Eskers and Outwash Plains:
Skeins of Connectivity in the Liard Basin

Patrick Williston[1], Paula Bartemucci[1] and Jim Pojar[2]
December 2004
[1] Gentian Botanical Research
[2] Canadian Parks and Wilderness Society, Yukon Chapter

Abstract

Glaciofluvial landforms are frequent in the Liard Basin, an intermontane plain in the northern Yellowstone to Yukon (Y2Y) region straddling 60º N in southeast Yukon-northeast British Columbia. They cover little area but are nevertheless critical components of the linear infrastructure of regional biodiversity, part of the surficial geological template that underlies patterns of rare plant species and community occurrence as well as patterns of movement and use by vertebrates. Two common glaciofluvial landforms are eskers and outwash plains. Eskers are linear and often wavy ridges of rapidly drained sand, gravel, and cobbles deposited by fast streams that flowed under the glacial ice. Outwash plains are broad, tabular landforms of similar materials deposited beyond rapidly melting glacier fronts. On occasion, outwash plains are pitted by kettle holes, depressions formed by melting remnant ice.

In the largely forested landscapes of the Liard Basin, glaciofluvial deposits form among the driest habitats, often are lightly timbered or non-forested, and are good sites for regionally rare or uncommon plant species and communities. They are also frequently associated with wetlands that host a suite of rare and uncommon species. These wetland-upland complexes are important sites for colonization, persistence, migration, and reassembly of such plants, vegetation, and their invertebrate associates. Furthermore, they provide key habitat for several vertebrate species that preferentially use these landforms for travel, feeding, rest, and denning.

Such landforms are targeted as sources of sand and gravel for road construction during industrial development, which is poised to expand in the Liard Basin. Development also threatens to disrupt the hydrology of the wetlands commonly associated with these landforms.

To clarify the role of glaciofluvial landforms in regional biodiversity and landscape connectivity, our study tests the hypotheses that glaciofluvial landforms, specifically eskers and pitted outwash plains: (1) differ in diversity and composition from the mesic forest matrix; (2) have more rare/uncommon plant species and plant communities than the forest matrix; and (3) are used more than the forest matrix by some vertebrates (beaver, wolf, caribou, black bear, moose, marten, grouse, and snowshoe hare).

We selected seven pairs of glaciofluvial and forest matrix (i.e., mature coniferous forests on morainal landforms) sampling sites. Four sites were established on pitted outwash plains and three were along eskers, each paired with an adjacent forest matrix site. We established two 500-m long belt-transects, each 2 m wide, at all sites. Wildlife sign (e.g., droppings, beds, mark trees, browse) and the presence of vascular plant species and plant communities were recorded along each transect. We also conducted a time-limited 30-minute opportunistic search in the vicinity of each transect for uncommon vascular plant species and additional wildlife sign.

Glaciofluvial landforms harbour several rare and uncommon plants that were not found in the forest matrix of the Liard Basin. We found 44 % of the total study flora and 17 of 26 rare (listed by the Yukon Territory) and infrequent plant species (found 10 or fewer times in the Yukon) restricted to glaciofluvial landforms. Steep dry slopes and "pocket wetlands", wetlands in kettle holes, supported the greatest number of rare plant species. Rare plants of dry habitats included the grasses *Oryzopsis pungens, O. asperifolia*, *Koeleria macrantha* and a locoweed, *Oxytropis sericea* ssp. *spicata*. We encountered the following six rare species in pocket wetlands: *Carex interior*, *Drosera anglica*, *Eriophorum viridi-carinatum*, *Salix pedicellaris*, *Scheuchzeria palustris* ssp. *americanum* and *Utricularia minor*.

Glaciofluvial landforms also support plant communities that are uncommon in the Liard Basin. Eskers and pitted outwash plains have a greater variety of plant communities per ha than do adjacent mesic forests. Interactions between parent material and topography create complex surficial and hydrological templates for a diversity of plant communities in close proximity. Plant communities of glaciofluvial landforms range from those of dry habitats on well-drained sunny sites, drier and warmer than found in the surrounding forest matrix, to those of wet, poorly drained depressions at the base of eskers or kettle holes. Such complexity was not observed in the forest matrix sites.

Total wildlife use was very similar between glaciofluvial landforms and the forest matrix, largely because of the widespread abundance of moose, grouse and snowshoe hare. These three species have broad niches and occupy a range of habitats. Limited sign of the remaining nine wildlife species was encountered in the study, but the available evidence indicated that eight of these species were more common on glaciofluvial landforms: beaver, black bear, wolf, coyote, caribou, woodchuck, porcupine and ground squirrel. We found sign of many of these species only on glaciofluvial landforms. We speculate that wolf, coyote and black bear use glaciofluvial landforms as movement corridors—every esker we visited featured a well-used game trail along the crest. We did not, however, locate wolf or bear dens. We did find evidence of black bears foraging on eskers, particularly on southern aspects, where berry production was high. Caribou also frequently use glaciofluvial landforms for travel and forage. We found that caribou winter forage (ground lichens) was generally more abundant on eskers and outwash plains than in the surrounding forest matrix, where feathermosses predominate.

These findings are important for conservation and resource planning in the Liard Basin and the Kaska Dena traditional territory. The results support the assertion that glaciofluvial landforms are now and, as climate changes, will continue to be key elements of connectivity in the northern part of the Yellowstone to Yukon region.

INTRODUCTION

The Liard Basin, situated in the northern Yellowstone to Yukon (Y2Y) region, is a biogeographic crossroads with a mixture of Cordilleran, Boreal, Great Plains, Subarctic, and Amphiberingian biotic elements. The area supports a functioning, large mammal, predator-prey system, including moose, caribou, wolf, black and grizzly bear, wolverine, and lynx. Though largely undeveloped, the basin contains sizeable tracts of productive forest and significant deposits of coal and natural gas. Further industrial development in the region is predicted along with the associated construction of roads. The ecological effects of roads have been well documented, with the general conclusion that they degrade the ecological integrity of both terrestrial and aquatic ecosystems (Forman and Alexander 1998; Trombulak and Frissell 2000). Traditionally, road engineers and builders have sought sand and gravel in glaciofluvial deposits. Several glaciofluvial deposits along the Alaska highway are currently used for these purposes. Additional sources will likely be targeted for construction materials as the industrialization of the Liard Basin proceeds.

Typically glaciofluvial landforms are linear or elongate, valley-bottom features, locally frequent in the landscape but of very small aerial extent. Two common glaciofluvial landforms in the Liard Basin are eskers and outwash plains. Eskers are

Figure 1. Aerial photograph of an esker along Esker Lake (top).

Figure 2. Aerial photograph of a pitted outwash plain near Barney Lakes.

linear and often wavy ridges of rapidly drained parent material derived largely from sand, gravel, and cobbles deposited by fast streams that flowed under the glacial ice (Figure 1). Outwash plains and terraces are broad, tabular landforms deposited beyond rapidly melting glacier fronts. On occasion they are pitted by kettle holes, depressions formed by melting remnant ice (Figure 2).

In the largely forested landscapes of the Liard Basin, glaciofluvial deposits form among the driest habitats, often are lightly timbered or non-forested, and provide habitat for regionally rare or uncommon plant species and communities. They are also frequently associated with wetlands that provide habitat for a suite of rare and uncommon species. These wetland-upland complexes are important sites for colonization, persistence, migration, and reassembly of such plants, vegetation, and their invertebrate associates. Furthermore, they provide key habitat for several vertebrate species (e.g., beaver, wolf, caribou, black bear), which preferentially use these landforms for travel, feeding, rest, and denning.

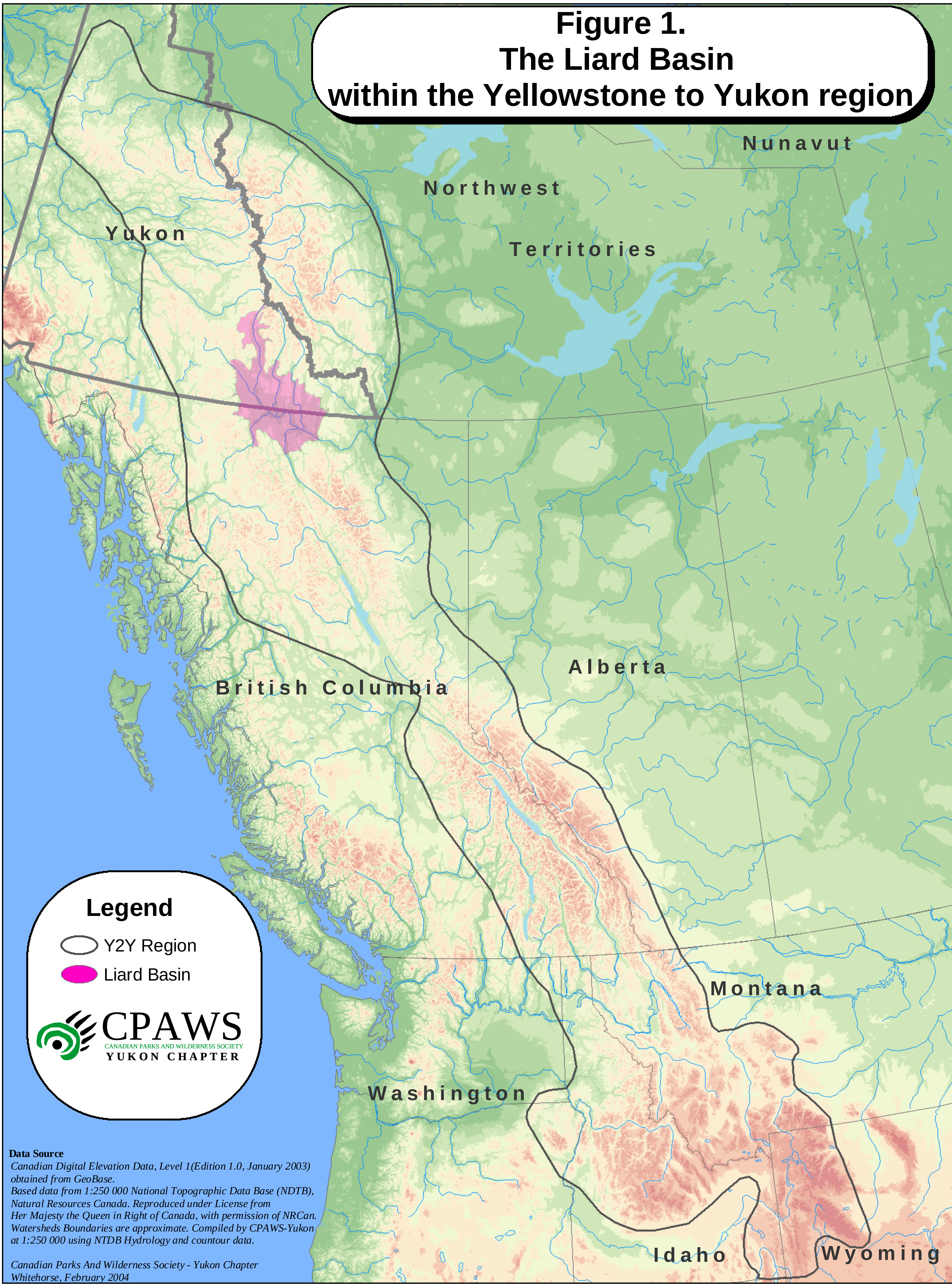
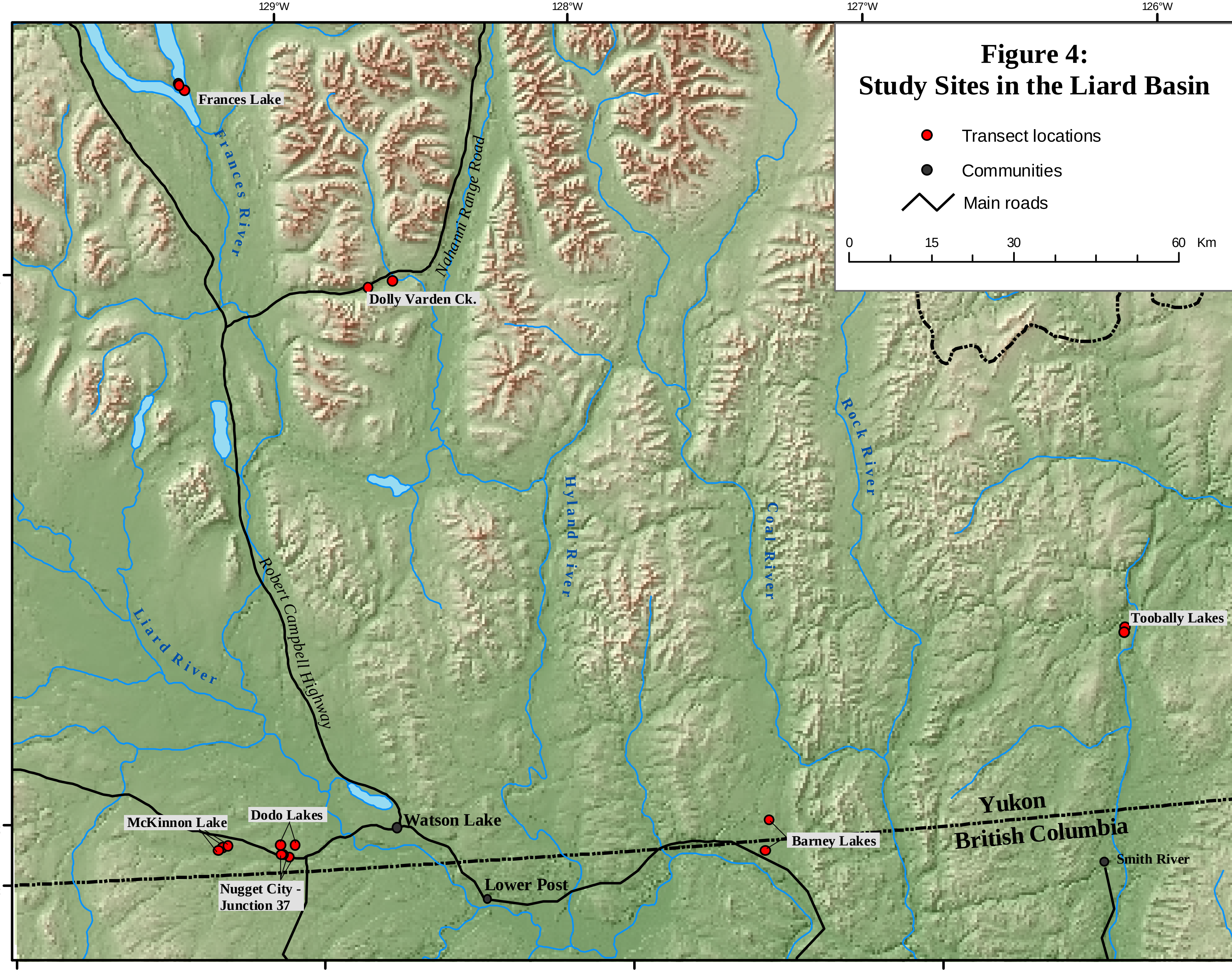


Figure 1.
The Liard Basin
within the Yellowstone to Yukon region

Figure 4:
Study Sites in the Liard Basin



With the objective of better understanding the role of glaciofluvial landforms in patterns of regional biodiversity and connectivity in the Liard Basin, three questions were addressed:

1. How do glaciofluvial landforms and the surrounding forest matrix differ in terms of diversity and composition?
2. Do glaciofluvial landforms support more uncommon plant species and plant communities than the surrounding forest matrix?
3. Are glaciofluvial landforms used more than the forest matrix by some vertebrates (beaver, wolf, caribou, black bear, moose, marten, grouse, and snowshoe hare)?

We also sought to document rare plant occurrences within wetlands associated with glaciofluvial landforms.

STUDY AREA

Our study was conducted in the Liard Basin of the southeast Yukon, which is comprised of the Liard Plain and Hyland Plateau physiographic units (Bostock 1948), ringed by a series of mountain ranges (Figures 3 & 4). The basin is largely forested, has rolling hills to 1300 m and broad valleys. Morainal deposits (glacial till) dominate the surficial geology of the basin; glaciolacustrine silt and clay and glaciofluvial sand and gravel are frequent but subordinate deposits (Bostock 1966).

The subarctic, continental climate of the Liard Basin region is recorded at the Watson Lake weather station, which reports a mean annual precipitation of 404 mm (197 cm snow, 255 mm rain) and a mean annual temperature of -3ºC, with a high monthly mean in July of 14ºC and low mean in January of -25ºC (Environment Canada 2005). The region receives moderate amounts of precipitation, ranging from about 400 to 600 mm annually, with the heavier amounts falling over the higher terrain (Smith et al. 2004).

The Liard Basin is part of the Boreal forest region of Rowe (1972), also now termed the Boreal Cordillera Ecozone. Dominant tree species are white spruce, black spruce, and lodgepole pine, which form pure, and more often mixed stands in a mosaic of age classes resulting from an active history of disturbance—largely wildfire. Relatively good forest growth occurs locally in the region – especially along the major rivers – as a result of the combination of low elevation, plentiful precipitation, and warm summers. Wetlands are common and sometimes extensive. Shrub-herb fens and permafrost-associated, black spruce-*Sphagnum* peat bogs are typical wetland types (Smith et al. 2004).

METHODS

We selected seven pairs of glaciofluvial and forest matrix sampling sites using 1:250 000 topographical maps (Canada Centre for Mapping; Department of Energy, Mines and Resources) and aerial photographs. Four sites were established on pitted outwash plains and three were along eskers, each paired with a site in the surrounding forest matrix (representative mature coniferous forests developed on moderately-drained morainal deposits (glacial till)).

We established two 500-m long belt-transects, each 2 m wide at each of the 14 sites. Each 500-m long transect was divided into 100-m long sub-transects for vascular plant sampling, but not for vertebrate and plant community data. We also established five 100-m^2 plots per site, where composition and cover of moss and lichen layers was estimated.

Wildlife sign (e.g. droppings, beds, browse) and the presence of vascular plant species and plant communities were recorded along each transect. We also conducted a time-limited 30-minute opportunistic search in the vicinity of each transect for uncommon vascular plant species (2 field researchers) and additional wildlife sign (one field researcher).

Each glaciofluvial site supported, or was closely associated with wetlands, a legacy of the complex topography, hydrology, and glacial history. We opportunistically surveyed vascular plants within these wetlands without specified search criteria, and documented rare species in these habitats.

During this study we collected voucher specimens of noteworthy species (unusual distributions and low numbers of collections) and species suspected of being rare in the Yukon Territory or British Columbia (if populations exceeded 20 individuals; collecting protocol of Alberta Native Plant Council 2000). We collected, identified and submitted for curation 171 specimens of vascular plants. Plant specimens were identified using Cody (1996), Hultén (1968), Douglas et al. (1998a, 1998b, 1999a, 1999b, 2000, 2001a, 2001b, 2002a, 2002b), with the nomenclature following Cody (1996).

Statistical Methods

Differences between the vegetation of glaciofluvial landforms and the forest matrix, in terms of species richness (vascular and non-vascular species), diversity (Shannon's H' index), evenness index (Whittaker 1972) and total number of rare species were analysed using paired *t*-tests. Wildlife data were analysed in the same manner. Differences in bryophyte and lichen cover were analysed using two-sample *t*-tests.

We used detrended correspondence analysis (DCA) to obtain an indirect gradient ordination of plant community composition along line transects. Statistical analyses were performed using Systat 6.0 (Systat Inc. 1996), and DCA ordinations and diversity indices were performed using PCORD v. 4 (McCune and Mefford 1997).

RESULTS

Plant Transects

In total, 131 vascular plant species were encountered along the 14 km of line transects (Table 1). There were 115 species found on glaciofluvial landforms and 93 species found on morainal deposits. Forty-five species were restricted to glaciofluvial landforms, while 15 species were found only on till.

Table 1. Frequency (% occurrence) of vascular plant species in 100-m x 2-m plots along sample transects.

Species	Glaciofluvial n=70	Forest Matrix n=70
Abies lasiocarpa	6	37
Achillea millefolium	17	4
Aconitum delphinifolium	3	3
Actaea rubra	4	1
Alnus crispa	41	174
Alnus incana ssp. *tenfuifolia*	1	1
Amelanchier alnifolia	43	0

Species	**Glaciofluvial n=70**	**Forest Matrix n=70**
Andromeda polifolia	3	0
Androsace septentrionalis	4	0
Anemone multifida	37	1
Anemone parviflora	0	3
Anemone richardsonii	0	1
Antennaria rosea	4	0
Apocynum androsaemifolium	13	0
Aquilegia formosa	3	0
Arabis holboelli var *retrofracta*	16	0
Arctostaphylos rubra	0	33
Arctostaphylos uva-ursi	70	34
Arnica cordifolia	1	24
Artemisia campestris	9	0
Aster ciliolatus	1	0
Aster conspicuus	1	0
Aster sibiricus	3	0
Astragalus canadensis	13	0
Betula glandulosa	49	36
Betula neoalaskana	73	80
Calamagrostis canadensis	31	74
Calamagrostis purpurascens	37	0
Calypso bulbosa	1	1
Carex aenea	1	1
Carex aquatilis	9	0
Carex concinna	23	9
Carex gynocrates	0	1
Carex limosa	3	0
Carex loliacea	3	0
Carex macloviana	1	0
Carex media	0	1
Carex rossii	17	0
Carex utriculata	4	0
Carex vaginata	0	3
Corallorhiza trifida	1	7
Cornus canadensis	54	67
Cornus stolonifera	6	0
Delphinium glaucum	1	19
Elymus calderi	13	0
Elymus trachycaulus	26	11
Elymus trachycaulus ssp. *subsecundus*	1	0
Empetrum nigrum	19	46
Epilobium angustifolium	77	64
Equisetum arvense	7	10
Equisetum pratense	4	10
Equisetum scirpoides	16	49
Equisetum sylvaticum	0	3

Species	Glaciofluvial n=70	Forest Matrix n=70
Erigeron acris	1	0
Eriophorum vaginatum	1	0
Festuca altaica	40	20
Festuca saximontana	20	0
Fragaria virginiana	41	3
Galium boreale	44	6
Gentianella propinqua	7	0
Geocaulon lividum	79	93
Geranium bicknellii	1	0
Goodyera repens	30	20
Hedysarum alpinum	9	0
Hieracium umbellatum	4	0
Hierochloe hirta	1	0
Juniperus communis	60	4
Ledum decumbens	3	0
Ledum groenlandicum	53	89
Leymus innovatus	7	0
Linnaea borealis	94	87
Listera cordata	0	6
Lupinus arcticus	73	26
Lycopodium annotinum	11	34
Lycopodium complanatum	17	37
Maianthemum trifolium	3	0
Menyanthes trifoliata	1	0
Mertensia paniculata	24	54
Mitella nuda	7	31
Moneses uniflora	0	9
Orthilia secunda	50	90
Oryzopsis asperifolia	16	9
Oryzopsis pungens	41	0
Oxycoccus microcarpus	6	3
Oxytropis sericea	11	0
Pedicularis labradorica	46	19
Penstemon procerus	16	0
Petasites frigidus	0	1
Petasites palmatus	9	31
Picea glauca	147	134
Picea mariana	131	227
Pinus contorta	126	114
Platanthera obtusata	0	6
Polygonum viviparum	0	1
Populus balsamifera	16	33
Populus tremuloides	127	87
Potentilla fruticosa	1	3
Pyrola asarifolia	10	61
Pyrola chlorantha	23	21

Species	Glaciofluvial n=70	Forest Matrix n=70
Pyrola minor	1	0
Ranunculus aquatilis	1	0
Ribes hudsonianum	1	1
Ribes lacustre	3	10
Ribes oxyacanthoides	6	0
Ribes triste	9	24
Rosa acicularis	81	74
Rubus chamaemorus	6	3
Rubus idaeus	1	7
Rubus pubescens	10	14
Salix arbusculoides	0	6
Salix barclayi	9	3
Salix bebbiana	77	63
Salix drummondiana	0	1
Salix glauca	7	20
Salix myrtillifolia	9	30
Salix planifolia	9	10
Salix pseudomonticola	0	3
Salix scouleriana	114	123
Saxifraga tricuspidata	13	0
Senecio indecorus	1	0
Senecio lugens	0	1
Shepherdia canadensis	70	30
Solidago canadensis	1	0
Solidago simplex	31	4
Vaccinium caespitosum	0	4
Vaccinium uliginosum	17	19
Vaccinium vitis-idaea	96	99
Viburnum edule	73	46
Viola nephrophylla	1	0
Viola renifolia	3	20
Zygadenus elegans	1	0

During transect sampling, we found six species that are considered rare in the Yukon Territory (Table 2), all were restricted to glaciofluvial landforms except *Oryzopsis asperifolia*, which we also found in a drier microsite in the forest matrix.

Table 2. Rare species found along sample transects.

Species	Ranking*	Sites
Aquilegia formosa	S2	Toobally Lakes esker
Aster ciliolatus var. *ciliolatus*	S2	McKinnon Lake esker
Oryzopsis asperifolia	S1	Junction 37 outwash plain and mesic forest, Dolly Varden outwash plain, Barney Lakes outwash plain, Toobally Lakes esker

Oryzopsis pungens	S2	Junction 37 outwash plain, Dolly Varden Creek outwash plain, Barney Lakes esker, McKinnon Lake esker, Dodo Lakes esker
Oxytropis sericea ssp. *spicata*	S2	McKinnon Lake esker
Viola nephrophylla	S1	Toobally Lakes esker

*Rankings obtained from a list provided by NatureServe Yukon (Bruce Bennett, pers. comm. 2004).

In addition to the species considered territorially rare by NatureServe Yukon, we found 8 species that had been collected ten or fewer times in the Yukon Territory (Cody 1996). Nine occurrences of these species were found on glaciofluvial landforms and four occurrences were in the forest matrix (Table 3).

Table 3. Uncommon species found along sample transects.

Species	Number of localities reported in Cody (1996)	Sites
Apocynum androsaemifolium	8	Toobally Lakes esker, Junction 37 outwash plain, Dodo Lakes esker
Calypso bulbosa	10	Dodo Lakes esker, Junction 37 mesic matrix
Carex aenea	9	Dodo Lakes mesic matrix, Barney Lakes outwash plain
Geranium bicknellii	9	Toobally Lakes esker
Hieracium umbellatum	4	McKinnon and Dodo Lakes eskers
Listera cordata	5	Dolly Varden Creek outwash plain and mesic matrix
Maianthemum trifolium	8	Dolly Varden Creek outwash plain
Salix drummondiana	8	Dolly Varden Creek mesic matrix.

Richness, evenness and Shannon's diversity index were not significantly different between glaciofluvial and forest matrix sites (*t*-tests, $p>0.50$, df =13). There were, however, substantial differences in species composition (Figure 5). Ordination (DCA) of plant species revealed differences in composition between glaciofluvial and morainal sites along axis 1. Axis 1 accounted for 52% of the variation in the ordination. There was a host of species associated with glaciofluvial landforms (strong positive correlation with Axis 1; Table 4), while other species were found more frequently in the forest matrix sites (strong negative correlation with Axis 1; Table 5). There were larger differences in composition between landforms for sites at McKinnon Lake (MAC), Dodo Lakes (DOD), Junction 37 (NUG) and Toobally Lakes (TOO) (Figure 5). The remaining sites had similar species composition irrespective of landform type, as shown by dense clustering of all four transects (e.g., Frances Lake: FRA).

Table 4. Plant species showing strong positive correlation with axis 1 of the detrended correspondence analysis (DCA) ordination of landform types. These species are therefore positively associated with glaciofluvial landforms.

Species	Correlation with DCA Axis 1
Amelanchier alnifolia	0.812
Anemone multifida	0.903
Apocynum androsaemifolium	0.487
Calamagrostis purpurascens	0.870
Carex rossii	0.829
Elymus calderi	0.686
Festuca saximontana	0.828
Galium boreale	0.762
Fragaria virginiana	0.685
Juniperus communis	0.867
Oryzopsis pungens	0.695
Saxifraga tricuspidata	0.450
Shepherdia canadensis	0.510
Solidago simplex	0.862

Table 5. Plant species showing strong negative correlation with axis 1 of the detrended correspondence analysis (DCA) ordination of landform types. These species are therefore positively associated with the surrounding forest matrix.

Species	Correlation with DCA Axis 1
Alnus crispa	-0.480
Arctostaphylos rubra	-0.440
Calamagrostis canadensis	-0.746
Cornus canadensis	-0.523
Equisetum scirpoides	-0.500
Ledum groenlandicum	-0.804
Lycopodium annotinum	-0.530
Lycopodium complanatum	-0.473
Mertensia paniculata	-0.555
Mitella nuda	-0.498
Orthilia secunda	-0.634
Petasites palmatus	-0.478
Pyrola asarifolia	-0.556
Salix myrtillifolia	-0.511

Plant Searches

During opportunistic searches, 98 species were detected, 88 species on glaciofluvial landforms and 53 species in the forest matrix. Fifty-seven of these species were not found in transect sampling (Table 6), thereby bringing the total number of vascular plant species in this study to 188. The mean number of species per site (i.e., richness) was significantly greater (13 species) on glaciofluvial landforms than on morainal landforms (7 species) (t = 2.596, df = 6, p = 0.041).

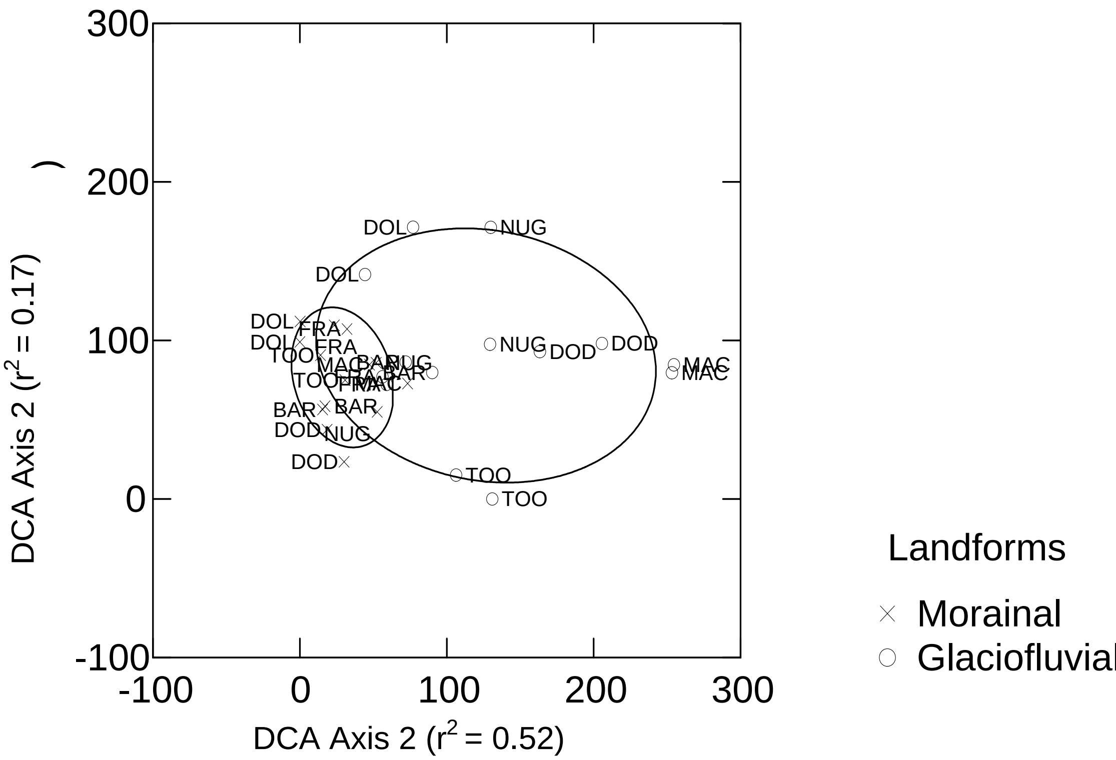


Figure 5. Detrended correspondence analysis (DCA) ordination of plant community composition.

Table 6. Vascular plant species documented during searches, in addition to the species already reported during transect sampling.

Species	Occurences Glaciofluvial	Forest matrix
Alnus crispa ssp. *sinuata*	2	1
Artemisia tilesii	1	1
Botrychium lunaria		1
Botrychium minganense		1
Calamagrostis canadensis	1	
Calamagrostis stricta ssp. *stricta*	1	
Cardamine sp. (*C. pratensis*?)	1	
Carex arcta	1	
Carex atratiformis ssp. *raymondii*	1	
Carex brunnescens	1	
Carex disperma	1	
Carex interior	1	
Carex leptalea	2	

	Occurences	
Species	**Glaciofluvial**	**Forest matrix**
Carex saxatilis		1
Chrysosplenium tetrandrum		1
Corydalis aurea	1	
Corydalis sempervirens		2
Deschampsia caespitosa	1	
Drosera anglica	1	
Equisetum fluviatile	1	
Eriophorum scheuchzeri	1	
Eriophorum viridi-carinatum	1	
Galium trifidum	2	1
Glyceria pulchella	2	
Koeleria macrantha	2	
Larix laricina		1
Myrica gale	1	
Myriophyllum sp.	1	
Parnassia palustris	1	
Phacelia franklinii	1	
Platanthera hyperborea	1	
Platanthera orbiculata		1
Polygonum amphibium	1	
Polygonum persicaria	2	
Potamageton richardsonii		1
Potamogeton filiformis var. *borealis*	2	
Potentilla norvegica	1	
Potentilla palustris	2	
Pulsatilla ludoviciana	6	
Ranunculus flammula	1	
Ranunculus gmelinii ssp. *purshii*	1	
Rorippa palustris	1	1
Rubus arcticus ssp. *acaulis*	2	
Rumex occidentalis	1	
Salix lanata ssp. *richardsonii*		1
Salix pedicellaris	1	
Scheuchzeria palustris	1	
Senecio pauperculus	2	
Sorbus scopulina		1
Stellaria calycantha	1	
Stellaria crassifolia	1	1
Stellaria longifolia		
Utricularia intermedia	1	
Utricularia minor	1	
Utricularia vulgaris ssp. *macrorhiza*	1	
Veronica scutellata		1

Nine species found during the searches are considered rare in the Yukon Territory (Table 7). Eight rare species were found only on glaciofluvial landforms, four of which were found only in kettle holes of the Junction 37 pitted outwash plain. *Alnus crispa* ssp. *sinuata* was found at two sites on morainal deposits.

Table 7. Rare species found in plant searches.

Species	Ranking*	Sites
Alnus crispa ssp. *sinuata*	S2	Toobally Lakes and Dolly Varden Creek mesic forest matrix
Carex interior	S1	Dodo Lakes esker
Drosera anglica	S2S3	Junction 37 outwash plain
Eriophorum viridi-carinatum	S2	Junction 37 outwash plain
Koeleria macrantha	S2	Toobally Lakes esker and Frances Lake outwash plain
Platanthera orbiculata	S2	Toobally Lakes esker
Salix pedicellaris	S1	Junction 37 outwash plain
Scheuchzeria palustris ssp. *americanum*	S2	Junction 37 outwash plain
Utricularia minor	S2S3	Dolly Varden Creek outwash plain

*Rankings obtained from Bruce Bennett, NatureServe Yukon, pers. comm. 2004

In addition to this list of rare species, *Botrychium minganense* was found on morainal deposits at the Dolly Varden Creek site. This species was not documented in the Yukon flora (Cody 1996), nor in the list of rare plants of the Yukon (Bruce Bennett, pers. comm. 2004), and is documented here as new to the Yukon flora. We also found two additional species recorded fewer than 10 times in Cody (1996): *Polygonum persicaria* and *Veronica scutellata*.

The total number of rare species (including transects and searches) was significantly greater on glaciofluvial sites (mean = 3.3 species) compared to the forest matrix (mean = 0.6 species; $t=5.203$, $p=0.002$).

Associated Wetlands

Shorelines of lakes and wetland complexes adjacent to our study sites but still within a larger glaciofluvial complex harboured a number of rare plants. Nine additional rare species were documented in these wet areas as well as five new localities for five rare species already recorded in the study (Table 8).

Table 8. Rare vascular plants found in wetlands adjacent to glaciofluvial study sites.

Species	Ranking*	Locations
Records for species not documented along transects		
Pedicularis macrodonta	S1	Lake shore of 2nd Dodo Lake, north of Alaska Highway
Scutellaria galericulata var. *pubescens*	S2	Lake shore of 2nd Dodo Lake, north of Alaska Highway
Eriophorum gracile	S1	Lake shore of 2nd Dodo Lake, north of Alaska Highway, floating fen in middle Toobally Lake kettle hole
Carex lasiocarpa ssp. *americana*	S1S2	Lake shore of 2nd Dodo Lake, north of Alaska Highway and lake shore near Barney Lakes glaciofluvial site
Isoetes maritima	S1	Shoreline of Frances Lake
Isoetes echinosperma	S1	Shoreline of Frances Lake
Pedicularis groenlandica	S2	McKinnon Lake wetland
Botrychium pinnatum	S2S3	Meadow near Dolly Varden Creek
Primula egaliksensis	S2S3	Shoreline of Dolly Varden Creek
Additional records for species documented along transects		
Eriophorum viridi-carinatum	S2	Wetland at middle Toobally Lake
Salix pedicellaris	S1	McKinnon Lake wetland complex
Drosera anglica	S2S3	McKinnon Lake wetland complex
Utricularia minor	S2S3	McKinnon Lake wetland complex
Carex interior	S1	McKinnon Lake wetland complex

*Rankings obtained from Bruce Bennett, NatureServe Yukon, pers. comm. 2004

Bryophytes and Lichens

The average bryophyte cover on glaciofluvial sites was significantly lower (47% ± 39%) than on morainal deposits (72% ± 29%; t = -3.122, df=71, p=0.003). Conversely, lichen cover was significantly higher on glaciofluvial deposits (21% ± 30%) compared to the forest matrix (7% ± 11%; t = 2.844, df=51, p=0.006). Species richness of the bryophyte layer (lichen and bryophyte species combined) was usually lower in the forest matrix (mean = 14 species) than on glaciofluvial sites (19 species) but the difference was not significant (p = 0.22).

Plant Communities

There were more plant communities encountered along transects on glaciofluvial landforms than in the forest matrix (Table 9). This was true for all sites except Barney Lakes, which had equal numbers of plant communities on each landform type. Pitted outwash plains at Junction 37, Barney Lakes and Dolly Varden Creek had at least twice as many plant communities as the forest matrix. The kettle holes or pits and the topography of the various slopes and ridges provided a diversity of habitats from lakes and wetlands to dry steppe communities. Rare plants in fens and bogs included *Drosera anglica*, *Salix pedicellaris*, and *Scheuchzeria palustris*, which grew with more common wetland species such as *Carex aquatilis*, *Carex utriculata*, *Potentilla palustris*, and *Menyanthes trifoliata*. Eskers at Dodo Lakes and McKinnon Lake had south-facing steppe communities with lots of grasses plus *Apocynum androsaemifolium*, *Juniperus communis*, *Amelanchier alnifolia*, *Populus tremuloides*, and *Arctostaphylos uva-ursi*.

At the foot of an esker at the Dodo Lakes site, we encountered a seepage site supporting a plant community not found elsewhere in the study area. The dominant species in this community included *Juncus balticus*, *Equisetum hyemale*, *Oryzopsis* *pungens, O. asperifolia, Pulsatilla ludoviciana, Anemone multifida, Apocynum androsaemifolium* and *Hieracium umbellatum*. Other fens and lakeshores also harboured unique assemblages of species, for example, a large fen complex at McKinnon Lake, lakeshores at Dodo Lakes, Toobally Lakes and France Lake, and kettle holes at Junction 37.

Table 9. Plant community types over glaciofluvial and morainal landforms.

	Number of Plant Community Types per 1000 m	
Site	Glaciofluvial	Forest matrix
Barney Lakes	10	5
Dodo Lakes	7	3
Dolly Varden Creek	10	6
Frances Lake	4	4
McKinnon Lake	6	2
Junction 37	9	3
Toobally Lakes	6	4
Total	**52**	**29**

Wildlife Transects

Along 14 km of transects on glaciofluvial and morainal landforms, 158 records of wildlife use were documented. We documented wildlife sign by eight species: moose, caribou, grouse, snowshoe hare, black bear, beaver, marten and wolf. Pellets and signs of moose were most abundant, followed by grouse, snowshoe hare and black bear (Table 10). Moose browsing was the most common wildlife sign (33 records) followed by moose beds (11). Moose browsing occurred at similar frequency in the two landform types, while moose beds were mostly in the forest matrix (91%).

Total pellet counts, other sign, and total records were virtually the same on glaciofluvial landforms and in the forest matrix ($p>0.62$) (Table 10). Similarly, the number of wildlife species noted on each landform type was very similar ($t=-1.933$, $df=13$, $p=0.075$). However, evidence of beaver, black bear, wolf and caribou was frequent on glaciofluvial landforms. For example, felling of aspen trees by beavers was often associated with glaciofluvial landforms (3 of 4 occurrences). Only moose and grouse had sufficient numbers for statistical tests but no preference was evident.

Table 10. Total wildlife use on glaciofluvial landforms and in the forest matrix, by vertebrate species. Values represent occurrences per 14 km.

	Beaver	Black bear	Caribou	Grouse	Marten	Moose	Snowshoe hare	Wolf	**Total**
Pellets/scat									
Glaciofluvial	0	6	4	7	1	15	4	1	**38**
Forest matrix	0	1	1	10	1	17	6	0	**36**
Other sign									
Glaciofluvial	5	1	1	3	0	29	3	0	**41**
Forest matrix	1	2	0	4	0	32	3	0	**40**
Total records									
Glaciofluvial	5	7	5	10	1	44	7	1	**80**
Forest matrix	1	3	1	14	1	49	9	0	**78**

Overall, no differences were observed between total winter and summer pellet counts ($p>0.79$, paired *t*-tests; Table 11). We found only summer scat of black bear, marten and wolf.

Table 11. Total pellet/scat counts by species, landform, and season.

Species	Glaciofluvial		Forest Matrix	
	Summer	Winter	Summer	Winter
Beaver	0	0	0	0
Black bear	6	0	1	0
Caribou	2	2	0	1
Grouse	2	5	4	6
Marten	1	0	1	0
Moose	6	8	9	8
Snowshoe hare	2	2	4	2
Wolf	1	0	0	0
Total	**20**	**18**	**19**	**17**

Wildlife Searches

In the time-limited searches, 142 further occurrences of wildlife use by eleven species were detected (Table 12). Species additional to those already reported on line transects were woodchuck, ground squirrel, porcupine and coyote. Again, there was little difference in total wildlife use between landform types (paired *t*-tests, $p>0.41$). Individual species did show differences in use between landforms but there was insufficient statistical power to test these differences. Despite the low number of occurrences, we found sign of six species limited to glaciofluvial landforms: beaver, wolf, coyote, ground squirrel, porcupine and woodchuck.

Table 12. Pellet/scat counts and other wildlife use detected in all searches.

	Bear	Beaver	Caribou	Coyote	Ground squirrel	Grouse	Moose	Porcu-pine	Snow shoe hare	Wolf	Wood chuck
Pellets /scat											
Glacio-fluvial	1	0	0	1	1	7	17	0	0	5	0
Forest matrix	1	0	0	0	0	10	15	0	1	0	0
Other signs											
Glacio-fluvial	4	5	0	0	1	2	26	1	4	0	1
Forest matrix	0	0	1	0	0	4	33	0	2	0	0
Total											
Glacio-fluvial	5	5	0	1	2	9	43	1	4	5	1
Forest matrix	1	0	1	0	0	14	48	0	3	0	0

DISCUSSION AND CONCLUSIONS

Glaciofluvial landforms of the Liard Basin support habitats for a range of plants, plant communities, and vertebrates that are less common or absent in morainal forests. The distribution of rare plants, plant communities, and vertebrates reflect patterns in the defining attributes of glaciofluvial deposits, most importantly coarse, rapidly drained parent materials and complex topography.

Glaciofluvial landforms harbour several rare and uncommon vascular plants that we did not find in the forest matrix of the Liard Basin. During our study, we found that 44 % of the total study flora and 17 of 26 (65%) rare and infrequent species were restricted to glaciofluvial landforms. Nine additional rare species were encountered in nearby wetlands.

Glaciofluvial landforms support plant communities that are infrequent in the Liard Basin. Eskers and pitted outwash plains were found to support a greater variety of plant communities per ha than the nearby forest matrix. Interactions between parent material and topography create complex surficial and hydrological templates, which results in high plant community diversity in close proximity. Plant communities of glaciofluvial landforms range from those of dry habitats on well-drained sunny sites (drier and warmer than found in the surrounding mesic forests) to those of wet, poorly drained depressions at the base of eskers or kettle holes. Even kettle hole wetlands showed remarkable diversity; some supported floating mats of vegetation and open water while others were had filled in with sedge and *Sphagnum* peat. Such complexity is generally not associated with morainal forests.

In the Liard Basin, precipitation and aspect affect distinctions among plant communities on landform types. We found that glaciofluvial landforms in moister local climates or with moister cooler microclimates (as on northern aspects) tend to have more mesic vegetation, even on well-drained substrates. For example, plant communities of glaciofluvial landforms at Barney Lakes and Frances Lake resembled the forest matrix, with a well-developed feathermoss ground cover, sparse herbs and shrubs, and a coniferous canopy of white spruce and lodgepole pine. Conversely, where the climate is drier, as at the Junction 37 and Dodo Lakes sites, differences in the vegetation between landforms was more pronounced.

Plant communities in the study area are also influenced by biotic factors. For example, beaver harvesting of aspen and willow (retarding recruitment of mature deciduous woody stems), and ant-mediated exposure of mineral soil lead to plant community changes on eskers. These processes were not evident in morainal forests.

Total wildlife use was very similar between the two landform types, largely because of the widespread abundance of moose, grouse and snowshoe hare. These three species have broad niches and occupy both mesic and drier habitats. There were relatively low numbers of the remaining nine wildlife species noted in the study, but our results indicated that eight of these species were more common on glaciofluvial landforms: beaver, black bear, wolf, coyote, caribou, woodchuck, porcupine and ground squirrel. For many of these species, sign was found exclusively on glaciofluvial landforms.

Eskers and pitted outwash plains create wetland-upland complexes that are especially important habitat for beaver. Beaver forage on deciduous trees growing on upland sites and make trails to reach adjacent wetlands to escape predators and to access lodges.

Figure 6. Kinnikinnick bear scat on an esker.

We speculate that wolf, coyote and black bear use these glaciofluvial landforms as movement corridors—every esker we visited featured a well-used game trail along the lightly forested crest—and as denning sites, owing to the loose soil structure and rapid drainage. Recent studies in the Northwest Territories and Nunavut showed that eskers are important habitat for wolf dens (Traynor 2001, Cluff et al. 2002). It is possible that bears require similar habitat attributes for denning. We did not, however, locate dens of wolf or bear in our study. We did find evidence of black bears foraging on eskers (Figure 6), particularly on southern aspects, where kinnikinnick, lingonberry, and soapberry fruit production was high.

Caribou similarly use glaciofluvial landforms for movement (Traynor 2001) and forage. Terrestrial forage lichens (especially *Cladina* reindeer lichens) were more abundant on glaciofluvial landforms than in the forest matrix, where feathermosses predominate.

Associated Wetlands

By examining the flora of wetlands associated with glaciofluvial study sites, we were able to document 16 new records of 14 rare vascular plants. These wetlands are important contributors to regional biodiversity; they support an aquatic flora that is poorly represented at the landscape level, and a suite of plant communities very different from those of the upland forest matrix. Additionally, they provide habitat for an array of waterbird species during breeding, staging and migration. These wetlands are products of hydrological systems vulnerable to disturbance of adjacent uplands by gravel extraction and road construction.

Conservation Applications

Our results support the hypotheses that glaciofluvial deposits play a critical role in regional biodiversity, and are important for land use planning and conservation area design in the Liard Basin and Kaska Dena Traditional Territory.

These landforms are now and will continue to be key elements of connectivity in the northern part of the Y2Y region. As climate continues to change, they will function as loci of colonization, establishment, stepwise migration, and reassembly for rare/uncommon plant species and communities; and not just the primary producers, but also the biota (especially parasites and invertebrates) associated with them, or that favour such coarse-textured, relatively dry and warm habitats (e.g., ants). Glaciofluvial landforms also underlie patterns of preferential use by several animals. They form linear templates of movement, foraging and reproductive activity for focal species like beaver, wolf, black bear and woodland caribou. Furthermore, wetlands frequently associated with glaciofluvial landforms are also key habitat for rare plants and for animals. Extraction of sand and gravel from these landforms should therefore be managed carefully to minimize impacts to vulnerable species and habitats.

Some of the sample sites are close to existing developments and are the most likely to be subjected to human disturbance in the future: Junction 37 pitted outwash plain, and the eskers at Dodo and McKinnon Lakes. The Yukon Territory lacks a list of rare plant associations or community types, but the plant communities and the landforms that support them at these three sites warrant conservation status, and should be recognized in landscape level management decisions prior to human development. Conservation of such special elements across the landscape requires inclusion of glaciofluvial landforms in conservation assessments and protected areas planning. For instance, a Habitat Protection Area for the Little Rancheria woodland caribou herd would include the Dodo Lakes and McKinnon Lake as part of the core winter range of the caribou.

As land use decisions are made in the Liard Basin (particularly ecosystem-based forest management planning) and conservation areas are assessed, glaciofluvial landforms should be given special consideration due to their complexity of habitat types and diversity of plants and animals. These deposits are incompletely mapped in the region but aerial photography can be used to determine the location and extent of eskers and other glaciofluvial landforms in the Liard Basin and beyond.

ACKNOWLEDGEMENTS

We are grateful to Jerry Porter for collecting wildlife data and for sharing his local expertise, and to Bruce Bennett for providing information on the Yukon Territory's rare flora. Funding and research support was provided by the Yellowstone to Yukon Conservation Initiative and by the Canadian Parks and Wilderness Society, Yukon Chapter.

REFERENCES

Alberta Native Plant Council. 2000. www.anpc.ab.ca/rareplant.pdf

Bostock, H.S. 1948. Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel. Geological Survey of Canada, Memoir 247.

Bostock, H.S. 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-56, 18 p.

Cody, W.J. 1996. Flora of the Yukon Territory. NRC Research Press, Ottawa, Ontario, Canada. 643 p.

Cluff, H.D., Walton, L.R. and P.C. Paquet. 2002. Movements and habitat use of wolves denning in the central Arctic, Northwest Territories, and Nunavut, Canada. West Kitikmeot/Slave Study Society, Yellowknife, Northwest Territories. 85 p.

Douglas, G.W., Straley, G.B., Meidinger, D. and J. Pojar. 1998a. Illustrated Flora of British Columbia. Volume 1: Gymnosperms and Dicotyledons (Aceraceae through Asteraceae) and Pteridophytes. British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 436 p.

Douglas, G.W., Straley, G.B., Meidinger, D. and J. Pojar. 1998b. Illustrated Flora of British Columbia. Volume 2: Dicotyledons (Balsaminaceae through Cucurbitaceae) and Pteridophytes. British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 401 p.

Douglas, G.W., Meidinger, D. and J. Pojar. 1999a. Illustrated Flora of British Columbia. Volume 3: Dicotyledons (Diapensiaceae through Onagraceae) and Pteridophytes. British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 423 p.

Douglas, G.W., Meidinger, D. and J. Pojar. 1999b. Illustrated Flora of British Columbia. Volume 4: Dicotyledons (Orobanchaceae through Rubiaceae) and Pteridophytes. British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 427 p.

Douglas, G.W., Meidinger, D. and J. Pojar. 2000. Illustrated Flora of British Columbia. Volume 5: Dicotyledons (Salicaceae through Zygophyllaceae) and Pteridophytes. British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 389 p.

Douglas, G.W., Meidinger, D. and J. Pojar. 2001a. Illustrated Flora of British Columbia. Volume 6: Monocotyledons (Acoraceae through Najadaceae). British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 361 p.

Douglas, G.W., Meidinger, D. and J. Pojar. 2001b. Illustrated Flora of British Columbia. Volume 7: Monocotyledons (Orchidaceae to Zosteraceae). British Columbia Ministry of Sustainable Resource Management and Ministry of Forests, Victoria. 379 p.

Douglas, G.W., Meidinger, D., and Penny, J.L. 2002a. Rare native vascular plants of British Columbia, 2nd edition. Min. Sustainable Resource Management, Victoria, B.C. 358 p.

Douglas, G.W., D. Meidinger, and Pojar, J. 2002b. Illustrated Flora of British Columbia, Volume 8: General Summary, Maps and Keys. Ministry of Sustainable Resource Management, Victoria, B.C. 457 p.

Environment Canada. 2005. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

Hultén, E. 1968. Flora of Alaska and neighbouring territories. Stanford University Press, Stanford, CA. 1008 p.

McCune, B., and M.J. Mefford 1997. PC-ORD. Multivariate analysis of ecological data, version 4.0 edition. MjM Software Design, Gleneden Beach, Ore.

Rowe, J.S. 1972. Forest regions of Canada. Publication 130 Department of Environment, Canadian Forestry Service. Ottawa, ON. 172 p.

Smith, C.A.S., J.C. Meikle, and C.F. Roots, editors. 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01. Summerland, B.C. 313 p.

Systat, Inc. 1996. Systat for Windows: statistics, version 6.0 edition. SYSTAT, Inc., Evanston, Ill.

Traynor, S. 2001. Esker habitat characteristics and traditional use study in the Slave Geological Province. West Kitikmeot/Slave Study Society, Yellowknife, Northwest Territories. 66 p.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. Taxon 21: 213-251.