the unusually warm spring temperatures that year (Table 6-2).

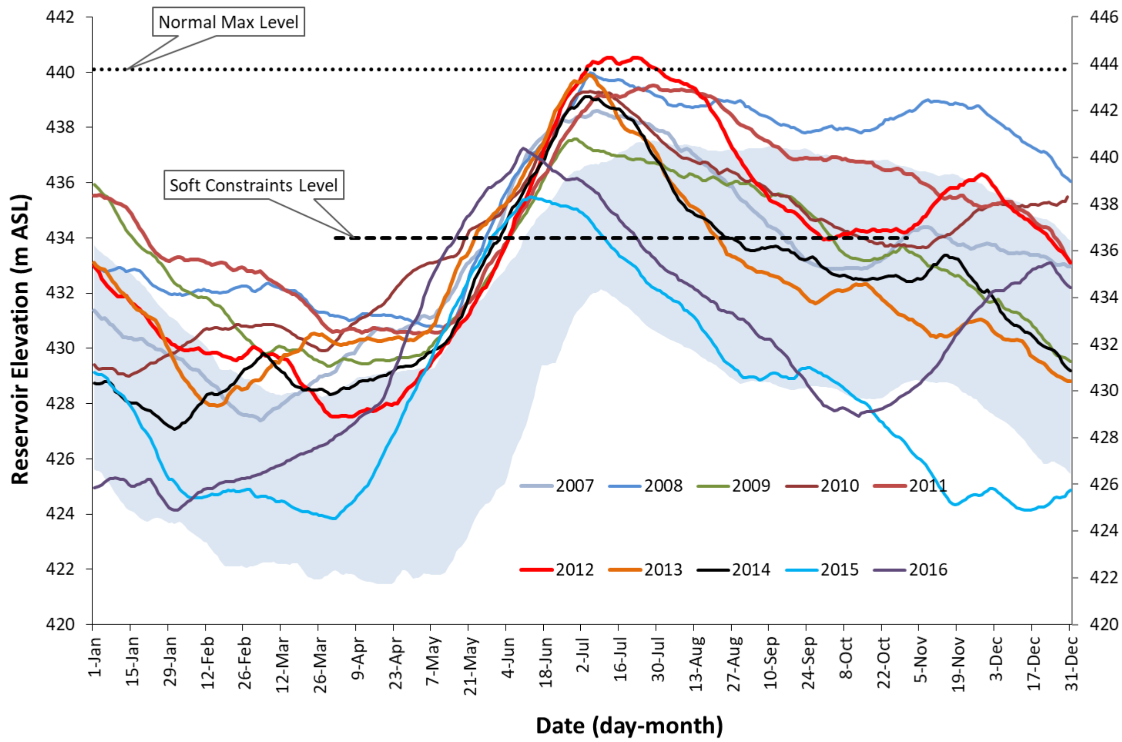


Figure 6-1: Daily water levels in Arrow Lakes Reservoir shown by year for 2006–2016. . Shaded area illustrates the range of the daily 10th and 90th percentile of water levels across all years. Normal Max Level: normal maximum operating level of the reservoir (440.1 m ASL). Soft Constraints Level: maximum reservoir level targeted under soft constraints for vegetation for the period April 1 to Oct. 31. Target was met 48 per cent of the time between 2008 and 2016.

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, 2006–2016. For visual reference, cells are arbitrarily colour-coded to reflect relative monthly exposure times: red: < 0.1 or ~0-3 days; yellow: 0.1–0.9 or ~3-27 days; green: > 0.9 or ~27-31 days. Note: period for soft constraints is May-October; present analyses are based on the period April-September to coincide with the main growing season.

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

Table 6-2: Available monthly GDDs during each year (2006-2016) within each 1-m elevation band from 434–440 m ASL in Arrow Lakes Reservoir. The total calculated GDDs for an elevation band based on daily mean temperatures for each month were weighted by the proportion of time the elevation band was above water that month. For visual reference, cells are arbitrarily colour-coded to reflect relative GDD accumulation: red: 0 GDDs; yellow: > 0 ≤ 150 GDDs; green: > 150 GDDs.

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

6.2 Landscape-level Assessment

6.2.1 Community Composition

The most frequently recorded VCT in random point samples of aerial imagery was the reed canarygrass-dominated community, PC, followed (in similar proportions) by BE–Sandy beach, BE–Gravelly beach, and PE–Horsetail lowland (Figure 6-2).

Observed VCT frequencies (pooled and by elevation band; Appendix 11.4, 11.5) did not significantly deviate over time from their expected frequencies, either in Revelstoke Reach or Arrow Lakes (χ^2, p>0.6 in all instances). Similarly, Kappa statistics (Appendix 11.6, Appendix 11.7) were very high both for Revelstoke Reach (k=0.96, Z=110, p<0.0001) and Arrow Lakes (k=94, Z=184, p<0.0001), implying a high degree of agreement among yearly point samples.

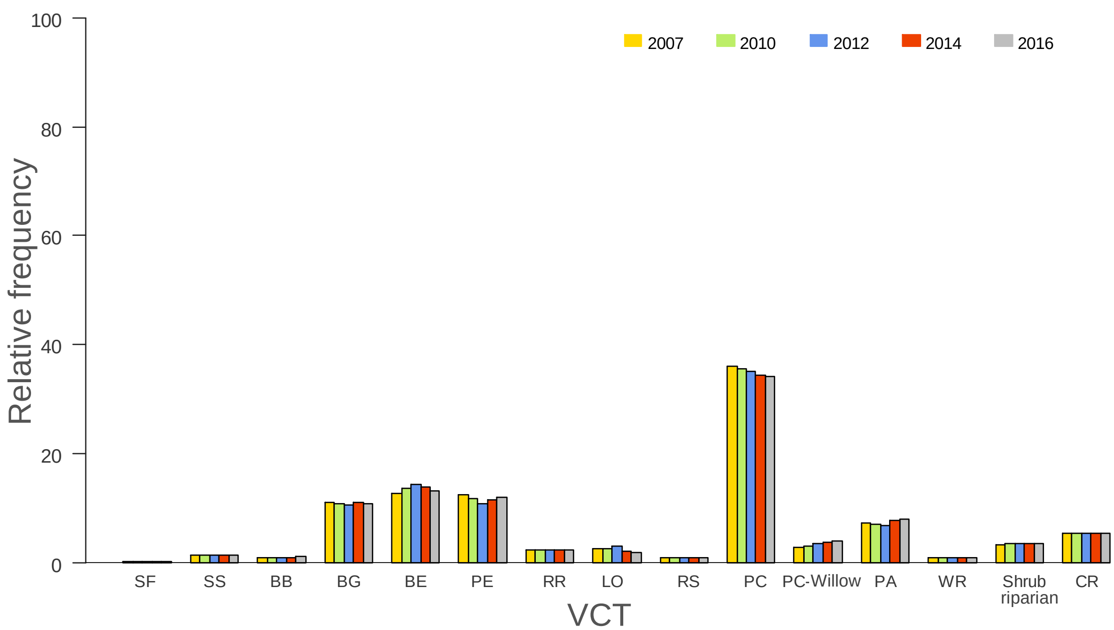


Figure 6-2: Relative frequency (proportion) of vegetation community types (VCTs) in point samples (*n*=936) of aerial imagery obtained for Arrow Lakes Reservoir from 2007 to 2016. The VCT categories assessed were limited to those visible at the scale of the available imagery, and do not differentiate among some of the finer-scale VCTs defined in Table 5-1. χ^2 test results indicated non-significant changes in VCT frequency over time.

On a case-by-case basis, the comparison of sample points from just 2007 and 2016 indicated that, out of 310 points sampled in Revelstoke Reach, a total of 15 (5 per cent) had transitioned to a different state at the end of the 10-year period. Most changes involved PE at low elevation (transitioning either to BE, PC, or SF) and PC at mid elevation (transitioning to BE or PC–shrub). No changes were recorded for the high-elevation band (Table 6-3).

Out of 676 points sampled in Arrow Lakes, a similarly modest proportion (6 per cent) changed state between 2007 and 2016 (Table 6-4). In this instance, changes affected a small number of BB, BG, PE, and PC at low elevation (with the latter two VCTs both transitioning to BE); some BG, LO, PC, and PA at mid elevation; and BE, LO, PC, PA, and CR at high elevation. Most of the recorded changes were at high elevation and involved shifts in and out of LO (the woody debris or "log zone”). There were also some instances of increased shrub cover in the reed canarygrass (PC) zone, resulting in a reclassification to PC–shrub (Table 6-4).

Table 6-3: Number of orthophoto sample points that transitioned between vegetation community types (VCTs) or remained stable from 2007 to 2016, along with the VCT to which the points changed, in Revelstoke Reach (Arrow Lakes Reservoir).

Elevation band	Vegetation Community	Number of points				
		Total	changed	stable	Per cent changed	changed for what
Low	SF	--	--	--	--	--
	SS	--	--	--	--	--
	BB	1	0	1	0	--
	BG	1	0	1	0	--
	BE	17	1	16	6	PC
	PE	36	3	33	8.3	BE(1), PC(1), SF(1)
	RR	1	0	1	0	--
	LO	--	--	--	--	--
	RS	--	--	--	--	--
	PC	95	1	94	1.1	PE(1)
	PC-shrub	1	0	1	0	--
	PA	--	--	--	--	--
	WR	4	0	4	0	--
	Shrub-riparian	--	--	--	--	--
	CR	--	--	--	--	--
Mid	SF	--	--	--	--	--
	SS	--	--	--	--	--
	BB	2	0	2	0	--
	BG	5	0	5	0	--
	BE	--	--	--	--	--
	PE	4	0	4	0	--
	RR	--	--	--	--	--
	LO	--	--	--	--	--
	RS	--	--	--	--	--
	PC	49	9	40	18	BE(1), PC-shrub(8)
	PC-shrub	13	1	12	8	PC
	PA	10	0	10	0	--
	WR	--	--	--	--	--
	Shrub-riparian	2	0	2	0	--
	CR	1	0	1	0	--
High	SF	--	--	--	--	--
	SS	--	--	--	--	--
	BB	--	--	--	--	--
	BG	1	0	1	0	
	BE	--	--	--	--	--
	PE	--	--	--	--	--
	RR	--	--	--	--	--
	LO	--	--	--	--	--
	RS	--	--	--	--	--
	PC	19	0	19	0	
	PC-shrub	10	0	10	0	--
	PA	9	0	9	0	--
	WR	3	0	3	0	--
	Shrub-riparian	9	0	9	0	--
	CR	17	0	17	0	--

Table 6-4: Number of orthophoto sample points that transitioned between vegetation community types (VCTs) or remained stable from 2007 and 2016, along with the VCT to which the points changed, in Arrow Lakes (Arrow Lakes Reservoir)

Elevation band	Vegetation Community	Number of points				
		Total	changed	stable	Per cent changed	changed for what
Low	SF	1	0	1	0	--
	SS	10	0	10	0	--
	BB	3	1	2	33	PC
	BG	48	3	45	6	BB(1), BE(1), PC(1)
	BE	88	0	88	0	--
	PE	66	2	64	3	BE(2)
	RR	18	0	18	0	
	LO	--	--	--	--	--
	RS	2	0	2	0	--
	PC	60	1	59	2	BE
	PC-shrub	--	--	--	--	--
	PA	--	--	--	--	--
	WR	1	0	1	0	--
	Shrub-riparian	--	--	--	--	--
	CR	--	--	--	--	--
Mid	SF	--	--	--	--	--
	SS	1	0	1	0	--
	BB	4	0	4	0	--
	BG	27	1	26	3.7	PC(1)
	BE	9	0	9	0	--
	PE	8	0*	8	--	* changed to BE from 2010 to 2014, but back to PE in 2016
	RR	3	0	3	0	--
	LO	2	1	1	50	PA
	RS	3	0	3	0	--
	PC	73	4	69	5	shrub-riparian(2), BG(1), LO(1)
	PC-shrub	1	0	1	0	--
	PA	14	2	12	14	BG(1), LO(1)
	WR	1	0	1	0	--
	Shrub-riparian	--	--	--	--	--
	CR	2	0	2	0	--
High	SF	--	--	--	--	--
	SS	2	0	2	0	--
	BB	--	--	--	--	--
	BG	14	0	14	0	--
	BE	5	1	4	20	PC
	PE	1	0	1	0	--
	RR	--	--	--	--	--
	LO	24	11	13	46	BE(2), PA(7), PC(2)
	RS	2	0	2	0	--
	PC	41	7	34	17	LO(4), PC-shrub(3)
	PC-shrub	2	0	2	0	--
	PA	37	4	33	11	BG(1), LO(2), shrub-riparian(1)
	WR	--	--	--	--	--
	Shrub-riparian	18	0	18	0	--
	CR	32	1	31	3	RS

6.2.1.1 Statistical Conclusion

Based on these results, we accept the null hypothesis H_{0A}: "Under the soft constraints operating regime, there no significant change in the spatial extent (number of hectares) of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir."

6.2.2 Structural Composition

The most frequently recorded structural stage in random point samples of aerial imagery was the herbaceous stage. The relative frequencies of this stage and of the sparse/pioneer stage fluctuated somewhat over time, with the former decreasing and the latter increasing toward the middle years of the monitoring period. Frequency of shrubland showed a slight increasing trend over time. However, none of the structural stages showed a substantial net change between 2007 and 2016, the start and endpoints of the monitoring period (Figure 6-3).

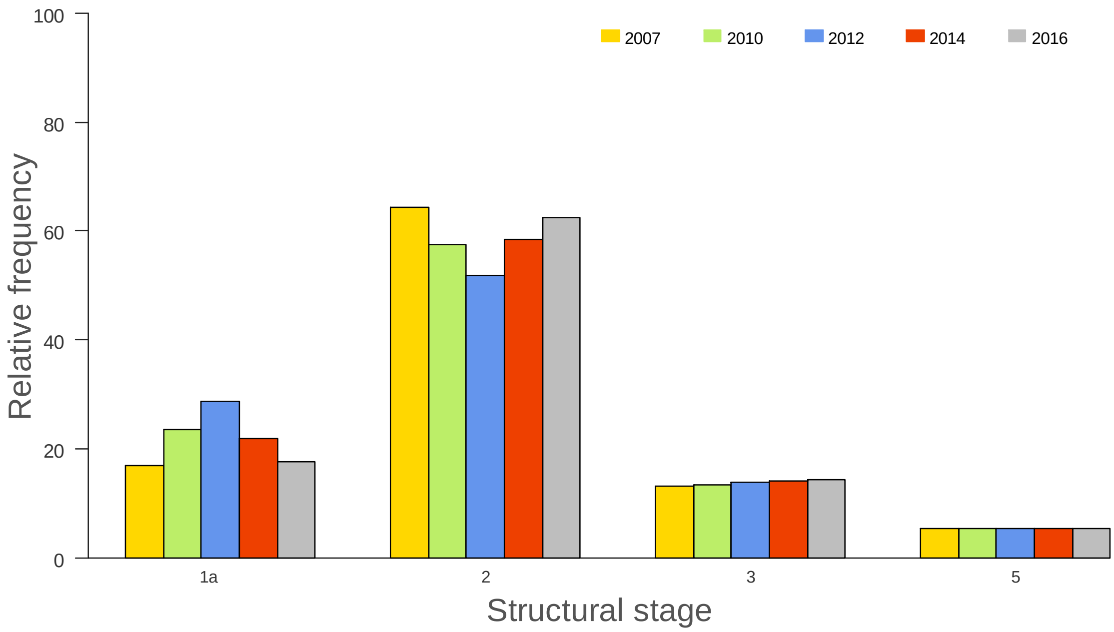


Figure 6-3: Relative frequency (proportion) of structural stages in point samples (*n*=936) of aerial imagery obtained for Arrow Lakes Reservoir from 2007 to 2016. Stages: (1a) sparse or pioneer vegetation; (2) herb-dominated; (3) shrubland; and (5) young forest. The stage categories assessed were limited to those visible at the scale of the available imagery, and do not include all possible vegetation stages.

For frequency counts in Revelstoke Reach (Appendix 11.8), chi-square tests were significant for low-elevation point samples (χ^2=11.5, p=0.0198) but not mid-elevation, high-elevation, or pooled point samples (p>0.3). In other words, the structural composition of vegetation was contingent on year in the low-elevation band (434-436 m ASL), but was independent of year in other elevation bands.

Post-hoc Freeman-Tukey deviates tests indicated that, at low elevations, the relative frequency of the sparse/pioneering stage was significantly different than expected for 2007 and 2012 (lower in 2007 and higher in 2012).

For Arrow Lakes, chi-square tests suggest a significant difference in counts (Appendix 11.9) for elevations combined (χ^2=51.9, p=0.0001) and for low elevations (χ^2=65.4, p=0.0001), but not for mid or high elevations (p>0.65). Thus, as for Revelstoke Reach, structural composition was contingent on year, with most of this dependence related to changes occurring at low elevation.

Post-hoc Freeman-Tukey deviates tests indicated that, overall, the relative frequency of the sparse/pioneer and herb stages in 2007 and 2012 deviated from expected frequencies (lower for sparse/pioneering in 2007 and for herb in 2012, but higher for herb in 2007 and for sparse/pioneering in 2012). At low elevation, frequencies for these two stages were statistically different than expected for 2007, 2012 and 2016 (lower for sparse/pioneer in 2007, herb in 2012, and sparse pioneer in 2016; and higher for herb in 2007, sparse pioneer in 2012, and herb in 2016).

Kappa statistics (Appendix 11.10) were high both for Revelstoke Reach (K=0.8905, Z=71.1, p<0.0001) and Arrow Lakes (K=0.805, Z=91.1, p<0.0001), implying a high degree of agreement among yearly point samples. Among elevation bands, structural stages in the low band tended to have the lowest K values, indicating lower levels of agreement compared to other elevation bands. For one structural stage (shrubland), K was actually slightly negative (-0.002), implying a significant change in shrub cover—but this result was influenced by incidental changes affecting a very small sample of shrubby plots occurring within this elevation band (Appendix 11.9).

6.2.2.1 Hypothesis $H0_B$: no change in structure/composition of VCTs in Arrow Lakes Reservoir

Based on these findings, we conclude that there have been significant changes in the composition of vegetation communities within the existing vegetated zones of Arrow Lakes Reservoir over the time frame of this study. Therefore, we reject hypothesis $H0_B$.

6.2.3 Aerial imagery

A side-by-side comparison of aerial images from different years helps visually illustrate some of the broad-scale structural changes that have, or have not, occurred in drawdown zone vegetation since 2007. The first set of images (Figure 6-4) provides an example of relatively stable, mid-elevation, reed canarygrass-dominated flats at Drimmie Creek, in Revelstoke Reach. At the scale of the photos, coverage is visually indistinguishable across years. In other areas of the drawdown zone where it was remotely sampled, this habitat type likewise exhibited little temporal variability in cover or extent at the landscape scale. This is likely because reed canarygrass forms a successionally stagnant stand that is largely impervious to annual reservoir fluctuations.

The second example (Figure 6-5) shows an overview of the extensive alluvial flats near the mouth of Burton Creek in Arrow Lakes. Here, a pattern of vegetation recession, beginning around 2010, is visible at low elevation near the beach–vegetation interface. The recession, which may be related to increases in sediment deposition, appears to peak around 2012 and to persist into 2014. By 2016, plant cover in the affected polygons has increased again, with indications of having recovered back to its original (2007) extent. Figure 6-6 contains a finer-scale detail of this overview, focusing on one polygon (1755) supporting PE-type vegetation where the pattern of change between years is especially clear.

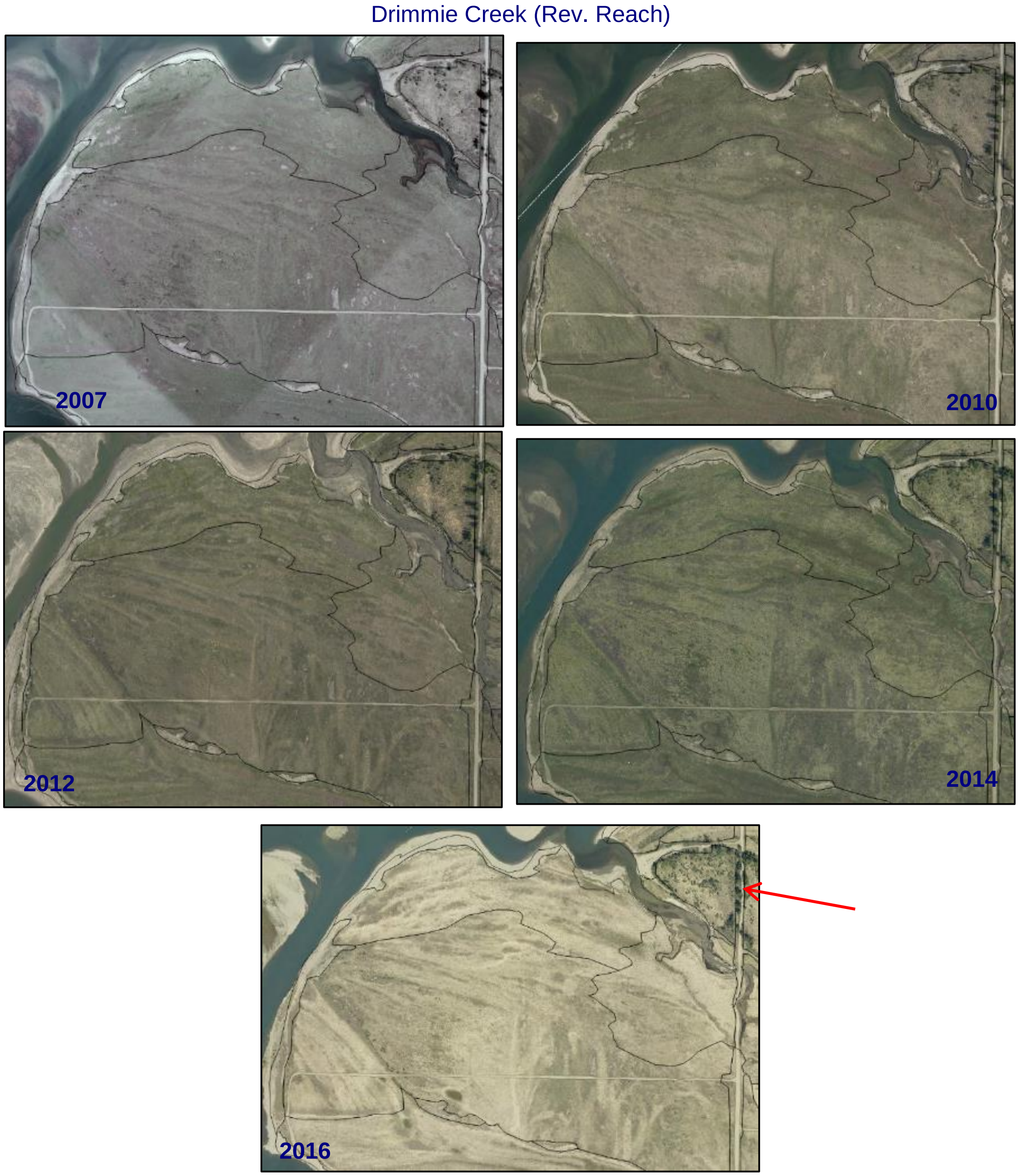


Figure 6-4: Example of the lack of significant change over time (2007-2016) in the mid-elevation reed canargyrass community (PC–Reed canargrass) in Revelstoke Reach. Shown is an overview of the Drimmie Creek flats (12 Mile). Difference in colour hue between images can be ascribed to differences in film type (analog vs. digital) and/or the phenological stage of vegetation. The apparent increase in shrub cover in the top right polygon (red arrow) is due to revegetation treatments (cottonwood plantings) applied to this site as part of CLBWORKS-2. Scale: 1:3600.

Figure 6-5: Example of VCT shifts over time (2007-2016) in low-elevation flats at Burton Creek (Arrow Lakes). Compared to 2007, some recession of vegetation is apparent at the the beach-vegetation interface between 2010 and 2012, followed by signs of recolonization in 2016. Overall cover in 2007 and 2016 appears similar. Scale: 1:3600.

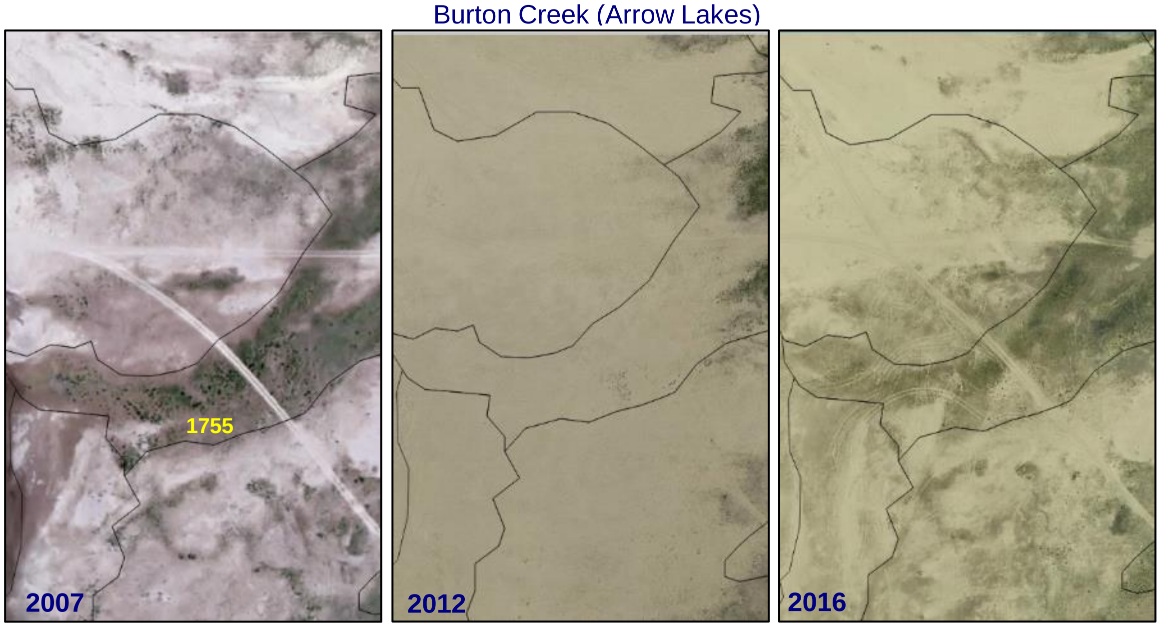


Figure 6-6: Detail of polygon 1755 (Burton Creek) from Figure 6-5, showing differences in cover of the PE–Sedge VCT between 2007, 2012, and 2016. Between 2007 and 2012, portions of this polygon underwent sediment deposition resulting in the loss of visible vegetation cover. By 2016, vegetation cover had begun to re-establish. Scale: 1:1000.

The Burton Creek example is not strictly representative of low-elevation dynamics across the reservoir, but neither is it an exceptional case. A similar pattern consisting of a decline in visible herbaceous cover between 2007 and 2012 (possibly associated with sediment deposition), followed by a partial return to initial (2007) levels by 2016, was repeated at several locations in Arrow Lakes, including at Dixon Creek on the reservoir's west side, and Fairhurst Creek (south Arrow Park) on the east side (Figure 6-7). In the Dixon Creek example, a vegetated beach community (PC type) appears to lose most of its herbaceous cover in 2012 before recovering to 2007 levels, while in the Fairhurst Creek example, a composite herb community consisting of elements of RR (associated with an open creek), PE, and PC VCTs was in evident recession in 2012 before partially recovering in 2016 (Figure 6-7).

The review of orthophoto point samples indicated that, in most areas of the drawdown zone, woody shrub cover was either supported or enhanced by the operating regime during the monitoring period. While isolated die-backs of woody plants were occasionally observed, there were no recorded instances of shrubland *per se* (PC–Shrub and Shrub riparian community types) reverting to a more herbaceous state. Most polygon overviews exhibited stable or increased cover of shrubs, with at least some of the increase occurring after 2010—such as at Illecillewaet River and West Revelstoke in north Revelstoke Reach (Figure 6-8).

One of the more frequent classes of VCT transition in Arrow Lakes (Table 6-4), though not in Revelstoke Reach (Table 6-3), were those involving LO or woody debris-affected sites. Floating piles of debris get deposited in accumulation zones, usually near the upper flood line, where they may remain in place for some years until removed by a subsequent high water event. Impacts from woody debris deposition can be relatively transitory if the underlying seed and/or rhizome banks remain intact, allowing for regrowth to occur once the wood is removed. Examples of declines in woody debris cover (with concurrent increases in vegetation cover) at Arrow Park, south of Nakusp, are shown in Figure 6-9.

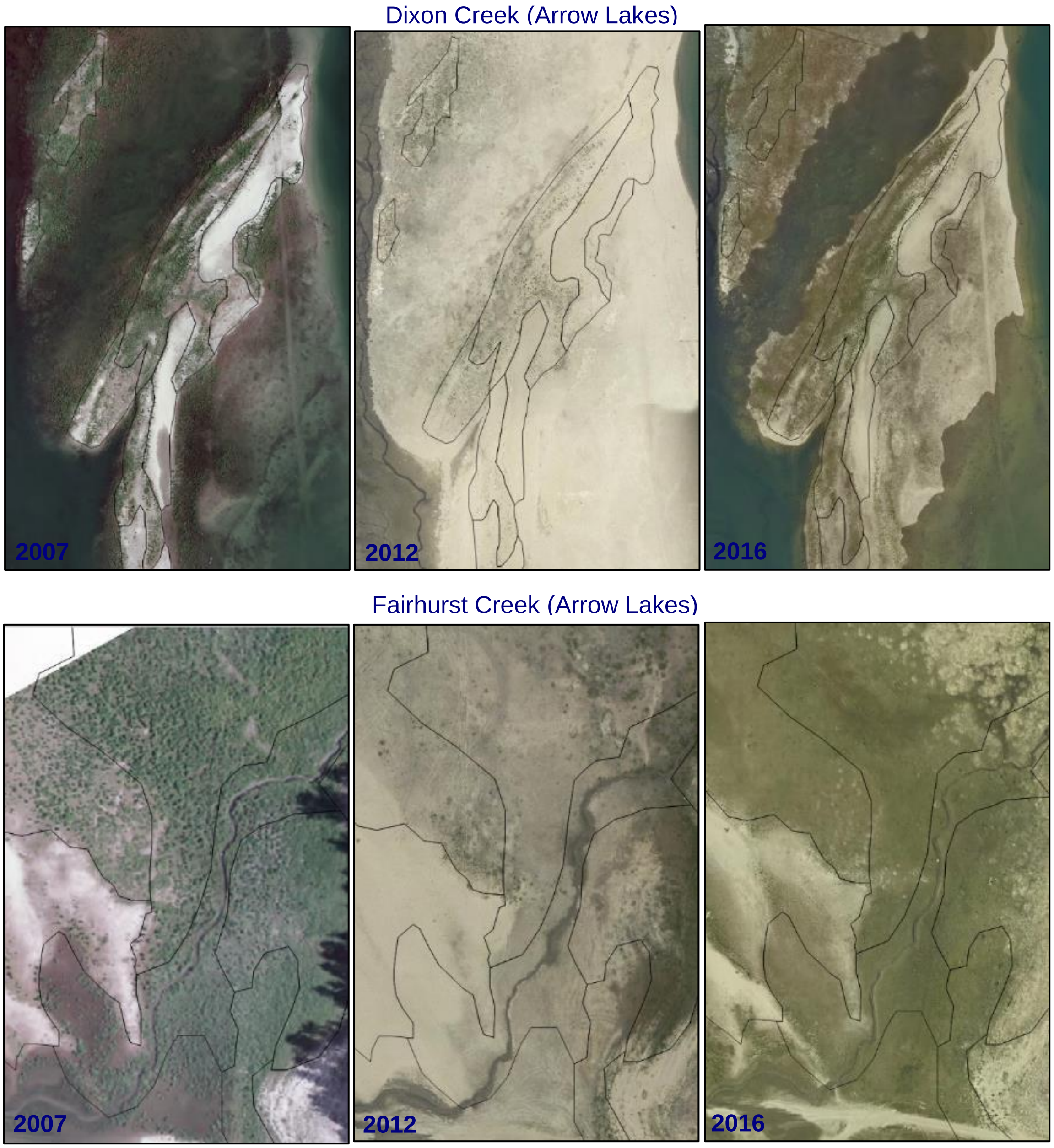


Figure 6-7: Examples of shifts in vegetation cover between 2007, 2012, and 2016 on low-elevation PE sites at Dixon Creek (top) and on PE, PC, and RR sites at Fairhurst Creek (bottom), Arrow Lakes. Pattern of sedimentation (2012) and subsequent recovery (2016) is similar to that observed for Burton Creek (Figure 6-6). Scale is 1:2100 (top) and 1:850 (bottom).

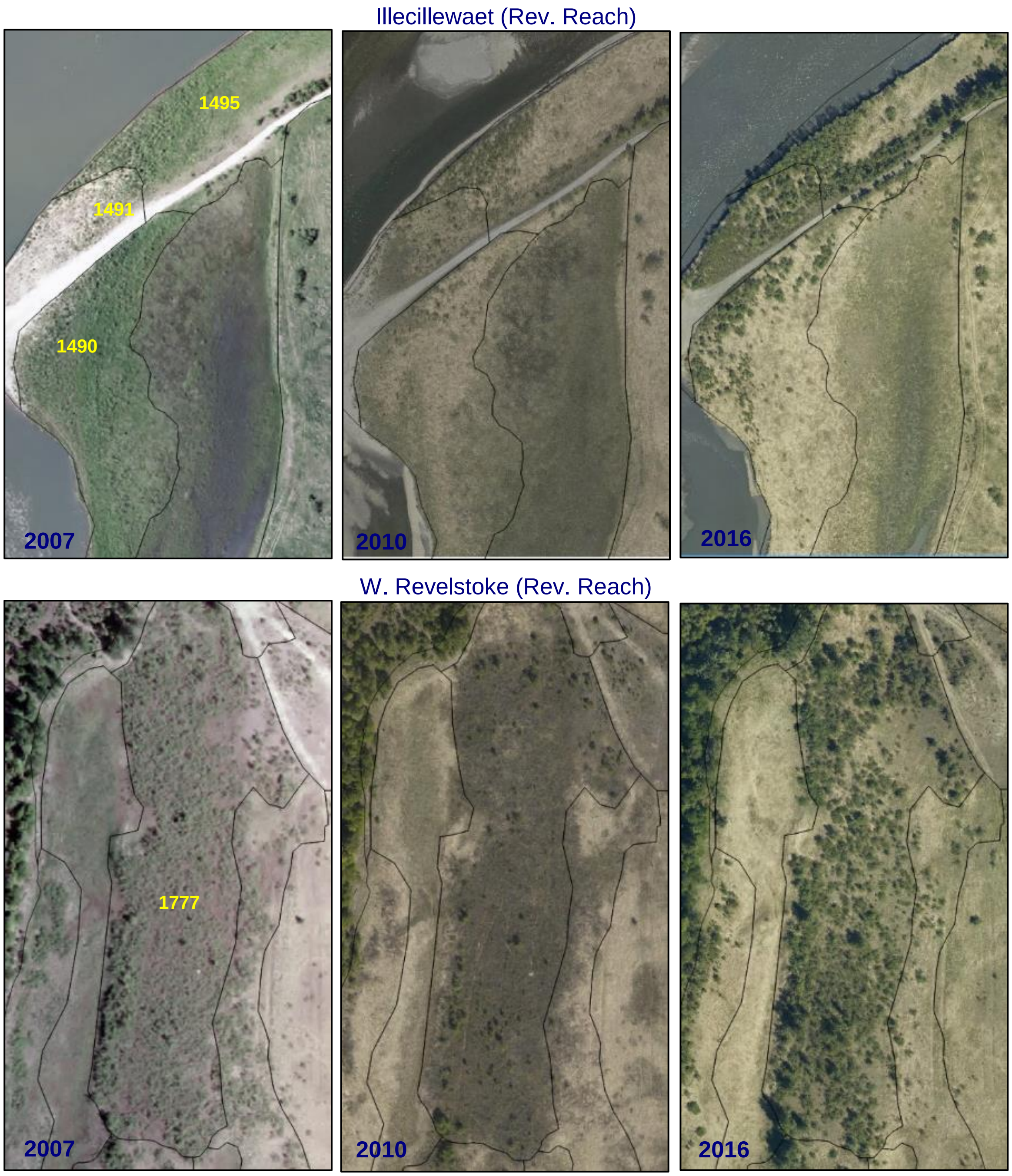


Figure 6-8: Examples of increases in shrub cover between 2007 and 2016 at Illecillewaet River (top; polygon 1490, 1491, 1495) and West Revelstoke (bottom; polygon 1777). Scale is 1:1200 (top) and 1:1100 (bottom).

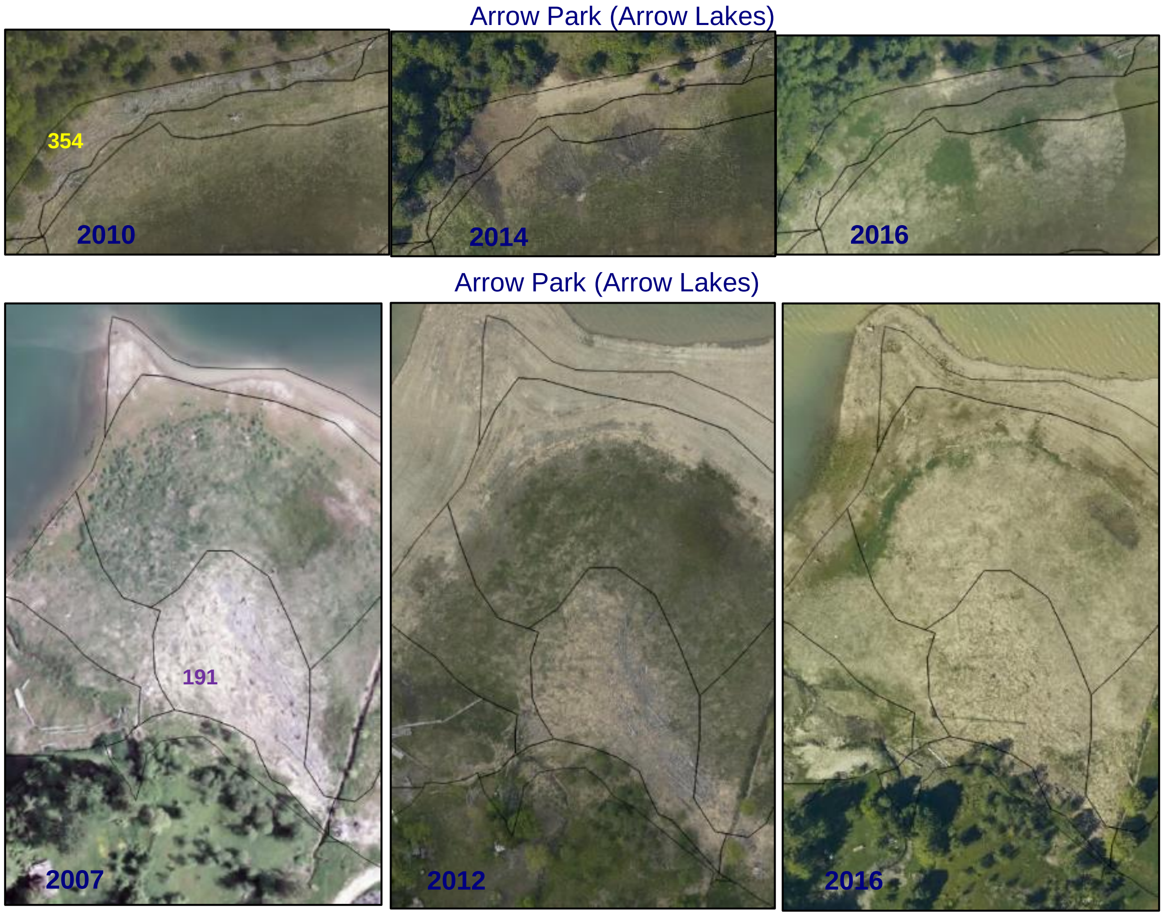


Figure 6-9: Top: example of woody debris deposition, removal, and subsequent vegetation recovery in polygon 354, Arrow Park (Arrow Lakes). Debris covering the site in 2010 had floated away by 2014, allowing for vegetation to recover in 2016. Bottom: example of shifts in cover at the beach–vegetation interface over time at Arrow Park. A change from 2012 to 2016 in the ratio of woody debris to vegetation cover is also evident (polygon 191, lower middle). Scale: 1:900.

These visual examples, which illustrate the analytical findings of low net change in vegetation cover and spatial extent between the photo-monitoring start and endpoints (2007 and 2016), also help highlight the dynamical nature of the system over shorter (2-year) time frames. In this instance, the overall vegetation trajectory can be characterized as slightly negative (if viewed over the full 10-year time frame between 2007 and 2016) or as positive (if viewed over just the last 5 years since 2012). With the exception of some changes related to increased shrub cover and shifts in wood debris deposition, trajectory directions have been mainly driven by events at low-elevation sites, where sediment depositions (a water energy effect) occurring sometime prior to the 2012 growing season appear to have had the effect of temporarily pushing the beach–vegetation interface inland (upslope). Based on the graph of recent historical reservoir levels (Figure 6-1), the 2011 hydroperiod was characterized by relatively deep and prolonged spring and fall inundations. The year prior (2010) saw a rapid early spring increase in water elevation and an extended fall inundation period. Such an operational sequence could, conceivably, have contributed to the elevated sedimentation levels observed in 2012. The subsequent readvancement of vegetation downslope could be a response to the lower late-summer reservoir elevations (and presumably lower sediment inputs), in combination with the increase in available growing degree days (GDDs; Table 6-2), that have prevailed since 2013. In subsequent sections, we examine some of these operational influences more closely as they pertain to vegetation trends at the local, site level.

6.3 Site-level Assessment

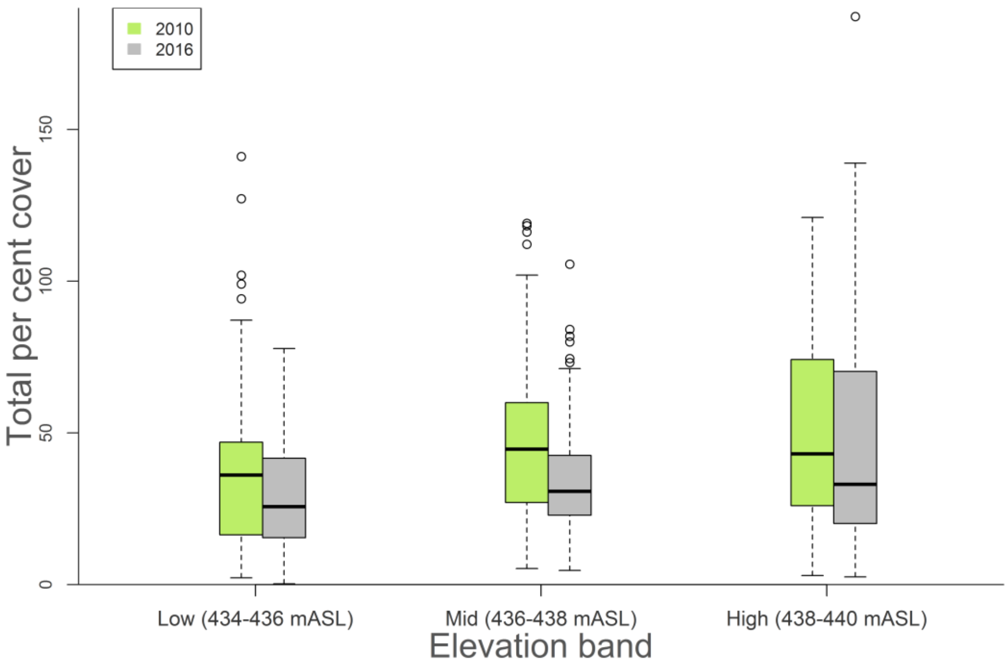
6.3.1 Total Cover, Richness, Diversity

At field-monitored sites, total vegetation cover (all species combined) appeared to decrease slightly at all elevations between 2010 and 2016 (Figure 6-10). This trend was consistent for both regions of the reservoir (Revelstoke Reach and Arrow Lakes; Figure 6-10).

It is unclear if the observed change in cover between 2010 and 2016 indicates a long-term tendency, or if it rather reflects an inflection point in a continuously fluctuating vegetation cycle (i.e. an outcome of the sample time frame). We note that for the subset of study plots revisited annually between 2010 and 2016 (with the exception 2014), year-to-year cover trajectories were highly variable and—seemingly—non-directional (Appendix 11.10). Cover in the 14 mid-elevation band plots seemed to peak for most plots in 2012 and 2013, declining slightly afterwards. In the case of the 14 regularly resampled low-elevation plots, covers tended to oscillate on an annual basis (Appendix 11.10).

In contrast to cover, species richness appeared to increase between 2010 and 2016 (Figure 6-11). A statistically significant increase in richness over time was recorded for Arrow Lakes, though not for Revelstoke Reach (Figure 6-11). Again, it is unclear if the difference represents a real increase in the number of species establishing in the drawdown zone, or if it reflects a sampling artifact. In this case, some of the increase can likely be ascribed to increased botanical resolution over time, as our understanding of the drawdown zone flora has tended to improve with each successive sampling year. For example, in 2014, field crews discovered well-established populations of the rare annual grass *Coleanthus subtilis* (moss grass), the existence of which had not been previously noted (likely due to the species' inconspicuous habit; Miller *et al.* 2015).

Species diversity (Shannon's H) was quite variable within elevation bands and years (Figure 6-12). While median diversity increased slightly in Arrow Lakes and declined slightly in Revelstoke Reach, the changes were not statistically significant (Figure 6-12).



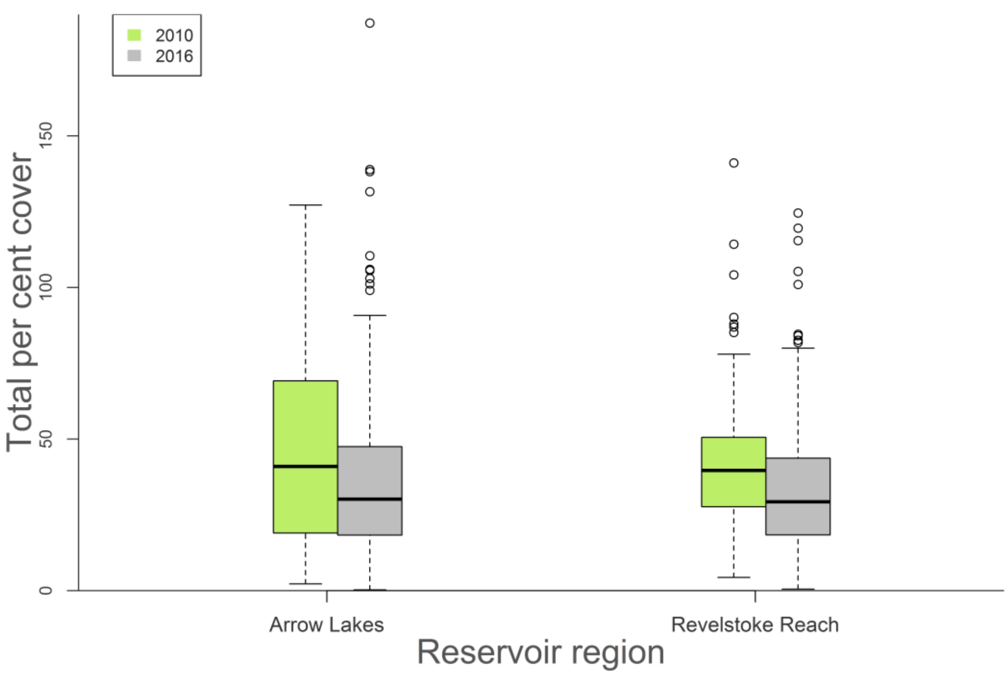


Figure 6-10: Median total per cent cover of vegetation by elevation band (top panel) and reservoir region (bottom panel) in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir. Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. *n*=319 plots. **Top:** differences were significant between years (GLMM, F=20.7, *p*<0.0001) and among elevation bands (GLMM, F=7.01, *p*=0.001). Interactions were not significant. **Bottom:** Differences were significant between years (GLMM, F=8.3, *p*=0.004) but not between regions (GLMM, F=1.6, *p*=0.2). Interactions were not significant.

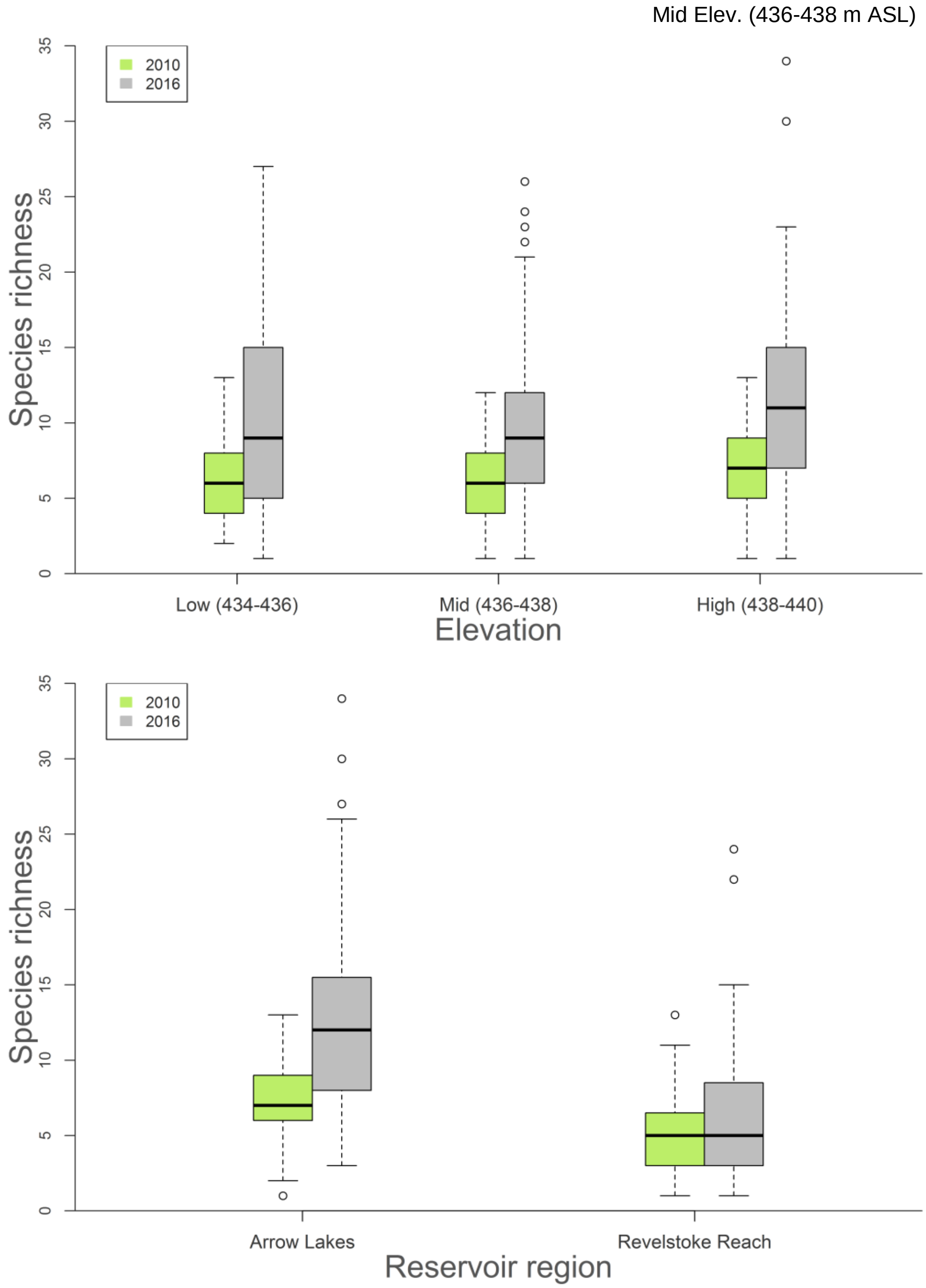


Figure 6-11: Median species richness by elevation band (top panel) and reservoir region (bottom panel) in plots sampled in 2010 and 2016. Boxes = 25th and 75th percentiles; whisker ends = min and max values; circles are outliers. n=319 plots. **Top:** differences were significant between years (GLMM, F=146.3, p<0.0001) and among elevation bands (GLMM, F=3.3, p=0.039). Interactions were not significant. **Bottom:** differences were significant between years (GLMM, F=147.4, p<0.0001) and between regions (GLMM, F=144.9, p<0.0001). Interactions were also significant (GLMM, F=23.2, p<0.0001).

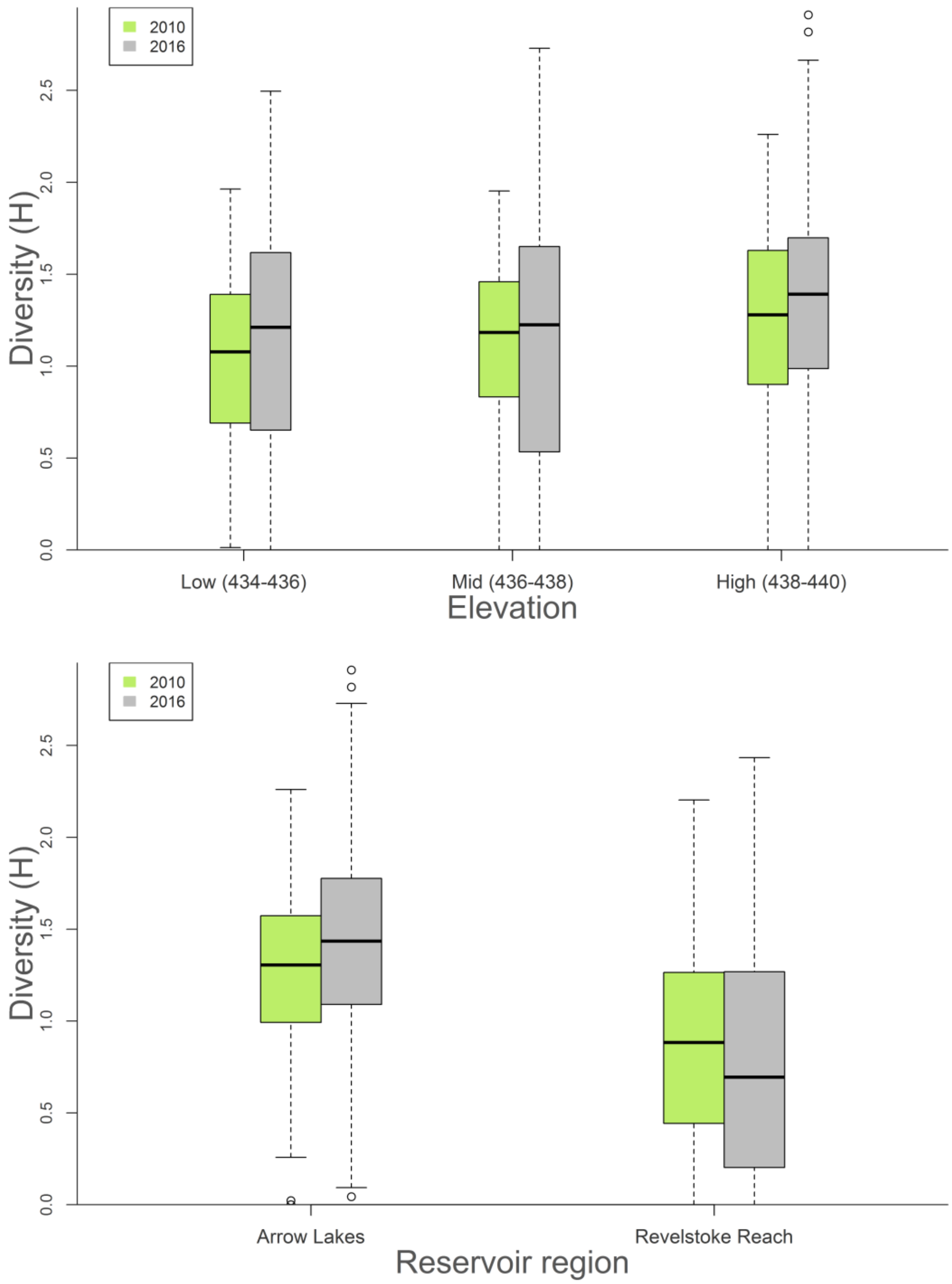


Figure 6-12: Median species diversity (H) by elevation band (top panel) and reservoir region (bottom panel) in plots sampled in 2010 and 2016. Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. *N*= 319 plots. **Top:** differences were not significant between years, but were significant among elevation bands (GLMM, F=4.4, *p*=0.01). Interactions were not significant. **Bottom:** differences were not significant between years, but were significant between regions (GLMM, F=57.0, *p*<0.0001). Interactions were also significant (GLMM, F=6.2, *p*=0.01).

Cover had significant positive regression coefficients with July water depth (*t*=4.69, *p*=<0.0001) and subhydric (wet) soils (*t*=1.85, *p*=0.0651). Cover had negative coefficients with year (t=-7.4, p=<0.0001) slope (t=-3.3, p=0.0027), July GDDs (t=-3.33, p=0.0009), and June water depth (t=-5.92, p<0.0001). Cover was also reduced on gullied sites (t=-3.59, p=0.0004), sites exposed to stream-flooding (t=-2.47, p=0.0138), xeric substrates (t=-5.03, p<0.0001) and disturbed ground (t=-2.87, p=0.0042; Appendices 11.12 and 11.13).

Species richness tended to increase over time (t=8.92, p<0.0001), and with April GDDs (t=7.66, p<0.0001) and July water depth (t=2.63, p=0.0087). Richness was also positively correlated with sites affected by scouring, erosion, and/or deposition (t=2.05, p=0.0415). Richness had negative coefficients with latitude (t=-3.81, p=0.0002), June water depth (t=-3.84, p=0.0001), July GDDs (t=-3.88, p=0.0001), September GDDs (t=-1.77, p=0.0777), fine-textured substrates (t=-1.76, p=0.0785) and medium to low soil moisture (t=-3.31, p=0.0010; Appendices 11.12 and 11.13).

6.3.2 Vegetation Communities

The cover of vegetation within different community types (VCTs) fluctuates from year to year, with some VCTs exhibiting stronger directional trends than others (Figure 6-13). For example, median cover of low-elevation pioneering habitats such as sandy and gravelly beaches (BE and BG), and coarse-textured uplands (PA), did not change much between 2010 and 2016. In contrast, there was an apparent decrease in cover for the RR VCT, representing seepage sites and other habitats influenced by upland water flow. The decrease may be related to stochastic changes in upland flow rates, such as might accrue from fluctuations in precipitation or snowpack, or to other chance alterations in flow pattern over time. There are indications that low-elevation PE community types have increased somewhat in total cover since 2010, likewise the cover of the riparian shrub strip (Shrub riparian) at the upper margin of the drawdown zone. In contrast, it appears there has been an overall decline in cover within the mesic reed canarygrass-dominated habitat types (PC–Foxtail/horsetail, PC–Reed canarygrass, PC–Sedge, and PC–Willow). Reed canarygrass thrives under wet conditions, and we surmise the decrease in cover of associated VCTs may be related to the generally shallower and briefer summer inundation events that have prevailed at mid and upper elevations since 2013 (Figure 6-1).

The operating regime since 2010 appears to be, at the least, maintaining species richness levels for most community types (Figure 6-14). Richness was relatively constant between 2010 and 2016 in the case of BG, BE, and the various PC community types, and appeared to increase somewhat in the PE, RR, PA, and Shrub riparian VCTs. As noted above (Section 6.3.1), it is unclear of the observed increases in species richness reflect a biological change or researchers' changing taxonomic insights over time. In contrast to the findings for Kinbasket Reservoir (Hawkes and Gibeau 2017), species richness in Arrow Lakes Reservoir does not appear to be strongly correlated with elevation. The highest recorded species numbers were obtained in 2017 samples of the low-elevation Kellogg's sedge (aka lenticular sedge) community (PE–Sedge), while the mid-and high-elevation PC–Reed canarygrass VCT was consistently the least speciose (Figure 6-14).

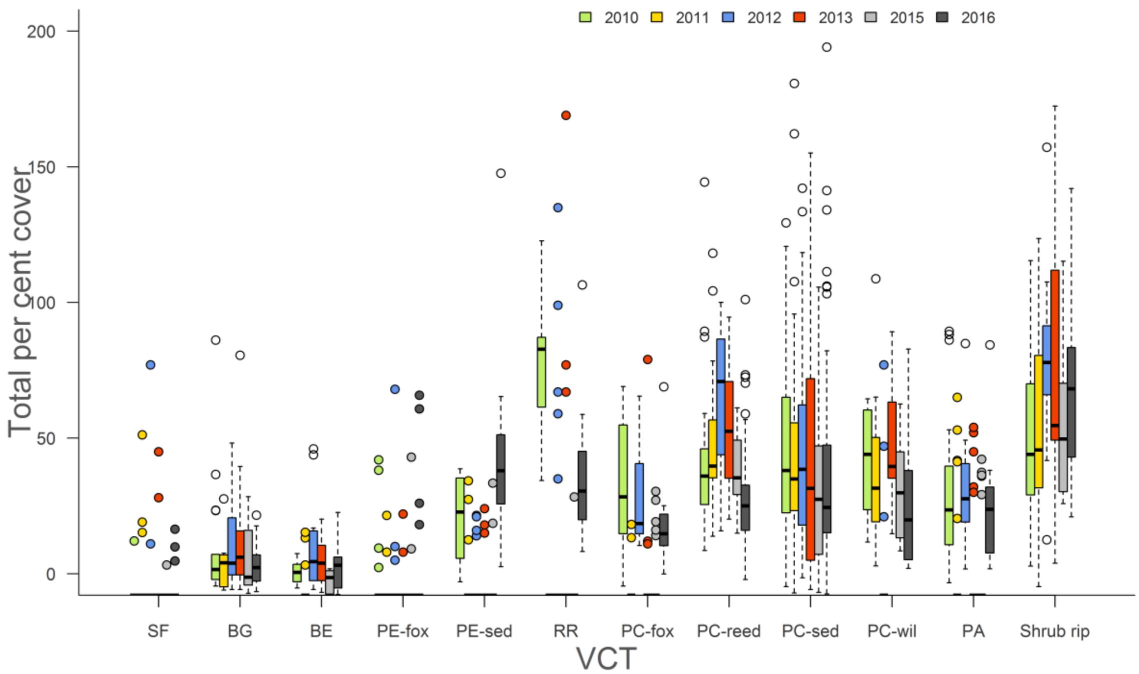


Figure 6-13: Total vegetation cover, per vegetation community type (VCT), in plots revisited in all sampling years (2010-2016) in Arrow Lakes Reservoir. Sample sizes for some VCTs were not sufficient for complete boxplots. PE-fox = PE–Foxtail; PE-sed = PE–Sedge; PC-fox = PC–Foxtail/horsetail; PC-reed = PC–Reed canarygrass; PC-sed = PC–Sedge; PC-wil = PC–Willow; Shrub rip = Shrub riparian. Refer to Table 5-1 for a full list of VCT names.

The Shannon diversity index, which weights species richness by the evenness of the abundance, quantifies the uncertainty in predicting the species identity of an individual sampled at random in a study plot (Figure 6-14). Not surprisingly, given its general domination by a single species, the most predictable VCT in the drawdown zone by this measure is PC-Reed canarygrass. Relatively diverse VCTs include PE–Sedge, BG, RR, and PA. With the exception of the BE VCT, which may have increased, and the PC-Reed canarygrass VCT, which may have decreased, there were few notable directional changes in diversity between 2010 and 2016 (Figure 6-14). This implies that the composition of VCTs has remained relatively stable over time.

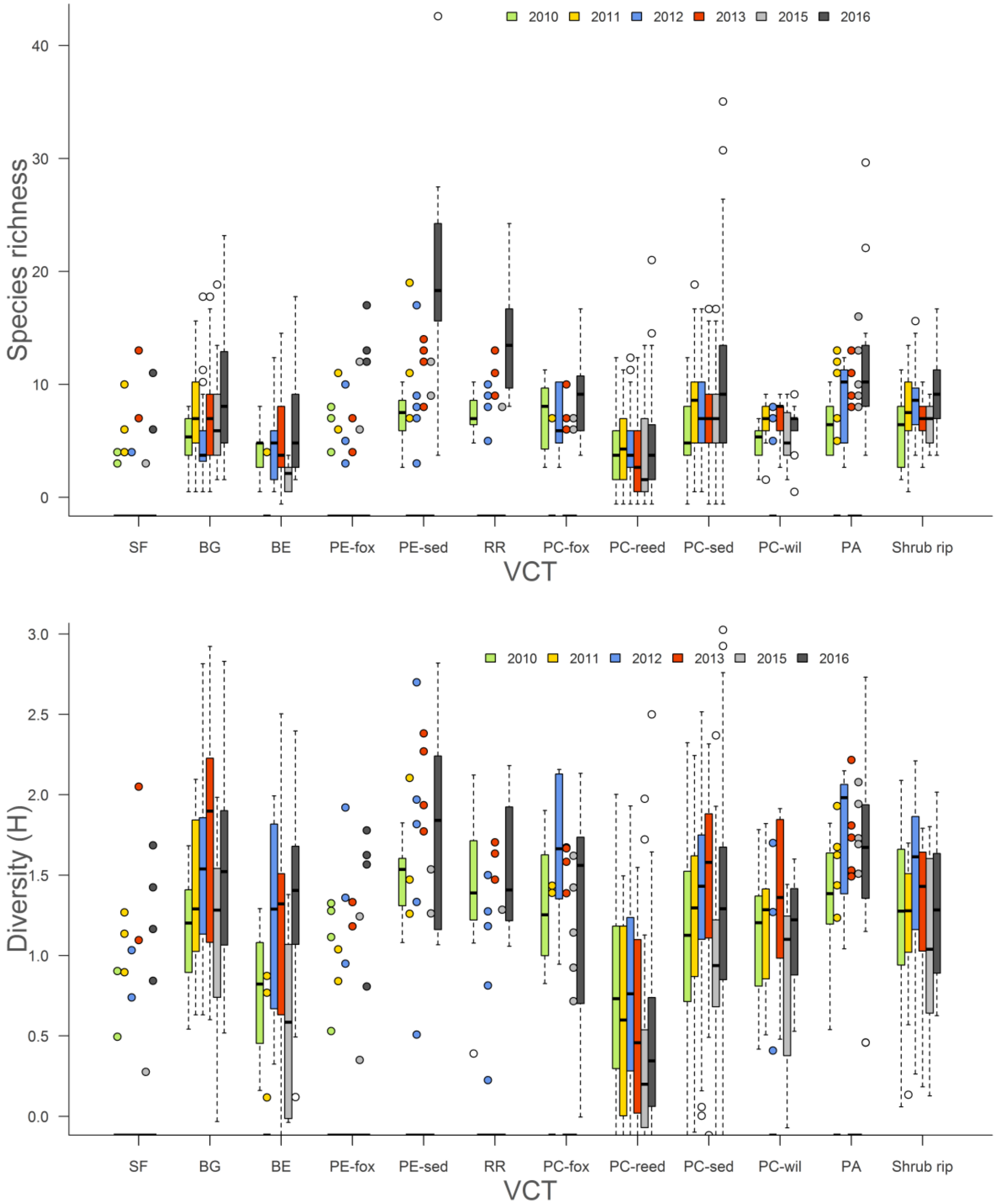


Figure 6-14: Species richness (top panel) and diversity (Shannon's H, bottom panel) per vegetation community type (VCT), in plots revisited in all sampling years (2010-2016) in Arrow Lakes Reservoir. Sample sizes for some VCTs were not sufficient for complete boxplots. PE-fox = PE–Foxtail; PE-sed = PE–Sedge; PC-fox = PC–Foxtail/horsetail; PC-reed = PC–Reed canarygrass; PC-sed = PC–Sedge; PC-wil = PC–Willow; Shrub rip = Shrub riparian. Refer to Table 5-1 for a full list of VCT names.

6.3.3 Plant Guilds

6.3.3.1 Cover and Species Richness

To compare trends for different subsets of vegetation, we partitioned cover and richness among six plant guilds or functional groups: forbs, sedges and rushes, pteridophytes, grasses, shrubs, and trees (Figure 11-3 to Figure 11-7; tree data not displayed). Results of significance testing (GLMM-based ANOVAs) are provided with the figure captions; however, these tests were likely strongly influenced by numerous outliers and zeros in the sample sets (and non-normality of residuals), and thus should be viewed with caution. Below, we restrict discussion to qualitative descriptions of the observed variation as displayed by box-and-whisker plots (Appendix 11.14, Figure 11-3 to Figure 11-7).

Median forb cover in the low-elevation band was similar between 2010 and 2016 but appeared to decline slightly over time at mid and high elevations (Figure 11-3). Forb species richness appeared to increase at all elevations (Figure 11-3), possibly for the reasons noted above relating to evolving species identifications (Section 6.3.1).

The cover of sedges and sedge-like plants also declined slightly between 2010 and 2016. Species richness was stable for mid and low elevations and increased slightly in the upper elevation band (Figure 11-4).

Cover of pteridophytes (horsetails) declined marginally between 2010 and 2016. Species richness was consistently low, usually represented by just one species per plot (Figure 11-5).

Grass cover did not undergo any clear directional change over time, but species richness did increase slightly across all elevation bands (Figure 11-6).

Shrub cover in repeated plots exhibited a slight increase over time at mid and upper elevations, along with a slight increase in species richness (Figure 11-7).

6.3.3.2 Composition

We estimated the annual proportional contribution of different plant guilds to the total vegetation cover of the drawdown zone based on cover data obtained from 2010 to 2016 (Figure 6-15). Proportions were calculated from all available cover data for each year, with each year’s data serving as an independent snapshot of drawdown zone vegetation condition. This estimate thus differs from the repeated-measures comparisons between 2010 and 2016 (previous section), which exclusively relied on data from repeated plots. To explore the potential role of inundation timing and duration in modulating guild structure, shifts in cover were examined in relation to the total growing degree days (GDDs) for each May-September growing season (Figure 6-15; note that cover was plotted against GDD values from the previous year, to allow for a presumed one-year lag in plant guild response to inundation events).

In terms of relative overall cover, the vegetation structure of the drawdown zone is dominated by graminoids (grasses and sedges) at low elevations, by grasses at mid elevations, and by grasses, shrubs, and trees at upper elevations. This basic zonation pattern has persisted over the monitoring period (Figure 6-15), supporting the conclusion of the landscape-level analysis that drawdown zone vegetation has been maintained in a more or less steady state by the current operating regime (Section 6.2). Nevertheless, there has been some variation in the relative proportions of cover over time. For example, at mid elevation, forb cover appears to have decreased relative to cover of graminoids, pteridophytes, and shrubs, while the relative proportion of plots under shrub cover appears to have held steady. At low elevation, the proportional cover of grasses (family Poaceae) versus that of sedges and rushes (family Cyperaceae) has fluctuated over time. Whereas the two groups had similar coverage on average in 2013, grasses were more than twice as abundant (on average) as sedges and their allies in 2016 (Figure 6-15).

Since 2012, the reservoir has experienced an incremental increase in seasonal GDDs at low elevation (434-436 m ASL) that appears to coincide with the declining trend in the covers of forbs, sedges, and pteridophytes over the same period. At mid elevation, where GDDs declined from 2009 until the middle of the monitoring period before increasing again, cover of grasses has tended to follow a slightly divergent pattern, with highest average covers recorded in 2012 and lower covers thereafter (Figure 6-15).

Comparable patterns were harder to distinguish in the case of the high-elevation band, although forb cover appeared to be positively correlated with GDDs. Guild proportions for this elevation band, which straddles the drawdown zone proper and upland riparian forest, may have been biased by the specific set of plots selected for sampling each year. For example, fewer upland forest plots were sampled in 2015 and 2016 than in previous years (due to their lower perceived diagnostic value), which likely contributed to the relatively lower cover values recorded for trees in those years (Figure 6-15).

The first MRT analysis (GDDs alone) distinguished two clusters of plots based on a difference in June GDDs (Figure 6-16). Grasses, sedges, and pteridophytes were identified as indicator guilds (i.e., guilds with relatively high index values, where the index is defined as the product of relative cover and relative frequency of occurrence of the guilds) for sites characterized by June GDDs < 138. Trees, forbs, and shrubs were indicator guilds for sites with June GDDs > 138. Grass-indicator sites were further distinguished from sedge- and pteridophyte-indicator sites on the basis of lower (< 94) June GDDs, while tree- and forb-indicator sites were distinguished from shrub-indicator sites on the basis of lower (< 326) July GDDs (Figure 6-16).

The GDD-based MRT explained only a modest 12 per cent of variance in guild composition. When other environmental variables were modeled in conjunction with GDDs, the importance of GDDs as a predictor of guild composition was reduced.

The second MRT analysis (using multiple environmental variables), which explained 32 per cent of guild variance, gave an eight-leaf tree with splits based only on geographic location (latitude/longitude) and soil moisture regime (Figure 6-16). The primary split was between plot groups south and north of UTM-Y 5635000, corresponding to Drimmie Creek in Revelstoke Reach. Sedges/rushes and forbs were indicators for more southerly plot groups, while trees, grasses, pteridophytes, and shrubs were indicators for more northerly plot groups. Within the southerly branch, sedges/rushes were indicators for moderately moist to moist sites, while forb-indicator sites tended to have wet soils. North of Drimmie Creek, drier sites had relatively high indicator values for tree cover. Plots to the west of UTM-X 415600 (including Illecillewaet River and West Revelstoke) had relatively high indicator values for grasses, while shrubs and pteridophytes were indicator guilds for plots to the east (Figure 6-16).

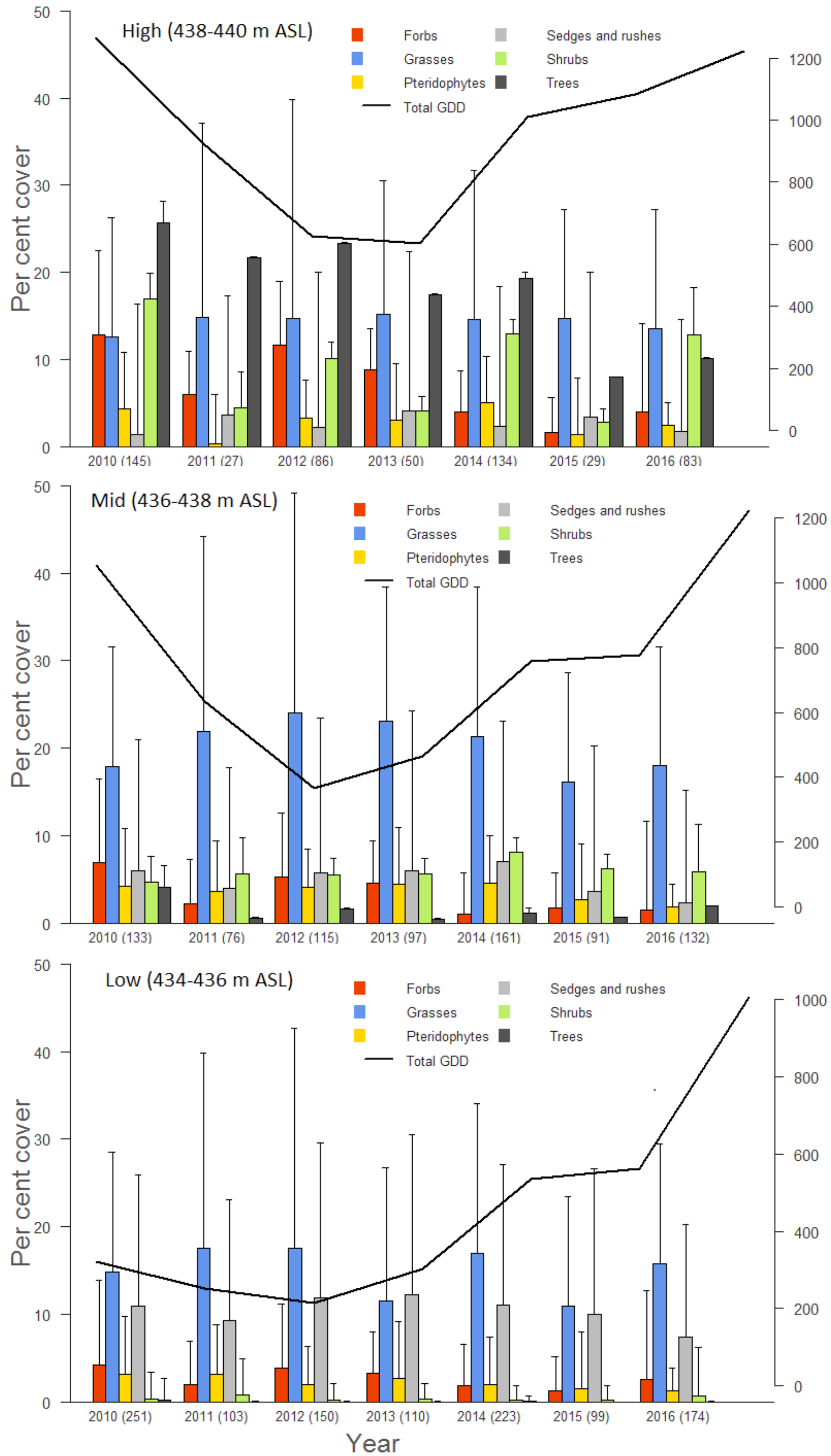


Figure 6-15: Relative covers of different plant guilds in Arrow Lakes Reservoir from 2010 to 2016. Bars are the plot averages. Values in () are the sample sizes. The total cumulative growing degree days (GDDs) from April-Sept. of each year is also shown (right y-axis). Cover at year *t* was plotted against the GDD value for *t* - 1, to allow for a presumed one-year lag in plant guild response to inundation events.

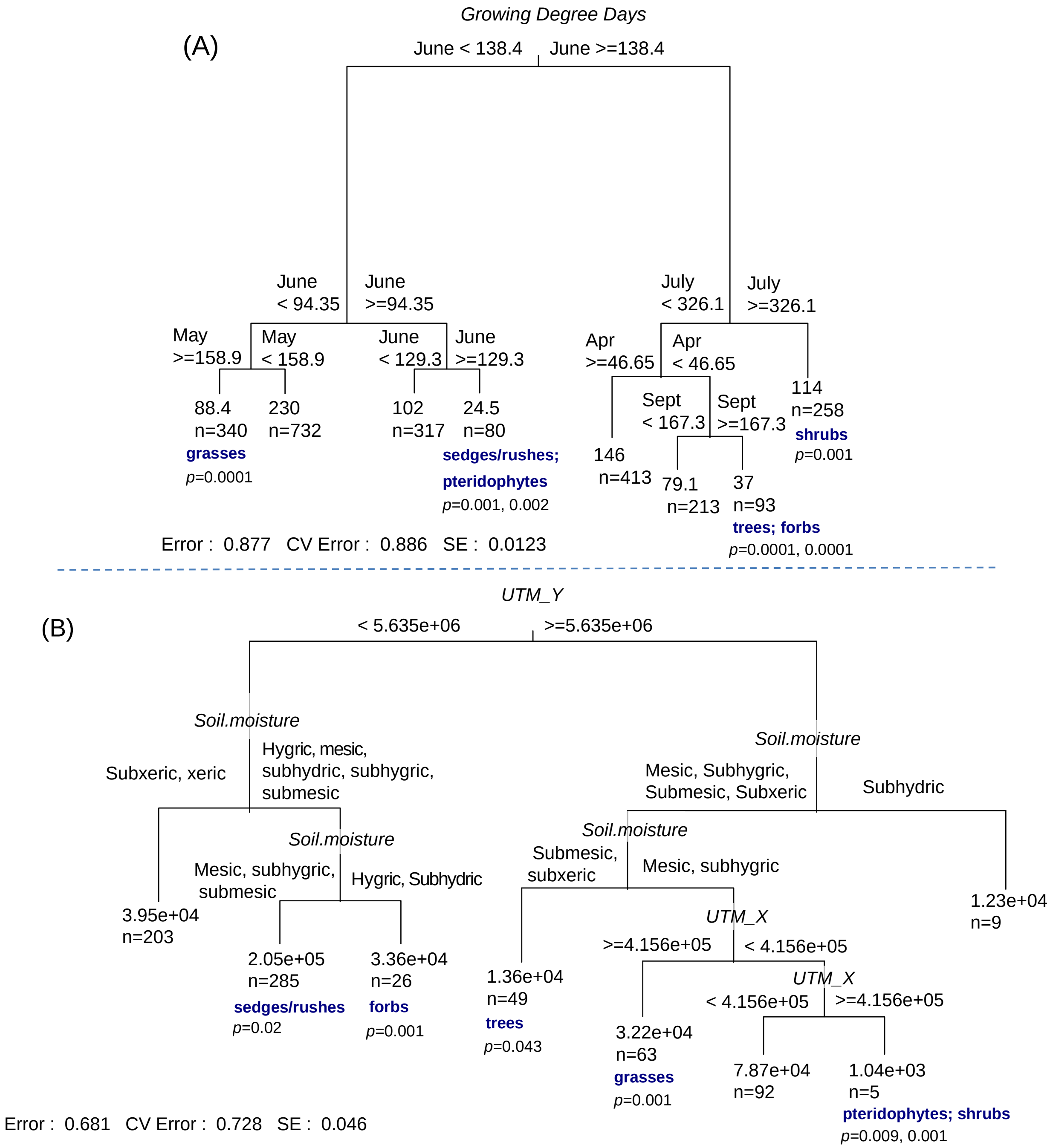


Figure 6-16: Multivariate regression trees (MRT) for the plant guild cover data. Variables included were (A) cumulative monthly growing degree days (GDDs, with these set to time *t*-1 to allow for a 1-yr lag in vegetation response) from April to September; and (B) GDD together with average monthly water depth, UTM-X, UTM-Y, slope, heat load, year, surface topography, soil moisture, and substrate texture. Numbers below terminal leaves are, in descending order: relative errors; number of plots (*n*) per group; indicator guild; and indicator (indvall) p-value. Total variance explained by Tree A is 12%; total variance explained by Tree B is 32%. For (A), all available plot data were used. For (B), the dataset consisted of plots sampled in at least four different years.

6.3.4 Species

Approximately 230 vascular plant species have been recorded to date at CLBMON-33 study sites (Appendix 11.15). A proportion of recorded species are restricted to the upland forests immediately adjacent the drawdown zone proper but were recorded during sampling of the CR–Cottonwood riparian community type. Appendix 11.16 lists some widespread species in the study area as well as species thought to be diagnostic of certain habitat conditions.

Reservoir-wide, the most ubiquitous species in study plots are reed canarygrass, Kellogg's sedge, common horsetail, Canada bluegrass, and Columbia sedge, which together account for 35 per cent of all species records between 2010 and 2016 (Figure 6-17). The 15 most frequent species account for 58 per cent of all species occurrences. In Revelstoke Reach, black cottonwood is one of the most frequent species while in Arrow Lakes, little meadow-foxtail has one of the highest encounter frequencies (Figure 6-17).

Viewed by elevation band, Kellogg's sedge accounts for 11.1 per cent of species records at low elevation; this species along with reed canarygrass, little meadow-foxtail, common horsetail, and Columbia sedge account for 41.5 per cent of total species frequency at low elevation (Figure 6-18). Mid- and high-elevation sites support many of the same common species as low-elevation sites but have higher frequencies of perennial grasses and woody shrubs. Aside from reed canarygrass, the most common grasses are Canada bluegrass, quackgrass, and redtop. The most common shrubs are black cottonwood and Sitka willow (Figure 6-18).

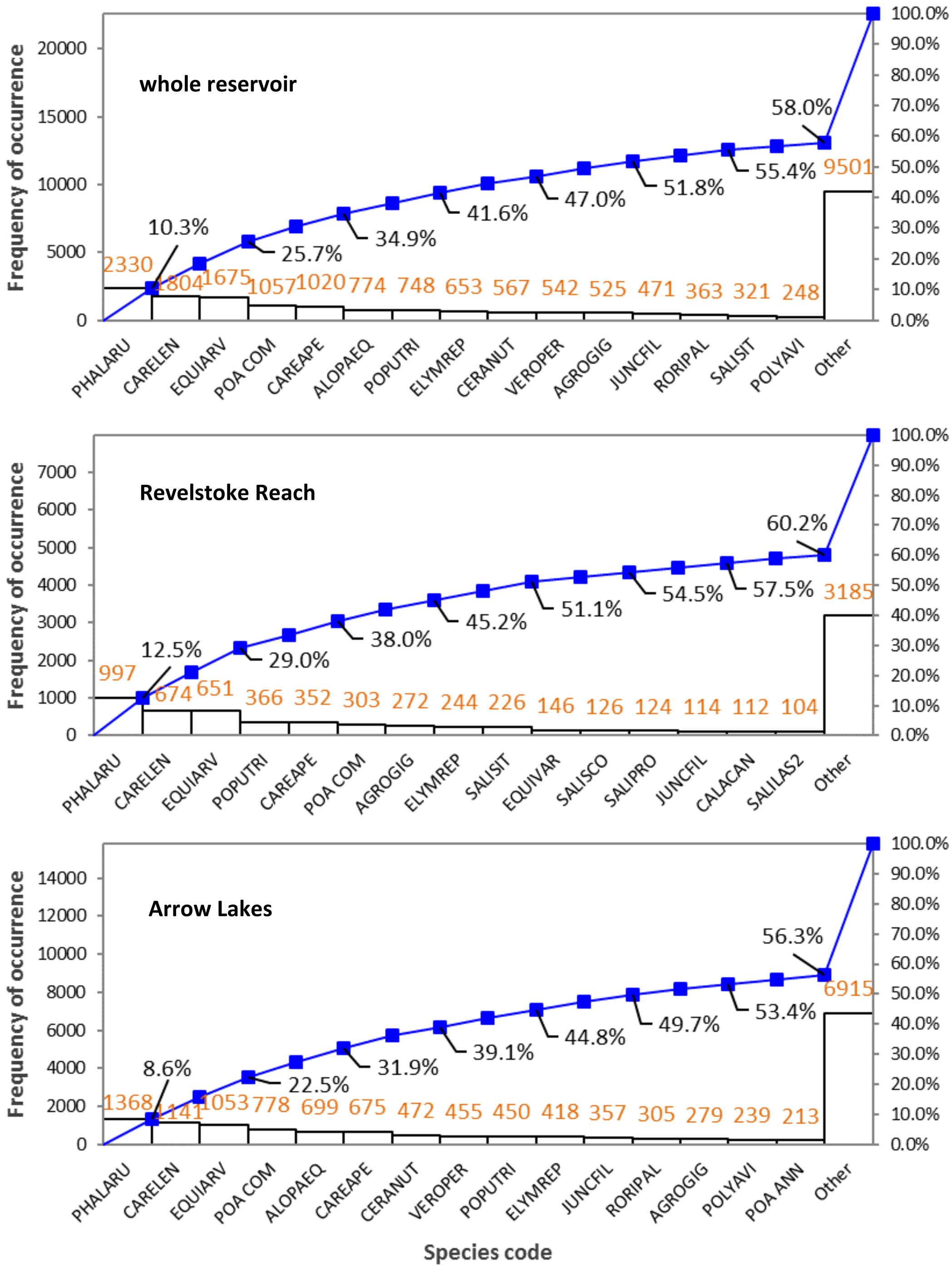


Figure 6-17: Pareto chart showing the total number of times different plant species were recorded in all sample plots from 2010 to 2016 (*n*=2835) in the Arrow Lakes Reservoir drawdown zone. Top panel: whole reservoir; middle panel: Revelstoke Reach; bottom panel: Arrow Lakes (incl. Beaton Arm). The 15 species with the highest encounter frequencies are ordered from left to right in descending order of frequency. The cumulative per cent of total encounters is shown by the ascending line. For example, across the whole reservoir, the first fifteen species account for 58.0% of all species occurrences recorded.

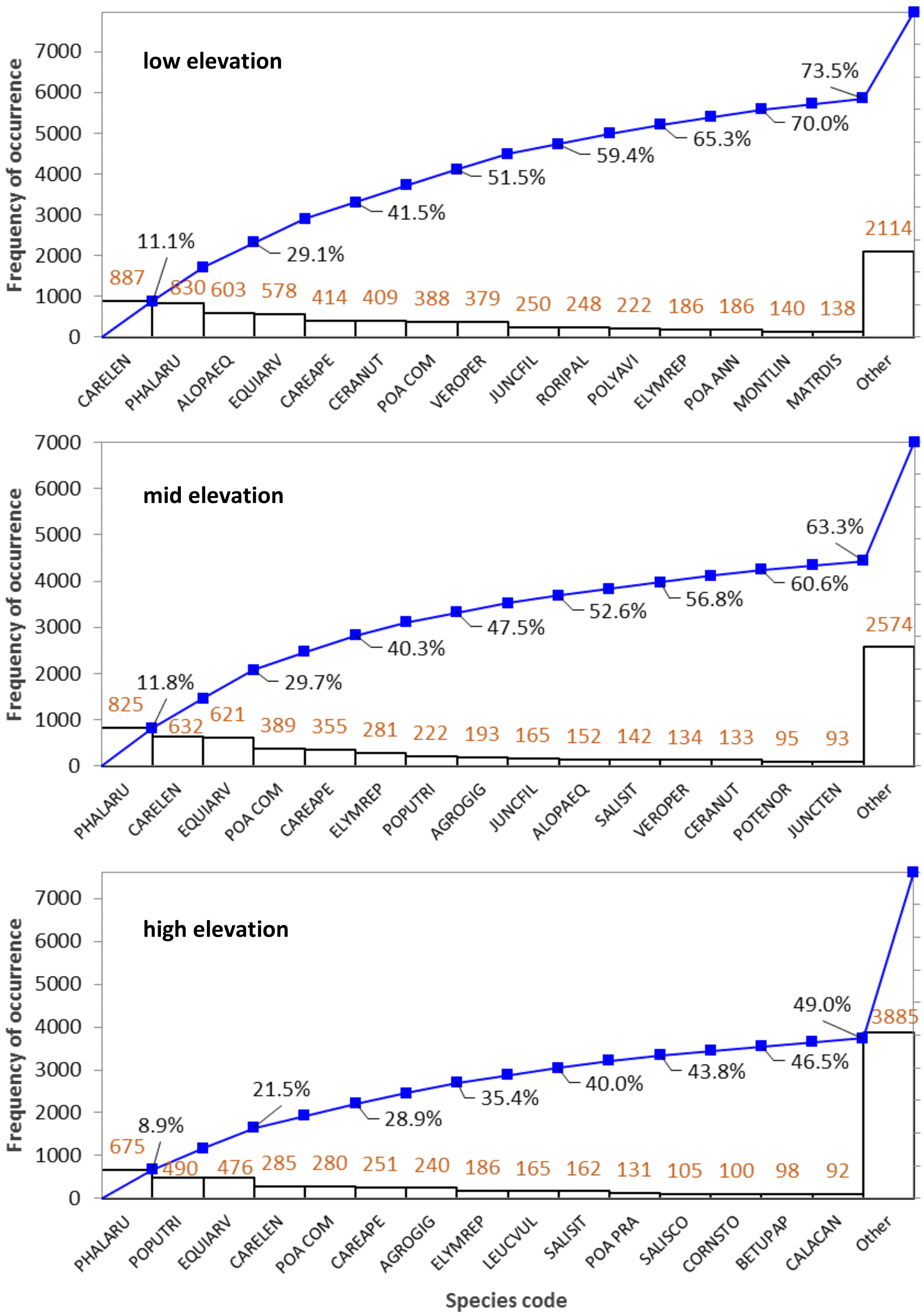


Figure 6-18: Pareto chart showing the total number of times different plant species were recorded in sample plots from 2010 to 2016, for each of three elevation bands: low (434-436 m ASL; top panel), mid (436-438 ma ASL; middle panel), and high (438-440 m ASL bottom panel). The 15 species with the highest encounter frequencies are ordered from left to right in descending order of frequency. The cumulative per cent of total encounters is shown by the ascending line. Infrequent species are grouped together under the category "Other."

The multivariate regression tree (MRT) of species cover data that included elevation as a variable (Figure 6-19) distinguished several species clusters on the basis of north-south position in the reservoir, soil moisture regime, and elevation. For example, high PHALARU (reed canarygrass) cover was associated with latitudes north of Nakusp, moist to wet sites, and elevations < 437.5 m ASL. SALISIT (Sitka willow) indicated a similar suite of habitat relationships except that, for this species, higher cover was associated with elevations > 437.5 m ASL. The weedy species SCLEANN (annual knawel), TRIFARV (hare's-foot clover), and HORDBRA (meadow barley) are associated with dry conditions on southerly sites at elevations > 436.5 m ASL. Cover of CARELEN (Kellogg's sedge) and JUNCFIL (thread rush) is correlated with southerly latitudes, low elevations (< 435.5 m ASL), and uneven microtopography (Figure 6-19).

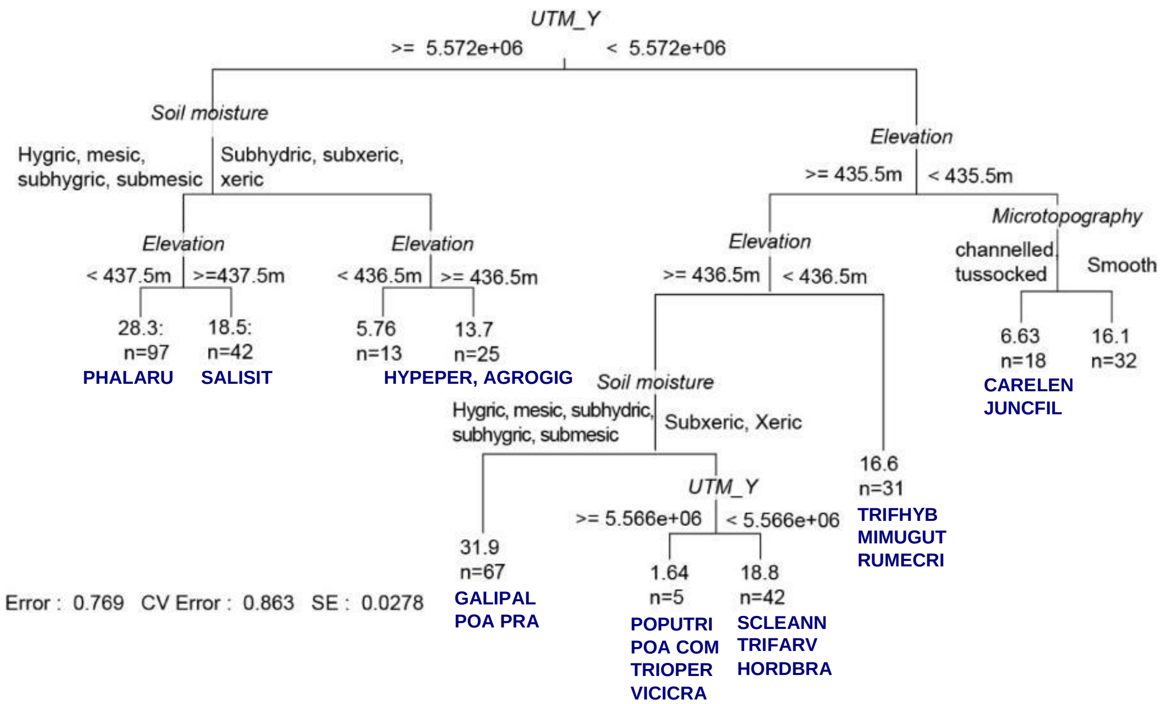


Figure 6-19: Multivariate regression tree (MRT) for plant species cover data. Variables included were elevation, UTM-X, UTM-Y, reservoir reach, slope, heat load, surface topography, primary water source, soil moisture, substrate texture, disturbance, and scouring/erosion/deposition. Numbers below terminal leaves are, in descending order: relative errors; number of plots (*n*) per group; and indicator species. Data from 2016 were modeled. The 66-included species were those present in at least 10 plot samples. Total variance explained by the tree is 23%.

The second MRT (Figure 6-20), which included total monthly growing degree days (GDDs) and average monthly inundation depths as variables (in place of elevation), identified indicator species clusters defined, as before, by north-south position in the reservoir and soil moisture regime. However, in this instance, habitat types were also defined by June GDDs and primary water source (Figure 6-20). For example, wet to moist sites in Beaton Arm with June GDDs < 205 were associated with high covers of the facultative wetland species CARELEN, JUNCFIL, RORIPAL (marsh yellowcress), POTENOR (Norwegian cinquefoil), CARDPEN (Pennsylvanian bittercress), and EQUIPAL (marsh horsetail), among others. Two willows, SALILAS2 (Pacific willow) and SALISIT, were indicators of moist to wet sites at northerly latitudes with minimal to nil June inundation (GDDs > 205. Another two clusters of facultative wetland species were distinguished south of Beaton

Arm in Arrow Lakes. High covers in one cluster, consisting of species such as MIMUGUT (yellow monkey-flower) and MYOSSCO (European forget-me-not), are indicated by the presence of upslope water sources (seepages and sub-irrigation) and moderate to low June inundation—implying that this group is not highly dependent on reservoir operations for summer moisture inputs. The other cluster, consisting of herbs such as ALOPAEQ (little meadow-foxtail) and VEROPER (purslane speedwell), appears, in contrast, to be generally defined by prolonged June inundation (GDDs < 154; Figure 6-20).

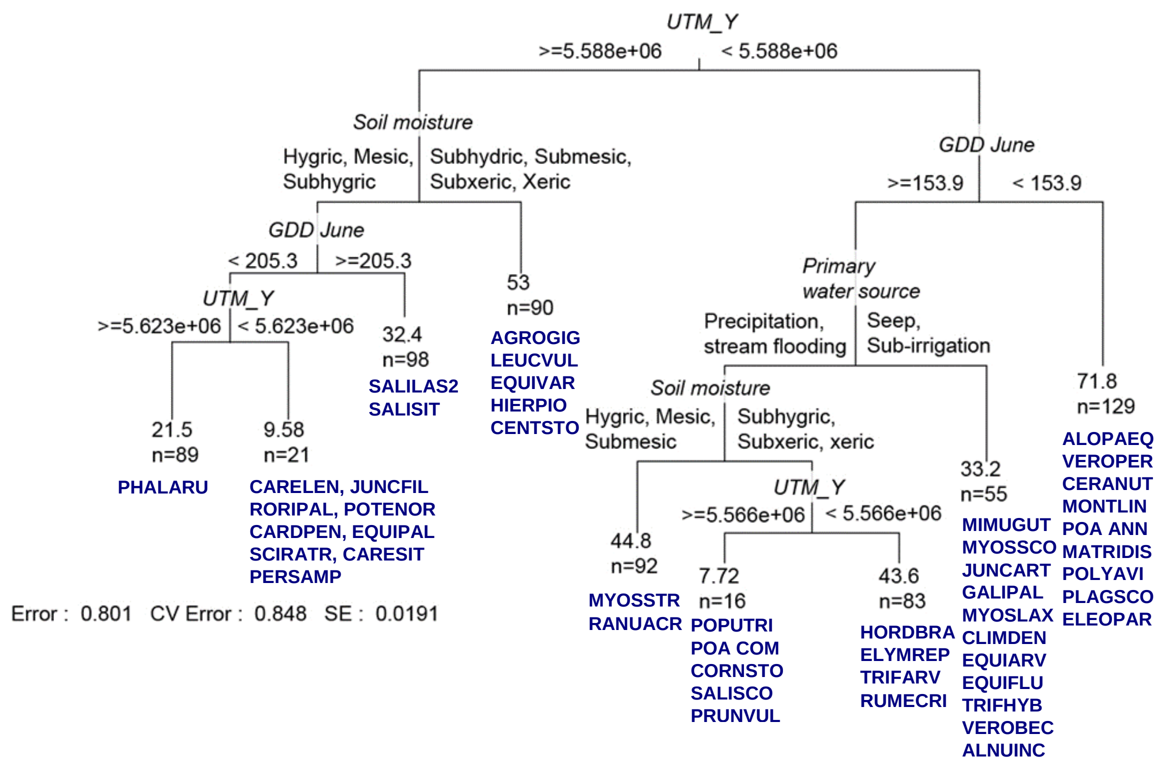


Figure 6-20: Multivariate regression tree (MRT) for plant species cover data. Variables included were as for Figure 6-19 but excluding elevation and including cumulative monthly growing degree days (GDDs) from April to September; and average monthly water depths from June to September (with both set to time *t*-1 to allow for a 1-yr lag in vegetation response to inundation). Numbers below terminal leaves are, in descending order: relative errors; number of plots (*n*) per group; and indicator species. Data from 2010 and 2016 were modeled. The 70-included species were those present in at least 15 plot-year samples. Total variance explained by the tree is 20%.

6.3.4.1 Provincially-tracked Rare Plants

One rare vascular plant of note has been recorded in the Arrow Lakes Reservoir drawdown zone: the annual grass, *Coleanthus subtilis* (moss grass). Moss grass (Figure 6-21) is Blue-listed (S2S3) in British Columbia. The status of this plant has been informally monitored in Arrow Lakes Reservoir since 2014, when its presence was first discovered by botanists during the course of field work for CLBMON-33 (Miller and Hawkes 2015). Prior to this range expansion, moss grass was known from only two locations in B.C. (Hatzic and Shuswap Lakes) and was provincially Red-listed (S1).

Figure 6-21: Moss Grass (*Coleanthus subtilis*), photographed May 25 2015 (top) and May 15 2014 (bottom) at 9 Mile, Revelstoke Reach. Photos © M. Miller from Miller and Hawkes (2015).

Moss grass is a small-statured, pioneer species of receding shorelines, mud flats, mud-bottoms of ephemeral lake beds, and sand bars (Douglas et al. 2001, Long 2003, Catling 2009). Within the Arrow Lakes Reservoir drawdown zone, it occurs on drying mud flats at low elevations on both sides of the reservoir. There are presently 10 confirmed locations in lower Arrow Lakes between south Edgewood and Arrow Park, and a single confirmed location in Revelstoke Reach (9 Mile; Miller and Hawkes 2015). All occurrences lie within the 431 to 436 m ASL elevation band and are subject to regular summer inundation. Some occurrences are extensive, supporting many tens of thousands of plants (and in at least one case, possibly more than one million plants; M. Miller, pers. obs. 2015). Based on our recent observations, the ALR population may be one of the largest in North America, representing a significant proportion of the total North American population.

Within the reservoir environment, moss grass ecology and phenology appear to be closely tied to the hydroperiod. Germination typically occurs in spring, following reservoir draw-down. Plants flower and set seed by May, prior to the onset of summer inundation. Occupied habitats usually remain submerged into the late summer or fall, and inundation may play a key role in maintaining open wet conditions needed for establishment and growth. In 2015, a year in which reservoir levels peaked at 435 m and receded to 430 m by late August, moss grass was observed to undergo a fall (October) germination episode at some sites that would typically still be under water at that time (Miller *et al.* 2016). In 2016, no moss grass plants were observed at any of the previously confirmed locations visited, including at the largest recorded site at Fairhurst Creek. It is unclear at present if the widespread germination failure in 2016 is tied to recent reservoir operations, to the 2015 fall germination event, or to some other undetermined factor related to the species' autecology.

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 the 1990s. As part of monitoring, aerial photographic images of selected regions of the drawdown zone have been captured in alternating years (2007, 2008, 2010, 2012, 2014, and 2016) 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), 2012 imagery was compared with that of 2010 (Enns *et al.* 2012), and 2014 imagery was compared with that of 2007 (Miller *et al.* 2015) 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 sixth and final reporting year of the monitoring program, aerial imagery from 2016 was compared with all previously photographed years back to 2007, representing a 10-year span in photo captures.

Concurrent with aerial photo capture, species composition and cover, and other biophysical attributes, were monitored at established field plots during ground surveys in each study year. The available dataset includes comparable information collected during alternate calendar years as part of the related vegetation study, CLBMON-12. These field data were used to support the interpretation of aerial imagery, and to provide a site-level complement to vegetation processes occurring at the landscape scale.

The 2016 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; Miller *et al.* 2015). The objective here is not to fully 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 initially addressed by Enns *et al.* (2007; 2008; and 2010), who defined 16 vegetation community types (VCTs) based on a combination of similar topography, soils, and vegetation features (Section 3.0, Appendix 11.1). The 2014 field verifications suggested that some refinements to this classification were required before this management question could be properly addressed (Miller *et al.* 2015). For the 2016 assessment, we followed the recommendation of Miller *et al.* (2015) and identified seven additional plant associations (Table 5-1) based on further field observations in 2015 and 2016. These additions do not represent an attempt to "remake" the existing classification, but rather to build on that classification by highlighting different species- or structural-based phases or variants of some VCTs that, it was felt, were not adequately represented under the current system. For example, the PC–Reed Canarygrass mesic VCT was subdivided into four different types based on the relative dominance of reed canarygrass; little meadow-foxtail and horsetails; sedges and rushes; and woody shrubs (willows).

The newly-recognized VCTs are described in Section 5.1.4. It should be noted that, even after refinements, boundaries between different VCTs are not always obvious, either for orthophoto interpreters or for observers working on the ground. This is partly due to the gradual environmental gradients that define much of the vegetated space. Plant assemblages in these transition zones often show qualities intermediate between two or more VCTs, making consistent categorization challenging. That said, the division of drawdown zone vegetation into separate "communities" is by nature a somewhat arbitrary exercise aimed at introducing order to what is essentially a rather fluid environment for the purpose of addressing the project management questions. Semantically, it may be more accurate to regard the vegetation of the drawdown zone as single complex community composed of an affiliation of numerous intergrading species associations, with certain associations (e.g., PC–Reed Canarygrass) being more clearly demarcated on floristic grounds than others (e.g., BG–Gravely beach, SS–Steep sand, WR–river entry).

Given the practical challenges around community typing, we found it useful to cast vegetation pattern and process in terms of two other organizational levels, in addition to VCTs: (i) vegetation structure; and (ii) plant species functional groups, or "guilds." Compared to VCT delineations, data on structure and guild composition may have more direct bearing on wildlife values of management interest. 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 scales, and vice versa at local scales, is also consistent with hierarchical models of habitat selection in animal communities (Saab 1999, Harvey and Weatherhead 2006).

For purposes of remote sampling, we divided vegetation cover into four broad structural attributes readily distinguishable at the scale of the bi-annual orthophotos: *sparse* or *pioneer* vegetation; denser (> 10 per cent) *herbaceous* cover; *shrubland*; and young *forest*. Because permanent wetlands were rare in the areas being directly monitored, aquatics were not included as a separate structural class. However, we note that wetland vegetation comprises an important component of the drawdown zone flora, particularly in the northeast quadrant of Revelstoke Reach. These aquatic and semi-aquatic communities have been previously characterized and monitored under a separate WLR study, CLBMON-11B4 (Hawkes *et al.* 2011, Miller and Hawkes 2014).

To complement VCT assessments at the site level, the total set of vascular plant species was partitioned into six functional groups, or “guilds”: *flowering forbs*, *grasses*, *sedges/rushes* (and their allies), *pteridophytes* (horsetails), *shrubs* (including shrub-sized trees), and *trees*. Finer taxonomic distinctions could have been drawn (e.g., between annuals and perennials, natives and exotics), but benefits accruing from finer distinctions had to be weighed against the need to ensure adequate sample sizes for comparison.

By tying retrospective assessments (in part) to coarse habitat structure and plant guilds, we were able to circumvent certain information gaps in the multi-year database. This included missing or incorrect species identifications (for purposes of guild assignment, identification to genus or family was sufficient) and inconsistencies in VCT assignments between years (there were numerous instances of plots being typed to different VCTs in different years even though the vegetation composition had not changed).

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 VCTs. Results in 2016 confirmed earlier findings that the PC–Reed Canarygrass mesic VCT was the most ubiquitous vegetation type in the drawdown zone, accounting for over 35 per cent of aerial photo point samples in 2016. Reed canarygrass stands cover many mid-elevation sites, especially in Revelstoke Reach, where they often form extensive monocultures or near-monocultures. The PC VCT ranges from strictly herbaceous (the dominant phase) to partial shrubland. The shrubland phase (PC–Willow), which is limited to mid- and upper-elevations, is relatively infrequent at the landscape scale, accounting for around five per cent of vegetated cover.

After PC, BE–Sandy beach, BE–Gravelly beach, and PE–Horsetail lowland associations are the next most extensive VCTs, with each accounting for between 10 and 15 per cent of vegetation cover at the landscape scale. Like PC, these VCTs are largely herbaceous, although BE and BG are occasionally associated with some limited early seral shrub establishment (consisting largely of scattered black cottonwood stems). BE and BG are both associated with low-nutrient soils and are among the most lightly vegetated VCTs. Because BE occurs on sand generally at low elevation, it tends to be highly unstable and temporally variable, consisting mainly of early pioneering vegetation and characterized by low species richness. Adjacent to BE, the PE association (including the two sub-categories, PE–Foxtail/horsetail and PE–Sedge) occurs on relatively compacted, non-aerated soils with higher moisture content than that of BE or its typical upslope neighbour, PC. PE is more stable than BE and supports higher cover and species richness. In 2016, sample plots within this habitat type supported the highest average richness of any VCT in the drawdown zone. However, low-elevation PE habitats can be prone to sediment deposition from adjacent beaches, which can lead to fluctuations over time in both the total cover and spatial extent of this VCT.

PA–Redtop upland was the next most frequent vegetation type in point samples, with a relative frequency of around eight per cent. This VCT represents the sometimes weedy, well-drained sites found on coarse substrates at upper elevations between the PC type and the upland forest (CR). PA is primarily herbaceous but is sometimes associated with a shrub component (willow and black cottonwood). It tends to be one of the more speciose vegetation types with a median richness of around 10 species per 50-m^2 plot area. Relative frequency of other VCTs followed in descending as follows: CR–Cottonwood riparian > Shrub riparian = PC–Willow > LO–Log zone = RR–Reed-rill > SS–Steep Sand > RS–Willow stream entry = BB–Boulders, steep = WR–River entry > SF–Slope failure. In terms of the frequency ranking, CR represents a special case. This VCT actually forms a more or less continuous band of habitat (in undeveloped regions) along the upper margin of the reservoir at and above 440 m ASL. The orthophoto-based landscape assessment was stratified to emphasize the 434-440 m elevation band. Consequently, this upland forest type was under-represented in the point samples and its relative ubiquity can probably be assumed to be higher than indicated here.

In terms of vegetation structural stage, over 50 per cent of vegetated terrain in the drawdown zone can be categorized as herb stage (having an established cover of forbs, graminoids, or horsetails, and lacking significant shrub or tree cover). Approximately 20 per cent of terrain is essentially unvegetated or supports a sparse cover of pioneering vegetation. The relative extents of these two stages varied significantly between 2007 and 2016 and did so in inverse direction to one another. Whereas herb frequency decreased from 2007 to 2012, then increased until 2016, the amount of sparsely vegetated to unvegetated terrain increased after 2007, reaching a peak in 2012 before receding toward the end of the monitoring period. Around 10 per cent of drawdown zone vegetation can be characterized as early successional shrubland, with another five per cent represented by young riparian cottonwood forest (with similar caveats applying to this value as were noted for CR, above). Based on the time series of orthophoto imagery, there is some indication that the spatial extent of shrubland has slowly but steadily increased between 2007 and 2016. Relative forest cover, on the other hand, has remained stable.

Previous assessments (Miller *et al.* 2015) indicated that percentage values for the herb stage were similar for both Arrow Lakes and Revelstoke Reach. Arrow Lakes supported a relatively higher percentage of sites at the sparse/pioneer stage, and a lower percentage of shrub-dominated sites, compared 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 (Miller *et al.* 2015).

7.3 MQ3: 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 Arrow Lakes 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.

7.4 MQ4: 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 annual reports. Based on the lack of significant change observed in community frequency and composition between 2007 and 2015 (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) and Miller *et al.* (2015):

- 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 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.

In 2016, multivariate models (GLMM, MRT) incorporating multiple years of vegetation data, air temperatures, and daily reservoir levels yielded further insights into vegetation zonation patterns and their relationship to inundation and topo-edaphic site conditions. Models predicted that plant cover is limited by several factors, some but not all of which are directly linked to annual reservoir operations. For example, cover had a negative association with dry soils, erosion, slope, and disturbance. Slope and disturbance are non-operational variables; soil moisture and erosion may or may not be operationally-linked. However, cover was also negatively correlated with July growing degree days (GDDs) and June water depth and had a positive association with July water depth (all directly inundation-related). Our results suggest that while cover is limited by available growing days in early summer, soil moisture availability becomes a greater limiting factor by mid summer due to the poor water-holding capacity of some substrates. Operationally, the prediction is that existing vegetation cover will be favoured over time by delaying inundation in the spring, but not necessarily by limiting summer inundation.

Species richness was negatively correlated with latitude, dry substrates, June water depth, and July GDDs, and was positively associated with scouring and deposition, warm April temperatures, and increased July water depth. These results imply that richness, like cover, may be mediated by a combination of operational and non-operational factors working in concert. For example, positive effects appear to accrue from reduced June inundation and increased July inundation (both operational factors) but also from warm ambient spring temperatures (a non-operational factor represented by April GDDs), a southerly locale (another non-operational factor), and high soil moisture content (an attribute that, because it is sampled in spring prior to the onset of inundation, is more reflective of local topo-edaphic conditions and upstream water inputs than direct reservoir inputs). Operationally, the implication, as with cover, is that richness will be favoured over time by delaying the onset of inundation in May and June, but not necessarily by reducing the depth and duration of inundation later in the summer.

In terms of the environmental relationships of different plant groups (guilds), high relative abundance of grasses, sedges, and pteridophytes was associated with sites receiving between 94 and 138 June GDDs (roughly corresponding to the 436-438 m elevation bands), with high relative grass cover also associated with sites receiving < 94 June GDDs (corresponding to the 434-436 m band). Trees, forbs, and shrubs were indicator groups for sites with June GDDs > 138 (i.e., upper elevations with minimal June inundation). At high elevations, sites receiving > 326 July GDDs (indicating minimal inundation) were more likely to be associated with high relative shrub cover than sites with more regular July inundation (< 326 GDD), which were more strongly correlated with high relative herb or tree cover. Sedges/rushes and forbs were indicators for more southerly plot groups, while trees, grasses, pteridophytes, and shrubs were indicators for more northerly plot groups. At southerly latitudes, sedges/rushes were indicators for moderately moist to moist sites, while forb-indicator sites tended to be characterized by wetter soils.

In terms of species–environmental relationships, MRT models distinguished several species clusters on the basis of north-south position in the reservoir, soil moisture regime, and elevation. Different habitat types were also defined by June GDDs and primary water source. For example, high cover of reed canarygrass was associated with latitudes north of Nakusp, moist to wet sites, and elevations < 437.5 m ASL. Cover of Kellogg’s sedge and thread rush was correlated with southerly latitudes, low elevations (< 435.5 m ASL), and uneven microtopography. Wet to moist sites in Beaton Arm with June GDDs < 205 were associated with high covers of the facultative wetland species marsh yellowcress, Norwegian cinquefoil, Pennsylvanian bittercress, and marsh horsetail, among others. Another two clusters of facultative wetland species were distinguished in Arrow Lakes. High covers in one cluster, consisting of species such as yellow monkey-flower and European forget-me-not, are indicated by the presence of upslope water sources (seepages and sub-irrigation) and moderate to low June inundation—implying that this group is not highly dependent on reservoir operations for summer moisture inputs. The other cluster, consisting of herbs such as little meadow-foxtail and purslane speedwell, appears, in contrast, to be generally defined by prolonged June inundation.

These results illustrate the influence that reservoir operations exert on plant zonation in the drawdown zone and support the conclusion of Miller *et al.* (2015) that growing degree days (when weighted by exposure time) can serve as a useful complement to elevation for predicting plant species assemblages. They also illustrate the utility of multivariate techniques such as MRT in identifying groups of species based on habitat commonalities and in distinguishing reservoir influences from other likely sources of influence. From a management perspective, MRTs provide a useful way of predicting species composition at sites for which only environmental data are available. They could also be useful for identifying suitable receptor sites for revegetation or other physical works aimed at habitat enhancement, and for ensuring that the species chosen for out-planting are an appropriate match for existing habitat conditions at receptor sites. These topics will be explored at greater length in the upcoming CLBMON-35 program.

7.5 MQ5: 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?

Analysis of aerial imagery captured (roughly) biannually since 2007 points to a moderate degree of inter-annual fluctuation, but little net (directional) long-term change in the spatial configuration, frequency, and composition of vegetation community types or VCTs at the landscape scale. The short-term fluctuations that have occurred have primarily been in the structural status of vegetation at the transition zones between VCTs, in particular at the low-elevation beach–vegetation interface where shifting sediment depositions create a dynamic and changeable environment. Some of these may be related to annual changes in the reservoir operation regime: there was, in some places, a marked pullback in the extent of low-elevation herbaceous cover between 2007 and 2012, possibly coinciding with the extended summer inundation events that characterized this time period. Since 2012, the lower limits of established cover have been re-advancing back downslope and now largely sit where they did in 2007. This is possibly a response to the series of relatively briefer and shallower summer inundations that have obtained during the past few years. We can surmise that an extended sequence of inundation events mirroring either one or the other of these contrasting sorts of operational regime would result in a directional change in vegetation spatial limits over time. But this prediction cannot be tested with the data at hand. Based on observed trends over the last 10 years we conclude that, at a landscape scale, the soft constraints operating regime maintains overall vegetation spatial limits, structure and composition.

At the local, intra-community level, there have been small but statistically significant declines in overall per cent plant cover at all elevations, and in the cover of some plant guilds (forbs, sedges and sedge allies, pteridophytes), between 2010 and 2016. Per cent cover of grasses has not changed, while that of shrubs may have increased slightly. At mid elevation, forb cover appears to have decreased relative to cover of graminoids, pteridophytes, and shrubs. At low elevation, the proportional cover of grasses versus that of sedges and sedge-like plants has fluctuated over time. Whereas the two groups had similar coverage on average in 2013, grasses were more than twice as abundant (on average) as sedges and their allies in 2016. Since 2012, the reservoir has experienced an incremental increase in seasonal GDDs at low elevation (434-436 m ASL) that appears to coincide with the declining trend in the covers of forbs, sedges, and pteridophytes over the same period. At mid elevation, where total cumulative GDDs declined from 2010 until the middle of the monitoring period before increasing again, cover of grasses has tended to follow a slightly divergent pattern, with highest average covers recorded in 2012 and lower covers thereafter.

The implication is that, with the probable exception of shrubs, decreases in late summer inundation do not necessarily translate into an increase in plant density or abundance at the local scale. Regression models (GLMM) further showed that plant cover was significantly negatively correlated with June water depth, but positively correlated with July water depth. Such an outcome may seem counterintuitive, but it should be remembered that many dominant drawdown zone species, such as reed canarygrass, require some exposure during the early summer growing period but thrive under wet conditions and may be summer moisture-limited (Hawkes *et al.* 2014). We surmise the decrease in cover of associated VCTs may be related to the generally shallower and briefer summer inundation events that have prevailed at mid and upper elevations since 2013. It is unclear if the observed reservoir-wide changes in local plant cover between 2010 and 2016 reflect a longer-term trend or merely an inflection point in a continuously fluctuating vegetation cycle. However, the more or less consistent pattern of step-wise declines recorded over time for some groups such as forbs and sedges raises reasonable doubts about the effectiveness of the soft constraints operating regime in maintaining the vegetation status quo at the site level.

7.6 MQ6: 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 levels that were sometime higher, and sometimes lower, than in 2004/2005, so from this perspective the soft constraints goal has been partially, though not completely, met. Despite this, there is no *a priori* reason to suspect that targeting consistently lower reservoir levels is an effective strategy for maintaining the existing vegetation status quo above 434 m ASL. On the contrary, such an approach would likely result in at least some directional vegetation changes, by (for example) facilitating the advancement of shrubland into upper and mid elevations of the drawdown zone, and grasses into low elevation habitat, while reducing the covers of forb, sedges, rushes, and horsetails at mid and low elevations. Such changes could run counter to the soft constraints goal for vegetation. It is possible that some of these changes (such as increased shrubland development) would have desirable benefits for vegetation quality, wildlife habitat, and/or social values. However, any such benefits remain hypothetical until a reduced flooding regime can actually be tested in practice. The below-average reservoir levels of 2015 and 2016 could, if repeated in subsequent years, help elucidate the effects (either positive or negative) of holding reservoir levels relatively low for multiple seasons in succession.

The present composition of drawdown zone vegetation is the cumulative outcome of the hydroperiod experienced over the last five decades, since the impoundment of the Columbia River by the Hugh Keenleyside Dam in 1968. This decadal regime has resulted in community whose species composition, a substantial proportion of which is non-native, is maintained in a persistent seral state by a frequent but variable disturbance regime. Most of the plant species that thrive in the drawdown zone environment 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 tolerances to submergence. We thus predict that the Water Use Plan operating regime can continue to maintain existing vegetation in its present state so long as the historical pattern of variability in hydroperiod is maintained. In other words, the vegetation equilibrium that has been achieved in the drawdown zone is the product of, and thus depends on, the ongoing disequilibrium of the underlying system.

At the same time, we should expect to see directional changes in vegetation cover and composition in response to any consistent, directional changes in the timing, depth, frequency, and duration of inundation. For example, successive years of below-average reservoir levels could eventually lead to a more shrub-dominated system supporting lower overall covers of herbaceous groups such as forbs and sedges. On the other hand, if the objective is to enhance existing vegetation types, rather than simply maintain the current status quo, the findings from this study provide a useful operational roadmap for effecting desired changes within the soft constraints framework. For example, models suggest that both cover and structural diversity at all elevations can be maximized in the following way: (i) by delaying inundation in the spring (preferably until June or later) to allow time for germination, establishment, and the completion of reproductive cycles; (ii) by allowing for sufficient June/July inundation at low and mid elevations (434-438 m ASL) to reduce summer drought stress for inundation-adapted species; and (iii) by minimizing (but not eliminating) the depth and duration of inundation at high elevations (>438 m ASL), to maintain herbaceous cover while facilitating woody shrub establishment and growth.

8.0 SUMMARY AND CONCLUSIONS

In this final 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 (2014), 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 2016). There is currently no compelling evidence to indicate that the Water Use Plan operating regime of Arrow Lakes Reservoir is failing to maintain vegetation spatial limits, structure, and composition of existing vegetation communities in the drawdown zone.

A further summary of the multi-year findings and study limitations associated with each management question is provided in the Executive Summary table (p. iii).

9.0 CONSIDERATIONS FOR FUTURE WORK

As indicated in the Executive Summary table (p. iii), some data gaps still exist in this final year of CLBMON-33. No additional mapping or monitoring is currently planned under CLBMON-33. That said:

1. Decisions regarding the location and frequency of future vegetation work can be informed by additional gap analysis results coming out of the related program CLBMON-35 (Arrow Lakes and Kinbasket Reservoirs Plant Response to Inundation).
2. Currently available 10-cm and 20-cm orthophotos are adequate for identifying course structural changes at the landscape scale, but lack the resolution needed for estimating sparse herbaceous plant cover or for distinguishing reliably among different vegetation community types. Alternative approaches to monitoring existing vegetation areas (e.g. using LiDAR remote sensing technology) could be considered in the future if linked to specific revegetation programs.
3. Findings from CLBMON-35 can be used to inform on whether obtaining quantitative data on soil moisture, soil structure, and soil organic content would improve our understanding of how spatial extent, structure and composition of vegetation communities relate to topo-edaphic site conditions (such as substrate, drainage, aspect, and slope).
4. Future considerations for vegetation and revegetation monitoring in Arrow Lakes Reservoir can be discussed at the revegetation technical forum attended by agencies and First Nations following the completion of Year 2 of the CLBMON-35 program in 2019.

10.0 LITERATURE CITED

Baskerville, G.L. and P. Emin. 1968. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology 50:514-517.

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

BC Hydro. 2007. Columbia River Project Water Use Plan - Monitoring Program Terms of Reference. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources. 29 pp.

BC Hydro. 2008. Terms of Reference, Kinbasket and Arrow Lakes Reservoir Revegetation Management Plan. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis. 28 pp.

British Columbia Ministry of Forests and Range and British Columbia Ministry of Environment. 2010. Field manual for describing terrestrial ecosystems. 2nd ed. Forest Science Program, Victoria, B.C. Land Management Handbook No. 25.

Catling, P.M. 2009. *Coleanthus subtilis* (Poaceae) new to Northwest Territories, and its status in North America. Rhodora 111:109-119.

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

De'ath, G. 2002. Multivariate regression trees: a new technique for modeling species-environment relationships. Ecology 83:1105-1117.

Douglas, G.W., D. Meidinger, and J. Pojar. 2001. Illustrated Flora of North America. Vol. 7 Monocotyledons (Orchidaceae through Zosteraceae). B.C. Min. of Environment, Lands, and Parks and B.C. Min. of Sustainable Resource Management. Victoria, BC. 379 p.

Enns, K.A. 2007. Arrow Lakes Reservoir Inventory of Vegetation Resources (2007). Report prepared by Delphinium Holdings Inc. for BC Hydro. 14 pp + appendices

Enns, K., and H.B. Enns. 2012. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis: 2011 Final Report. Unpublished report by Delphinium Holdings Inc. for BC Hydro Generation, Water Licence Requirements, Castlegar, BC. 102 pp + appendices

Enns, K.A., R. Durand, P. Gibeau and B. Enns. 2007. Arrow Lakes Reservoir Inventory of Vegetation Resources (2007) – Addendum to 2007 Final Report. Report prepared by Delphinium Holdings Inc. for BC Hydro. 90 pp + appendices

Enns, K.A., P. Gibeau and B. Enns. 2008. Arrow Lakes Reservoir Inventory of Vegetation Resources – 2008 Final Report. Report prepared by Delphinium Holdings Inc. for BC Hydro. 67 pp + appendices

Enns, K., P. Gibeau and B. Enns. 2009. CLBMON-12 Monitoring of revegetation efforts and vegetation composition analysis. Report prepared by Delphinium Holdings Inc. for BC Hydro. Castlegar, B.C. 94 pp + appendices

Enns, K.A., H.B. Enns and A.Y. Omule. 2010. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources: 2010 Final Report prepared by Delphinium Holdings Inc. for BC Hydro. 86 pp + appendices

Enns, K. H.B. Enns and J. Overholt. 2012. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources: 2012 Final Report prepared by Delphinium Holdings Inc. for BC Hydro, 79 pp + appendices

Harvey, D.S. and P.J. Weatherhead. 2006. A test of the hierarchical model of habitat selection using eastern massasauga rattlesnakes (*Sistrurus c. catenatus*). Biological Conservation 130:206-216.

Hawkes, V.C and P. Gibeau. 2015. CLBMON-10 Kinbasket Reservoir Inventory of Vegetation Resources. Annual Report – 2014. LGL Report EA3532. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 74 pp + Appendices.

Hawkes, V.C and P. Gibeau. 2017. CLBMON-10 Kinbasket Reservoir Inventory of Vegetation Resources. Annual Report–2016. LGL Report EA3532D. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water License Requirements, Burnaby, B.C. In prep.

Hawkes, V.C., M.T. Miller, J.D. Fenneman, and N. Winchester. 2011. CLBMON-11B4 monitoring wetland and riparian habitat in Revelstoke Reach in response to wildlife physical works. Annual Report – 2010. LGL Report EA3232. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water Licence Requirements, Burnaby, B.C.

Hawkes, V.C., M.T. Miller, and P. Gibeau. 2013. CLBMON-10 Kinbasket Reservoir Inventory of Vegetation Resources. Annual Report – 2012. LGL Report EA3194A. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 86 pp + Appendices.

Hawkes, V.C., H. van Oort, M. Miller, N. Wright, C. Wood, and A. Peatt. 2014. CLBWORKS-30 Ecological Impact Assessment – Wildlife Physical Works Project 14 & 15A. Unpublished Report by LGL Limited environmental research associates, Cooper, Beauchesne and Associates, Ecofish Research Ltd. and Okanagan Nation Alliance for BC Hydro, Burnaby BC. 92 pp. + Appendices.

Legendre, P. and L. Legendre. 2012. Numerical Ecology, Vol. 24 (Developments in Environmental Modelling). 3rd edition. Elsevier, Amsterdam.

Landis, J.R. and GG. Koch. 1977. The measurement of observer agreement for categorical data. Biometrics, 33: 159-174.

Long, S. 2003. *Coleanthus*, modified by Barkworth from Barkworth et al. (eds.), Flora of North America vol. 25, viewed at http://herbarium.usu.edu/ webmanual [June 15 2015].

Omule, A.Y. and K.A. Enns. 2010. CLBMON-33: determination of optimal sample size for repeated measures analysis. For B.C. Hydro. Delphinium Holdings, Inc. 22 pages.

McCune, B. and D. Keon. 2002. Equations for potential annual direct incident radiation and heat load. Journal of Vegetation Science 13: 603–606.

Miller, M.T. and V.C. Hawkes. 2014. CLBMON-11B4: Monitoring wetland and riparian habitat in Revelstoke Reach in response to Wildlife Physical Works. Annual Report – 2013. LGL Report EA3413. Unpublished report by Okanagan Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 34 pp + Appendix.

Miller, M.T. and V.C. Hawkes. 2015. Moss Grass (*Coleanthus subtilis*) Survey, Upper Revelstoke Reach – Summary Report, June 2015. LGL Report EA3632. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for B.C. Hydro Generation, Revelstoke Unit 6 Project and Water Licence Requirements, Burnaby, BC. 14 pp.

Miller, M.T., J.E. Muir, P. Gibeau, and V.C. Hawkes. 2015. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources. Year 8 Annual Report – 2014. LGL Report EA3545. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 55 pp + Appendices.

Miller, P. W. Lanier, and S. Brandt. 2001. Using Growing Degree Days to predict plant stages. Ag/Extension Communications Coordinator, Communications Services, Montana State University-Bozeman, Bozeman, MO.

R Development Core Team. 2007. R: A language and environment for statistical computing. R foundation for Statistical Computing, Vienna, Australia. Version 3.3.1; http://www.R-project.org.

Saab, V. 1999. Importance of spatial scale to habitat use by breeding birds in riparian forests: a hierarchical analysis. Ecological Applications 9: 135-151.

Sim, J. and C.C. Wright. 2005. The Kappa statistic in reliability studies: use, interpretation, and sample size requirements. Physical Therapy, 85: 257-268.

Wiens, J.A. and J.T. Rotenberry. 1981. Habitat associations and community structure of birds in shrubsteppe environments. Ecological Monographs 51:21–41.

Zuur, A.F., E.N. Leno, and G.M. Smith. 2007. Analysing Ecological Data. Springer, New York, NY. 672 pp.

11.0 APPENDICES

11.1 Vegetation Community Types (VCTs)

11.1.1 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.* 2013). 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 Kellogg's Sedge, Common Horsetail, and Pennsylvania Bitter-cress. Reed Canarygrass can be monospecific and form very dense, mostly pure stands of 1 ha or larger in size, especially in Revelstoke Reach. This type has been heavily grazed by geese in the Arrow Lakes, and in this this condition it can be invaded by several species of sedges, grasses, cranesbill, bedstraw, and other inundation-tolerant or requiring plants.

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

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 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 (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.

11.2 Aerial Photography MetaData[4]

Flight Details

- The Arrow Lake Reservoir foreshore was photographed on May 7th and 10th by Terrasaurus Aerial Photography Ltd.
- Photos were captured at 15-cm pixel size and subsequently reprocessed to 20-cm orthophotos.
- The area covered by the ortho-mosaics is outlined in a shapefile: (ArrowLake_2016_total_ortho_coverage.shp).
- A GPS moving map display was used for survey flight guidance.
- Pilot: Chuck Rebstein. Photographer: Jamie Heath.

Camera Details & Calibration

- Alpha Metric FPS medium format digital camera, vertically mounted on a gimballed mount.
- Focal length = 99.8 mm
- Principal point offset: x= 0.0 y= -0.0
- Chip Size = 53.904 x 40.4 mm, 50 megapixel (downsampled), pixel size 6.6micron
- Radial Distortion: K0= 0.0, K1= 5.37641e-007, K2= -3.85502e-009, and K3= 4.25875e-012.
- Decentering: P1: -3.25839e-006, P2: -6.11757e-006
- All photos taken as 16bit raw imagery, reprocessed to the optimum 8bit tiffs.

Aerial Triangulation / Ortho Details

- Aerial triangulation was completed by Terrasaurus.
- Airborne GPS (ABGPS) and IMU data were used in the AT process.
- GPS ground control points were used for areas around the City of Revelstoke. Outside the City of Revelstoke area, existing 2008 and 2011 orthophotos and DEM were used as ground control to aid gps/imu positions.
- All colour balancing was completed by Terrasaurus using their proprietary colour program.
- Orthorectifying and stitching of mosaics was completed by Terrasaurus.
- A new DTM was created for the Needles / Edgewood area (12.8km2)
- All mosaics were delivered in both Geotiff and ECW formats.

[4] Contributed by Terrasaurus Aerial Photography Ltd.

11.3 Example of data form used to record vegetation and associated site-specific information in plots sampled in 2016

Project ID **CLBMON-33: Arrow Lakes Reservoir Inventory of Vegetation Resources** | **Reach:**

Date: | **Site:** | **Surv:** | **VCT:**

Plot #: | **Wpt. #:** | **UTM:**

Plot Photo # (N, E, S, W): | **Garmin #:**

Aspect: ° | **Slope:** ° | **Extra 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 (per cent -- should total 1):
cobble______ gravel______ loam______ sand______ silt______ clay______ mud______ wood______ organics______

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

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

Recent evidence of scouring, erosion, or deposition:

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	Species	B1	B2	Tot

HERB LAYER (C)				
Species	%	Species	%	**Notes**

Notes

11.4 Frequency counts of VCTs (vegetation community types), by elevation band, in point samples (*n*=310) of aerial imagery obtained for Revelstoke Reach (Arrow Lakes Reservoir) obtained from 2007 to 2016.

Elevation band	Vegetation Community	Frequency of points				
		2007	2010	2012	2014	2016
Low	SF	1	1	1	1	1
	SS	10	10	10	10	10
	BB	3	3	3	3	5
	BG	50	50	50	50	49
	BE	89	94	104	96	92
	PE	68	65	57	63	66
	PC	64	62	60	62	65
	RR	18	18	18	18	18
	RS	2	3	3	3	3
	Shrub - riparian	1	1	1	1	1
	WR	1	1	0	0	1
Mid	SS	1	1	1	1	1
	BB	4	4	4	4	3
	BG	30	30	30	30	30
	BE	9	12	10	10	9
	PE	8	7	7	7	8
	RR	3	3	3	3	3
	LO	2	2	2	3	3
	RS	5	4	4	4	4
	PC	75	73	73	72	67
	PA	14	14	14	14	15
	WR	1	1	1	1	0
	Shrub - riparian	1	1	3	3	3
	CR	2	2	2	2	2
High	SS	2	2	2	2	2
	BG	19	17	16	19	19
	BE	7	8	7	9	9
	PE	1	1	1	1	1
	LO	24	24	28	18	15
	RS	2	2	2	2	2
	PC	42	43	42	37	37
	PC - shrub	2	3	4	5	5
	PA	37	35	33	42	44
	Shrub - riparian	18	19	19	19	19
	CR	32	32	32	32	32

11.5 Frequency counts of VCTs (vegetation community types), by elevation band, in point samples (*n*=676) of aerial imagery obtained for Arrow Lakes (Arrow Lakes Reservoir) obtained from 2007 to 2016.

Elevation band	Vegetation Community	Frequency of points				
		2007	2010	2012	2014	2016
Low	SF	1	1	1	1	1
	SS	10	10	10	10	10
	BB	3	3	3	3	5
	BG	50	50	50	50	49
	BE	89	94	104	96	92
	PE	68	65	57	63	66
	PC	64	62	60	62	65
	RR	18	18	18	18	18
	RS	2	3	3	3	3
	Shrub - riparian	1	1	1	1	1
	WR	1	1	0	0	1
Mid	SS	1	1	1	1	1
	BB	4	4	4	4	3
	BG	30	30	30	30	30
	BE	9	12	10	10	9
	PE	8	7	7	7	8
	RR	3	3	3	3	3
	LO	2	2	2	3	3
	RS	5	4	4	4	4
	PC	75	73	73	72	67
	PA	14	14	14	14	15
	WR	1	1	1	1	0
	Shrub - riparian	1	1	3	3	3
	CR	2	2	2	2	2
High	SS	2	2	2	2	2
	BG	19	17	16	19	19
	BE	7	8	7	9	9
	PE	1	1	1	1	1
	LO	24	24	28	18	15
	RS	2	2	2	2	2
	PC	42	43	42	37	37
	PC - shrub	2	3	4	5	5
	PA	37	35	33	42	44
	Shrub - riparian	18	19	19	19	19
	CR	32	32	32	32	32

11.6 Kappa test results for VCT changes in orthophoto point samples of Revelstoke Reach (Arrow Lakes Reservoir) over time (2007, 2010, 2012, 2014, 2016).

Shown is the exact (or asymptotic) p-value of the test of the null hypothesis that the Kappa estimate K = 0 (two-tail, 95 per cent probability) (i.e., no agreement between 2007 and 2010). The null hypothesis is that a change has occurred over time. If the null hypothesis is rejected it means there is agreement in VCTs among years. That is, the change in VCTs over time is not statistically significant. The magnitude of the positive kappa statistic indicates the degree of agreement among years; values between 0.61 and 0.80 suggest substantial agreement, while values above 0.80 suggest almost perfect agreement (Landis and Koch 1977).

All elevations

VCT	Kappa	z	p.value
BB	1	54.681	0
BE	0.94	51.38	0
BG	1	54.681	0
CR	1	54.681	0
PA	1	54.681	0
PC	0.955	52.193	0
PC - shrub	0.895	48.931	0
PE	0.963	52.657	0
RR	1	54.681	0
SF	0.749	40.974	0
Shrub - riparian	1	54.681	0
WR	1	54.681	0

Low elevation

VCT	Kappa	z	p.value
BB	0.865	46.998	0
BE	0.942	51.162	0
BG	0.985	53.48	0
PC	0.972	52.81	0
PE	0.947	51.423	0
RR	1	54.314	0
RS	1	54.314	0
SF	1	54.314	0
SS	1	54.314	0
WR	1	54.314	0

Mid elevation

VCT	Kappa	z	p.value
BB	1	37.148	0
BE	0.925	34.345	0
BG	0.972	36.098	0
CR	1	37.148	0
LO	0.534	19.821	0
PA	0.919	34.157	0
PC	0.95	35.308	0
PE	0.957	35.557	0
RR	1	37.148	0
RS	1	37.148	0
Shrub - riparian	0.723	26.853	0
SS	1	37.148	0

High elevation

VCT	Kappa	z	p.value
BE	0.857	35.553	0
BG	0.984	40.792	0
CR	0.992	41.153	0
LO	0.632	26.221	0
PA	0.849	35.208	0
PC	0.899	37.302	0
PC - shrub	0.785	32.544	0
PE	1	41.473	0
RS	0.832	34.512	0
Shrub - riparian	0.988	40.978	0
SS	1	41.473	0

11.7 Kappa test results for VCT changes in orthophoto point samples of Arrow Lakes (Arrow Lakes Reservoir) over time (2007, 2010, 2012, 2014, 2016).

Shown is the exact (or asymptotic) *p*-value of the test of the null hypothesis that the Kappa estimate K = 0 (two-tail, 95 per cent probability) (i.e., no agreement among years). The null hypothesis is that a change has occurred over time. If the null hypothesis is rejected it means there is agreement in VCTs among years. That is, the change in VCTs over time is not statistically significant. The magnitude of the positive kappa statistic indicates the degree of agreement among years; values between 0.61 and 0.80 suggest substantial agreement, while values above 0.80 suggest almost perfect agreement (Landis and Koch 1977).

All elevations

VCT	Kappa	z	p.value
BB	0.933	72.544	0
BE	0.942	73.256	0
BG	0.981	76.303	0
CR	0.994	77.294	0
LO	0.648	50.377	0
PA	0.884	68.761	0
PC	0.949	73.832	0
PC - shrub	0.788	61.303	0
PE	0.953	74.147	0
RR	1	77.782	0
RS	0.967	75.247	0
SF	1	77.782	0
Shrub - riparian	0.961	74.712	0
SS	1	77.782	0
WR	1	77.782	0

Low elevation

VCT	Kappa	z	p.value
BB	0.865	46.998	0
BE	0.942	51.162	0
BG	0.985	53.48	0
PC	0.972	52.81	0
PE	0.947	51.423	0
RR	1	54.314	0
RS	1	54.314	0
SF	1	54.314	0
SS	1	54.314	0
WR	1	54.314	0

Mid elevation

VCT	Kappa	z	p.value
BB	1	37.148	0
BE	0.925	34.345	0
BG	0.972	36.098	0
CR	1	37.148	0
LO	0.534	19.821	0
PA	0.919	34.157	0
PC	0.95	35.308	0
PE	0.957	35.557	0
RR	1	37.148	0
RS	1	37.148	0
Shrub - riparian	0.723	26.853	0
SS	1	37.148	0

High elevation

VCT	Kappa	z	p.value
BE	0.857	35.553	0
BG	0.984	40.792	0
CR	0.992	41.153	0
LO	0.632	26.221	0
PA	0.849	35.208	0
PC	0.899	37.302	0
PC - shrub	0.785	32.544	0
PE	1	41.473	0
RS	0.832	34.512	0
Shrub - riparian	0.988	40.978	0
SS	1	41.473	0

11.8 Frequency counts of structural stages in point samples (*n*=310) of aerial imagery obtained for Revelstoke Reach (Arrow Lakes Reservoir) from 2007 to 2016. Stages: (1a) sparse or pioneer vegetation; (2) herb-dominated; (3) shrubland; and (5) young forest

Elevation band	Structural Stage	Frequency of points				
		2007	2010	2012	2014	2016
Low	1a	11	20	29	21	14
	2	147	139	131	139	148
	3	4	4	4	4	4
Mid	1a	4	4	4	4	4
	2	56	56	53	50	52
	3	30	29	32	35	37
	5	1	1	1	1	1
High	1a	2	3	3	3	3
	2	20	20	20	21	22
	3	28	28	28	27	27
	5	17	17	17	17	17

11.9 Frequency counts of vegetation structural stages, by elevation band, in point samples (*n*=676) of aerial imagery obtained for Arrow Lakes (Arrow Lakes Reservoir). Stages: (1a) sparse or pioneer vegetation; (2) herb-dominated; (3) shrubland; and (5) young forest

Elevation band	Structural Stage	Frequency of points				
		2007	2010	2012	2014	2016
Low	1a	94	138	185	136	110
	2	212	166	121	170	202
	3	1	4	1	1	1
Mid	1a	31	39	34	26	27
	2	111	103	106	114	116
	3	11	10	12	12	13
	5	2	2	2	2	2
High	1a	22	24	24	22	18
	2	77	74	72	73	79
	3	54	55	57	58	61
	5	33	33	33	33	33

11.10 Year-to-year change in vegetation cover

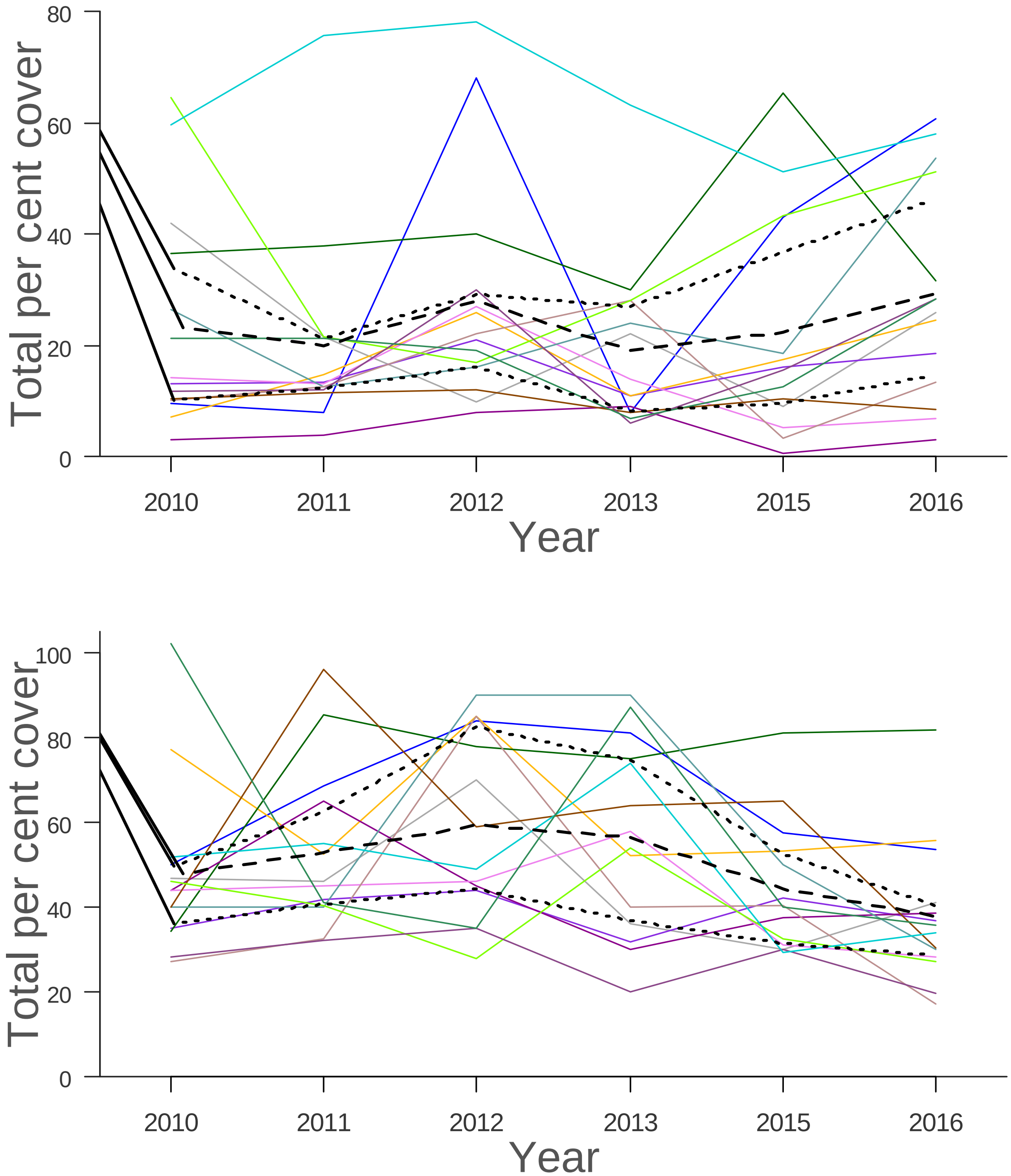


Figure 11-1: Year-to-year change in total per cent cover of vegetation within 14 low-elevation (top panel) and 14 mid-elevation (bottom panel) field plots visited each year between 2010 and 2016 (excepting 2014). The thick dark dashed line is the average cover over all plots, bounded by the 25th and 75th percentile. High-elevation band (438-440 m ASL) not shown due to low sample size.

11.11 Kappa test results for vegetation structural stage changes in orthophoto point samples of Arrow Lakes Reservoir (Revelstoke Reach and Arrow Lakes) over time (2007, 2010, 2012, 2014, 2016). Shown is the exact (or asymptotic) p-value of the test of the null hypothesis that the Kappa estimate K = 0 (two-tail, 95 per cent probability) (i.e., no agreement between 2007 and 2010). The null hypothesis is that a change has occurred over time. If the null hypothesis is rejected it means there is agreement in VCTs among years. That is, the change in VCTs over time is not statistically significant. The magnitude of the positive kappa statistic indicates the degree of agreement among years; values between 0.61 and 0.80 suggest substantial agreement, while values above 0.80 suggest almost perfect agreement (Landis and Koch 1977).

All elevations - Revelstoke

Structural Stage	Kappa	z	p.value
1a	0.754	41.754	0
2	0.887	49.129	0
3	0.937	51.894	0
5	1	55.408	0

Low elevation - Revelstoke

Structural Stage	Kappa	z	p.value
1a	0.698	27.572	0
2	0.745	29.408	0
3	1	39.497	0

Mid elevation - Revelstoke

Structural Stage	Kappa	z	p.value
1a	1	29.326	0
2	0.875	25.659	0
3	0.867	25.435	0
5	1	29.326	0

High elevation - Revelstoke

Structural Stage	Kappa	z	p.value
1a	0.701	17.883	0
2	0.977	24.915	0
3	0.968	24.686	0
5	1	25.495	0

All elevations - Arrow

Structural Stage	Kappa	z	p.value
1a	0.733	57.89	0
2	0.769	60.705	0
3	0.941	74.252	0
5	0.994	78.45	0

Low elevation - Arrow

Structural Stage	Kappa	z	p.value
1a	0.635	34.625	0
2	0.636	34.643	0
3	-0.002	-0.11	0.912

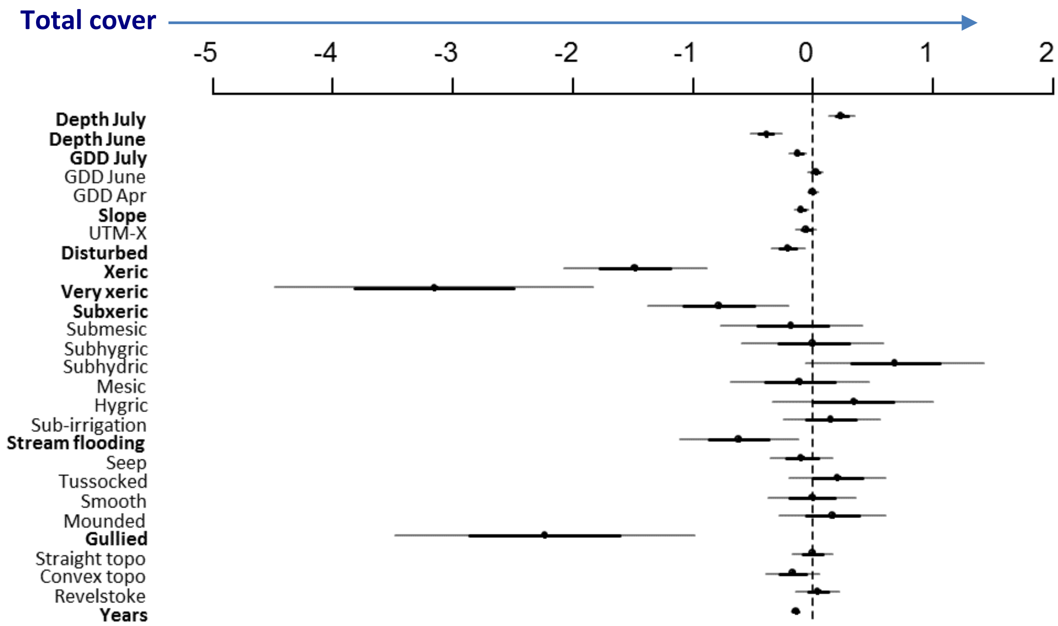
Mid elevation - Arrow

Structural Stage	Kappa	z	p.value
1a	0.792	30.47	0
2	0.825	31.731	0
3	0.921	35.448	0
5	1	38.471	0

High elevation - Arrow

Structural Stage	Kappa	z	p.value
1a	0.855	36.089	0
2	0.916	38.644	0
3	0.943	39.786	0
5	0.993	41.875	0

11.12 Coefficient plots for fixed effects including growing degree days (GGDs) and water depth



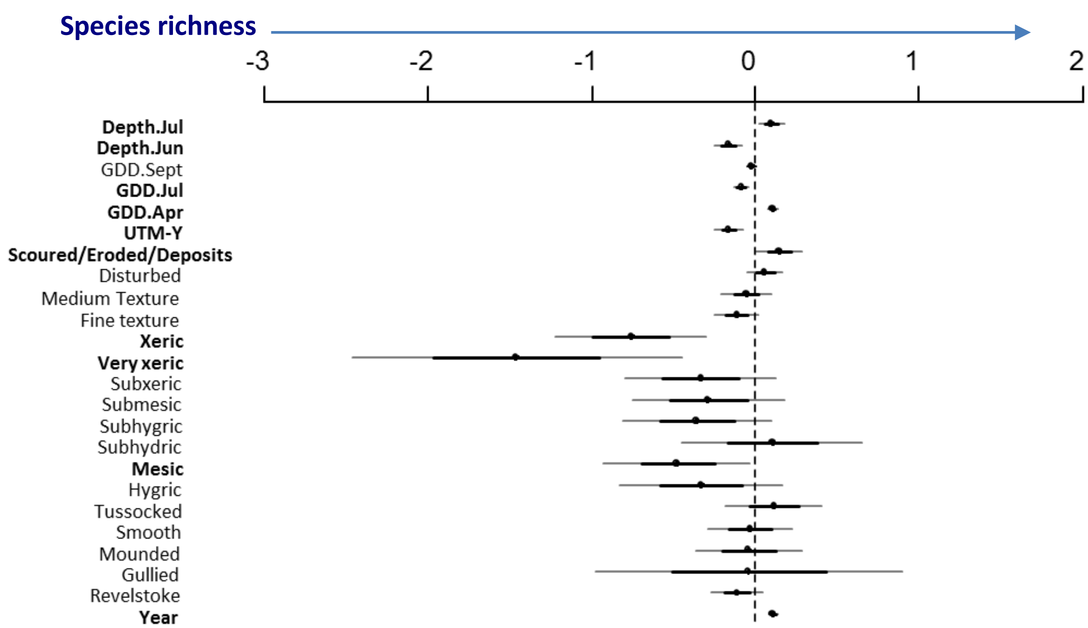


Figure 11-2: Coefficient plots showing the value of the standardized regression coefficient for each fixed effect included in the GLMM, along with the 95 per cent confidence interval (horizontal lines) and ± 2 SE (darker line) for fixed effects including monthly growing degree days (GDDs) and monthly water depth. Values < 0 indicate total cover (top panel) or species richness (bottom panel) was negatively correlated with the modelled explanatory variable while those > 0 indicate increasing cover or richness relative to the variable. The direction of the relationship is unreliable if the confidence interval crosses 0. t-values correspond to the Walt test statistic, evaluated at α=0.1. Variables with significant p-values are bolded. Full test results are shown in Appendix 11.13

11.13 Test results for GLMMs and wald tests associated with Figure 11-2. Top table: per cent cover. Bottom table: species richness.

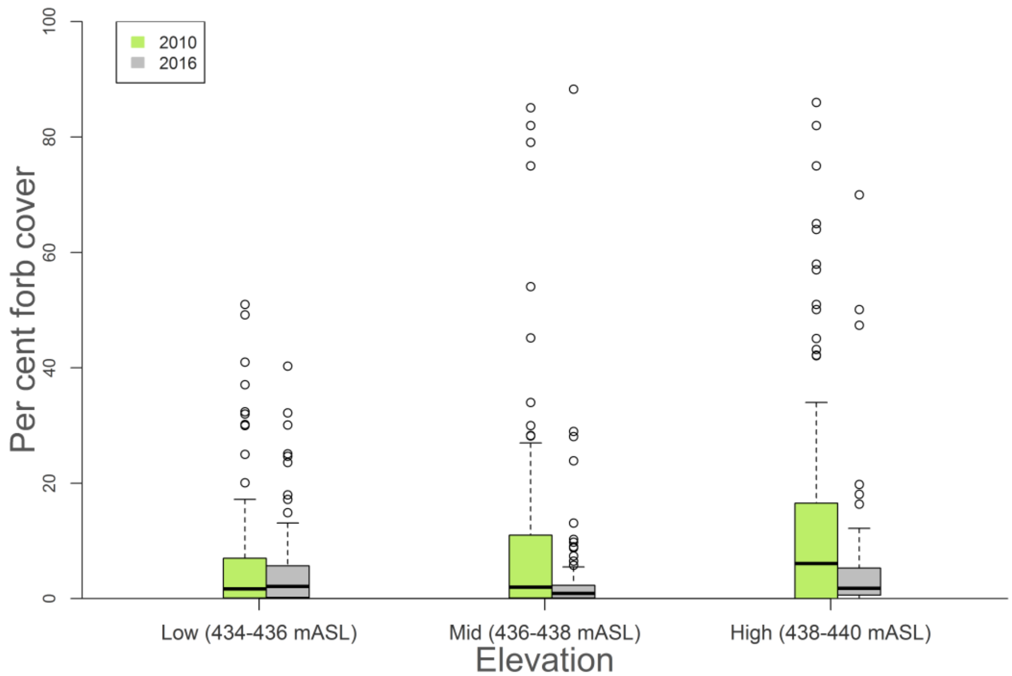
Per cent cover

Variables	Value	Std.Error	DF	t-value	p-value
Year	-0.14	0.02	866.00	-7.64	0.0000
ReachRevelstoke	0.05	0.09	866.00	0.52	0.6031
Gen..Surface.TopographyCONVEX	-0.16	0.11	353.00	-1.50	0.1343
Gen..Surface.TopographySTRAIGHT	0.00	0.08	866.00	0.01	0.9902
Microtopo.graphyGULLIED	-2.23	0.62	353.00	-3.59	0.0004
Microtopo.graphyMOUNDED	0.17	0.22	353.00	0.77	0.4430
Microtopo.graphySMOOTH	0.00	0.18	353.00	-0.02	0.9861
Microtopo.graphyTUSSOCKED	0.21	0.20	353.00	1.04	0.2991
Primary.water.sourceSEEP	-0.09	0.13	353.00	-0.69	0.4892
ᴾrimary.water.source StreamFloodinᵹ	-0.61	0.25	353.00	-2.47	0.0138
mary.water.sourceSTREAM subirrigat	0.15	0.20	353.00	0.76	0.4451
Soil.moistureHygric	0.34	0.33	353.00	1.02	0.3107
Soil.moistureMESIC	-0.10	0.29	353.00	-0.35	0.7237
Soil.moistureSUBHYDRIC	0.68	0.37	353.00	1.85	0.0651
Soil.moistureSUBHYGRIC	0.01	0.29	353.00	0.03	0.9793
Soil.moistureSUBMESIC	-0.17	0.30	353.00	-0.58	0.5628
Soil.moistureSubxeric	-0.78	0.29	353.00	-2.67	0.0079
Soil.moistureVERY xeric	-3.15	0.66	353.00	-4.79	0.0000
Soil.moistureXERIC	-1.48	0.29	353.00	-5.03	0.0000
DisturbanceTRUE	-0.20	0.07	866.00	-2.87	0.0042
UTM_X	-0.05	0.04	353.00	-1.16	0.2479
Slope	-0.09	0.03	353.00	-3.03	0.0027
GDD.Apr	0.00	0.02	866.00	0.00	0.9970
GDD.Jun	0.02	0.03	866.00	0.73	0.4651
GDD.Jul	-0.12	0.04	866.00	-3.33	0.0009
Depth.Jun	-0.39	0.07	866.00	-5.92	0.0000
Depth.Jul	0.24	0.05	866.00	4.69	0.0000

Species richness

Variable	Value	Std.Error	DF	t-value	p-value
Year	0.11	0.01	865	8.92	0.0000
ReachRevelstoke	-0.12	0.08	865	-1.46	0.1434
Microtopo.graphyGULLIED	-0.04	0.47	357	-0.09	0.9286
Microtopo.graphyMOUNDED	-0.04	0.16	357	-0.25	0.8041
Microtopo.graphySMOOTH	-0.03	0.13	357	-0.25	0.8065
Microtopo.graphyTUSSOCKED	0.11	0.15	357	0.76	0.4456
Soil.moistureHygric	-0.33	0.25	357	-1.33	0.1855
Soil.moistureMESIC	-0.48	0.22	357	-2.13	0.0338
Soil.moistureSUBHYDRIC	0.10	0.27	357	0.37	0.7144
Soil.moistureSUBHYGRIC	-0.36	0.23	357	-1.57	0.1175
Soil.moistureSUBMESIC	-0.29	0.23	357	-1.26	0.2102
Soil.moistureSubxeric	-0.34	0.23	357	-1.47	0.1425
Soil.moistureVERY XERIC	-1.46	0.50	357	-2.89	0.0040
Soil.moistureXERIC	-0.76	0.23	357	-3.31	0.0010
TextureFine	-0.12	0.07	865	-1.76	0.0785
TextureMedium	-0.06	0.08	865	-0.76	0.4497
DisturbanceTRUE	0.06	0.05	865	1.07	0.2829
Scouring.erosion.depositionTRUE	0.14	0.07	357	2.05	0.0415
UTM_Y	-0.16	0.04	357	-3.81	0.0002
GDD.Apr	0.11	0.01	865	7.66	0.0000
GDD.Jul	-0.09	0.02	865	-3.88	0.0001
GDD.Sept	-0.02	0.01	865	-1.77	0.0777
Depth.Jun	-0.17	0.04	865	-3.84	0.0001
Depth.Jul	0.10	0.04	865	2.63	0.0087

11.14 Plant guilds: cover and richness (2007 versus 2016)



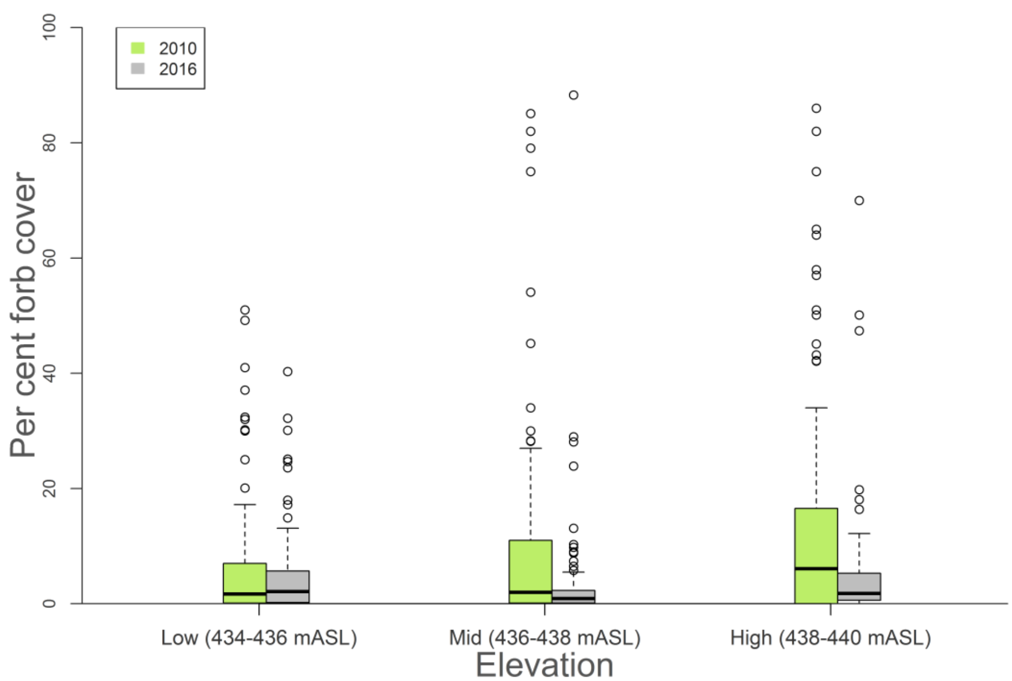


Figure 11-3: Median per cent cover (top panel) and species richness (top panel) of forbs by elevation band in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir. Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. n= 267 plots. **Top:** annual and elevation differences were non-significant based on GLMM. **Bottom:** annual and elevation differences were non-significant based on GLMM

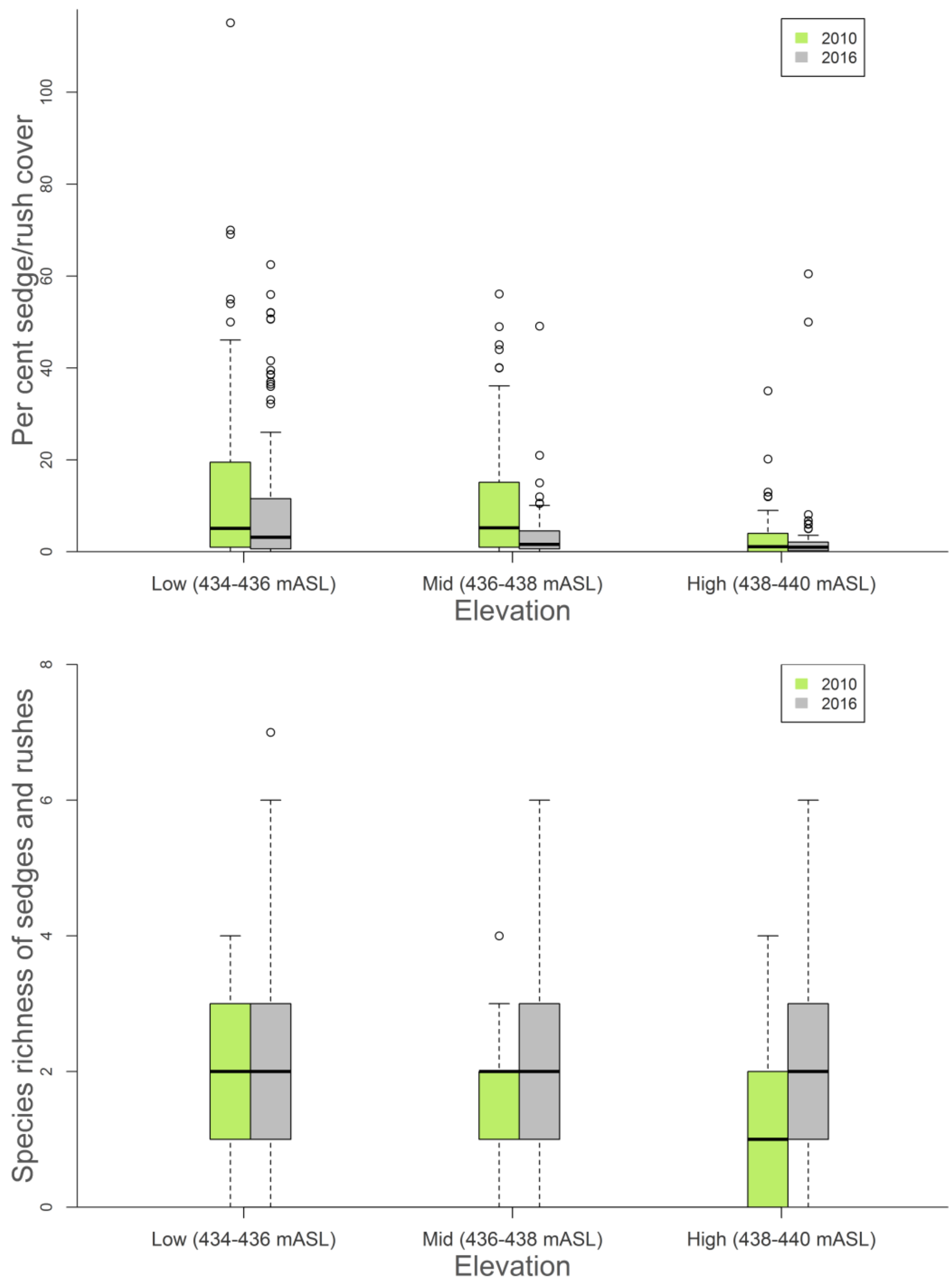


Figure 11-4: **Median per cent cover (top panel) and species richness (bottom panel) of sedges and rushes by elevation band in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir.** Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. n= 280 plots. **Top:** differences between years were non-significant; differences among elevation bands were significant (GLMM, F=13.6, p=0<0.0001). Interactions were significant (GLMM, F=9.03, p=0.0002). **Bottom:** differences were significant between years (GLMM, F=26.9, p<0.0001) and among elevation bands (GLMM, F=12.7, p<0.0001). Interactions were significant (GLMM, F=13.2, p<0.0001)

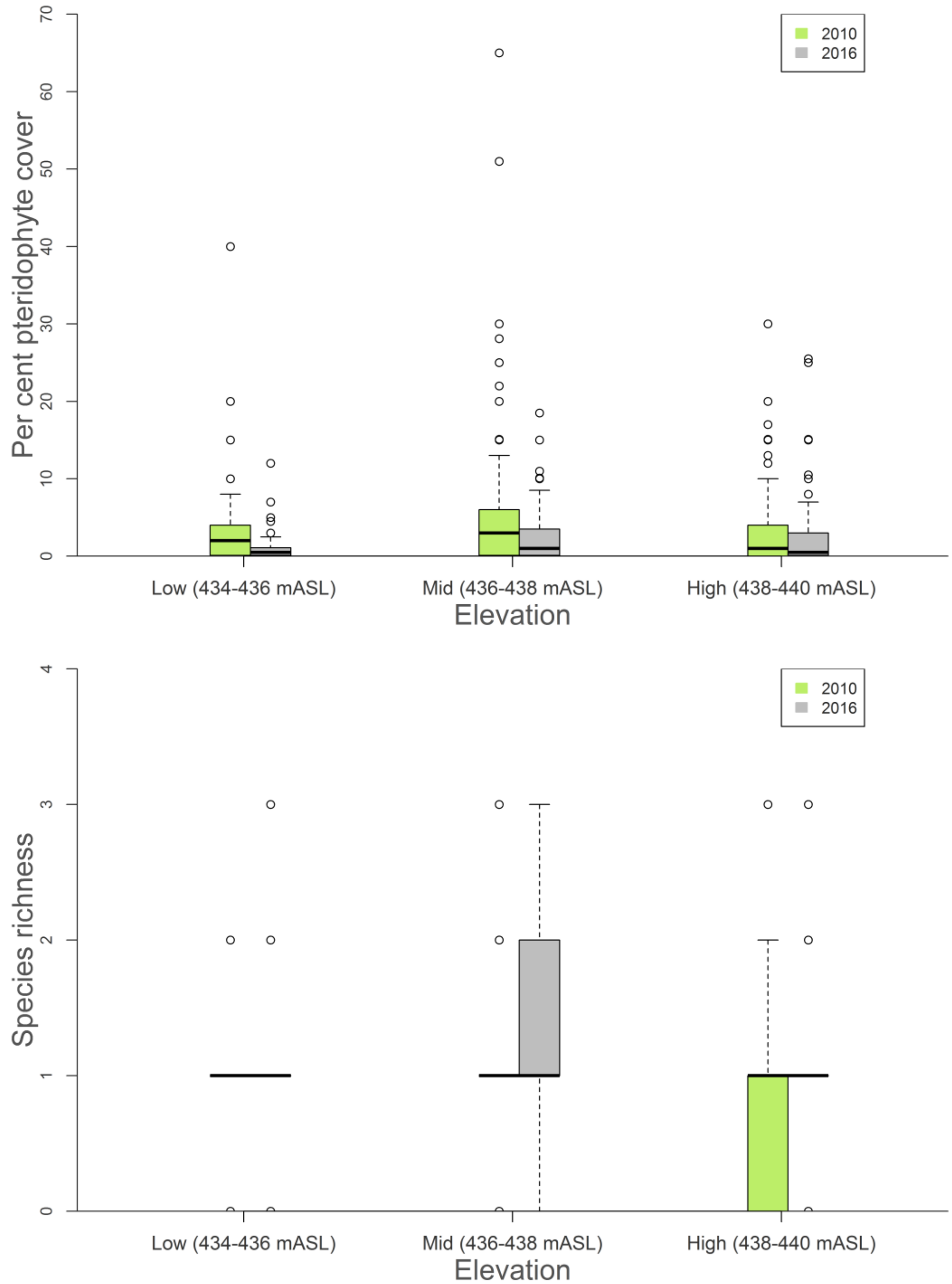


Figure 11-5: Median per cent cover (top panel) and species richness (bottom panel) of pteridophytes by elevation band in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir. Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. *n*= 261 plots. **Top:** differences between years were non-significant, but were significant among elevation bands (GLMM, F=3.2, *p*=0.041). Interactions were significant (GLMM, F=7.3, *p*=0.0008). **Bottom:** differences were significant between years (GLMM, F=10.3, *p*=0.0015) but not among elevation bands. Interactions were significant (GLMM, F=6.05, *p*<0.003).

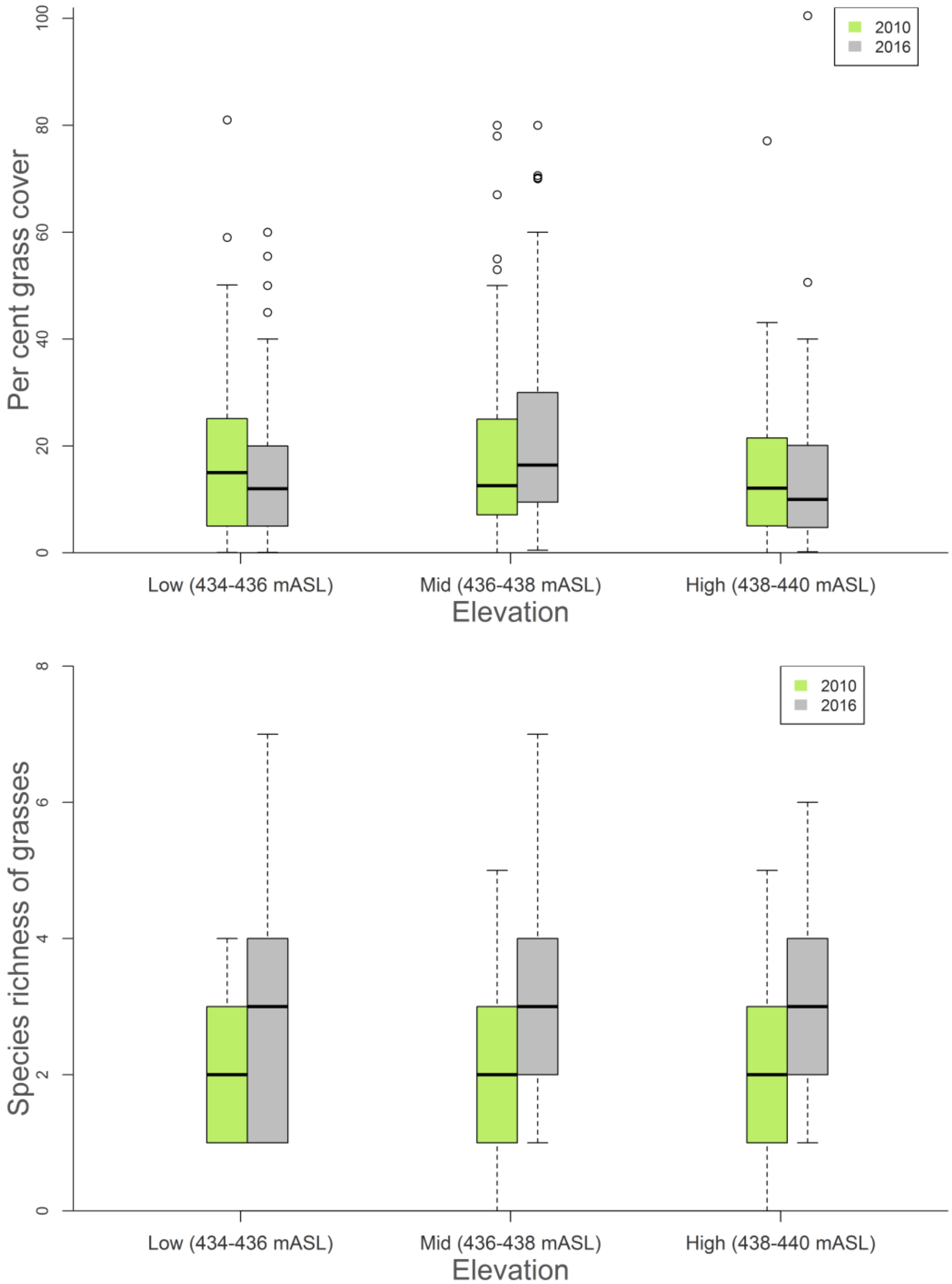


Figure 11-6: Median per cent cover (top panel) and species richness (bottom panel) of grasses by elevation band in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir. Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. *n*= 319 plots. **Top:** differences between years were non-significant, but were significant among elevation bands (GLMM F=5.8, *p*=0.0035). Interactions were non-significant. **Bottom:** differences were significant between years (GLMM, F=41.1, *p*<0.0001) but not among elevation bands. Interactions were significant (GLMM, F=4.03, *p*=0.019).

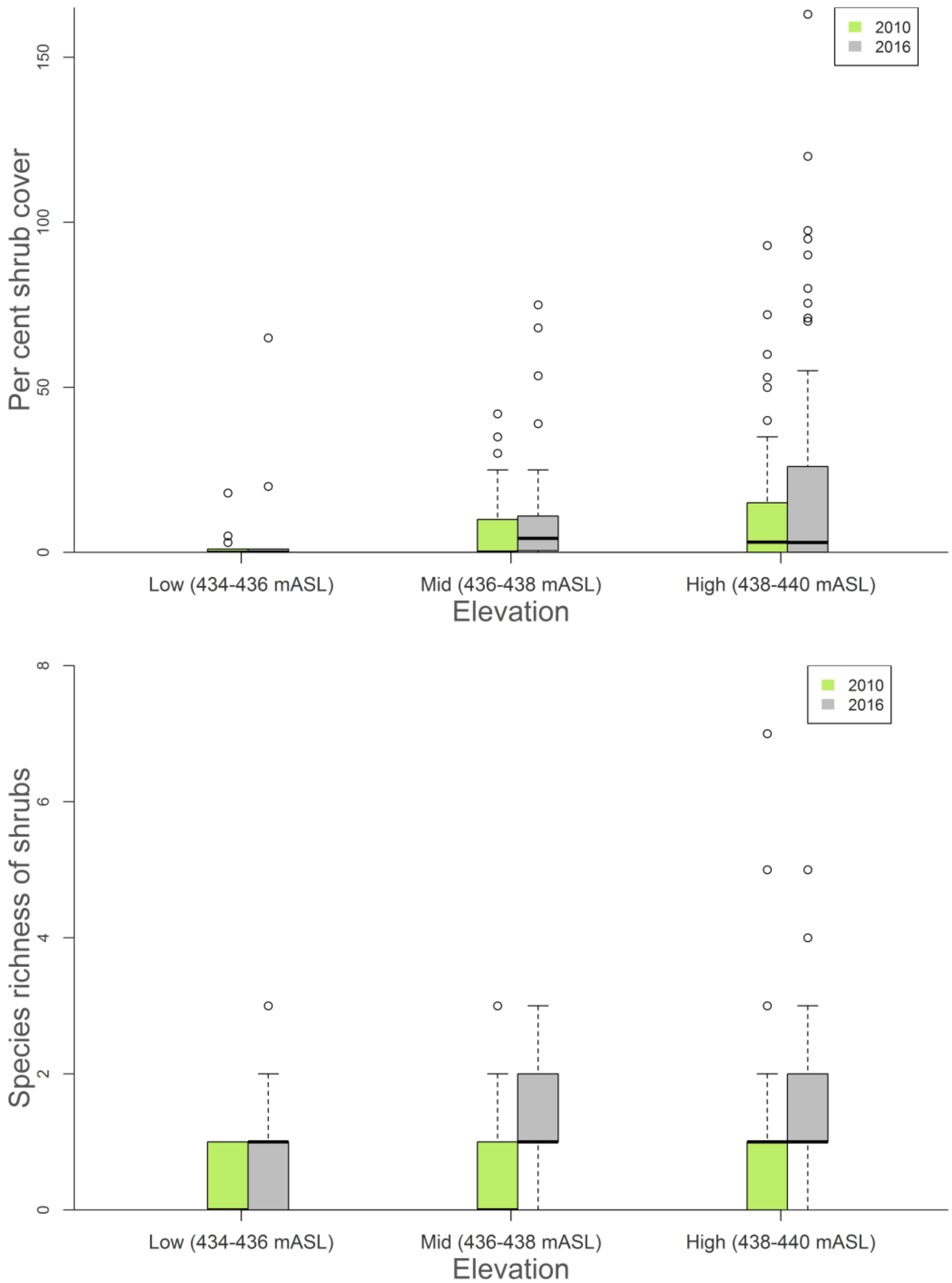


Figure 11-7: **Median per cent cover (top panel) and species richness (bottom panel) of shrubs by elevation band in plots sampled in 2010 and 2016 in Arrow Lakes Reservoir.** Boxes = 25th and75th percentiles; whisker ends = min and max values; circles are outliers. *N*= 319 plots. **Top:** differences were significant between years (GLMM, F=7.5, *p*=0.007) and among elevation bands (GLMM, F=4.6, *p*=0.012). Interactions were non-significant. **Bottom:** differences were significant between years (GLMM, F=11.97, *p*=0.0008) and among elevation bands (GLMM, F=4.6, *p*=0.013). Interactions were marginally significant (GLMM, F=3.1, *p*=0.051).

11.15 Plant species recorded in Arrow Lakes Reservoir drawdown zone (including adjacent upland riparian forests) within the CLBMON-33 and CLBMON-12 monitoring areas, 2010-2016.

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

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

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
FRAGVIR	*Fragaria virginiana*	wild strawberry	Forb (per.)	Rev, Arr
GALETET	*Galeopsis tetrahit*	hemp-nettle	Forb (ann.)	Rev, Arr
GALIPAL	*Galium palustre*	marsh bedstraw	Forb (ann.)	Arr
GALITRD	*Galium trifidum*	small bedstraw	Forb (ann.)	Arr
GALITRF	*Galium triflorum*	sweet-scented bedstraw	Forb (per.)	Arr
GALIUM	*Galium sp.*	bedstraw	Forb	Rev, Arr
GERABIC	*Geranium bicknellii*	Bicknell's geranium	Forb (ann.)	Arr
GERANIU	*Geranium sp.*	geranium	Forb	Arr
GEUMMAC	*Geum macrophyllum*	large-leaved avens	Forb (per.)	Arr
GLYCSTR	*Glyceria striata*	fowl mannagrass	Grass	Rev, Arr
GNAPULI	*Gnaphalium uliginosum*	marsh cudweed	Forb (ann.)	Arr
HIERACI	*Hieracium sp.*	hawkweed	Forb (per.)	Rev
HIERAUR	*Hieracium aurantiacum*	orange-red king devil	Forb (per.)	Rev
HIERCAE	*Hieracium caespitosum*	yellow king devil	Forb (per.)	Rev, Arr
HIERFLO	*Hieracium floribundum*	king devil hawkweed	Forb (per.)	Rev, Arr
HIERGLO	*Hieracium glomeratum*	yellowdevil hawkweek	Forb (per.)	Arr
HIERHIR	*Hierochloe hirta*	northern sweetgrass	Grass	Rev, Arr
HIERLAC	*Hieracium lachenalii*	European hawkweed	Forb (per.)	Arr
HIERPIO	*Hieracium piloselloides*	tall hawkweed	Forb (per.)	Rev, Arr
HORDBRA	*Hordeum brachyantherum*	meadow barley	Grass	Arr
HYPEPER	*Hypericum perforatum*	common St. John's-wort	Forb (per.)	Rev, Arr
HYPORAD	*Hypochaeris radicata*	hairy cat's-ear	Forb (per.)	Rev, Arr
JUNCARC	*Juncus arcticus*	arctic rush	Rush	Arr
JUNCART	*Juncus articulatus*	jointed rush	Rush	Rev, Arr
JUNCBAL	*Juncus balticus*	Baltic rush	Rush	Arr
JUNCBUF	*Juncus bufonius*	toad rush	Rush	Arr
JUNCENS	*Juncus ensifolius*	dagger-leaf rush	Rush	Rev, Arr
JUNCFIL	*Juncus filiformis*	thread rush	Rush	Rev, Arr
JUNCINT	*Juncus interior*	inland rush	Rush	Arr
JUNCTEN	*Juncus tenuis*	slender rush	Rush	Rev, Arr
JUNCUS	*Juncus sp.*	rush	Rush	Arr
LACTBIE	*Lactuca biennis*	tall blue lettuce	Forb (per.)	Arr
LACTUCA	*Lactuca sp.*	lettuce	Forb	Arr
LATHSYL	*Lathyrus sylvestris*	narrow-leaved everlasting peavine	Forb (per.)	Arr
LEPICAM	*Lepidium campestre*	field pepper-grass	Forb (ann.)	Arr
LEUCVUL	*Leucanthemum vulgare*	oxeye daisy	Forb (per.)	Rev, Arr
LIMOAQU	*Limosella aquatica*	water mudwort	Forb (ann.)	Arr
LINUCAT	*Linum catharticum*	fairy flax	Forb (per.)	Rev
LOGFARV	*Logfia arvensis*	field filago	Forb (ann.)	Arr
LUPIPOY	*Lupinus polyphyllus*	large-leaved lupine	Forb (per.)	Arr
LYSITHY	*Lysimachia thyrsiflora*	tufted loosestrife	Forb (per.)	Arr
MAHOAQU	*Mahonia aquifolium*	tall Oregon-grape	Shrub	Arr
MAIASTE	*Maianthemum stellatum*	star-flowered false Solomon's-seal	Forb (per.)	Rev

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
MATRDIS	*Matricaria discoidea*	pineapple weed	Forb (ann.)	Arr
MEDILUP	*Medicago lupulina*	black medic	Forb (ann.)	Rev, Arr
MEDISAT	*Medicago sativa*	alfalfa	Forb (per.)	Rev, Arr
MELIALB	*Melilotus alba*	white sweet-clover	Forb (ann.)	Arr
MENTARV	*Mentha arvensis*	field mint	Forb (per.)	Arr
MICRGRA	*Microsteris gracilis*	pink twink	Forb (ann.)	Arr
MIMUGUT	*Mimulus guttatus*	yellow monkey-flower	Forb (per.)	Arr
MONTFON	*Montia fontana*	blinks	Forb (ann.)	Arr
MONTLIN	*Montia linearis*	narrow-leaved montia	Forb (ann.)	Arr
MYCEMUR	*Mycelis muralis*	wall lettuce	Forb (ann.)	Arr
MYOSDIS	*Myosotis discolor*	common forget-me-not	Forb (ann.)	Arr
MYOSLAX	*Myosotis laxa*	small-flowered forget-me-not	Forb (per.)	Arr
MYOSOTI	*Myosotis sp.*	forget-me-not	Forb	Rev, Arr
MYOSSCO	*Myosotis scorpioides*	European forget-me-not	Forb (per.)	Rev, Arr
MYOSSTR	*Myosotis stricta*	blue forget-me-not	Forb (ann.)	Arr
OENOVIL	*Oenothera villosa*	yellow evening-primrose	Forb (per.)	Arr
OSMORHI	*Osmorhiza sp.*	sweet-cicely	Forb	Arr
PACKPAP	*Packera paupercula*	Canadian butterweed	Forb (per.)	Rev, Arr
PACKPSE	*Packera pseudaurea*	streambank butterweed	Forb (per.)	Arr
PERSAMP	*Persicaria amphibia*	water smartweed	Forb (per.)	Rev, Arr
PHALARU	*Phalaris arundinacea*	reed canarygrass	Grass	Rev, Arr
PHLEPRA	*Phleum pratense*	common timothy	Grass	Rev
PINUCON	*Pinus contorta*	lodgepole pine	Tree	Arr
PINUMON	*Pinus monticola*	western white pine	Tree	Rev, Arr
PLAGSCO	*Plagiobothrys scouleri*	Scouler's popcornflower	Forb (ann.)	Arr
PLANLAN	*Plantago lanceolata*	ribwort plantain	Forb (per.)	Rev, Arr
PLANMAJ	*Plantago major*	common plantain	Forb (per.)	Arr
PLANTAG	*Plantago sp.*	plantain	Forb (per.)	Arr
POA	*Poa sp.*	bluegrass	Grass	Arr
POA ANN	*Poa annua*	annual bluegrass	Grass	Rev, Arr
POA BUL	*Poa bulbosa*	bulbous bluegrass	Grass	Arr
POA COM	*Poa compressa*	Canada bluegrass	Grass	Rev, Arr
POA PAL	*Poa palustris*	fowl bluegrass	Grass	Rev, Arr
POA PRA	*Poa pratensis*	Kentucky bluegrass	Grass	Rev, Arr
POAPAL	*Poa palustris*	fowl bluegrass	Grass	Arr
POLYAVI	*Polygonum aviculare*	common knotweed	Forb (ann.)	Arr
POLYGON	*Polygonum sp.*	knotweed	Forb	Arr
POPUTRE	*Populus tremuloides*	trembling aspen	Tree	Arr
POPUTRI	*Populus trichocarpa*	black cottonwood	Tree	Rev, Arr
POTENOR	*Potentilla norvegica*	Norwegian cinquefoil	Forb (ann.)	Rev, Arr
PRIMULA	*Primula sp.*	primrose	Forb	Rev

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
PRUNUS	*Prunus sp.*	cherry	Shrub	Arr
PRUNVUL	*Prunella vulgaris*	self-heal	Forb (per.)	Rev, Arr
PTERAQU	*Pteridium aquilinum*	bracken fern	Pteridophyte	Arr
PYROASA	*Pyrola asarifolia*	pink wintergreen	Forb (per.)	Rev
RANUACR	*Ranunculus acris*	meadow buttercup	Forb (per.)	Rev, Arr
RANUFLA	*Ranunculus flabellaris*	yellow water-buttercup	Forb (per.)	Arr
RANUGME	*Ranunculus gmelinii*	small yellow water-buttercup	Forb (per.)	Arr
RANUMAC	*Ranunculus macounii*	Macoun's buttercup	Forb (per.)	Arr
RANUNCU	*Ranunculus sp.*	buttercup	Forb	Arr
RANUREP	*Ranunculus repens*	creeping buttercup	Forb (per.)	Arr
RHAMPUR	*Rhamnus purshiana*	cascara	Shrub	Arr
RHINMIN	*Rhinanthus minor*	yellow rattle	Forb (per.)	Rev, Arr
RIBES	*Ribes sp.*	currant or gooseberry	Shrub	Rev
ROBIPSE	*Robinia pseudoacacia*	black locust	Tree	Arr
RORICUR	*Rorippa curvipes*	blunt-leaved yellowcress	Forb (ann.)	Arr
RORIPAL	*Rorippa palustris*	marsh yellowcress	Forb (ann.)	Rev, Arr
RORISYL	*Rorippa sylvestris*	creeping yellowcress	Forb (per.)	Arr
ROSA	*Rosa sp.*	rose	Shrub	Rev
ROSAACI	*Rosa acicularis*	prickly rose	Shrub	Arr
ROSACAN	*Rosa canina*	dog rose	Shrub	Arr
ROSAGYM	*Rosa gymnocarpa*	baldhip rose	Shrub	Arr
ROSANUT	*Rosa nutkana*	Nootka rose	Shrub	Arr
ROSAWOO	*Rosa woodsii*	prairie rose	Shrub	Rev
RUBUIDA	*Rubus idaeus*	red raspberry	Shrub	Arr
RUBUPAR	*Rubus parviflorus*	thimbleberry	Shrub	Arr
RUMEACO	*Rumex acetosa*	green sorrel	Forb (per.)	Rev, Arr
RUMEACT	*Rumex acetosella*	sheep sorrel	Forb (per.)	Arr
RUMECRI	*Rumex crispus*	curled dock	Forb (per.)	Rev, Arr
RUMETRI	*Rumex triangulivalvis*	willow dock	Forb (per.)	Arr
RUMEX	*Rumex sp.*	dock	Forb	Arr
SAGIPRO	*Sagina procumbens*	bird's-eye pearlwort	Forb (per.)	Rev, Arr
SALIBEB	*Salix bebbiana*	Bebb's willow	Shrub	Rev, Arr
SALIFAR	*Salix farriae*	Farr's willow	Shrub	Rev
SALILAS2	*Salix lasiandra var. lasiandra*	Pacific willow	Shrub	Rev, Arr
SALIPRO	*Salix prolixa*	Mackenzie willow	Shrub	Rev
SALISCO	*Salix scouleriana*	Scouler's willow	Shrub	Rev, Arr
SALISIT	*Salix sitchensis*	Sitka willow	Shrub	Rev, Arr
SALIX	*Salix sp.*	willow	Shrub	Rev, Arr
SCHEPRA	*Schedonorus pratensis*	meadow fescue	grass	Arr
SCIRATR	*Scirpus atrocinctus*	wool-grass	Sedge/ sedge-like	Rev, Arr
SCIRMIC	*Scirpus microcarpus*	small-flowered bulrush	Sedge/ sedge-like	Arr
SCLEANN	*Scleranthus annuus*	annual knawel	Forb (ann.)	Arr

Species Code	Scientific Name	English Name	Guild	Reach
ABIELAS	*Abies lasiocarpa*	subalpine fir	Tree	Arr
SEDULAN	*Sedum lanceolatum*	lance-leaved stonecrop	Forb (per.)	Arr
SILELAT	*Silene latifolia*	white cockle	Forb (per.)	Arr
SISYMON	*Sisyrinchium montanum*	mountain blue-eyed-grass	Forb (per.)	Rev, Arr
SOLICAN	*Solidago canadensis*	Canada goldenrod	Forb (per.)	Rev, Arr
SOLIDAG	*Solidago sp.*	golden rod	Forb	Rev
SORBAUC	*Sorbus aucuparia*	European mountain ash	Shrub	Arr
SORBSCO	*Sorbus scopulina*	western mountain-ash	Shrub	Rev, Arr
SPERRUB	*Spergularia rubra*	red sand-spurry	Forb (ann.)	Rev, Arr
SPIRDOU	*Spiraea douglasii*	hardhack	Shrub	Rev, Arr
STELLAR	*Stellaria sp.*	starwort	Forb	Arr
SYMPCII	*Symphyotrichum ciliolatum*	Lindley's aster	Forb (per.)	Rev, Arr
TARAOFF	*Taraxacum officinale*	common dandelion	Forb (per.)	Rev, Arr
TELLGRA	*Tellima grandiflora*	fringecup	Forb (per.)	Arr
THLAARV	*Thlaspi arvense*	field pennycress	Forb (per.)	Arr
THUJPLI	*Thuja plicata*	western redcedar	Tree	Arr
TRAGDUB	*Tragopogon dubius*	yellow salsify	Forb (per.)	Arr
TRIFARV	*Trifolium arvense*	hare's-foot clover	Forb (per.)	Arr
TRIFAUR	*Trifolium aureum*	yellow clover	Forb (per.)	Rev, Arr
TRIFCAM	*Trifolium campestre*	low hop-clover	forb (ann.)	Arr
TRIFDUB	*Trifolium dubium*	small hop-clover	Forb (per.)	Arr
TRIFHYB	*Trifolium hybridum*	alsike clover	Forb (per.)	Rev, Arr
TRIFOLI	*Trifolium sp.*	clover	Forb	Rev, Arr
TRIFPRA	*Trifolium pratense*	red clover	Forb (per.)	Rev, Arr
TRIFREP	*Trifolium repens*	white clover	Forb (per.)	Rev, Arr
TRIOPER	*Triodanis perfoliata*	Venus' looking-glass	Forb (per.)	Arr
VERBTHA	*Verbascum thapsus*	great mullein	Forb (per.)	Arr
VEROBEC	*Veronica beccabunga*	American speedwell	Forb (per.)	Arr
VERONIC	*Veronica sp.*	speedwell	Forb	Rev
VEROPER	*Veronica peregrina*	purslane speedwell	Forb (ann.)	Rev, Arr
VEROSER	*Veronica serpyllifolia*	thyme-leaved speedwell	Forb (per.)	Rev, Arr
VICIA	*Vicia sp.*	vetch	Forb	Arr
VICIAME	*Vicia americana*	American vetch	Forb (per.)	Rev, Arr
VICICRA	*Vicia cracca*	tufted vetch	Forb (per.)	Rev, Arr
VIOLA	*Viola sp.*	violet	Forb	Arr
VIOLARV	*Viola arvensis*	European field pansy	Forb (ann.)	Arr
VIOLNEP	*Viola nephrophylla*	northern bog violet	Forb (per.)	Rev, Arr
VIOLPAL	*Viola palustris*	marsh violet	Forb (per.)	Rev
VULPBRO	*Vulpia bromoides*	barren fescue	Grass	Arr
VULPOCT	*Vulpia octoflora*	six-weeks grass	Grass	Arr

11.16 Common and/or diagnostic plant species recorded in Arrow Lakes Reservoir drawdown zone within the CLBMON-33 and CLBMON-12 monitoring areas, 2010-2016.

Rev = Revelstoke Reach; Arr = Arrow Lakes. Refer to Appendix 11.13 for a comprehensive species list.

Species Code	Scientific Name	English Name	Guild	Reach
AGROGIG	*Agrostis gigantea*	redtop	Grass	Rev, Arr
ALNUINC	*Alnus incana*	mountain alder	Shrub	Arr
ALOPAEQ	*Alopecurus aequalis*	little meadow-foxtail	Grass	Rev, Arr
BETUPAP	*Betula papyrifera*	paper birch	Tree	Arr
CALACAN	*Calamagrostis canadensis*	bluejoint reedgrass	Grass	Rev, Arr
CAREAPE	*Carex aperta*	Columbia sedge	Sedge/ sedgelike	Rev, Arr
CARELEN	*Carex lenticularis*	Kellogg's sedge	Sedge/ sedgelike	Rev, Arr
CARESIT	*Carex sitchensis*	Sitka sedge	Sedge/ sedgelike	Rev, Arr
CENTSTO	*Centaurea stoebe*	spotted knapweed	Forb (per.)	Rev, Arr
CERANUT	*Cerastium nutans*	nodding chickweed	Forb (ann.)	Rev, Arr
CORNSTO	*Cornus stolonifera*	red-osier dogwood	Shrub	Rev, Arr
ELEOPAR	*Eleocharis parvula*	small spike-rush	Sedge/ sedgelike	Arr
ELYMREP	*Elymus repens*	quackgrass	Grass	Rev, Arr
EQUIARV	*Equisetum arvense*	common horsetail	Pteridophyte	Rev, Arr
EQUIPAL	*Equisetum palustre*	marsh horsetail	Pteridophyte	Rev, Arr
EQUIVAR	*Equisetum variegatum*	northern scouring-rush	Pteridophyte	Rev, Arr
GALIPAL	*Galium palustre*	marsh bedstraw	Forb (ann.)	Arr
HIERPIO	*Hieracium piloselloides*	tall hawkweed	Forb (per.)	Rev, Arr
HORDBRA	*Hordeum brachyantherum*	meadow barley	Grass	Arr
HYPEPER	*Hypericum perforatum*	common St. John's-wort	Forb (per.)	Rev, Arr
JUNCART	*Juncus articulatus*	jointed rush	Rush	Rev, Arr
JUNCFIL	*Juncus filiformis*	thread rush	Rush	Rev, Arr
JUNCTEN	*Juncus tenuis*	slender rush	Rush	Rev, Arr
MATRDIS	*Matricaria discoidea*	pineapple weed	Forb (ann.)	Arr
MIMUGUT	*Mimulus guttatus*	yellow monkey-flower	Forb (per.)	Arr
MONTLIN	*Montia linearis*	narrow-leaved montia	Forb (ann.)	Arr
MYOSLAX	*Myosotis laxa*	small-flowered forget-me-not	Forb (per.)	Arr
MYOSSCO	*Myosotis scorpioides*	European forget-me-not	Forb (per.)	Rev, Arr
MYOSSTR	*Myosotis stricta*	blue forget-me-not	Forb (ann.)	Arr
PHALARU	*Phalaris arundinacea*	reed canarygrass	Grass	Rev, Arr
PLAGSCO	*Plagiobothrys scouleri*	Scouler's popcornflower	Forb (ann.)	Arr
POA ANN	*Poa annua*	annual bluegrass	Grass	Rev, Arr
POA COM	*Poa compressa*	Canada bluegrass	Grass	Rev, Arr
POA PRA	*Poa pratensis*	Kentucky bluegrass	Grass	Rev, Arr
POLYAVI	*Polygonum aviculare*	common knotweed	Forb (ann.)	Arr
POPUTRI	*Populus trichocarpa*	black cottonwood	Tree	Rev, Arr
POTENOR	*Potentilla norvegica*	Norwegian cinquefoil	Forb (ann.)	Rev, Arr

Species Code	Scientific Name	English Name	Guild	Reach
RANUACR	*Ranunculus acris*	meadow buttercup	Forb (per.)	Rev, Arr
RUMEACO	*Rumex acetosa*	green sorrel	Forb (per.)	Rev, Arr
RORIPAL	*Rorippa palustris*	marsh yellowcress	Forb (ann.)	Rev, Arr
RUMECRI	*Rumex crispus*	curled dock	Forb (per.)	Rev, Arr
SALILAS2	*Salix lasiandra var. lasiandra*	Pacific willow	Shrub	Rev, Arr
SALIPRO	*Salix prolixa*	Mackenzie willow	Shrub	Rev
SALISCO	*Salix scouleriana*	Scouler's willow	Shrub	Rev, Arr
SALISIT	*Salix sitchensis*	Sitka willow	Shrub	Rev, Arr
SCLEANN	*Scleranthus annuus*	annual knawel	Forb (ann.)	Arr.
TRIFARV	*Trifolium arvense*	hare's-foot clover	Forb (per.)	Arr
TRIFAUR	*Trifolium aureum*	yellow clover	Forb (per.)	Rev, Arr
TRIFHYB	*Trifolium hybridum*	alsike clover	Forb (per.)	Rev, Arr
TRIFPRA	*Trifolium pratense*	red clover	Forb (per.)	Rev, Arr
TRIOPER	*Triodanis perfoliata*	Venus' looking-glass	Forb (per.)	Arr
VEROPER	*Veronica peregrina*	purslane speedwell	Forb (ann.)	Rev, Arr
VICICRA	*Vicia cracca*	tufted vetch	Forb (per.)	Rev, Arr

11.17 Number of monitoring plots resampled in 2016 within each vegetation community type (VCT), stratified by reservoir region (Arrow Lakes and Revelstoke Reach) and elevation band (m ASL).

	Arrow				Rev. Reach				
VCT	**434-436**	**436-438**	**438-440**	**Arrow Total**	**434-436**	**436-438**	**438-440**	**Rev. Reach Total**	**Total**
BE-Sandy beach	13	8	6	27	6	6	2	14	41
BG-Gravelly beach	8	20	14	42	4	3	2	9	51
CR-Cottonwood riparian			1	1			2	2	3
CR-Shrub riparian		1	15	16		6	5	11	27
IN-Disturbance	1			1		3	1	4	5
LO-Log zone				0				0	0
PA-Redtop upland		2	28	30		7	4	11	41
PC-Willow		2	3	5		8	4	12	17
PC-Reed canarygrass	5	19	11	35	40	21	10	71	106
PC-Foxtail/horsetail	7	3		10	1	1		2	12
PC-Sedge	28	20	10	58	8	1	1	10	68
PE-Foxtail	8			8				0	8
PE-Sedge	13			13	2			2	15
RR-Reed-rill	6	12	5	23				0	23
RS-Willow stream entry			1	1	3	2		5	6
SF-Slope failure		1	1	2	2			2	4
Total	89	88	95	272	66	58	31	155	**427**