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Shoreline vegetation change in upstream and downstream reaches of three temperate streams dammed for hydroelectric generation in British Columbia.

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Executive Summary

Three rivers modified by BC Hydro reservoirs in the southeastern portion of British Columbia were sampled upstream and downstream of the reservoirs to determine if there were changes in riparian vegetation communities associated with flow management. Reaches of the Allouette, Coquitlam, and Cheakamus Rivers were sampled upstream and downstream of the reservoirs. At each of the 6 sites, five or six transects of 14 m length each were quantified for plant cover (total of 448 m^2 quadrats) of a total of 166 species of plants. Differences in vegetation communities (abundance, species richness, diversity) amongst sites were larger for the rivers than for the upstream versus downstream comparisons, indicating that any difference caused by reservoir management was within the natural range of variation found across streams. We found significant reductions in the occurrences of red alder and western red cedar downstream of reservoirs, both of which may eventually lead to broader changes in riparian and stream communities. The lack of regeneration of these two species may be attributable to the reduction in extremes of flow variation and lack of sediment transport due to the reservoirs.

Introduction

River flow regulation by building dams for hydroelectric generation, irrigation and flood control has been a common phenomenon worldwide for centuries but it has most intensified in the last century. In North America, Europe and the former Soviet Union 85% of the largest river systems representing 77% of the water flow are either strongly or moderately affected by flow regulation often by constructing multiple dams on the same river system (Dynesius and Nilsson 1994). Situated at the land-water interface, the riparian areas of rivers and streams support a disproportionately large diversity of plants and animals compared to the other habitat types of the landscape (). Apart from the biodiversity value, a healthy riparian plant community provides many other ecosystem services. Maintaining and healthy riparian plant community, particularly along rivers and streams is critical for maintaining nutrient inputs, moderating water temperature, regulating flow, erosion control and providing other ecological and aesthetic services (Palink et al. 2002; Richardson 2004). Riparian plant community also serves as necessary dispersal corridors and habitats for birds, snails, amphibians and reptiles (Hylander et al. 2003; Naiman et al. 1993; Welsh and Droege 2001; Hylander et al. 2003; Semlitsch and Bodie 2003). Riparian vegetation functions as ecotone between land and water (Chen et al. 1995; Lamb and Mallik 2003; Stewart and Mallik 2005). Many biophysical factors such as geomorphology, microclimate, soil water, nutrients, disturbance regimes and plant communities change across this ecotone (Chen et al 1995, 1999; Stewart and Mallik 2005). It is intuitive that the probability of plant communities having riparian functions is greater near the edge of water and it decreases away from the water. Consequently, the potential for affecting riparian habitats and by changing natural flow regimes with regulated regime will be high near stream banks and it will decrease as one move away from water's edge.

The riparian plant communities in natural streams are subjected to periodic flooding that vary widely in both frequency and intensity. Periodic flooding destroys and creates habitats for plant colonization contributing to species richness in the riparian area (Hibbs and Bower 2001, Richardson et al. 2005). Dams in rivers create barriers of natural water flow and interfere with the ecological process of riparian zone that can induce changes in species composition, richness and diversity. In a dammed river water flow remains unregulated in the upstream sections (provided it has long natural reaches) which experience intermittent pick flows during high rainfall season and low flows during low precipitation periods whereas below the dam normally water is released at a pre-determined rate in the absence of erratic high and low natural flows. Because of the slow regulated flow sedimentation may occur in stream reaches below the dam. The difference in hydrologic and geomorphic conditions between the upstream and downstream reaches can influence plant species richness, composition and diversity along a lateral gradient which in turn can influence other biotic communities.

The main objective of this study was to compare plant species richness, composition and diversity between upstream and downstream reaches of three temperate streams near Vancouver that were dammed for hydroelectric generation.

Materials and Methods

Study sites: Three temperate streams of coastal British Columbia were selected for this study based on the following criteria: i) the streams were similar in size (approximately 20 to 40 m bankfull width, with similar flow rates and in close proximity to each other, ii) streamside vegetation is dominated by forests dominated by western red ceder (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and red alder (*Alnus rubra*) iii) they had similar reservoir size and iv) were dammed roughly around that same time. These rivers were the Allouette River, Coquitlam River, and Cheakamus River, all in southwestern British Columbia.

Field survey: Approximately 300 m section of each of the streams was selected about 1.5 km above the hydroelectric reservoir. Because of steep relief we assumed that stream flow and vegetation of the upstream reaches were not influenced by the reservoir of the dams. Approximately 1 km below the dams we selected a 300 m section of shore line to conduct the vegetation survey. We assumed that the regulated flow from the reservoir have influenced the shoreline plant community so that the species composition, richness and diversity will below the dam will be different from that of the upstream well above the reservoir. In each section of the streams (above and below the reservoir at each river) five 14 m long transects were laid perpendicular to the stream length. Along these transects percent cover of all plant species was determined by eye estimation in consecutive 1 x 1 m quadrats. Quadrat 1 and 2 were placed in the stream below the low water mark, quadrate 3 at the stream edge and quadrate 4-14 were out side the stream edge toward the upland forest. Bryophytes and vascular plants were identified in the field and in Botany Department herbarium of UBC. Several unidentified grasses and sedges were combined.

Data analysis

Vegetation cover information was averaged in several ways, by site, or by transect within site. We analysed data for average plant cover by groups of plants, i.e., trees, shrubs, etc. Simple summaries of some groupings or species are simple means and standard errors. Analysis of differences associated with reservoirs was by 2-way ANOVA (PROC MIXED, SAS 9.1), testing for the effect of river and position relative to the reservoir (upstream or downstream).

Ordination of the plant communities (by transect) were analysed using CANOCO. Data were analysed by the correlation matrix without transformations.

Results

For each stream site (3 rivers, upstream and downstream of reservoir) 5 or 6 transects were assessed for percent cover of the plants. With 14 1-m^2 quadrats per transect, this represented 448 individual quadrats across the 6 sites. A total of 166 taxa of plants were noted (Appendix 1), although some of these could not be identified beyond genus or family when reproductive parts were unavailable to complete the identification.

Species richness: Among the three streams the Cheakamus River was found to be the most species poor having about half as many species (averaging only five species per 1 m^2 quadrate) in the upstream section compared to the Allouette River and the Coquitlam River where the average number of species per quadrate were ten and seven respectively (Figure 1a). Species richness below the dam was even lower for the Cheakamus River with less than three species per m^2). However, for the Allouette and Coquitlam Rivers species richness was higher in the above the dam reaches than the below dam reaches (Figure 1a). Plant species richness per transect followed the similar trend among the upstream and down stream reaches of the three rivers. However, because of the larger sample size (14 quadrats per transect) the richness values were higher per transect (Figure 1b).

Table 1: List of species significantly more common at the upstream or downstream reaches across all three rivers. Where noted by an asterisk the level of statistical significance is $p < 0.05$, and in other cases (not noted) it is $p < 0.1$.

More Common Upstream		**More Common Downstream**	
Species	**Comments**	**Species**	**Comments**
Alnus rubra	* common	*Lactuca muralis*	* rare
Thuja plicata	* common	*Tolmiea menziesii*	*
Cornus stolonifera	* only at one site	*Galium trifitum*	
Vaccinium alaskense	* only at one site	*Ranunculus reptans*	
Ribes laxiflorum	* only at one site	*Taraxacum officinale*	rare
Dicranum tauricum	* common moss	*Carex* spp.	rare
Conocephalum conicum		*Leucolepis acanthoneuron*	* rare
Pseudotaxiphyllum elegans		*Pellia* sp.	* rare
Blechnum spicant		*Polytrichum munitum*	*
		Atrichum selwynii	

Species cover: Although the tree species cover per 1 x 1 m quadrat was similar (39-42%) in the upstream reaches (i.e. above the reservoirs) of all the three rivers it was significantly low in the reaches below the reservoirs (Figure 2a). Average tree cover below the dams was 24-26 % for the Allouette and Coquitlam Rivers but for the Cheakamus River it was under 10 %. Cover of herbaceous plants was negligible in both upstream and downstream of Cheakamus River where as that for the upstream of the

Allouette River and both upstream and downstream of Coquitlam River was about 10%. However, the herbaceous cover was significantly high (26 %) in the downstream section of the Allouette River. Bryophyte cover was similar between the upstream, downstream of Allouette River and downstream of Cheakamus River (23-26 %). However, both upstream and downstream of Cheakamus River and upstream of Coquitlam River had substantially lower bryophyte cover (3-10 %) with the lowest cover in the upstream section of the Cheakamus River (3 %) (Figure 2c).

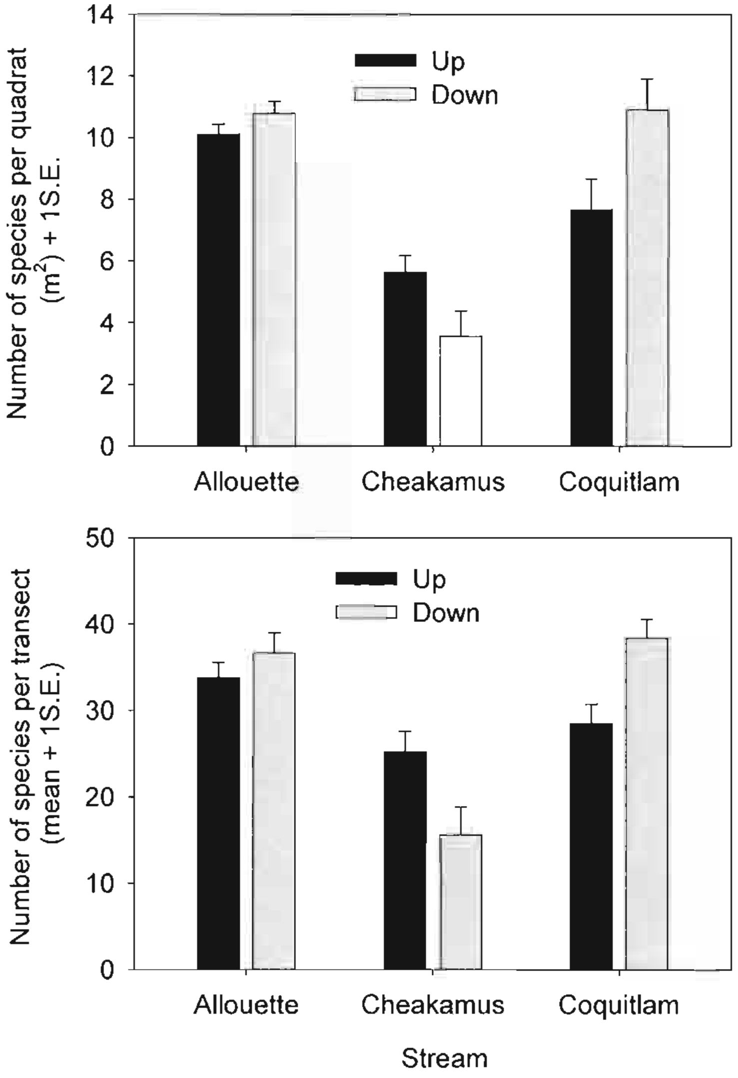

Figure 1. Species richness (number per m^2) above and below dam reaches of the Allouette, Cheakamus and Coquitlam Rivers, British Columbia; a) average number of plant species per quadrat and b) average number of plant species per transect.

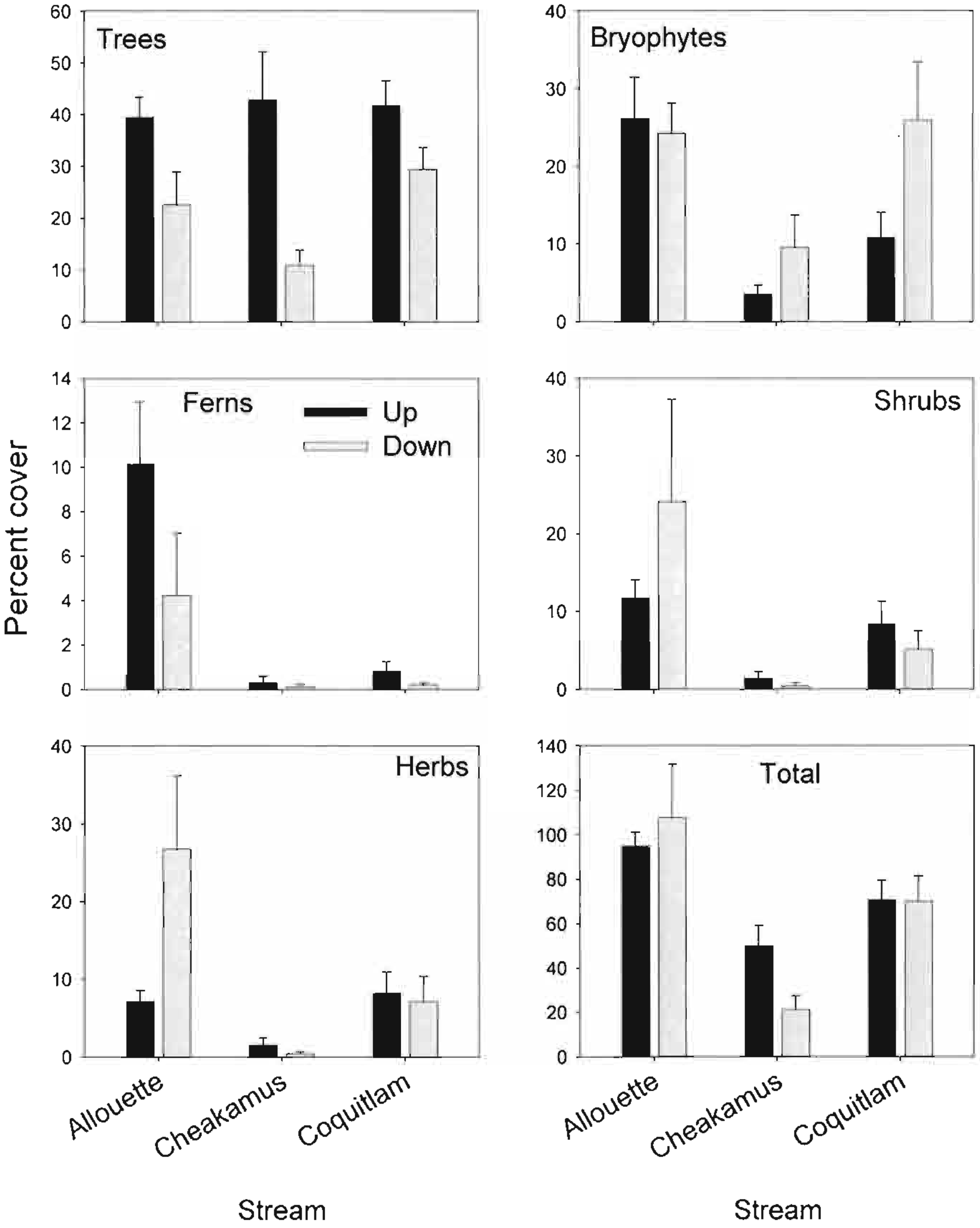

Figure 2. Plant species cover (mean % + 1 S.E.) in the above and below dam reaches of the Allouette, Cheakamus and Coquitlam Rivers in British Columbia; a) tree, b) herbaceous and c) bryophyte cover.

There were significant differences in the upstream versus downstream sites in the percent occurrences of some taxa (Table 1). There was a large amount of variation due to particular rivers, and this is reflected in the results in Figures 1 through 4. This site-to-site variation was significant for a number of taxa, but as that was not the question we were addressing, those results are summarised in the figures only. That drainage-specific variation is controlled for in the analysis. Some of the taxa that appeared to differ significantly above and below reservoirs were either very rare (< 0.2% cover) or only occurred at a single site (Table 1, Figs. 3 and 4). Red alder and western red cedar were both significantly less abundant in percent cover downstream of the reservoirs (Fig. 3). This difference in the cover by these two predominant riparian trees is also seen in Figure 2.

Ordination: Correspondence analysis with species cover data separated the vegetation of above and below dam reaches of the three rivers quite effectively along both Axes 1 and 2 (Figure 5). Although fairly close together in the ordination diagram the Allouette, Cheakamus and Coquitlam River study plots formed distinct groups. However, most sample sites of the below dam reach of Cheakamus River formed a separate group furthest from the rest of the sites reflecting the change in species richness, cover and possibly % cover (Figure 5a). The Principal Components Analysis including all species with more than 0.1 % cover (no transformation) from the six sites separated them even better with the Allouette river below dam reach and the Cheakamus River above dam reach being most dissimilar (Figure 5b). Above and below dam reaches of other streams also formed recognizable groupings reflecting the difference in species richness and cover and site location. There was no clear separation of upstream and downstream sites that was consistent across all three rivers in either of the ordination axes.

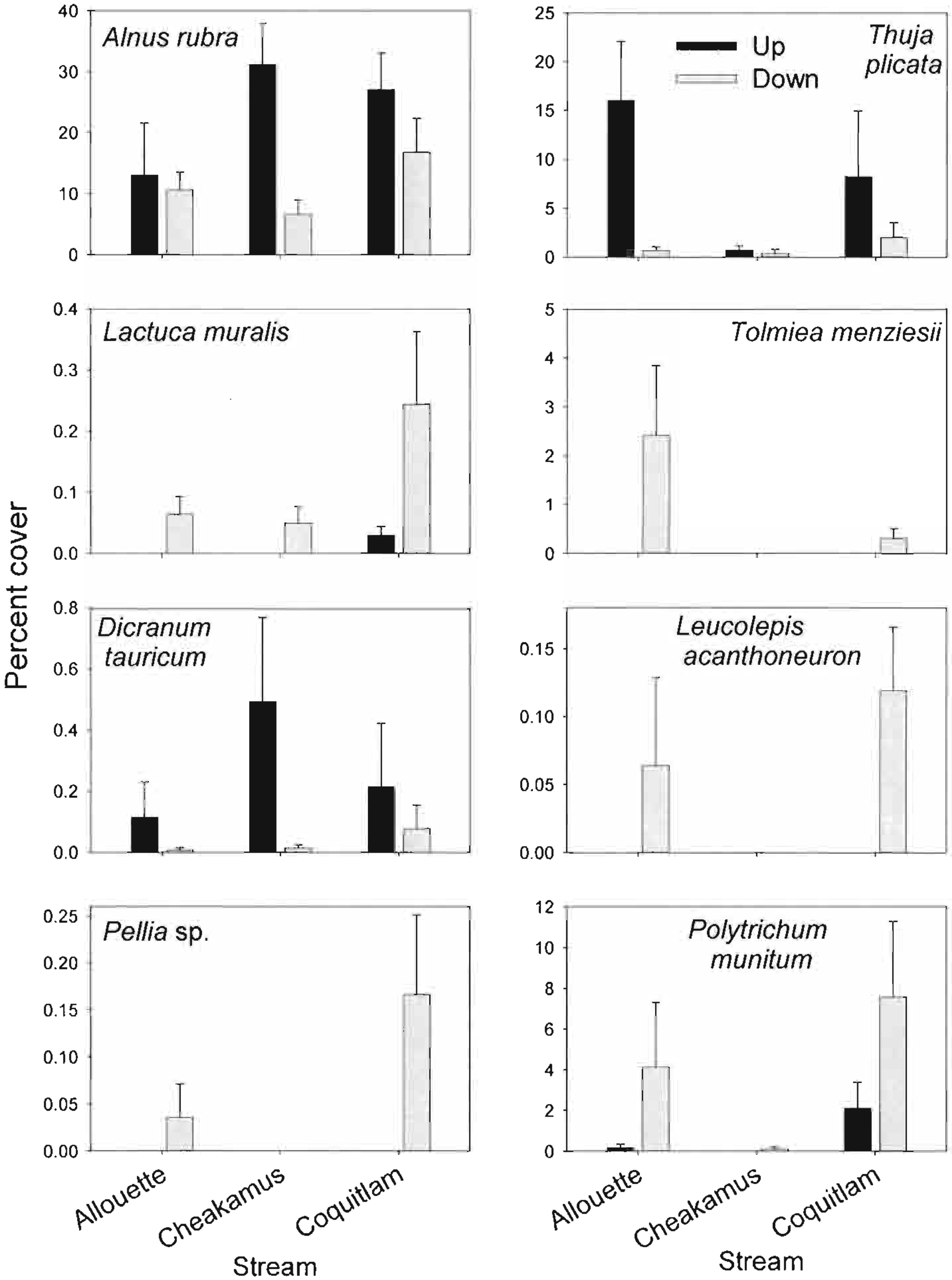

Figure 3. Mean percent cover (+ 1 S.E.) upstream and downstream of each of the reservoirs. All of these species showed significant differences in their percent cover relative to their position with respect to the reservoir (see Table 1).

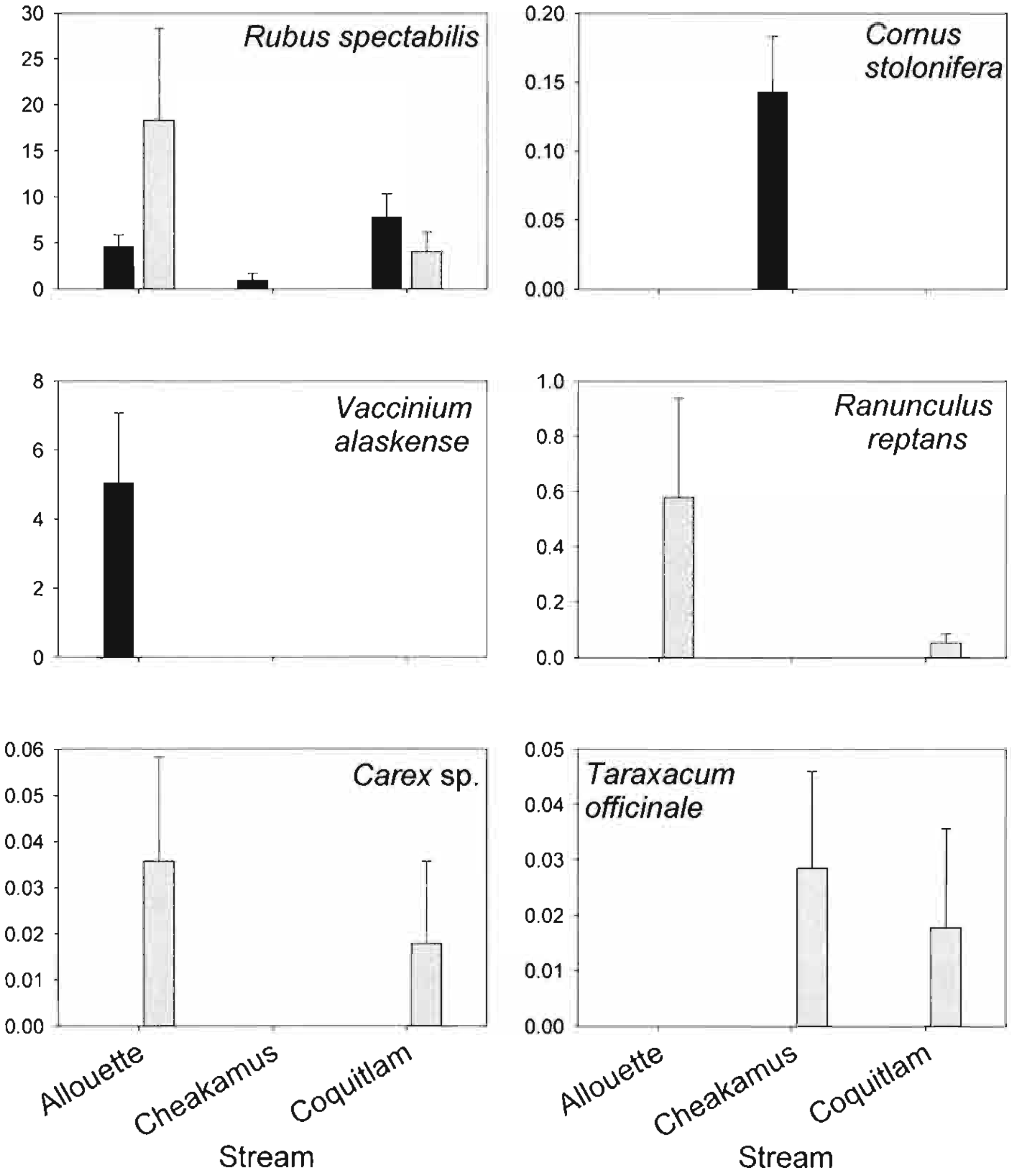

Figure 4. Mean percent cover (+ 1 S.E.) upstream and downstream of each of the reservoirs. Some, but not all, of these species showed significant differences in their percent cover relative to their position with respect to the reservoir (see Table 1).

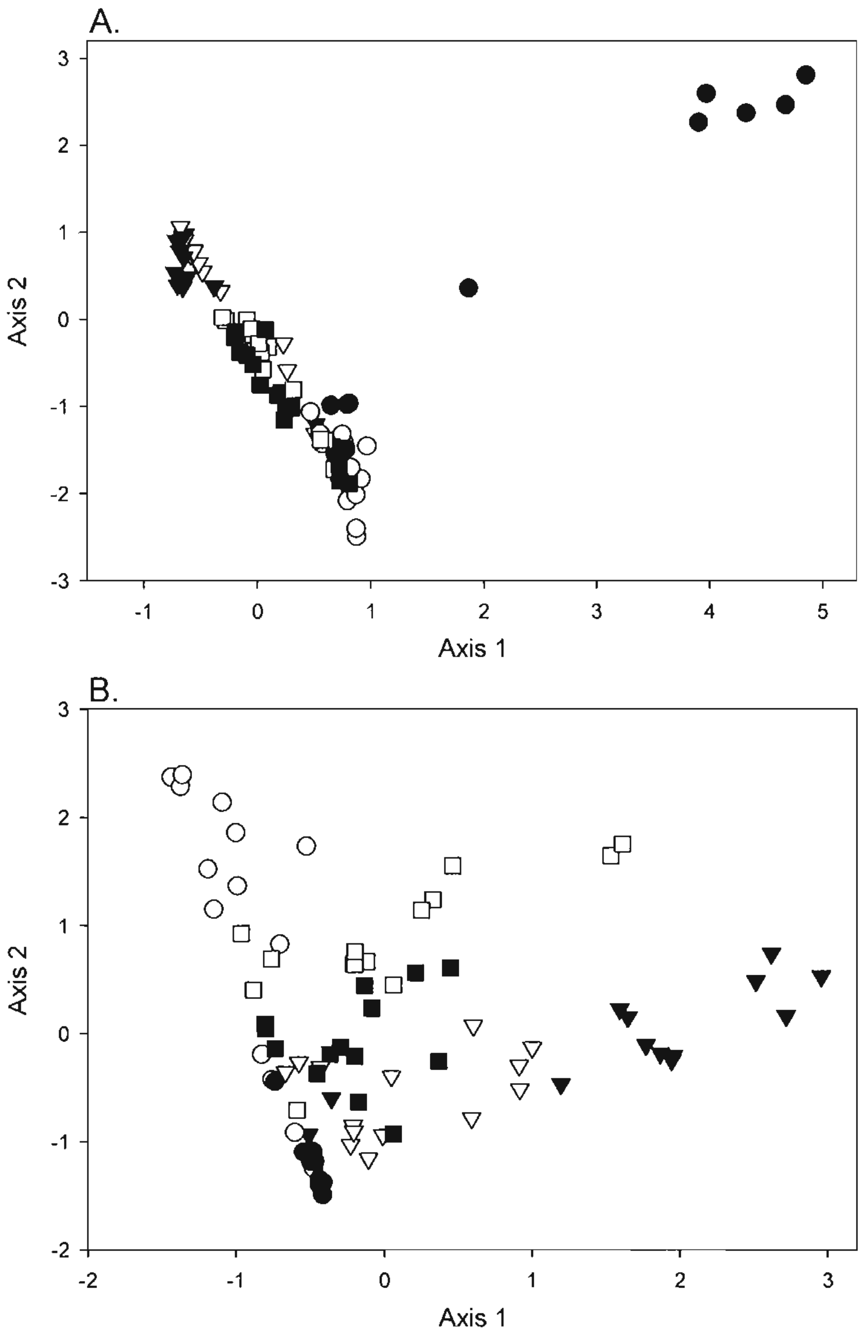

Figure 5. Ordination biplots of plant composition by distance band (n=14 per site) for all taxa representing >0.1 % of the total plant cover. A. Ordination by correspondence analysis. B. Ordination using Principal Components Analysis. In each figure open symbols are upstream of the reservoir and filled symbols are from downstream. Allouette River sites are shown by triangles, Cheakamus sites by circles, and Coquitlam sites by squares.

Discussion

Changes in plant species richness and composition due to river flow regulation by hydroelectric dams have been reported by several authors (Nilsson et al. 1989, 1991, 1997, Nilsson and Lansson 1995, Jansson et al. 2000, Elderd 2003). In unregulated rivers irregular high peak flows by causing floods create physical disturbance that influence plant mortality, colonization and establishment and patch structure in riparian zone. Upstream reaches free from the backwater effects of the reservoir are likely to experience natural flow regimes supporting the characteristic natural riparian vegetation. However, profound changes in vegetation structure and composition can occur downstream of the dams due to flow regulation which may have adverse consequences on water quality and stream aquatic community. The altered flow regimes, coupled with the creation of sediment supply limited conditions by trapping of sediments in reservoirs, can have large impacts on riparian vegetation communities. In this study we found that tree canopy cover for both western red cedar and red alder was significantly lower in downstream reaches of all the three rivers compared to the upstream reaches. It is possible that the uniform flow regulation in the downstream sections creates very few disturbed patches necessary for creating favourable seedbeds for tree colonization (Swanson et al. 1998, Hibbs and Bower 2000, Shaforth et al. 2002). The absence of tree canopy will have significant effects on down stream riparian species richness, diversity as well as physical, chemical and biological properties of the streams.

Red alder is a tree that requires disturbance to provide conditions suitable to colonise and germinate (Hibbs and Bower 2000). With the focus of the past century on timber values, red alder was previously regarded as a competitor and a nuisance to those values and managed with herbicides and mechanical brushing. The important roles provided by alder have come to be appreciated in the past decade. Alder fixes nitrogen in large quantities that subsequently become available to other forest vegetation and stream ecosystems. Alder also creates special forest floor conditions, particularly by its deciduous nature, which allows high amounts of light to reach the forest floor during the spring and autumn, which some species of plants and algae are able to capitalise upon (Hill et al. 2001). Since alder provides high quality detritus to stream food webs, its lower abundance in the downstream reaches can have significant negative effects on water quality and aquatic communities (Wipfli and Musslewhite 2004, Hernandez et al. 2005). The long-term reduction in percent cover and regeneration of alder in reaches downstream of dams will likely result in broader changes in riparian communities and declines in stream productivity as the currently present alders senesce and die.

Western redcedar was also lower in its percentage canopy cover downstream of the reservoirs. The reasons for this absence are not clear. One possibility is that while cedar can tolerate periodic groundwater saturation, it cannot tolerate persistent high water around its roots. As cedar is one of the slowest decomposing trees and also reaches very large sizes, it is considered a valuable source of large wood to streams and contributes to the geomorphic structure of rivers and provision of cover for stream fishes.

Significantly higher cover of the two herbaceous species, *Lactuca muralis* and *Tolmiea menziesii* in the down stream reaches may have resulted from the reduced tree cover that allowed sufficient light on the forest floor for them to grow. The acrocarpous mosses such as *Dicranum tauricum* prefers disturbed forest floor with mineral soil and its high cover in the upstream reaches can be attributed to flooding disturbance. On the other hand, mosses such as *Leucolepis acanthoneuron* and *Pellia* sp. prefer moist forest floor, organic humus and shade. These two mosses were altogether absent from Cheakamus River and the upstream reaches of the other two rivers. Their presence in the downstream sites of the Allouette and Coquitlam Rivers can be due to increased shade and organic matter deposition from the shrubs such as salmonberry thickets and relatively undisturbed conditions of the down streams reaches. It is important to note however that the cover of these two mosses was quite low. Difference in *Polytricum munitum* cover between up stream and down stream of the three rivers presents an interesting case. This acrocarpous moss prefers mineral soils with high moisture and light and as such should be common in the up stream reaches that are frequently disturbed by floods but we found them at a higher abundance in the down stream reaches. It is possible that the light penetration through the deciduous shrubs in the fall that allowed more light and consistent supply of soil moisture under the regulated flow regime of the down stream provided a better growing condition for this moss. Thus light and soil moisture may have played a bigger role than the disturbance effects. However, in interpreting these data one must keep in mind that this was a short-term study with limited sample size.

The number of significant effects of reservoirs on plant assemblages along the three rivers studied was no more than might be expected by chance with an error rate of 5%. Thus, one need consider these differences cautiously. It was also clear that there was a large river-to-river component of variation in the plant communities. In most instances the river-to-river differences were larger than any difference upstream and downstream of the reservoirs. The implication of this is that the natural range of variation between streams exceeds that of additional variation imposed on riparian communities as a consequence of flow regulation and diminution of sediment supplies. The change in the proportional cover by alder and lack of new germinants in the downstream reaches is likely to present a subtle, but detectable change in riparian and stream communities. These rivers, even below reservoirs, support diverse assemblages of riparian plants. There was no evidence of strongly negative consequences of flow management on these communities under the current flow management regimes.

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Appendix 1: list of plant species identified across the three river basins within the riparian areas, up to 11 m from the high water mark, and including vegetation within the maximum bankfull width.

Trees
Abies grandis
Acer circinatum
Betula papyrifera
Alnus rubra
Cornus nuttallii
Picea sitchensis
Populus balsamifera
Salix sp
Salix lucida
Salix scouleriana
Salix sitchensis
Taxus brevifolia
Thuja plicata
Tsuga heterophylla

Herbs
Agoseris aurantiaca
Anaphalis margaritacea
Aquilegia formosa
Claytonia siberica
Campanula scouleri
Digitalis purpurea
Epilobium ciliatum
Epilobium glaberimum
Galium trifitum
Luzaula sp. (grass/Iris)
Luzaula (iris #1)
Hieracium albiflorum
Impatiens glandulifera
Lactuca muralis
Lepidozia reptans
Lysichiton americanum
Lysimachia thyrsiflora
Mianthamum dil.
Moehringia macrophylla
Oenanthe sarmentosa
Ranunculus occidentalis
Ranunculus reptans
Ranunculus uncinatus
Rubus idaeus
Rubus leucodermis
Rubus nivalis
Rubus parviflorus
Rubus spectabilis
Rubus ursinus
Sisyrinchium
Stellaria calycantha
Stellaria crispa
Taraxacum officinale
Tellima grandiflora
Tiarella trifoliata
Tolmiea menziesii
Trifolium reptans
Mentha arvensis (vascular plant 3)
Viola sp.

Shrubs
Amelanchier alnifolia
Boykinia elata
Cornus stolonifera
Gaultheria shallon
Oplopanax horridus
Pachystima myrsinites
Physocarpus capitatus
Rhamnius purshiana
Ribes lacustre
Ribes laxiflorum
Ribes sanguineum
Sambucas racemosa
Spirea sp.
Vaccinium alaskense
Vaccinium ovalifolium
Vaccinium ovatum
Vaccinium parviflorum

Bryophytes (mosses and liverworts)
Atrichum selwynii
Aulacomnium androgynum
Aulacomnium palustre

Bartramia pomiformis
Brachythecium spp.
Calimecium dendroides
Claopodium crispifolium
Climacium dendroides
Conocephalum conicum
Dicranoweisia cirrata
Ulota sp.
Orthotrichum lyellii (*Dicranum* C)
Dicranum polysetum
Dicranum scoparium
Dicranum tauricum
Diplophyllum taxifolium
Ditricum flexicune
Eurhynchium oregana
Eurhynchium pralongum
Heterocladium procurrence
Hookeria lucens
Hygrohyphnum ochraceum
Hylocomium
Eurhynchium praelonga
("*Hylocomium* C")
Hylocomium splendens
Hypnum circinade
Hypnum subimponens
Frullania
Isothecium
Isothecium stoloniferum
Kindbergia oregana
Kindbergia praelonga
Leucolepis acanthoneuron
Scleropodium obtusifolium
Metanekara menziesii
Mnium spinulosus
Claupodium crispifolium
Schistidium apocarpum
Neckera sp.
Pellia sp.
Pellia neestana
Eurhynchium prael
Plagiochila porelloides
Plagiomnium insigne
Plagiomnium porelolius
Plagiomnium
Plagiothecium
Plagiothecium undulatum
Pogonatum contortum
Pogonotium urnigerum
Polytrichum munitum
Polytrichum alpinum
Polytrichum urigerum
Atrichum
Oligotrichum sp.
Frullania sp.
Pseudotaxiphyllum elegans
Racomitrium aciculari
Racomitrium sp.
Racomitrium seduticum
Racomitrium canescens
Racomitrium lanuginosum
Radula complanata
Rhizomnium glabrescens
Rhizomnium magnifolium
Rhytidiadelphus sp.
Rhytidiadelphus loreus
Rhytidiadelphus squarosus
Rhytidiadelphus triqueseris
Riccardia multifida
Scapania sp.
Scleropodium obtusifolium
Scouleria aquatica
Porella navicularis
Neekera douglasii
Sphagnum sp.
Tetraphis pellucida
Timmia austriaca
Tortula muralis

Ferns

Athyrium felixfemina
Blechnum spicant
Dryopteris expansa
Equisetum sp.
Polypodium glycyrrhiza
Polypodium amorphum
Polystichum lonchitis
Polystichum munitum
Thelypteris phagopteris

Grasses and sedges

Bromus sp.
Other grasses
Juncus effuses
Carex

Lichens
Hypogymnia physodes