Ecosystem Services Assessment for British Columbia's Interior Temperate Rainforest, Upper Columbia Region, and Southern Mountain Caribou Populations

Prepared for the Yellowstone to Yellowstone Conservation Initiative

Matthew Mitchell, PhD
Cameron Bullen, MSc

Vancouver, BC
October, 2020

Table of Contents

List of Tables

List of Figures

Executive Summary

This ecosystem services analysis has been prepared for the Yellowstone to Yukon Conservation Initiative (Y2Y) to assess and compare how ecosystem services are provided across different areas of conservation concern. The research included analysis of two key ecosystem services – carbon storage and freshwater provision – across British Columbia and for three geographies of interest: (1) the southern portion of BC's Interior Cedar-Hemlock Biogeoclimatic Zone, (2) the Upper Columbia Region (study area defined by Y2Y), and (3) BC's Southern Mountain Caribou Local Population Units.

We used new methods and free publicly available datasets to map three different components of ecosystem service provision:

- Capacity: the ability of ecosystems to supply ecosystem services to people;
- Demand: the demand for a particular ecosystem service by people; and
- Provision: the actual delivery of an ecosystem service to people when capacity and demand overlap or meet.

We identified critical areas, or "hotspots", by quantifying areas in BC with the top 20% of values across the province for ecosystem service capacity, demand, and provision. We assessed hotspots of aboveground, belowground, and total carbon, and assessed how hotspots of carbon and freshwater provision overlap.

Results indicate that the southern **Interior Cedar-Hemlock Biogeoclimatic (ICH) Zone** is a conservation priority for aboveground carbon, freshwater provision, and win-win actions to conserve carbon and freshwater provision in BC. It has above average aboveground carbon density and carbon hotspot density, as well as freshwater provision hotspot density due to the high demand for freshwater downstream. The combination of high freshwater provision hotspot density and moderate carbon densities in the ICH means that it contains a disproportionate amount of overlapping carbon and freshwater hotspots in BC, despite covering less than 5% of the province. The southern portion of the ICH zone has the highest density of overlapping carbon and freshwater provision hotspots in the province compared to all other BEC zones.

While the **Upper Columbia Region (UCR)** has only average densities of carbon hotspots compared to the rest of BC, it has a significantly higher density of freshwater provision hotspots. The Upper Columbia is one of three key areas in the province where freshwater capacity and provision hotspots overlap. It is an area where win-win conservation actions for both carbon and freshwater could be targeted, as it has two to five times the density of overlapping carbon and freshwater provision hotspots as BC overall.

The **Southern Mountain Caribou Local Population Units (LPUs)** are a conservation priority for freshwater provision and actions that can target and protect both carbon and freshwater. This is driven by the fact that the Southern Group LPUs have significantly higher densities of freshwater demand and provision hotspots and overlapping carbon and freshwater provision hotspots. Southern Group LPUs, and in particular the Revelstoke-Shuswap LPU, represent an important priority for conserving both Southern Mountain Caribou and carbon and freshwater ecosystem services.

1. Introduction

Ecosystem services are the benefits that people derive from natural ecosystems. They include a wide variety of benefits, including food, freshwater, pollination, pest control, flood control, places to recreate, aesthetic beauty, and culture and heritage. Increasingly, ecosystem services are being included in conservation decisions – not as a replacement to traditional biodiversity values and measures – but as added motivation for conserving and protecting natural ecosystems and the biodiversity that they contain. In particular, identifying key locations where high biodiversity and high ecosystem service provision occur simultaneously is seen as an effective way of conserving ecosystems for both people and nature and enabling win-win conservation actions. However, while the identification of key areas for biodiversity is relatively advanced (Eken *et al.* 2004; Mittermeier *et al.* 2011), similar methods for ecosystem services at national scales are lacking (Durán *et al.* 2013; Xu *et al.* 2017).

Important areas for biodiversity and ecosystem services do not always overlap (Chan *et al.* 2006; Anderson *et al.* 2009) because ecosystem service provision does not depend only on the presence of natural ecosystems and biodiversity, but occurs through complex interactions between ecosystems and people (Mace, Norris & Fitter 2012). The amount of a service required or desired by people, and the ability of people to interact with ecosystems to access and realize these benefits, are crucial to service provision (Tallis *et al.* 2012). Thus, ecosystem service provision depends on two distinct elements: the *capacity* of ecosystems to supply a service and *demand* for that service by people (Mitchell *et al.* 2015). When capacity and demand overlap or meet, *provision* can occur (Fig. 1-1). For example, many ecosystems have the capacity to deliver clean water, but freshwater provision only results when human demand for water is also present and hydrological connections connect upstream capacity to downstream demand (Brauman *et al.* 2007).

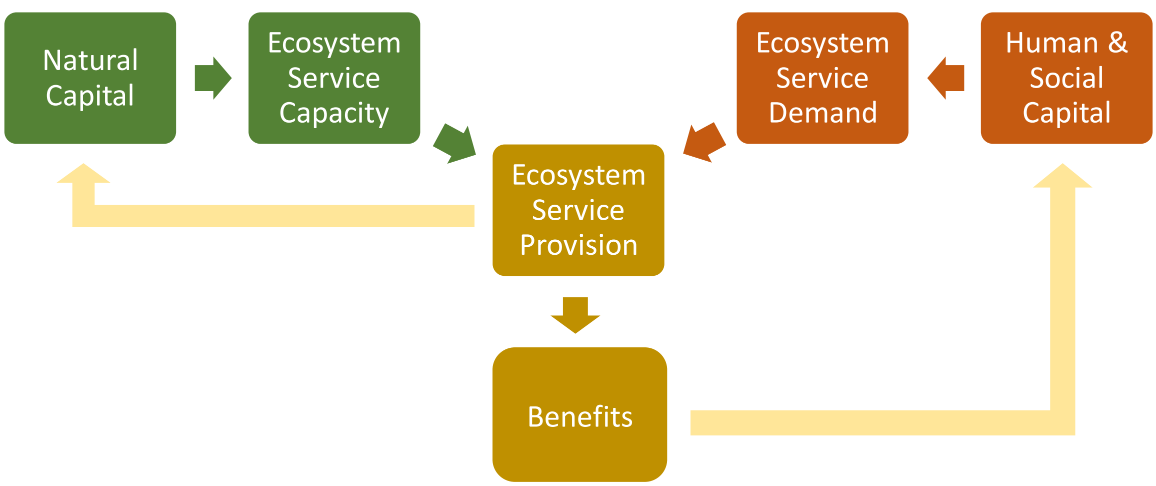


Figure 1-1. A conceptual diagram of how natural (*green*) and human/social (*orange*) systems interact to provide ecosystem services (*yellow*). Natural capital (ecosystems and biodiversity) influences the capacity of an area to provide ecosystem services, while human and social capital influence the level of demand for that service by people. When capacity and demand interact or meet, then ecosystem service provision can occur. In turn, the benefit derived from an ecosystem service affects service demand by altering human well-being and needs. Ecosystem service provision can also directly affect natural capital through overexploitation, land use change, pollution, and other impacts.

Unfortunately, our ability to evaluate these elements and their interactions at broad scales is limited, since most ecosystem service studies focus only on capacity (Ricketts *et al.* 2016) and therefore only capture part of the story.

As Canada seeks to increase protected area coverage to at least 17% of its terrestrial and freshwater area by 2020, 25% by 2025 (Government of Canada, 2020), and an aspirational 30% by 2030 (Prime Minister's Office, 2019), there is the potential to protect critical areas for ecosystem services and human well-being. Ambitious new conservation and protection targets that are expected as part of the 2020 Aichi updated targets for 2030 and 2050 are also likely to target both biodiversity and ecosystem services (Convention on Biodiversity, 2020). Improved methods to ensure that conservation initiatives consider where and how natural areas provide benefits to people will help conservation organizations like Y2Y, and decision makers, identify key locations for conservation and provide additional justification for conservation actions that protect biodiversity. In Canada, assessments of ecosystem service provision that explicitly include both service capacity and demand are rare and do not exist at the broad scales that Y2Y works.

We assessed two key ecosystem services across British Columbia: carbon storage and freshwater provision. We used new and robust methods that depend primarily on free, publicly available datasets to map service capacity, access/demand, and provision. We then identified critical areas, or hotspots, of service capacity, demand, and provision, by highlighting those locations with the highest values of each (i.e., top 20% of values across the province). We then used this information to assess and compare how ecosystem services are provided across different parts of the province that are of particular conservation concern and identify if any of these regions disproportionately provide carbon or freshwater. The areas of interest included: the southern portion of BC’s Interior Cedar Hemlock Biogeoclimatic Zone, the Upper Columbia Region (study area defined by Y2Y), and BC’s Southern Mountain Caribou Local Population Units.

2. Methods

2.1 General Approach

We used free, publicly available spatial data to estimate values for: (1) the *capacity* of ecosystems to provide ecosystem services; (2) the *demand* for those services by people; and (3) the *provision* of each service that results when capacity and demand overlap and people can access the service in question (Tallis *et al.* 2012; Villamagna, Angermeier & Bennett 2013; Mitchell *et al.* 2015). However, for carbon storage, where carbon stored in ecosystems provides a service globally due to atmospheric mixing (Costanza 2008), we assumed equal and uniform demand across the region in question and therefore quantified service provision solely as capacity (i.e., carbon storage).

The analysis focused on three study areas: the southern portion of the Interior Cedar Hemlock Biogeoclimatic Zone, the Upper Columbia Region, and BC's Southern Mountain Caribou Local Population Units. For each, the proportion of ecosystem service provision and service hotspots contained within the area of interest relative to BC were calculated.

2.2 Climate Regulation/Carbon Storage

We quantified the capacity of areas across the province of BC to provide climate regulation by calculating the total amount of carbon stored above- and belowground. Aboveground carbon data came from the Canadian National Forest Inventory 250 m resolution datasets of total live aboveground biomass (branch, foliage, stem bark, and stem wood biomass) and total dead biomass from 2015. Information on the methods used in the Canadian National Forest Inventory are available in Gillis, Omule & Brierley (2005) and Beaudoin *et al.* (2014). We estimated aboveground carbon by assuming that carbon makes up 48% of the aboveground biomass present (Asner *et al.* 2010). Belowground carbon estimates were obtained from the SoilGrids system (Hengl *et al.* 2017). We used their 250 m resolution dataset that provides soil organic carbon content from 0-1 m depth. Above- and belowground carbon stores were summed and then normalized between 0 and 1 for each region analyzed to calculate relative importance for the provision of climate regulation.

2.3 Freshwater Provision

For freshwater provision we quantified the capacity of natural and semi-natural ecosystems to provide freshwater runoff, estimated the demand for this water by people downstream, and connected this demand to upstream areas of capacity by analyzing hydrological connectivity, building on methods outlined in Ouellet Dallaire (2018). We assumed that upstream natural and semi-natural areas with high runoff (i.e., high capacity) that serve downstream areas with high demand are the most important for freshwater provision (Luck, Chan & Fay 2009).

We quantified freshwater capacity using pixel-level runoff data (15 arc-second or ~500 m resolution) as provided in the global HydroSHEDS database. HydroSHEDS data above 60°N were obtained from Bernhard Lehner (McGill University, Department of Geography) and are the only data we used that are not publicly available. These runoff data have been derived through a geospatial downscaling procedure (Lehner & Grill 2013) from the long-term (1971-2000) average runoff estimates of the global WaterGAP model (v.2.2 as of 2014) at 0.5° resolution (Döll, Kaspar & Lehner 2003). Water demand was defined as the relative amount of downstream demand from four principal beneficiaries of freshwater in Canada (Canada 2013; ECCC 2016): municipal consumption (household and institutional), agriculture, hydropower generation, and industrial activities (factories and thermal power stations). Proxies for freshwater demand across Canada and hydrologically connected areas of the U.S.A. included the number of people living in downstream settlements larger than 100 people (Global Rural-Urban Mapping Project) (Balk *et al.* 2006; CIESIN, IFPRICIAT 2011); agricultural surface area derived from 2005 land-use data (Latifovic & Pouliot 2005); and the number of dams, industrial facilities, and thermal power stations present in Canada (NRC 2003; 2010). It is important to note that this analysis does not include freshwater demand downstream in the USA by industry or dams due to lack of data availability, therefore results reported are likely an underestimate of transboundary freshwater provision importance.

To hydrologically connect areas of supply and demand, we created watersheds (representing upstream areas) for each pixel that was identified as a demand source. Overlapping watersheds for each demand type (i.e., industry, dams, agriculture, settlements) were then summed and normalized between 0 and 1 for the region in question to calculate relative demand downstream for any given upstream pixel. We then combined these four datasets into a single demand layer, weighting each demand type equally and normalizing the resulting values between 0 and 1 for the region in question.

Finally, we assigned high values of ecosystem service provision importance to those areas with high capacity (i.e. high runoff) that are linked to high downstream demand, while reducing these values for croplands, rangelands, and urban areas. Additionally, we included areas with low capacity but high downstream demand to capture those locations that provide a critical supply of freshwater to people.

2.4 Hotspot Analysis to Identify Areas of Importance for Ecosystem Services

We used a hotspot approach (Egoh *et al.* 2008; Anderson *et al.* 2009; Qiu & Turner 2013; Darvill & Lindo 2014) to identify areas important for ecosystem service capacity and provision and determine overlap between hotspots for capacity and provision. Hotspots were pixels with the top 20% of values across the province of BC. We then calculated the density of these hotspots (km^2 of hotspots per 100 km^2 of surface area) in the regions of interest to provide a measure of the concentration of these hotspots across different areas and the province.

2.5 Overlap of Ecosystem Service Hotspots

To identify areas with the potential for win-win actions to conserve both carbon and freshwater, we identified areas where carbon and freshwater hotspots overlap. This was performed both for aboveground carbon and freshwater provision, as well as for total carbon and freshwater provision. This overlap analysis provides a rough estimate of priority locations that if conserved will effectively protect both ecosystem services simultaneously. Similar to the hotspot analysis above, we then calculated the density of these overlapping hotspots in the regions of interest and across BC.

3. Ecosystem Service Provision in British Columbia's Biogeoclimatic Zones

3.1 Introduction

We assessed carbon storage and freshwater provision across BC's 16 biogeoclimatic (BEC) zones (Fig. 3-1), with a focus on the Interior Cedar Hemlock (ICH) zone. The ICH zone (also known as the Interior Wet Belt) occurs at middle to lower elevations and has an interior, continental climate with cool wet winters and warm dry summers (Meidinger & Pojar 1991). It is one of the wettest zones in BC, and is dominated by upland forests with the highest diversity of tree species of any zone in the province, with climax sites dominated by western hemlock and western redcedar. It also has the highest productivity for timber of all interior BEC zones in the province (Meidinger & Pojar 1991). The ICH zone includes an extensive section located in the southeast portion of the province and a northern section in the Hazelton and Skeena mountains. This analysis focussed on the southern section.

The assessment included estimating carbon stores and densities (carbon per hectare) as well as the total area and density of carbon and freshwater provision hotspots (pixels with the top 20% of values across the province). Densities of hotspots were quantified as km^2 of hotspot area per 100 km^2 of BEC zone area. These hotspot analyses provide a preliminary identification of key BEC zones across BC to target for the conservation of carbon and freshwater. We split carbon into aboveground, belowground, and total carbon pools, and split up freshwater provision into capacity (amount of runoff), demand (amount of downstream demand by humans), and provision (overlap of capacity and demand). Finally, to identify areas where win-win conservation actions might be targeted, we assessed the overlap in hotspot areas for carbon and freshwater.

3.2 Carbon Storage

The Interior Cedar Hemlock rainforest ecosystems in BC store disproportionately high amounts of aboveground carbon. The southern part of the Interior Coastal Hemlock BEC zone has the third highest density of aboveground carbon (91.47 MgC/ha) across all of BC's BEC zones, and the eighth (241.6 MgC/ha) and seventh (332.7 MgC/ha) highest belowground and total carbon densities, respectively (Figure 3-2, Table 3-1). Similarly, the southern zone of the ICH makes up 4.6% of BC by area, but stores 7.7% of the aboveground carbon in the province. These values drop to 4.1 and 4.7% for belowground and total carbon, respectively (Table 3-2).

Similar to overall carbon stores and densities, carbon storage hotspot densities in the southern ICH are high for aboveground carbon, but lower for belowground and total carbon. The southern ICH has the third highest density of aboveground hotspots (49.2 km^2 $100km^{-2}$) and the eleventh (4.8 $km^2/100km^2$) and eighth (9.7 $km^2/100km^2$) highest densities for belowground and total hotspots (Fig. 3-3, Table 3-3). Due to the fact that few belowground carbon hotspots occur in the southern ICH, it has only the fifth highest density of overlapping above- and belowground hotspots (2.4 $km^2/100km^2$) in the province, although this is the second highest density for interior ecosystems, behind just the northern portion of the ICH. Similarly, the southern ICH covers just under 5% of BC, but contains over a tenth of the aboveground carbon hotspots in the province (Table 3-4).

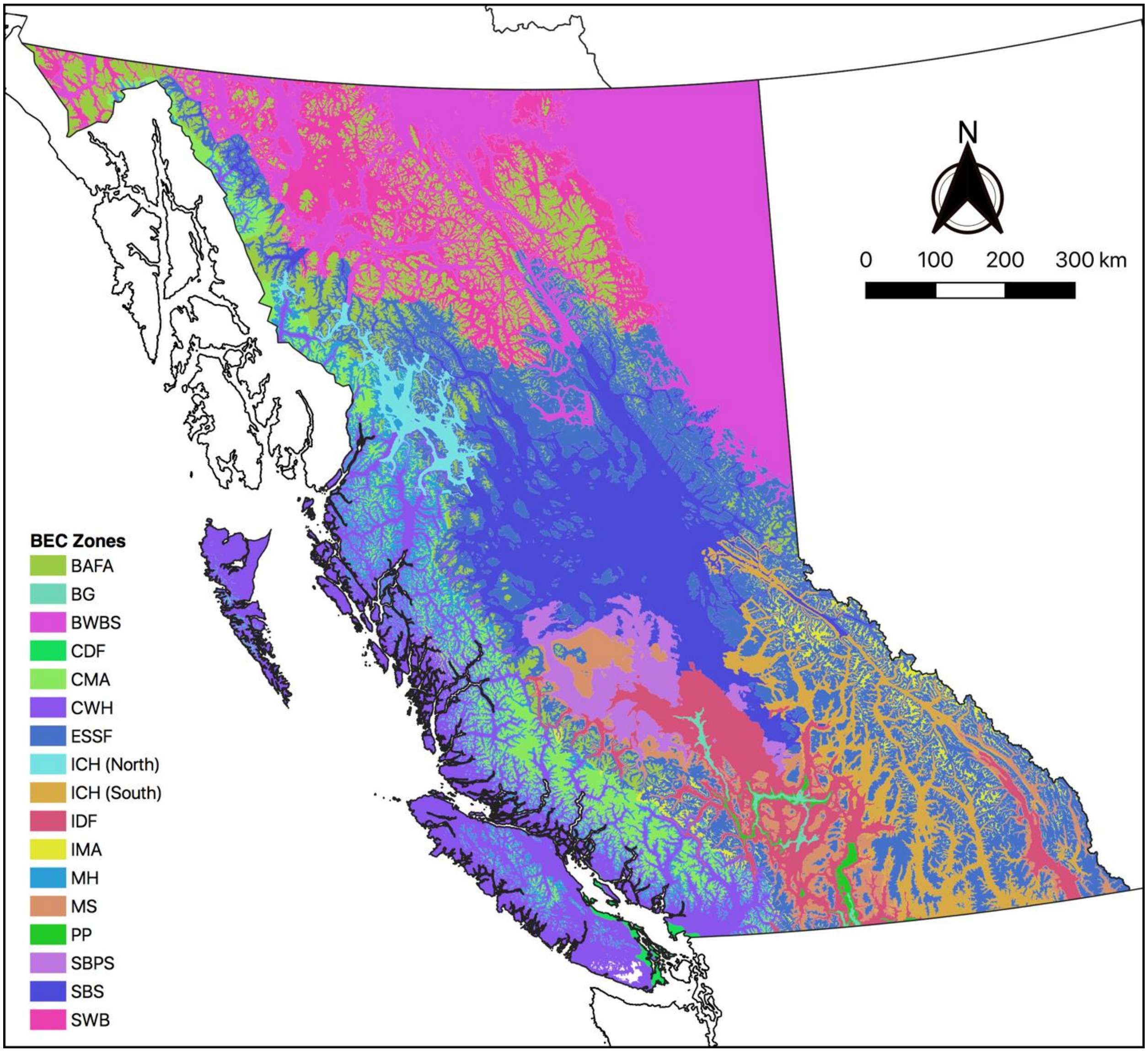


Figure 3-1. British Columbia's Biogeoclimatic zones. (see Table 3-1 for full names of zones)

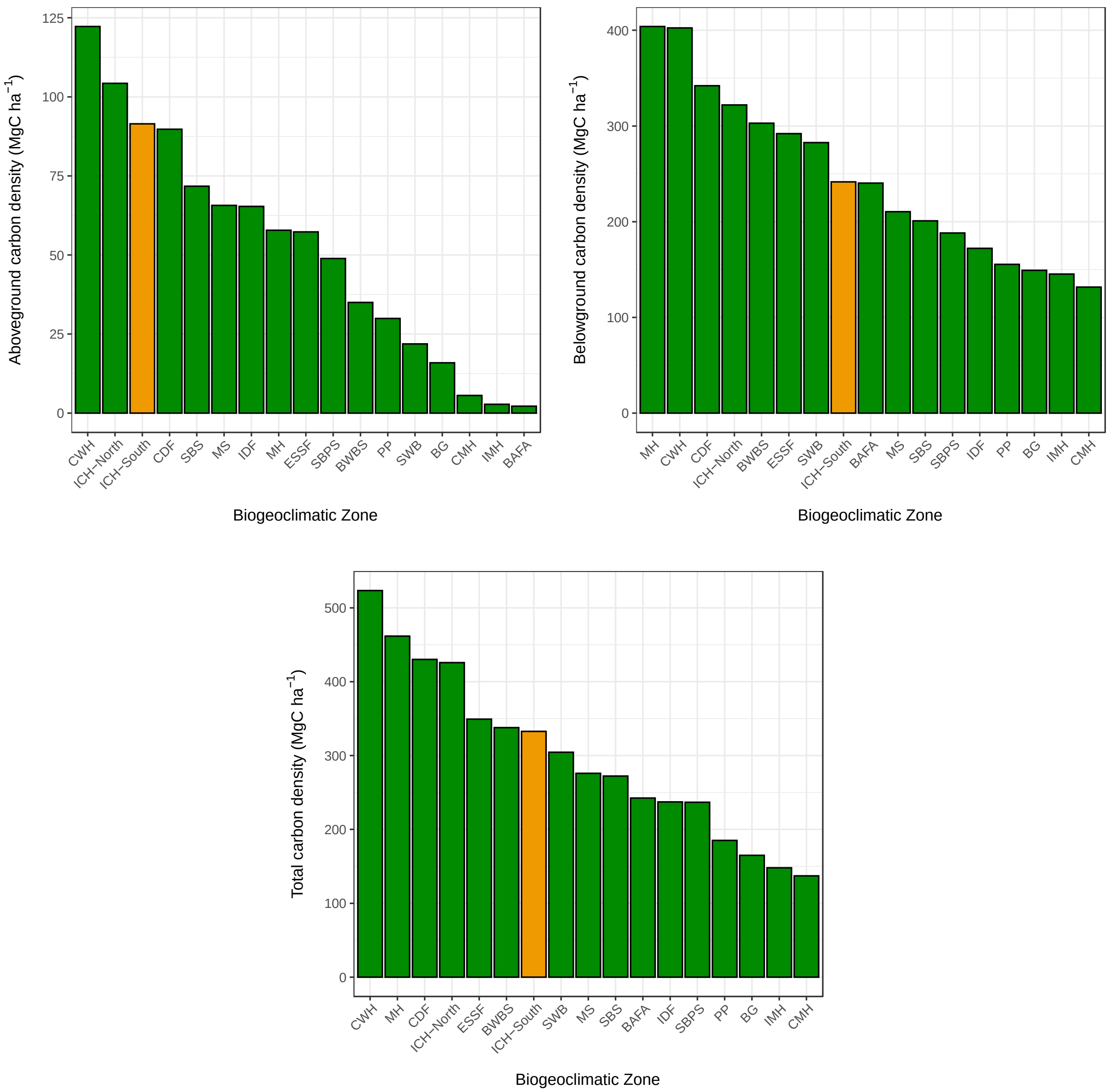


Figure 3-2. Average carbon densities of British Columbia's biogeoclimatic zones. The orange column identifies the southern portion of the Interior Cedar Hemlock zone.

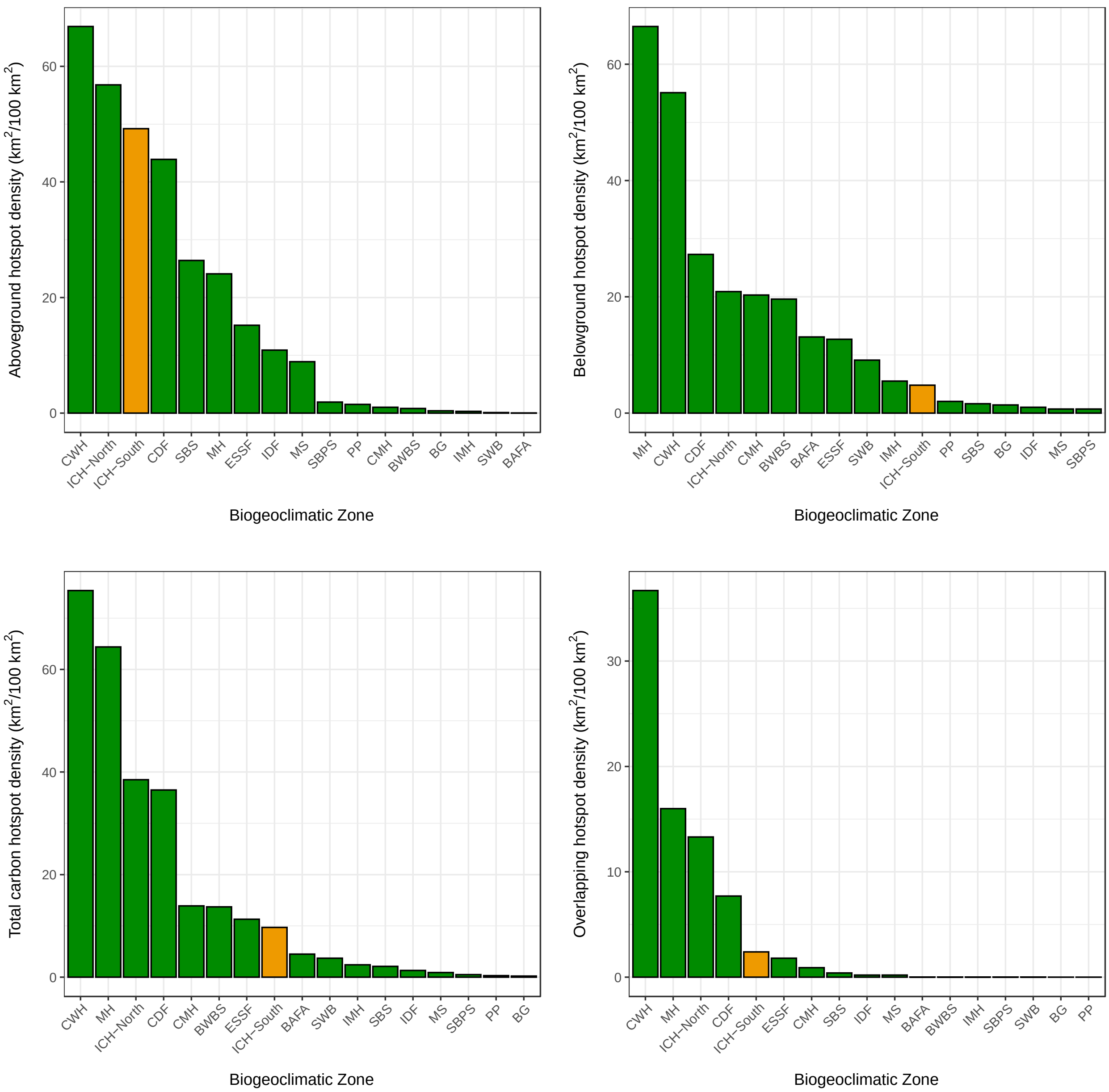


Figure 3-3. Carbon hotspot densities in British Columbia's biogeoclimatic zones. The overlapping hotspot density panel refers to overlapping hotspots of above- and belowground carbon. The orange column identifies the southern portion of the Interior Cedar Hemlock zone.

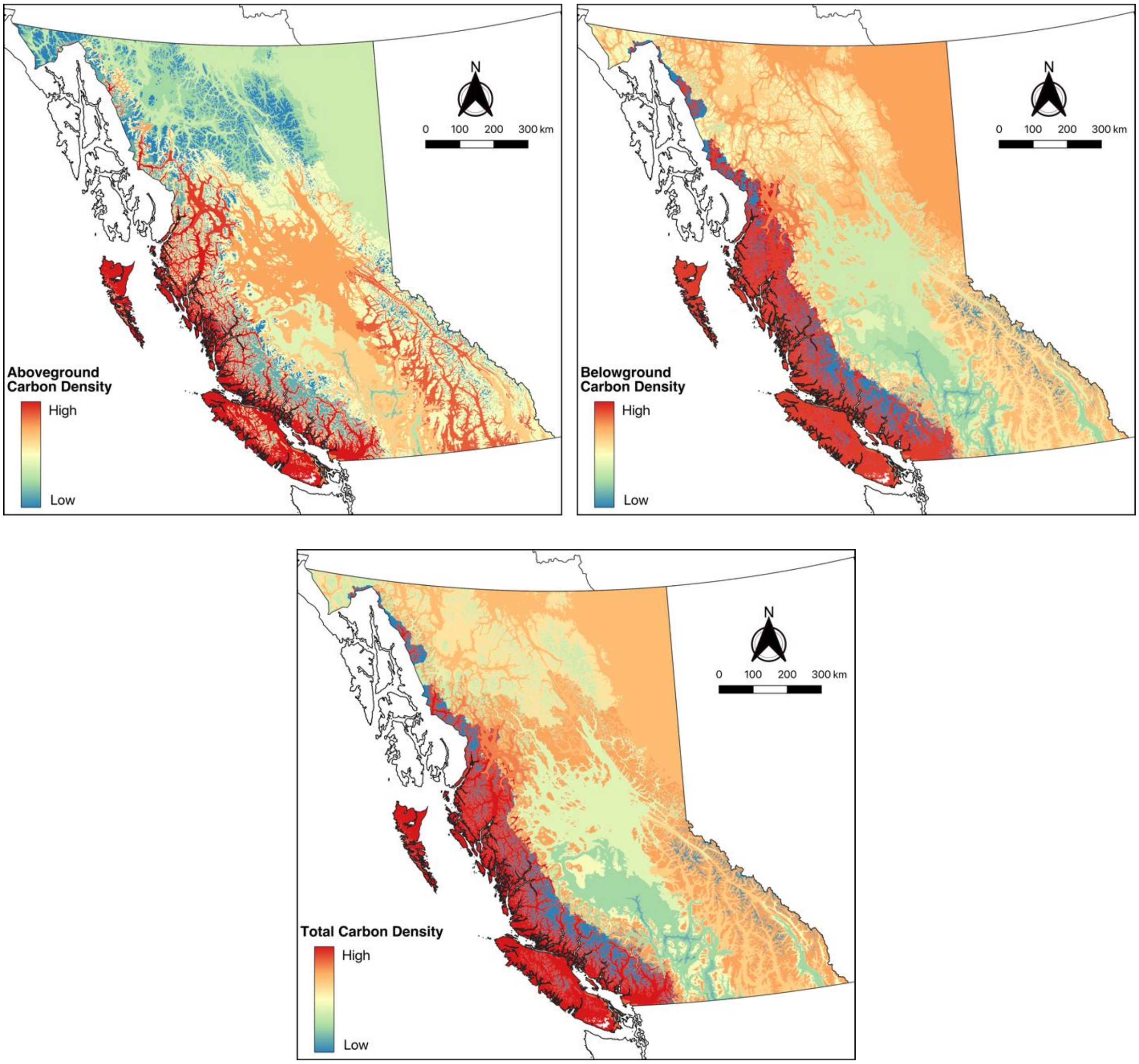


Figure 3-4. Average carbon densities (Mg/ha) across British Columbia's biogeoclimatic zones. A single average value (see Table 3-1) has been calculated and is shown for each BEC zone in the figures above.

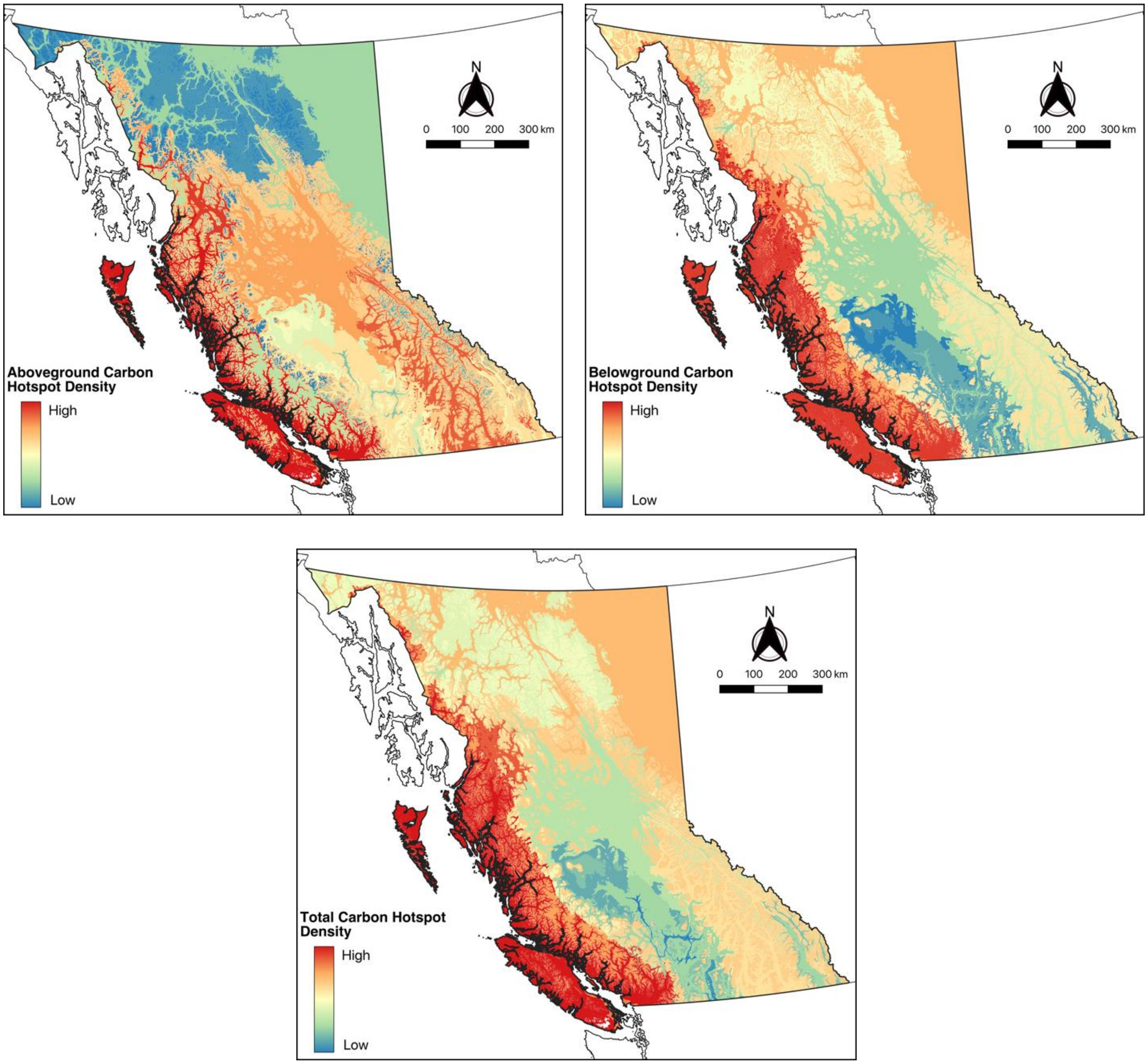


Figure 3-5. Carbon hotspot densities ($km^2/100km^2$) across British Columbia's biogeoclimatic zones. A single value (see Table 3-3) has been calculated and is shown for each BEC zone in the figures above.

Table 3-1. Average carbon densities in British Columbia's biogeoclimatic zones.

Biogeoclimatic Zone	**Aboveground Carbon Density (MgC/ha)**	**Belowground Carbon Density (MgC/ha)**	**Total Carbon Density (MgC/ha)**
Bunchgrass	15.90	149.24	164.98
Boreal White and Black Spruce	35.00	302.97	337.88
Coastal Mountain-Heather Alpine	5.59	131.66	137.18
Coastal Douglas-fir	89.76	342.05	430.23
Interior Mountain-Heather Alpine	2.79	145.32	148.09
Montane Spruce	65.68	210.41	276.00
Interior Douglas-fir	65.35	172.14	237.30
Sub-boreal Pine-Spruce	48.87	188.14	236.83
Sub-boreal Spruce	71.75	200.90	272.26
Spruce-Willow-Birch	21.89	282.59	304.44
Coastal Western Hemlock	122.26	402.50	523.45
Boreal Altai Fescue Alpine	2.19	240.28	242.46
Engelmann Spruce-Subalpine Fir	57.31	292.00	349.27
Mountain Hemlock	57.82	404.00	461.70
Ponderosa Pine	29.94	155.38	185.14
Interior Cedar-Hemlock (Northern)	104.27	322.00	425.85
Interior Cedar-Hemlock (Southern)	**91.47**	**241.64**	**332.69**
British Columbia	*55.34*	*275.66*	*330.74*

Table 3-2. Total carbon stored in different carbon pools in British Columbia's biogeoclimatic zones. Numbers in parentheses represent proportions within BC.

Biogeoclimatic Zone	**Area (km²)**	**Aboveground Carbon (MgC)**	**Belowground Carbon (MgC)**	**Total Carbon (MgC)**
Bunchgrass	2,570 (0.3%)	0.004 (0.1%)	0.038 (0.1%)	0.042 (0.1%)
Boreal White and Black Spruce	164,079 (17.3%)	0.574 (11.0%)	4.971 (19.0%)	5.544 (17.7%)
Coastal Mountain-Heather Alpine	35,713 (3.8%)	0.020 (0.4%)	0.470 (1.8%)	0.490 (1.6%)
Coastal Douglas-fir	2,477 (0.3%)	0.020 (0.4%)	0.085 (0.3%)	0.107 (0.3%)
Interior Mountain-Heather Alpine	12,576 (13%)	0.004 (0.1%)	0.183 (0.7%)	0.186 (0.6%)
Montane Spruce	28,636 (3.0%)	0.188 (3.6%)	0.603 (2.3%)	0.790 (2.5%)
Interior Douglas-fir	44,879 (4.7%)	0.293 (5.6%)	0.773 (3.0%)	1.065 (3.4%)
Sub-boreal Pine-Spruce	22,653 (2.4%)	0.111 (2.1%)	0.426 (1.6%)	0.536 (1.7%)
Sub-boreal Spruce	103,375 (10.9%)	0.742 (14.1%)	2.077 (8.0%)	2.815 (9.0%)
Spruce-Willow-Birch	86,544 (9.1%)	0.189 (3.6%)	2.446 (9.4%)	2.635 (8.4%)
Coastal Western Hemlock	107,022 (11.3%)	1.308 (25.0%)	4.308 (16.5%)	5.602 (17.9%)
Boreal Altai Fescue Alpine	62,869 (6.6%)	0.014 (0.3%)	1.511 (5.8%)	1.524 (4.9%)
Engelmann Spruce-Subalpine Fir	174,634 (18.4%)	1.001 (19.1%)	5.099 (19.5%)	6.1 (19.5%)
Mountain Hemlock	40,531 (4.3%)	0.234 (4.5%)	1.637 (6.3%)	1.871 (6.0%)
Ponderosa Pine	2,949 (0.3%)	0.009 (0.2%)	0.046 (0.2%)	0.055 (0.2%)
Interior Cedar-Hemlock (Northern)	11,406 (1.2%)	0.119 (2.3%)	0.367 (1.4%)	0.486 (1.5%)
Interior Cedar-Hemlock (Southern)	**43,984 (4.6%)**	**0.402 (7.7%)**	**1.063 (4.1%)**	**1.463 (4.7%)**
British Columbia	*947,536*	*5.244*	*26.120*	*31.339*

Table 3-3. Carbon storage hotspot densities in British Columbia's biogeoclimatic zones.

Biogeoclimatic Zone	**Aboveground Carbon Hotspot Density ($km^2/100km^2$)**	**Belowground Carbon Hotspot Density ($km^2/100km^2$)**	**Total Carbon Hotspot Density ($km^2/100km^2$)**	**Overlapping Above- and Belowground Carbon Hotspot Density ($km^2/100km^2$)**
Bunchgrass	0.4	1.4	0.2	0.0
Boreal White and Black Spruce	0.8	19.6	13.7	<0.1
Coastal Mountain-Heather Alpine	1.0	20.3	13.9	0.9
Coastal Douglas-fir	43.9	27.3	36.5	7.7
Interior Mountain-Heather Alpine	0.3	5.5	2.4	<0.1
Montane Spruce	8.9	0.7	0.9	0.2
Interior Douglas-fir	10.9	1.0	1.3	0.2
Sub-boreal Pine-Spruce	1.9	0.7	0.5	<0.1
Sub-boreal Spruce	26.4	1.6	2.1	0.4
Spruce-Willow-Birch	0.1	9.1	3.7	<0.1
Coastal Western Hemlock	66.9	55.1	75.4	36.7
Boreal Altai Fescue Alpine	<0.1	13.1	4.5	<0.1
Engelmann Spruce-Subalpine Fir	15.2	12.7	11.3	1.8
Mountain Hemlock	24.1	66.5	64.4	16.0
Ponderosa Pine	1.5	2.0	0.3	0.0
Interior Cedar-Hemlock (Northern)	56.8	20.9	38.5	13.3
Interior Cedar-Hemlock (Southern)	**49.2**	**4.8**	**9.7**	**2.4**
British Columbia	*18.4*	*18.1*	*18.2*	*5.5*

Table 3-4. Carbon storage hotspot areas within British Columbia's biogeoclimatic zones. Numbers in parentheses represent proportions within BC.

Biogeoclimatic Zone	Area (km²)	Aboveground Carbon Hotspot Area (km²)	Belowground Carbon Hotspot Area (km²)	Total Carbon Hotspot Area (km²)	Overlapping Above- and Below Carbon Hotspot Area (km²)
Bunchgrass	2,570 (0.3%)	11 (0.0%)	36 (0.0%)	6 (0.0%)	0 (0.0%)
Boreal White and Black Spruce	164,079 (17.3%)	1,236 (0.7%)	32,125 (18.7%)	22,403 (12.9%)	26 (0.0%)
Coastal Mountain-Heather Alpine	35,713 (3.8%)	369 (0.2%)	7,261 (4.2%)	4,954 (2.9%)	232 (0.4%)
Coastal Douglas-fir	2,477 (0.3%)	1,087 (0.6%)	677 (0.4%)	903 (0.5%)	191 (0.4%)
Interior Mountain-Heather Alpine	12,576 (1.3%)	42 (0.0%)	697 (0.4%)	297 (0.2%)	12 (0.0%)
Montane Spruce	28,636 (3.0%)	2,561 (1.5%)	194 (0.1%)	252 (0.1%)	46 (0.1%)
Interior Douglas-fir	44,879 (4.7%)	4,876 (2.8%)	450 (0.3%)	578 (0.3%)	111 (0.2%)
Sub-boreal Pine-Spruce	22,653 (2.4%)	421 (0.2%)	150 (0.1%)	106 (0.1%)	3 (0.0%)
Sub-boreal Spruce	103,375 (10.9%)	27,340 (15.7%)	1,616 (0.9%)	2,194 (1.3%)	393 (0.7%)
Spruce-Willow-Birch	86,544 (9.1%)	95 (0.1%)	7.892 (4.6%)	3,189 (1,8%)	8 (0.0%)
Coastal Western Hemlock	107,022 (11.3%)	71,651 (41.0%)	59,007 (34.3%)	80,681 (46.6%)	39,264 (74.7%)
Boreal Altai Fescue Alpine	62,869 (6.6%)	7 (0.0%)	8,212 (4.8%)	2,850 (1.6%)	3 (0.0%)
Engelmann Spruce-Subalpine Fir	174,634 (18.4%)	26,509 (15.2%)	22,105 (12.9%)	19,687 (11.4%)	3,156 (6.0%)
Mountain Hemlock	40,531 (4.3%)	9,770 (5.6%)	26,958 (15.7%)	26,091 (15.1%)	6,482 (12.3%)
Ponderosa Pine	2,949 (0.3%)	44 (0.0%)	59 (0.0%)	10 (0.0%)	0 (0.0%)
Interior Cedar-Hemlock (Northern)	11,406 (1.2%)	6,476 (3.7%)	2,379 (1.4%)	4,387 (2.5$)	1,516 (2.9%)
Interior Cedar-Hemlock (Southern)	**43,984 (4.6%)**	**21,652 (12.4%)**	**2,109 (1.2%)**	**4,265 (2.5%)**	**1,042 (2.0%)**
British Columbia	*947,536*	*174,614*	*171,993*	*173,198*	*52,538*

3.3 Freshwater Provision

The Interior Cedar Hemlock BEC zone is a key location of freshwater demand and provision, due to its relatively high capacity to supply freshwater compared to other interior BEC zones (but not compared to coastal BEC zones) and high downstream demand. Freshwater hotspot densities for the southern ICH are high for freshwater demand and provision but lower for freshwater capacity compared to other BEC zones (Fig. 3-6). The southern ICH has the second highest freshwater provision hotspot density (61.8 $km^2/100km^2$) and third highest freshwater demand hotspot density (46.9 $km^2/100km^2$) (Table 3-5). It has the ninth highest freshwater capacity hotspot density (5.2 $km^2/100km^2$), behind most coastal BEC zones. It also has a relatively high density of overlapping freshwater capacity and provision hotspots (4.3 $km^2/100km^2$), higher than twelve other BEC zones in BC. The southern ICH makes up just under 5% of BC by area, but contains twice that proportion of demand (10.9%) and overlapping capacity and provision (11.6%) hotspots, and almost three times that proportion of freshwater provision hotspots (14.4%) (Table 3-6).

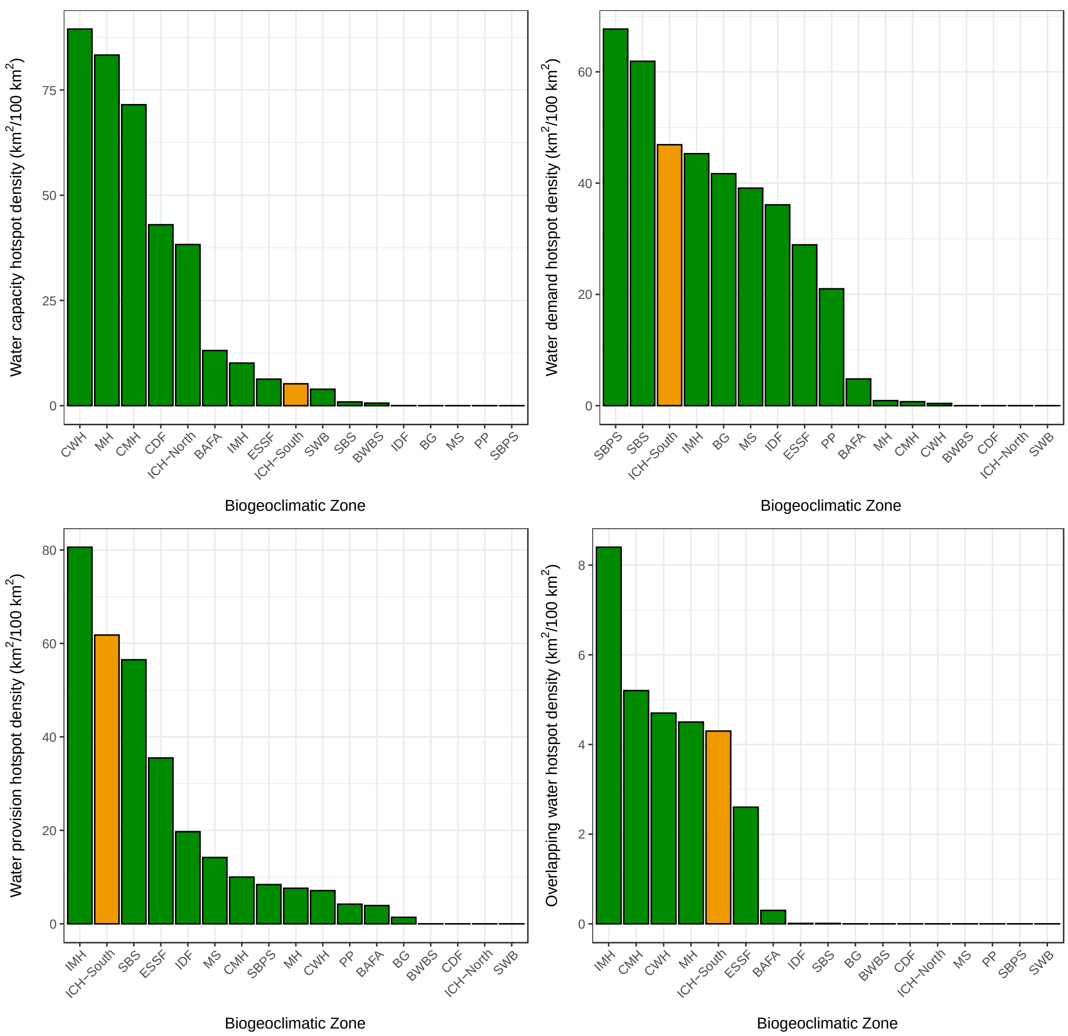


Figure 3-6. Freshwater hotspot densities in British Columbia's biogeoclimatic zones. The overlapping water hotspot plot refers to overlapping hotspots of freshwater capacity and provision. The orange column identifies the southern portion of the Interior Cedar Hemlock zone.

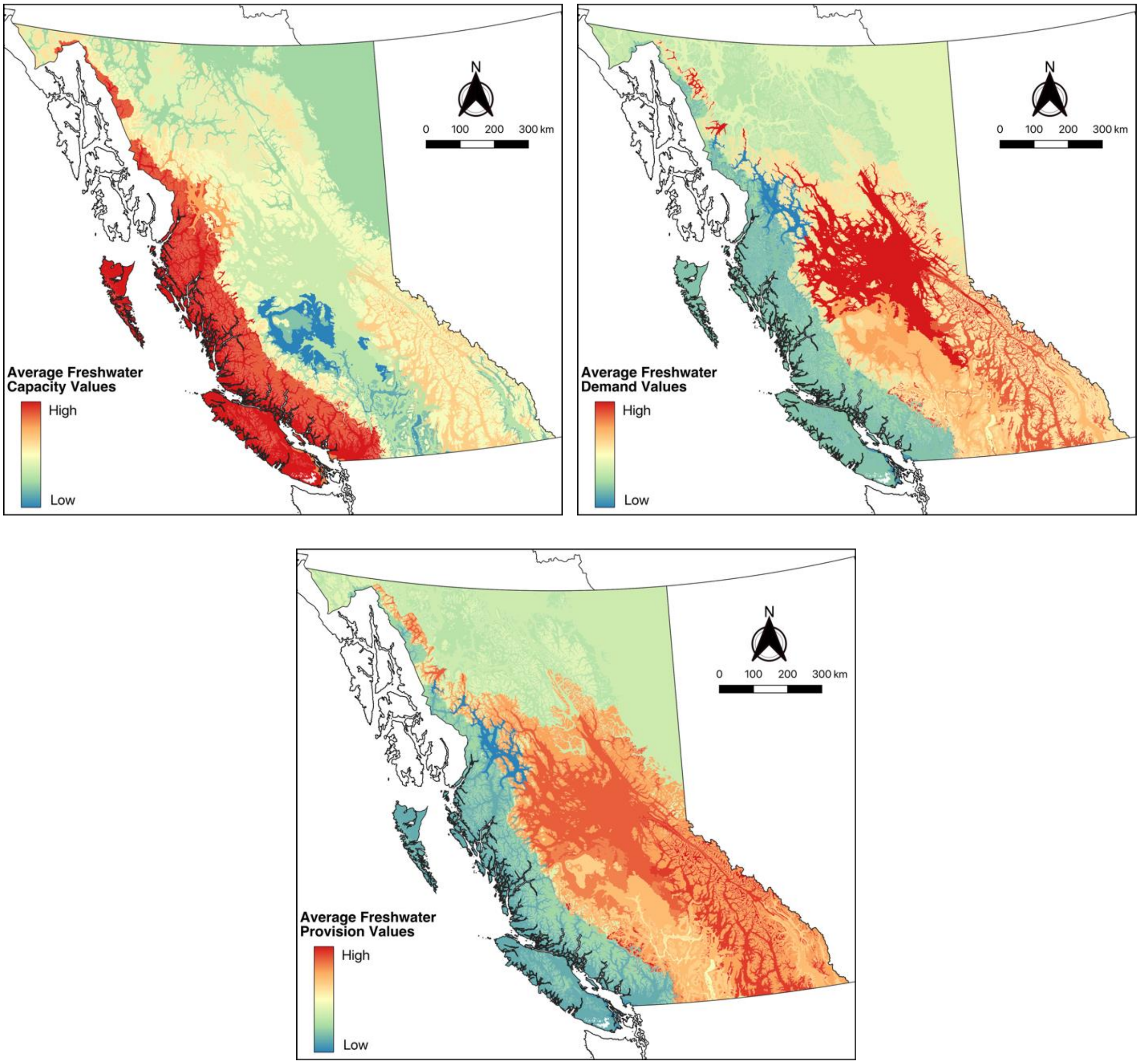


Figure 3-7. Average freshwater provision importance values across British Columbia's biogeoclimatic zones. A single average value has been calculated and is shown for each BEC zone in the figures above.

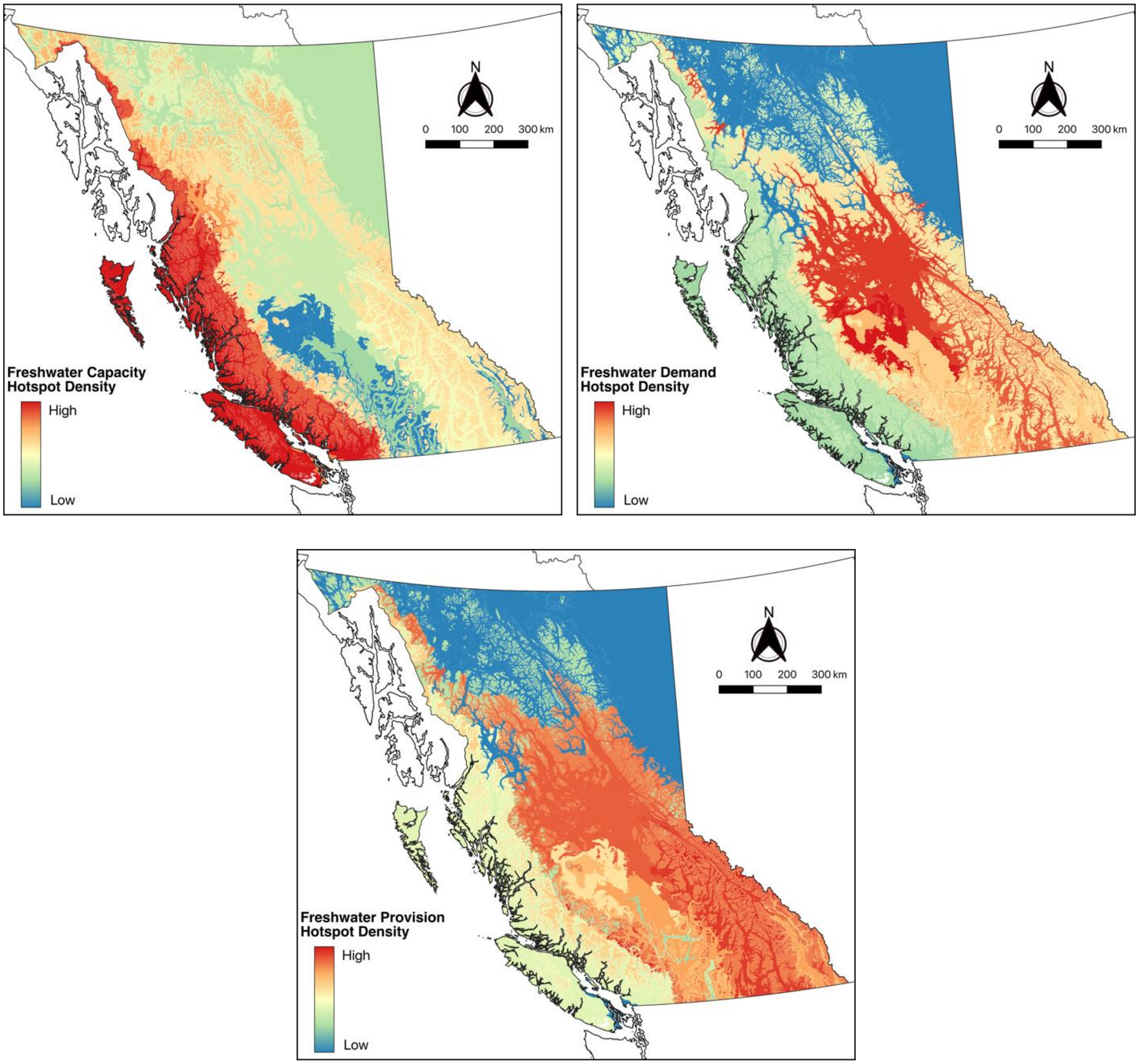


Figure 3-8. Freshwater provision hotspot densities across British Columbia's biogeoclimatic zones. A single value (see Table 3-5) has been calculated and is shown for each BEC zone in the figures above.

Table 3-5. Freshwater provision hotspot densities in British Columbia's biogeoclimatic zones.

Biogeoclimatic Zone	**Capacity Hotspot Density ($km^2/100km^2$)**	**Demand Hotspot Density ($km^2/100km^2$)**	**Provision Hotspot Density ($km^2/100km^2$)**	**Overlapping Capacity/Prov. Hotspot Dens. ($km^2/100km^2$)**
Bunchgrass	0.0	41.7	1.4	0.0
Boreal White and Black Spruce	0.6	0.0	0.0	0.0
Coastal Mountain-Heather Alpine	71.5	0.7	10.0	5.2
Coastal Douglas-fir	43.0	0.0	0.0	0.0
Interior Mountain-Heather Alpine	10.1	45.3	80.6	8.4
Montane Spruce	0.0	39.1	14.2	0.0
Interior Douglas-fir	<0.1	36.1	19.7	<0.1
Sub-boreal Pine-Spruce	0.0	67.7	8.4	0.0
Sub-boreal Spruce	0.9	61.9	56.5	<0.1
Spruce-Willow-Birch	3.9	0.0	0.0	0.0
Coastal Western Hemlock	89.5	0.4	7.1	4.7
Boreal Altai Fescue Alpine	13.1	4.8	3.9	0.3
Engelmann Spruce-Subalpine Fir	6.3	28.9	35.5	2.6
Mountain Hemlock	83.3	0.9	7.6	4.5
Ponderosa Pine	0.0	21.0	4.2	0.0
Interior Cedar-Hemlock (Northern)	38.3	0.0	0.0	0.0
Interior Cedar-Hemlock (Southern)	**5.2**	**46.9**	**61.8**	**4.3**
British Columbia	*20.0*	*20.0*	*20.0*	*1.7*

Table 3-6. Freshwater hotspot areas in British Columbia's biogeoclimatic zones. Numbers in parentheses represent proportions within BC.

Biogeoclimatic Zone	**Area (km²)**	**Aboveground Carbon Hotspot Area (km²)**	**Belowground Carbon Hotspot Area (km²)**	**Total Carbon Hotspot Area (km²)**	**Overlapping Above- and Belowground Carbon Hotspot Area (km²)**
Bunchgrass	2570 (0.3%)	0 (0.0%)	1,072 (0.6%)	37 (0.0%)	0 (0.0%)
Boreal White and Black Spruce	164,079 (17.3%)	991 (0.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Coastal Mountain-Heather Alpine	35,713 (3.8%)	25,531 (13.5%)	236 (0.1%)	3,558 (1.9%)	1,849 (11.2%)
Coastal Douglas-fir	2,477 (0.3%)	1,065 (0.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Interior Mountain-Heather Alpine	12,576 (1.3%)	1,267 (0.7%)	5,696 (3.0%)	10,136 (5.3%)	1,054 (6.4%)
Montane Spruce	28,636 (3.0%)	0 (0.0%)	11,210 (5.9%)	4,072 (2.1%)	0 (0.0%)
Interior Douglas-fir	44,879 (4.7%)	32 (0.0%)	16,183 (8.5%)	8,823 (4.7%)	30 (0.2%)
Sub-boreal Pine-Spruce	22,653 (2.4%)	0 (0.0%)	15,342 (8.1%)	1,899 (1.0%(	0 (0.0%)
Sub-boreal Spruce	103,375 (10.9%)	965 (0.5%)	64,036 (33.8%)	58,447 (30.8%)	2 (0.0%)
Spruce-Willow-Birch	86,544 (9.1%)	3,354 (1.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Coastal Western Hemlock	107,022 (11.3%)	95,805 (50.6%)	463 (02%)	7,606 (4.0%)	5,027 (30.5%)
Boreal Altai Fescue Alpine	62,869 (6.6%)	8,266 (4.4%)	3,039 (1.6%)	2,458 (1.3%)	219 (1.3%)
Engelmann Spruce-Subalpine Fir	174,634 (18.4%)	11,077 (5.9%)	50,506 (26.7%)	62,045 (32.7%)	4,566 (27.7%)
Mountain Hemlock	40,531 (4.3%)	33,752 (17.8%)	351 (0.2%)	3,076 (1.6%)	1,809 (11.0%)
Ponderosa Pine	2,949 (0.3%)	0 (0.0%)	618 (0.3%)	125 (0.1%)	0 (0.0%)
Interior Cedar-Hemlock (Northern)	11,406 (1.2%)	4,364 (2.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Interior Cedar-Hemlock (Southern)	**43,984 (4.6%)**	**2,272 (1.2%)**	**20,641 (10.9%)**	**27,204 (14.4%)**	**1,905 (11.6%)**
British Columbia	*947,536*	*189,336*	*189,399*	*189,500*	*16,462*

3.4 Overlapping Ecosystem Service Hotspots

The southern portion of the Interior Cedar-Hemlock zone has the highest density of overlapping carbon and freshwater provision hotspots in the province compared to all other BEC zones (Fig. 3-9). The fact that it has high importance for freshwater provision in BC, combined with its medium-high levels of aboveground and total carbon contribute to this ranking. For overlapping aboveground and freshwater provision hotspots, its density of 32.2 km^2 of hotspots per 100 km^2 of surface area is more than twice as high as the next nearest BEC zone (Sub-boreal Spruce). This difference is reduced somewhat when total carbon hotspots are considered, but the ICH still has a density value 43% higher than the next closest BEC zone (Mountain Hemlock). Despite being just under 5% of the province by area, the southern ICH has nearly one-third of the overlapping aboveground carbon-freshwater provision hotspots, and just under one-fifth of the overlapping total carbon-freshwater provision hotspots.

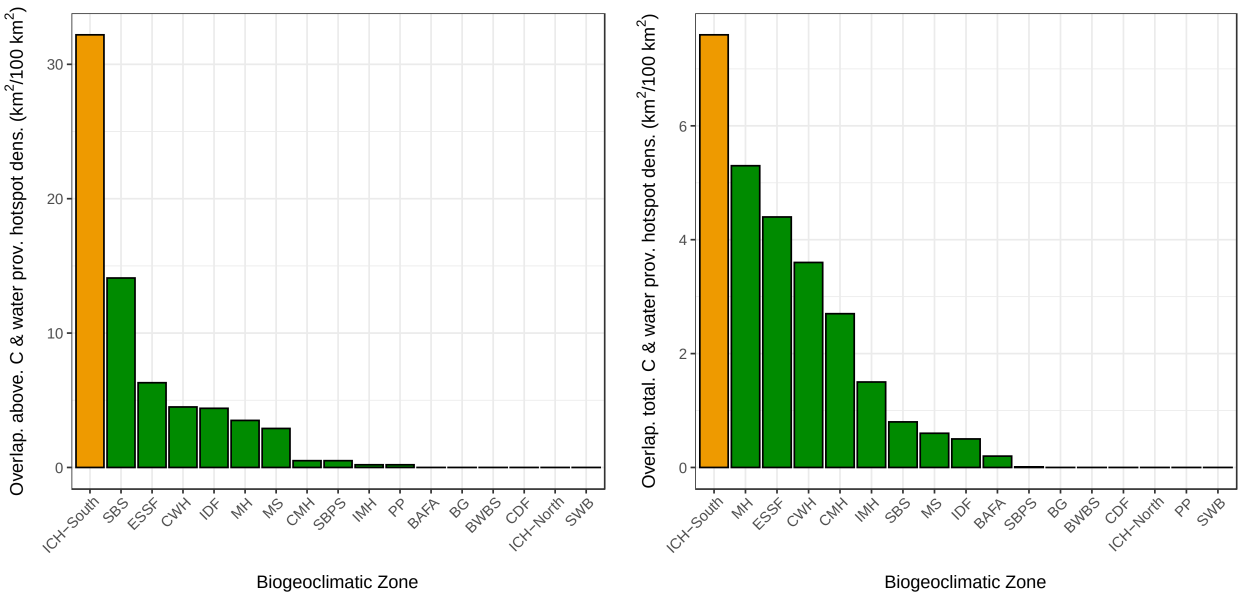


Figure 3-9. Overlapping ecosystem service hotspot densities in British Columbia's biogeoclimatic zones. The orange column identifies the southern portion of the Interior Coastal Hemlock zone.

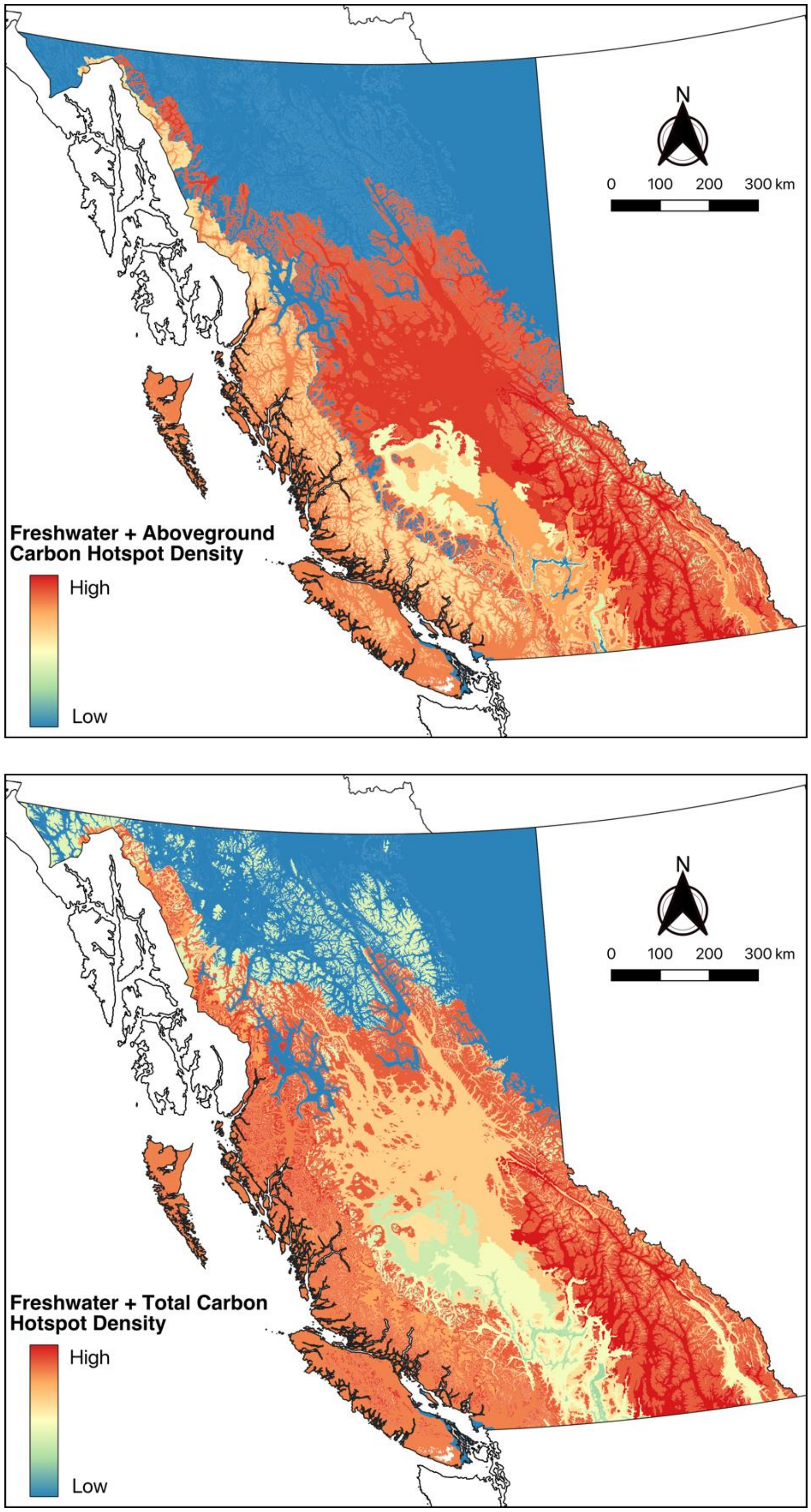


Figure 3-10. Overlapping ecosystem service hotspot densities across British Columbia's biogeoclimatic zones. A single value (see Table 3-7) has been calculated and is shown for each BEC zone in the figures above.

Table 3-7. Overlapping ecosystem services hotspot densities in British Columbia's biogeoclimatic zones.

Biogeoclimatic Zone	Aboveground Carbon & Freshwater Provision Hotspot Density ($km^2/100km^2$)	Total Carbon & Freshwater Provision Hotspot Density ($km^2/100km^2$)
Bunchgrass	0.0	0.0
Boreal White and Black Spruce	0.0	0.0
Coastal Mountain-Heather Alpine	0.5	2.7
Coastal Douglas-fir	0.0	0.0
Interior Mountain-Heather Alpine	0.2	1.5
Montane Spruce	2.9	0.6
Interior Douglas-fir	4.4	0.5
Sub-boreal Pine-Spruce	0.5	<0.1
Sub-boreal Spruce	14.1	0.8
Spruce-Willow-Birch	0.0	0.0
Coastal Western Hemlock	4.5	3.6
Boreal Altai Fescue Alpine	0.0	0.2
Engelmann Spruce-Subalpine Fir	6.3	4.4
Mountain Hemlock	3.5	5.3
Ponderosa Pine	0.2	0.0
Interior Cedar-Hemlock (Northern)	0.0	0.0
Interior Cedar-Hemlock (Southern)	**32.2**	**7.6**
British Columbia	*5.17*	*2.06*

Table 3-8. Overlapping ecosystem services hotspot areas in British Columbia's biogeoclimatic zones. Numbers in parentheses represent proportions within BC.

Biogeoclimatic Zone	**Area (km^2)**	**Aboveground Carbon & Freshwater Provision Hotspot Area (km^2)**	**Total Carbon & Freshwater Provision Hotspot Area (km^2)**
Bunchgrass	2,570 (0.3%)	0 (0.0%)	0 (0.0%)
Boreal White and Black Spruce	164,079 (17.3%)	0 (0.0%)	0 (0.0%)
Coastal Mountain-Heather Alpine	35,713 (3.8%)	196 (0.4%)	975 (5.0%)
Coastal Douglas-fir	2,477 (0.3%)	0 (0.0%)	0 (0.0%)
Interior Mountain-Heather Alpine	12,576 (1.3%)	20 (0.0%)	184 (0.9%)
Montane Spruce	28,636 (3.0%)	825 (1.7%)	165 (0.8%)
Interior Douglas-fir	44,879 (4.7%)	1,955 (4.0%)	226 (1.2%)
Sub-boreal Pine-Spruce	22,653 (2.4%)	110 (0.2%)	9 (0.0%)
Sub-boreal Spruce	103,375 (10.9%)	14,558 (29.7%)	808 (4.1%)
Spruce-Willow-Birch	86,544 (9.1%)	0 (0.0%)	0 (0.0%)
Coastal Western Hemlock	107022 (11.3%)	4,782 (9.8%)	3,882 (19.9%)
Boreal Altai Fescue Alpine	62,869 (6.6%)	0 (0.0%)	151 (0.8%)
Engelmann Spruce-Subalpine Fir	174,634 (18.4%)	10,973 (22.4%)	7,641 (39.2%)
Mountain Hemlock	40,531 (4.3%)	1,435 (2.9%)	2,132 (10.9%)
Ponderosa Pine	2,949 (0.3%)	5 (0.0%)	0 (0.0%)
Interior Cedar-Hemlock (Northern)	11,406 (1.2%)	0 (0.0%)	0 (0.0%)
Interior Cedar-Hemlock (Southern)	**43,984 (4.6%)**	**14,148 (28.9%)**	**3,336 (17.1%)**
British Columbia	*947,536*	*49,008*	*19,509*

3.5 Summary

The southern Interior Cedar-Hemlock zone should be a conservation priority for aboveground carbon, freshwater provision, and win-win actions that can conserve both carbon and freshwater provision in BC (Table 3-9). The southern ICH has above average aboveground carbon density and carbon hotspot density, as well as freshwater provision hotspot density due to the high demand for freshwater downstream. Finally, the combination of high freshwater provision hotspot density and moderate carbon densities in the ICH means that it contains a disproportionate amount of overlapping carbon and freshwater hotspots in BC, despite covering less than 5% of the province.

Table 3-9. Summary of ecosystem service hotspot densities across BC's biogeoclimatic zones. *Dark blue* squares indicate values (km^2 hotspot area/100 km^2) less than half of average provincial values, *light blue* half to equal values, *light green* equal to double values, and *dark green* greater than double provincial averages.

Biogeoclimatic Zone	**Carbon**			**Freshwater**			**Overlap**	
	Above	Below	Total	Capacity	Demand	Provision	Above C + Water Prov.	Total C + Water Prov.
Bunchgrass	0.4	1.4	0.2	0.0	41.7	1.4	0.0	0.0
Boreal White and Black Spruce	0.8	19.6	13.7	0.6	0.0	0.0	0.0	0.0
Coastal Mountain-Heather Alpine	1.0	20.3	13.9	71.5	0.7	10.0	0.5	2.7
Coastal Douglas-fir	43.9	27.3	36.5	43.0	0.0	0.0	0.0	0.0
Interior Mountain-Heather Alpine	0.3	5.5	2.4	10.1	45.3	80.6	0.2	1.5
Montane Spruce	8.9	0.7	0.9	0.0	39.1	14.2	2.9	0.6
Interior Douglas-fir	10.9	1.0	1.3	<0.1	36.1	19.7	4.4	0.5
Sub-boreal Pine-Spruce	1.9	0.7	0.5	0.0	67.7	8.4	0.5	<0.1
Sub-boreal Spruce	26.4	1.6	2.1	0.9	61.9	56.5	14.1	0.8
Spruce-Willow-Birch	0.1	9.1	3.7	3.9	0.0	0.0	0.0	0.0
Coastal Western Hemlock	66.9	55.1	75.4	89.5	0.4	7.1	4.5	3.6
Boreal Altai Fescue Alpine	<0.1	13.1	4.5	13.1	4.8	3.9	0.0	0.2
Engelmann Spruce-Subalpine Fir	15.2	12.7	11.3	6.3	28.9	35.5	6.3	4.4
Mountain Hemlock	24.1	66.5	64.4	83.3	0.9	7.6	3.5	5.3
Ponderosa Pine	1.5	2.0	0.3	0.0	21.0	4.2	0.2	0.0
Interior Cedar-Hemlock (Northern)	56.8	20.9	38.5	38.3	0.0	0.0	0.0	0.0
Interior Cedar-Hemlock (Southern)	**49.2**	**4.8**	**9.7**	**5.2**	**46.9**	**61.8**	**32.2**	**7.6**

4. Ecosystem Service Provision in the Upper Columbia Region

4.1 Introduction

We assessed carbon storage and freshwater provision in the Upper Columbia Region (UCR) compared to the rest of British Columbia. The assessment included estimating carbon stores and densities (amount of carbon per hectare) as well as the total area and density of carbon and freshwater provision hotspots (pixels with the top 20% of values across the province). Densities of hotspots were quantified as km^2 of hotspot area per 100 km^2 of terrestrial area. These hotspot analyses provide a preliminary comparison of the UCR to the rest of the province for the conservation of ecosystem services. We split carbon into aboveground, belowground, and total carbon pools, and split up freshwater provision into capacity (amount of runoff), demand (amount of downstream demand by humans), and provision (the overlap of capacity and demand). Finally, to identify areas where win-win conservation actions might be targeted, we assessed the overlap in hotspot/priority areas for carbon and freshwater; first the overlap between hotspot areas for aboveground carbon and freshwater provision, and then the overlap in hotspot areas for total carbon and freshwater provision.

4.2 Carbon Storage

The Upper Columbia (UCR) is estimated to store approximately 1.19 gigatonnes (GtC) of total carbon, with 0.20 GtC (16.8%) aboveground and 0.99 GtC (83.2%) belowground (Table 4-1). Mean carbon densities in the UCR are slightly lower than average densities across BC (96.4-96.7% of provincial values; Table 4-2), as coastal rainforest regions of the province have higher aboveground values and northern areas of BC with deep organic soils have higher belowground values.

Table 4-1. Carbon storage in British Columbia and the Upper Columbia Region.

Category	British Columbia	Upper Columbia Region	UCR Proportion of BC (%)
Area (km^2)	947,536	37,215	3.9
Total aboveground carbon (GtC)	5.244	0.199	3.8
Belowground carbon (GtC)	26.120	0.989	3.8
Total carbon (GtC)	31.339	1.187	3.8

Table 4-2. Average carbon densities in British Columbia and the Upper Columbia Region.

Region	**British Columbia**	**Upper Columbia**	**UCR Proportion of BC Densities (%)**
Aboveground carbon density (MgC/ha)	55.34	53.51	96.7
Belowground carbon density (MgC/ha)	275.66	265.71	96.4
Total carbon density (MgC/ha)	330.74	319.05	96.5

The UCR has a higher density of aboveground carbon hotspots (the top 20th percentile of carbon storage values in the province) compared to the entire province, but lower hotspot density for belowground and total carbon hotspots (Table 4-3, Figure 4-1). Of the 52,538 km^2 of overlapping above- and belowground carbon hotspots across BC, the UCR covers 1,224 km^2 (2.3%) of these hotspots (Table 4-4). This is a density of 3.3 km^2 of hotspot area per 100 km^2 of UCR area, which is approximately equal to 60% of the average provincial hotspot density across BC.

Table 4-3. Carbon storage hotspot density in BC and the Upper Columbia Region.

Category	**British Columbia**	**Upper Columbia**	**UCR Proportion of BC Densities (%)**
Aboveground carbon hotspot density (km^2/100 km^2)	18.4	20.3	110.3
Belowground carbon hotspot density (km^2/100 km^2)	18.2	12.8	70.3
Total carbon hotspot density (km^2/100 km^2)	18.3	14.5	79.2
Overlapping above- and belowground carbon hotspots (km^2/100 km^2)	5.5	3.3	60.0

Table 4-4. Carbon storage hotspot area in British Columbia and the Upper Columbia Region.

Category	**British Columbia**	**Upper Columbia**	**UCR proportion of BC (%)**
Area (km^2)	947,536	37,215	3.9
Aboveground carbon hotspots (km^2)	174,614	7,556	4.3
Belowground carbon hotspots (km^2)	171,992	4,768	2.8
Total carbon hotspots (km^2)	173,198	5,382	3.1
Overlapping above- & belowground carbon hotspots (km^2)	52,538	1,224	2.3

Within the UCR, aboveground carbon densities and overlapping above- and belowground carbon hotspots are concentrated at lower elevations along river valleys, especially near Golden and Nakusp (Fig. 4-2 and 4-5). These lower and more gently sloping areas have greater vegetation and tree growth, deeper soils, and store significantly more carbon that the steeper mountain slopes that surround them.

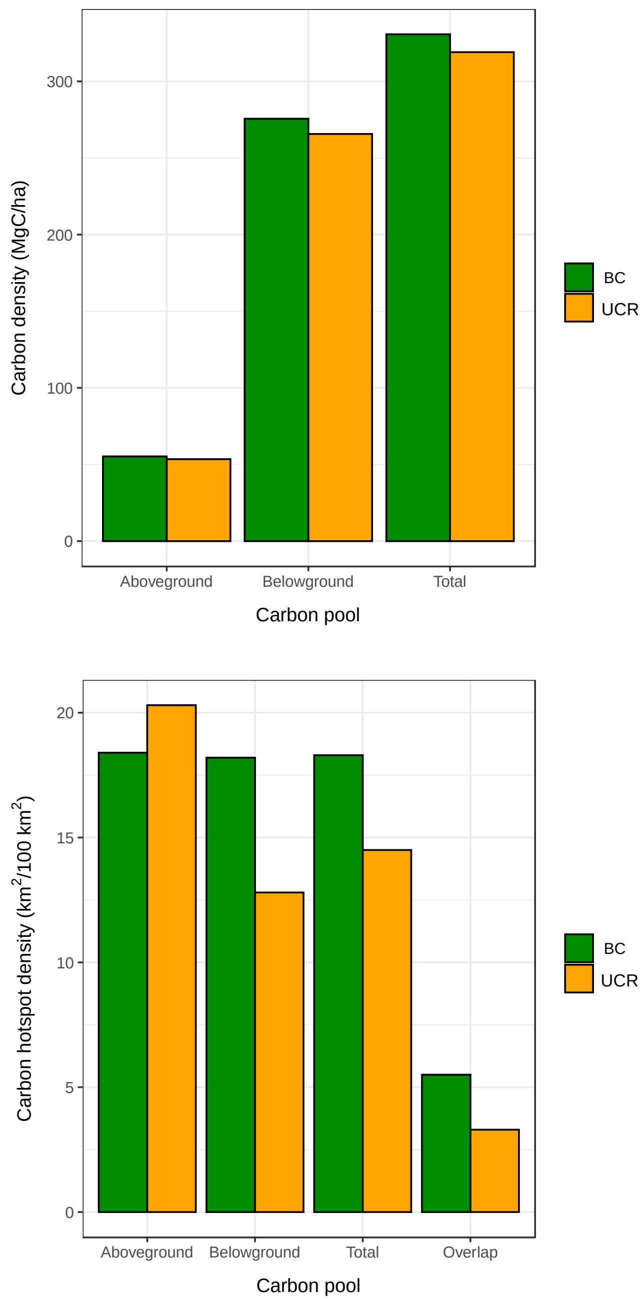


Figure 4-1. Comparison of carbon density and carbon hotspot densities for British Columbia and the Upper Columbia Region. (A) Carbon densities in different carbon pools and (B) density of aboveground, belowground and total carbon hotspots, as well as the density of overlapping above- and belowground hotspots.

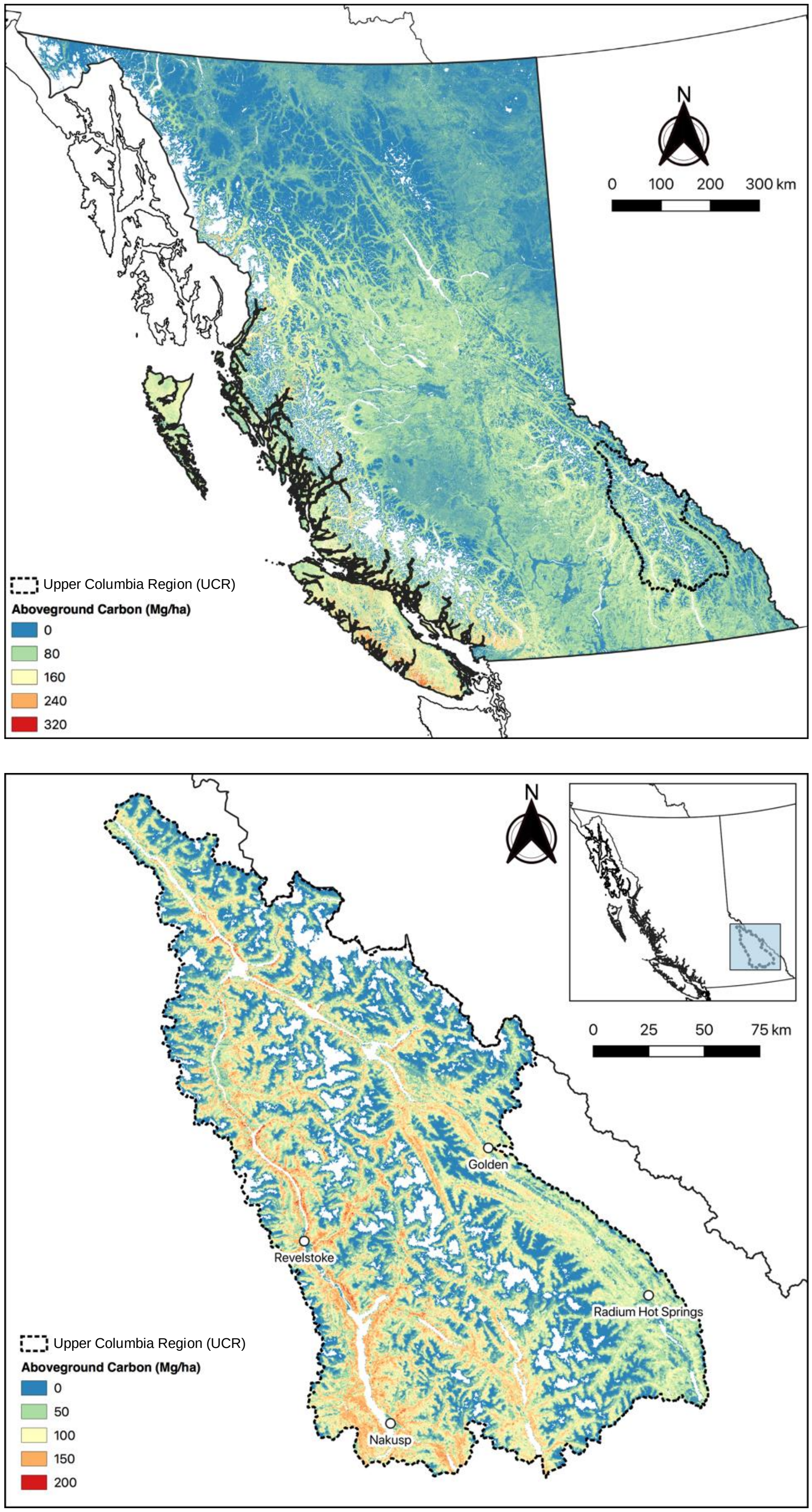


Figure 4-2. Aboveground carbon storage in Mg/ha in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.

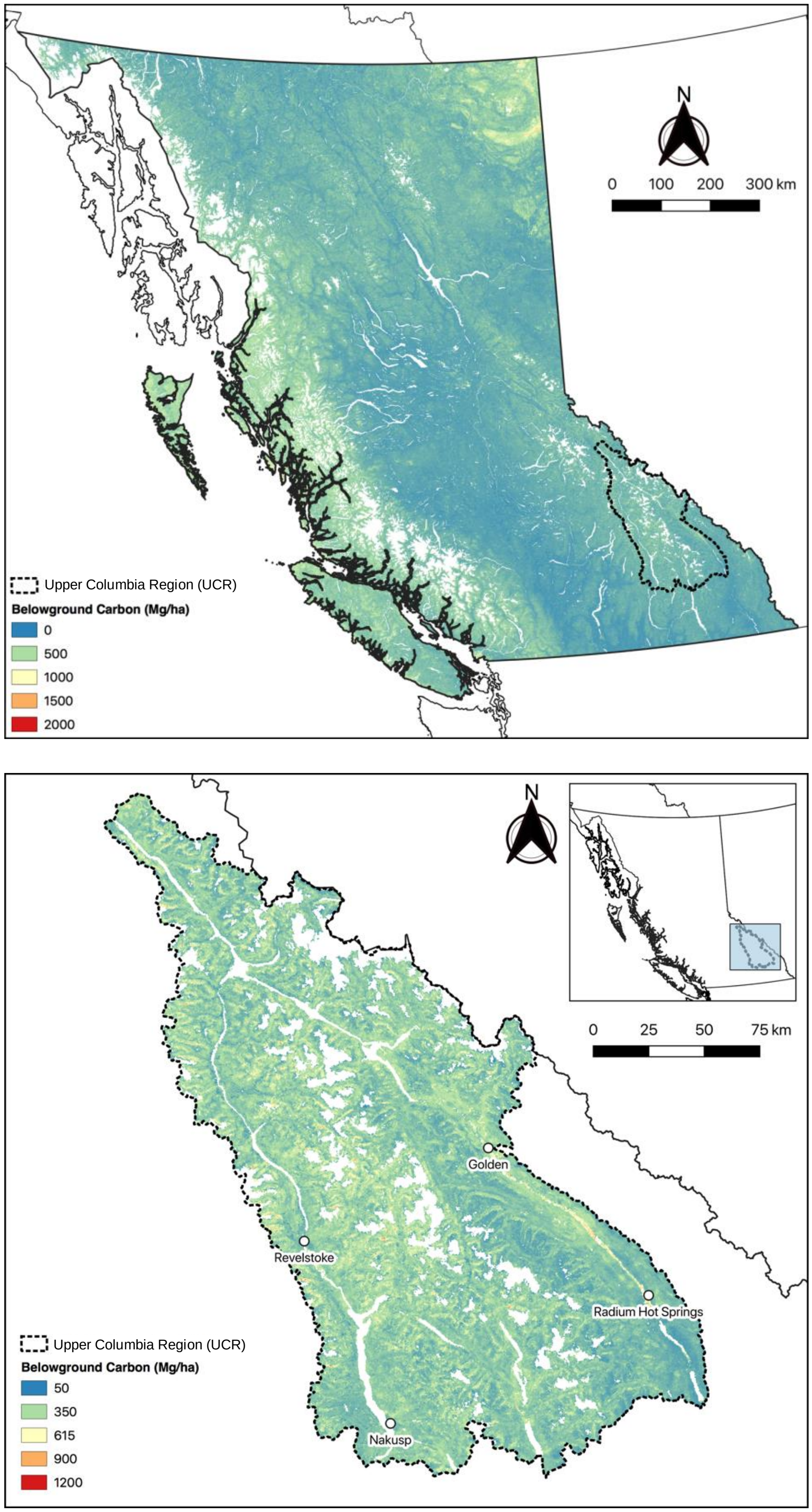
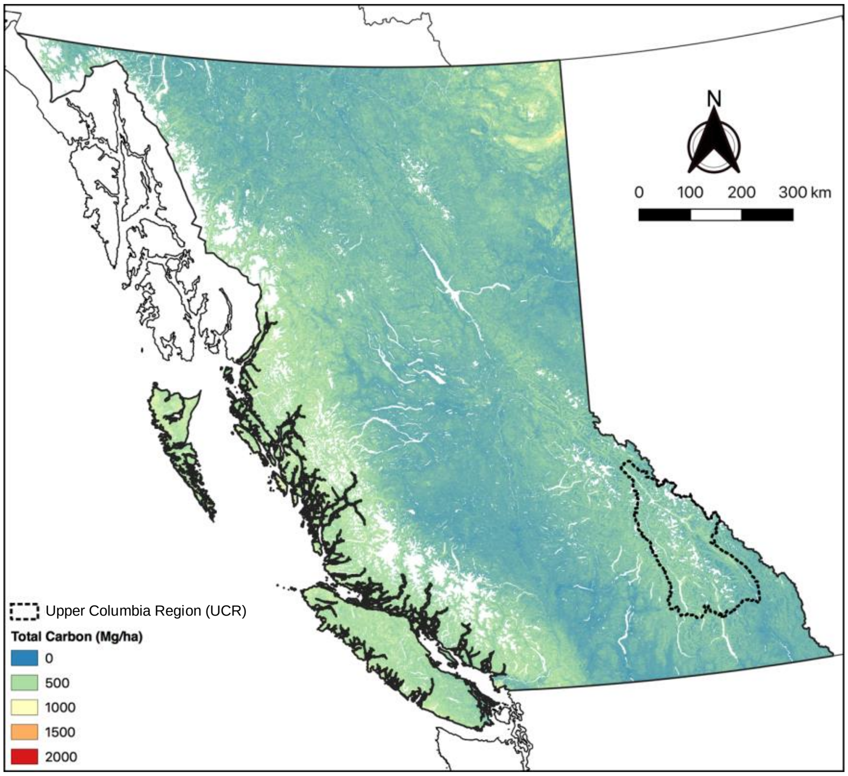


Figure 4-3. Belowground carbon storage in Mg/ha in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.



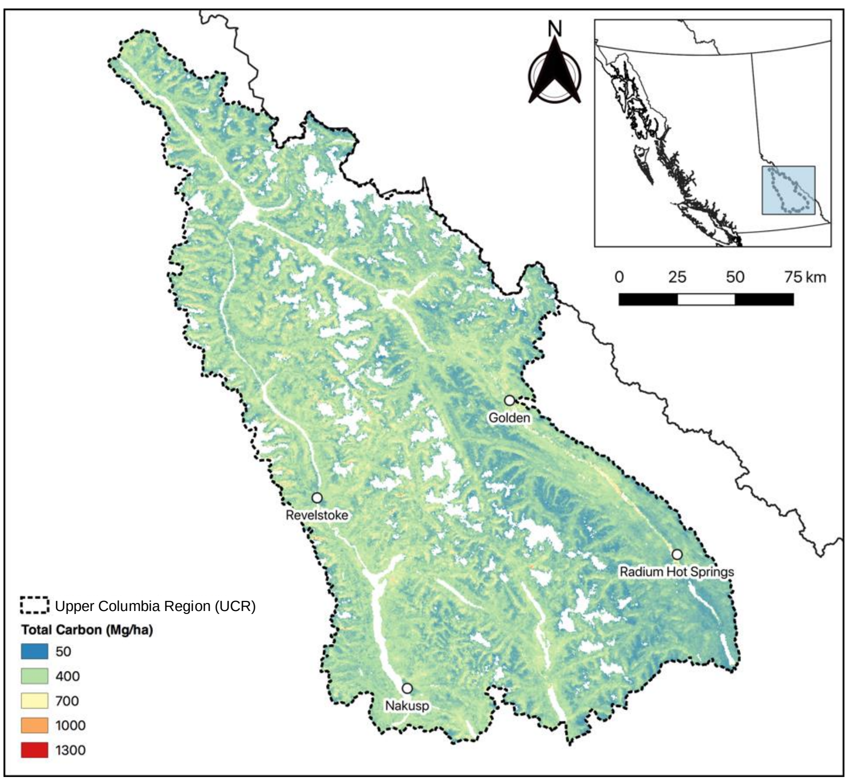


Figure 4-4. Total carbon storage in Mg/ha in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.

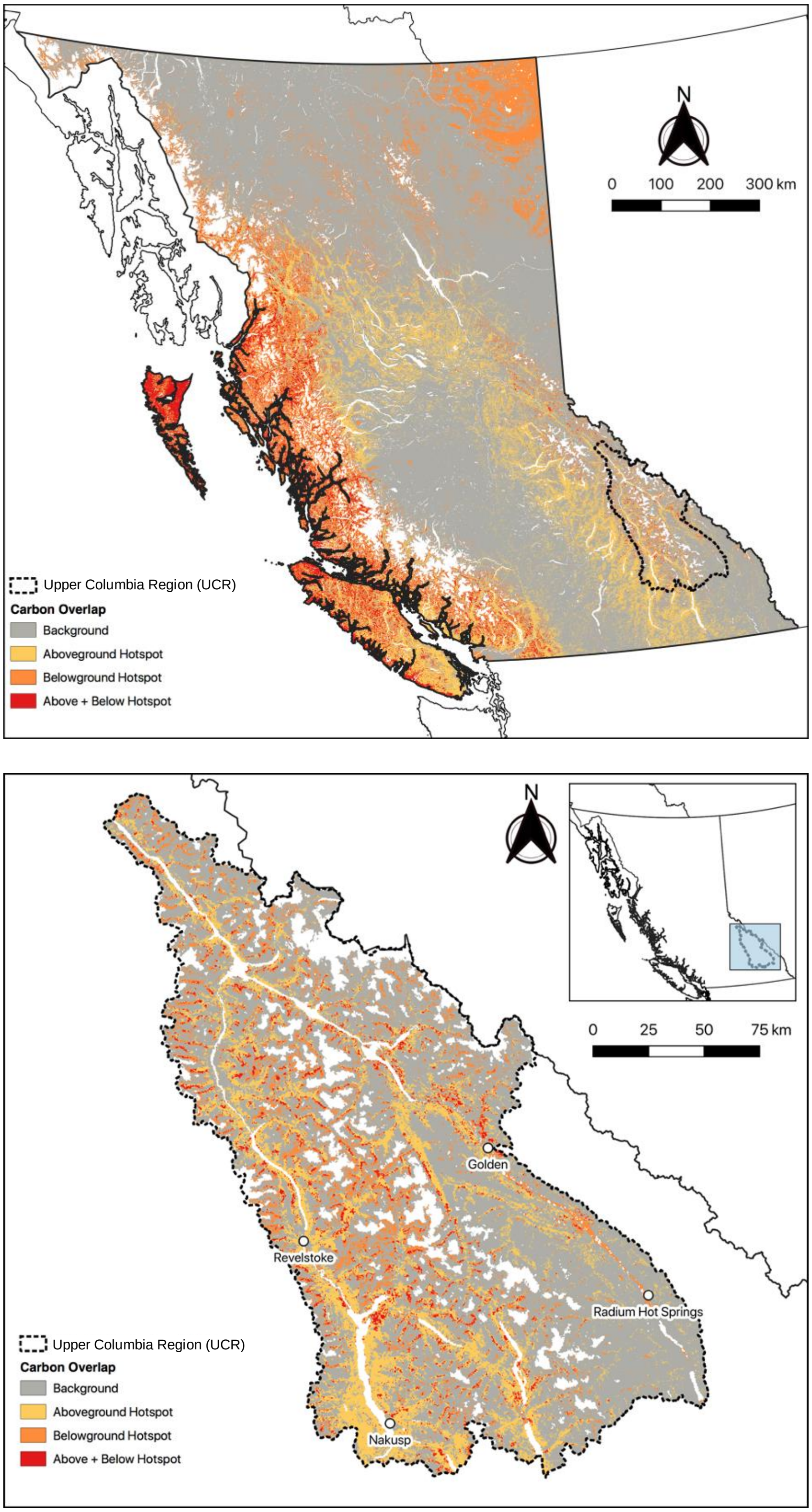


Figure 4-5. Provincial carbon storage hotspots (top 20th percentile of values) and overlap in British Columbia and the Upper Columbia Region.

4.3 Freshwater Provision

The UCR has a much higher density of freshwater capacity and provision hotspots compared to the entire province, and an especially high density of overlapping capacity and provision hotspots (Table 4-5, Fig. 4-6). UCR freshwater provision hotspot density is nearly four times the provincial density, while the overlap of capacity and provision hotspots is over ten times the provincial density. For freshwater demand, the UCR has a slightly lower density of hotspots compared to the rest of BC. The density of overlapping capacity and demand hotspots for freshwater emphasizes the importance of the UCR for providing freshwater in BC. It is one of only three areas in the province that combine relatively high runoff and capacity to provide freshwater and high downstream demand; the other two being the Coastal mountains around Vancouver and the Hazelton Mountains in west-central BC (Fig. 4-10). The fact that the UCR covers only 3.9% of the province but contains over 40% of overlapping freshwater capacity and provision hotspots highlights its significance and importance for water in the province (Table 4-6).

Conservation actions that target freshwater in the UCR have the potential to safeguard freshwater for a disproportionately large number of people downstream across BC. An important consideration is that the present analysis does not consider freshwater demand downstream in the USA by industry and dams, but does include estimates of demand from settlements and agriculture. It is therefore likely an underestimate of transboundary freshwater provision importance in the UCR.

Table 4-5. Freshwater hotspot density in British Columbia and the Upper Columbia Region.

Category	British Columbia	Upper Columbia	UCR Proportion of BC Densities (%)
Capacity hotspot density ($km^2/100km^2$)	20.0	22.3	111.5
Demand hotspot density ($km^2/100km^2$)	20.0	17.3	86.5
Provision hotspot density ($km^2/100km^2$)	20.0	77.1	385.5
Overlapping capacity and provision hotspot density ($km^2/100km^2$)	1.7	18.4	1,082.4

Table 4-6. Freshwater hotspot area in British Columbia and the Upper Columbia Region.

Category	British Columbia	Upper Columbia	UCR proportion of BC (%)
Area (km^2)	947,536	37,215	3.9
Capacity hotspots (km^2)	189,336	8,291	4.4
Demand hotspots (km^2)	189,399	6,443	3.4
Provision hotspots (km^2)	189,500	28,695	15.1
Overlapping capacity and provision hotspots (km^2)	16,462	6,842	41.6

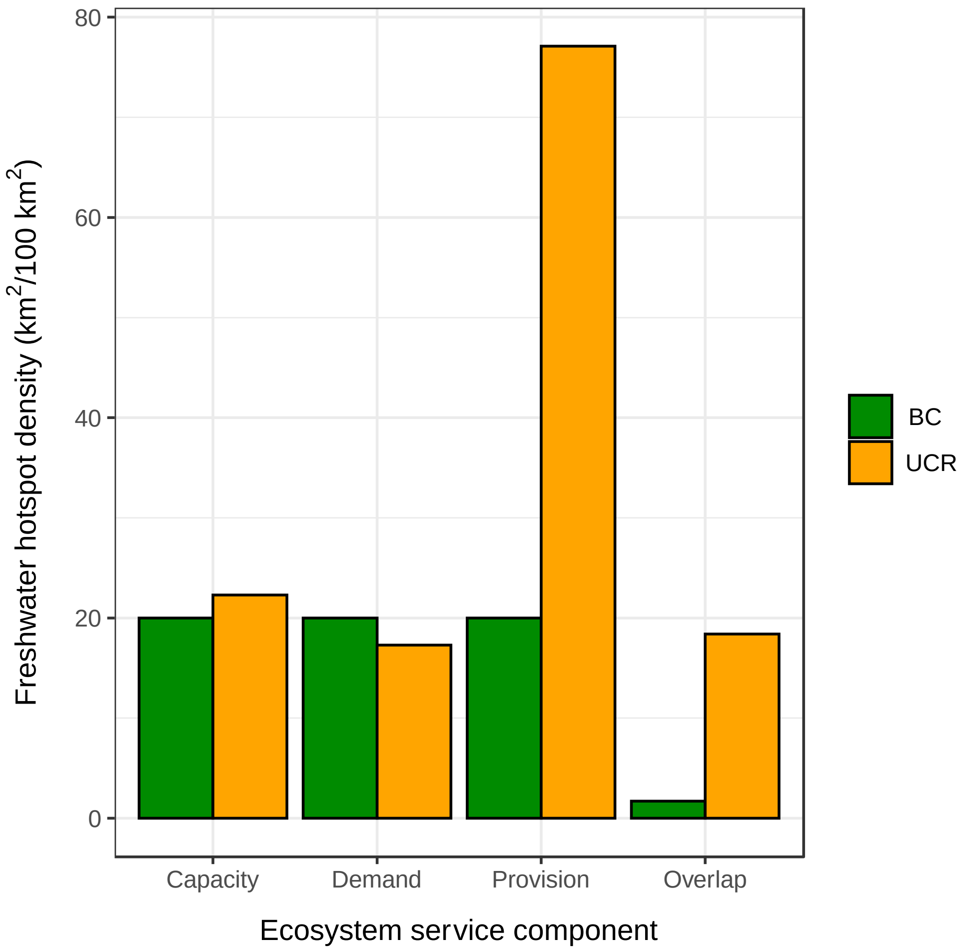


Figure 4-6. Comparison of freshwater hotspot densities for British Columbia and the Upper Columbia Region. Overlap refers to the overlap between freshwater capacity and provision hotspots.

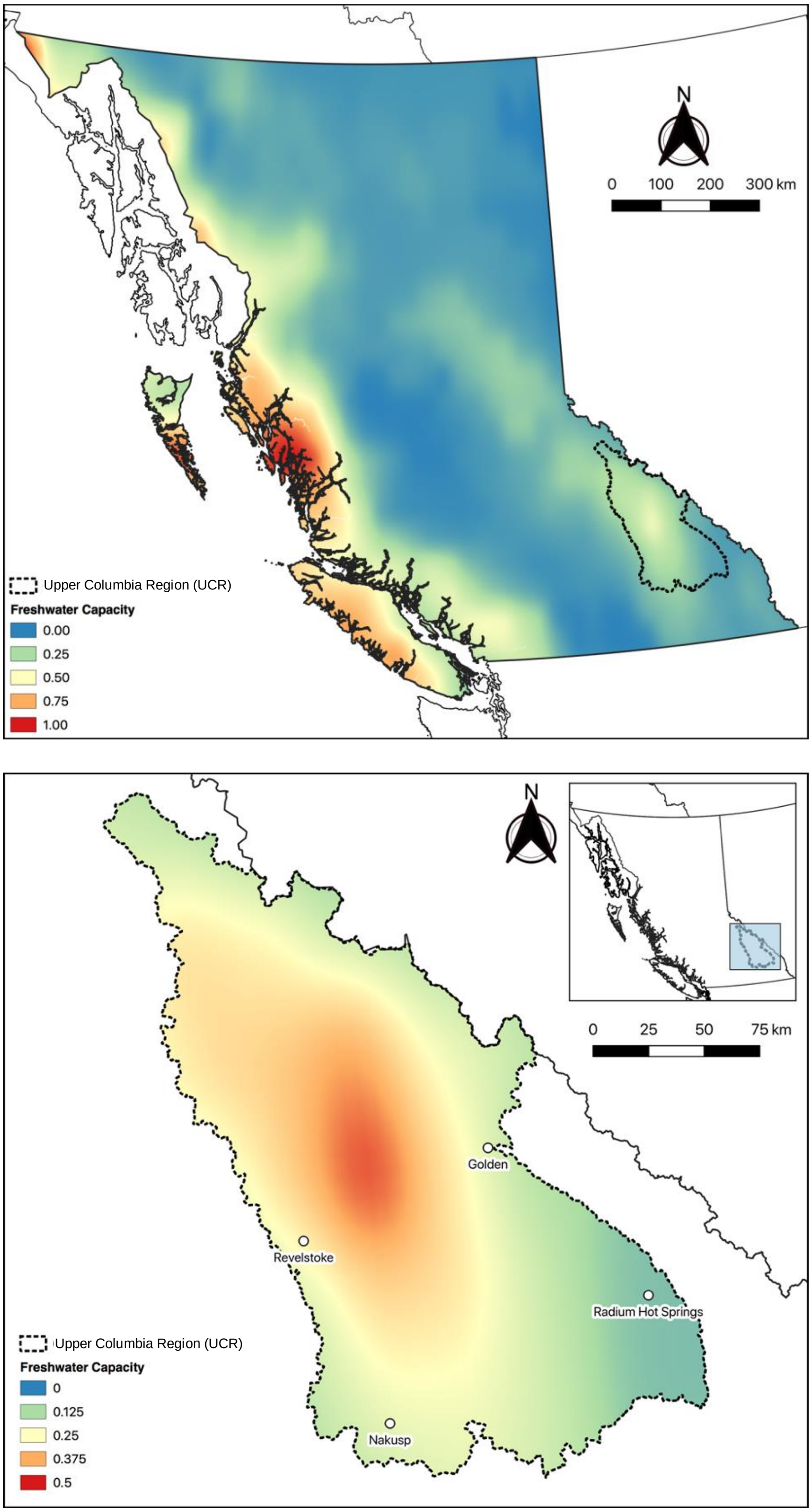
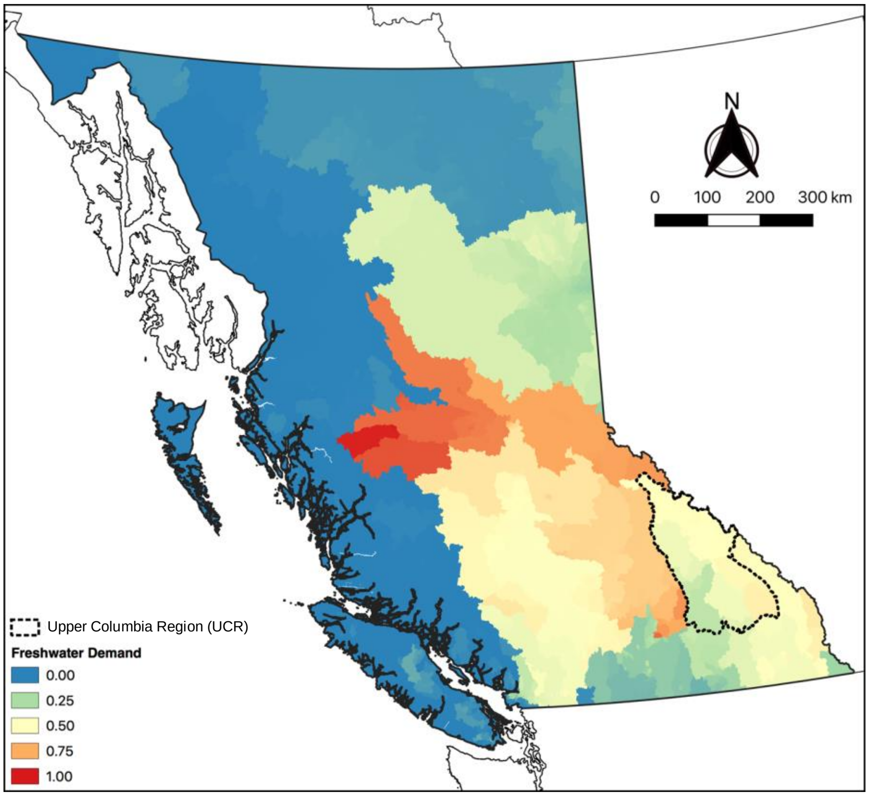


Figure 4-7. Freshwater capacity importance in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.



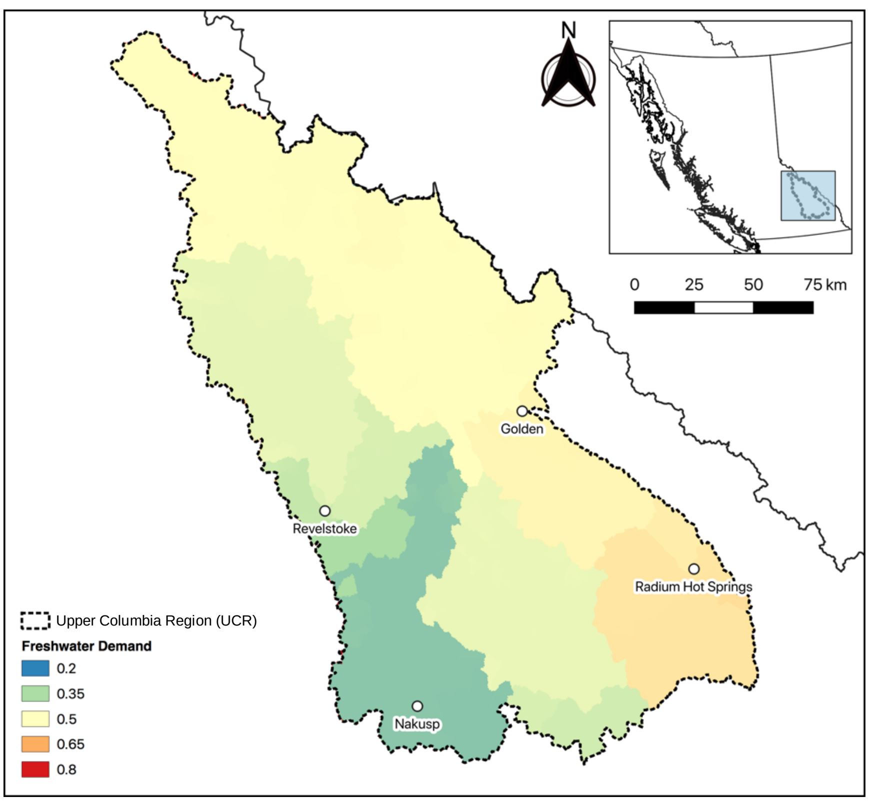
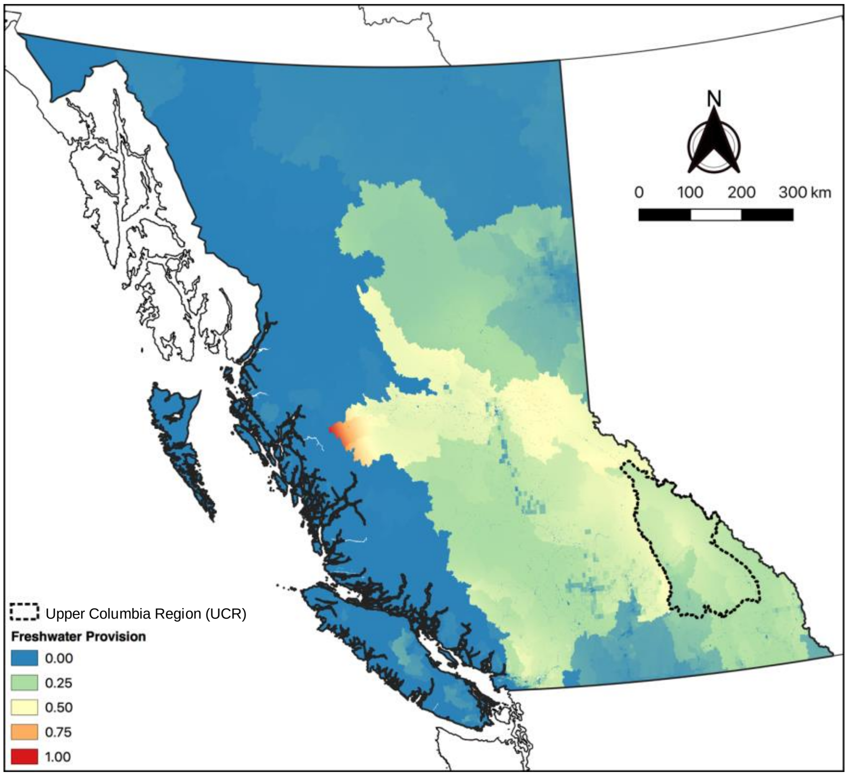


Figure 4-8. Freshwater demand importance in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.



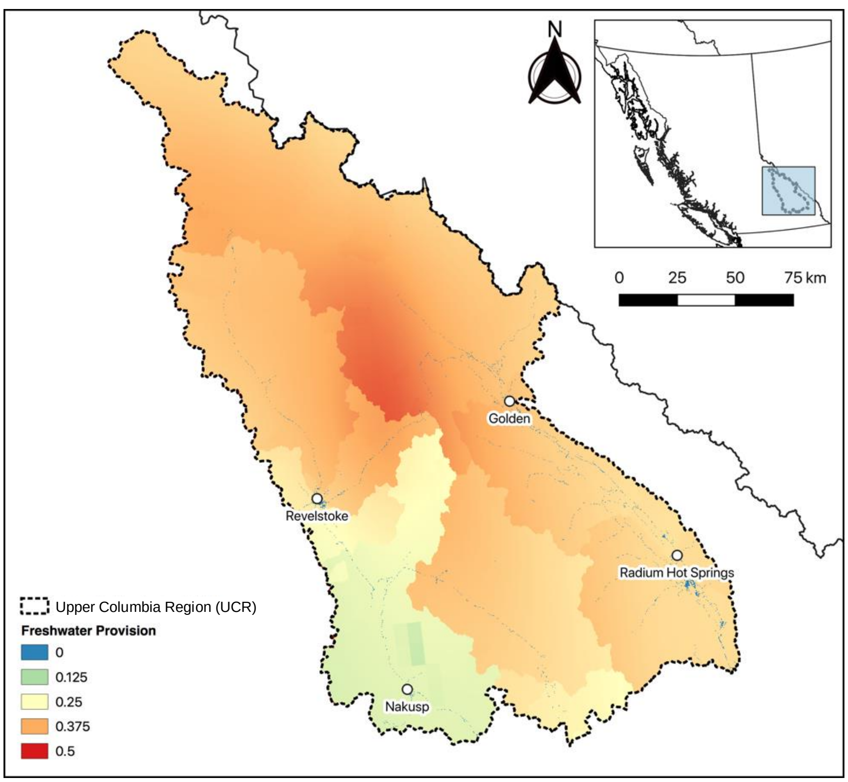
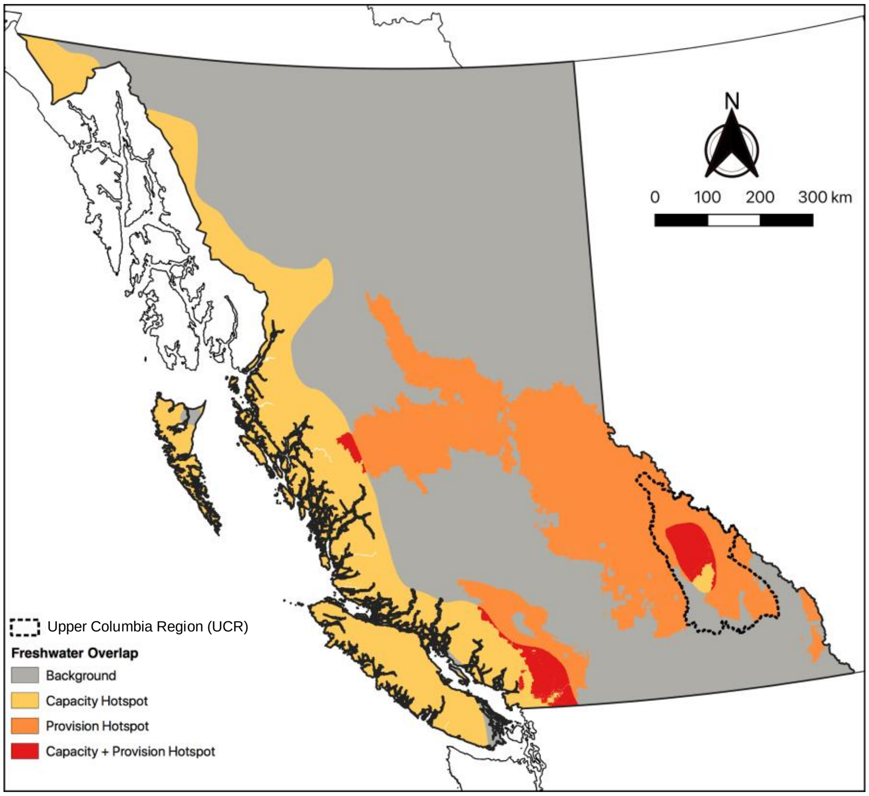


Figure 4-9. Freshwater provision importance in British Columbia and the Upper Columbia Region. Note that the legend has been rescaled for the UCR map.



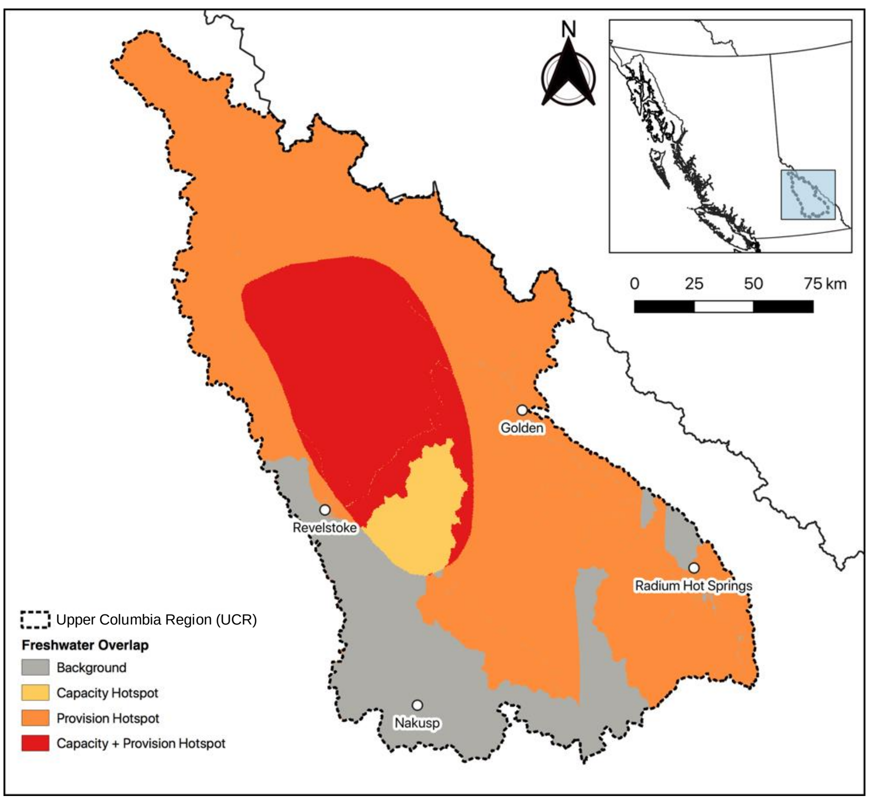


Figure 4-10. Provincial freshwater hotspots (top 20th percentile of values) and overlap in British Columbia and the Upper Columbia Region.

4.4 Overlapping Ecosystem Service Hotspots

To compare carbon storage and freshwater and identify areas where both could be conserved more efficiently, we compared the overlap between aboveground carbon and freshwater provision hotspots and total carbon and freshwater provision hotspots. The UCR has significantly higher densities of overlapping hotspots of carbon and freshwater than the average across BC. For aboveground carbon and freshwater provision hotspots, the UCR has densities 2.5 times higher than average, while total carbon and freshwater provision densities are over five times higher (Table 4-7). While the UCR is only 3.9% of BC by area, it contains over 10% of overlapping aboveground carbon and freshwater provision hotspots, and over 20% of overlapping total carbon and freshwater provision hotspots. This highlights the importance of the region for conserving both carbon and freshwater in BC.

Table 4-7. Ecosystem service hotspot overlap density in British Columbia and the Upper Columbia Region.

Category	British Columbia	Upper Columbia	UCR Proportion of BC Densities (%)
Overlapping aboveground carbon and freshwater provision hotspot density (km^2/100 km^2)	5.17	13.41	259.4
Overlapping total carbon and freshwater provision hotspot density (km^2/100 km^2)	2.06	10.73	520.9

Table 4-8. Ecosystem service hotspot overlap area in British Columbia and the Upper Columbia Region.

Category	British Columbia	Upper Columbia	UCR proportion of BC (%)
Area (km^2)	947,536	37,215	3.9
Overlapping aboveground carbon and freshwater provision hotspots (km^2)	49,008	4,991	10.2
Overlapping total carbon and freshwater provision hotspots (km^2)	19,509	3,994	20.5

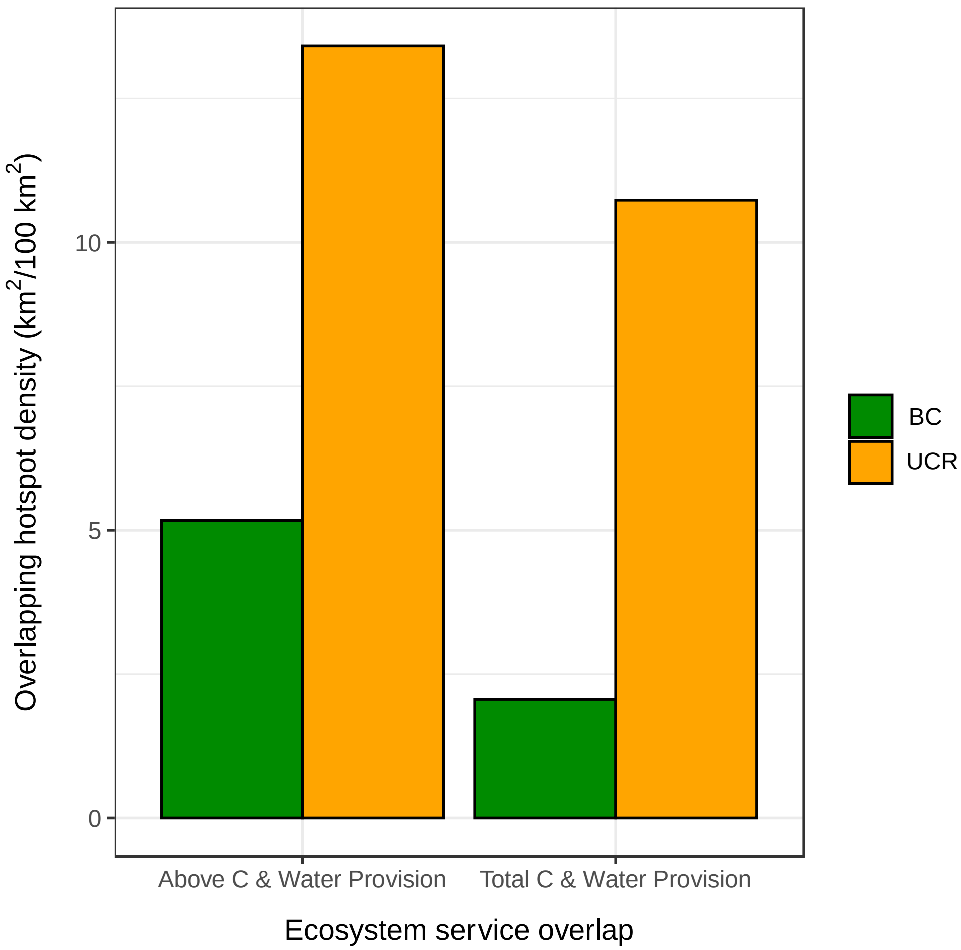
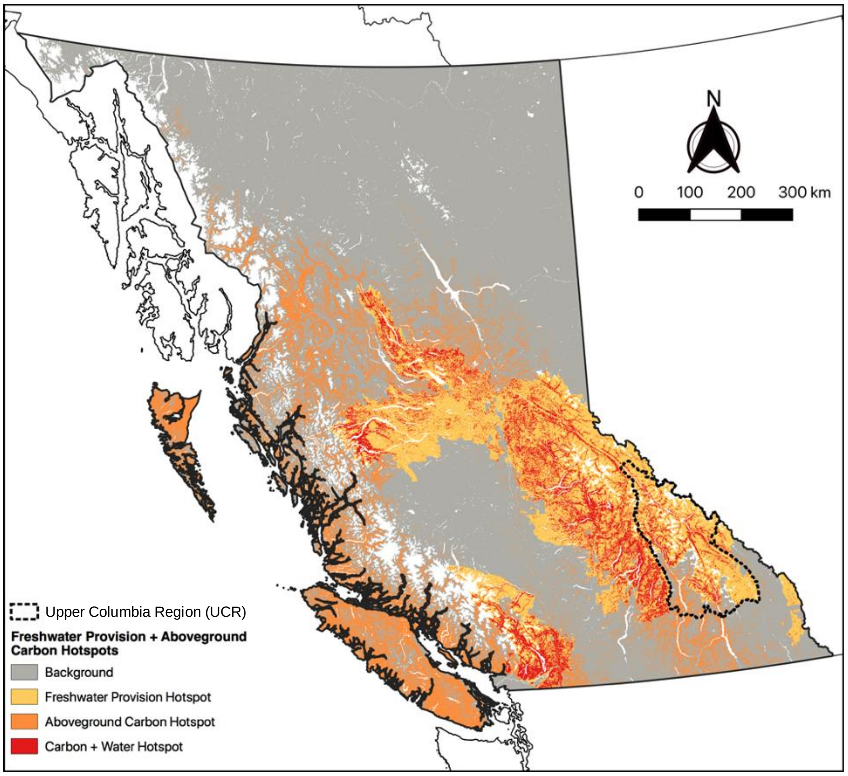


Figure 4-11. Comparison of overlapping ecosystem service hotspot densities for British Columbia and the Upper Columbia Region.



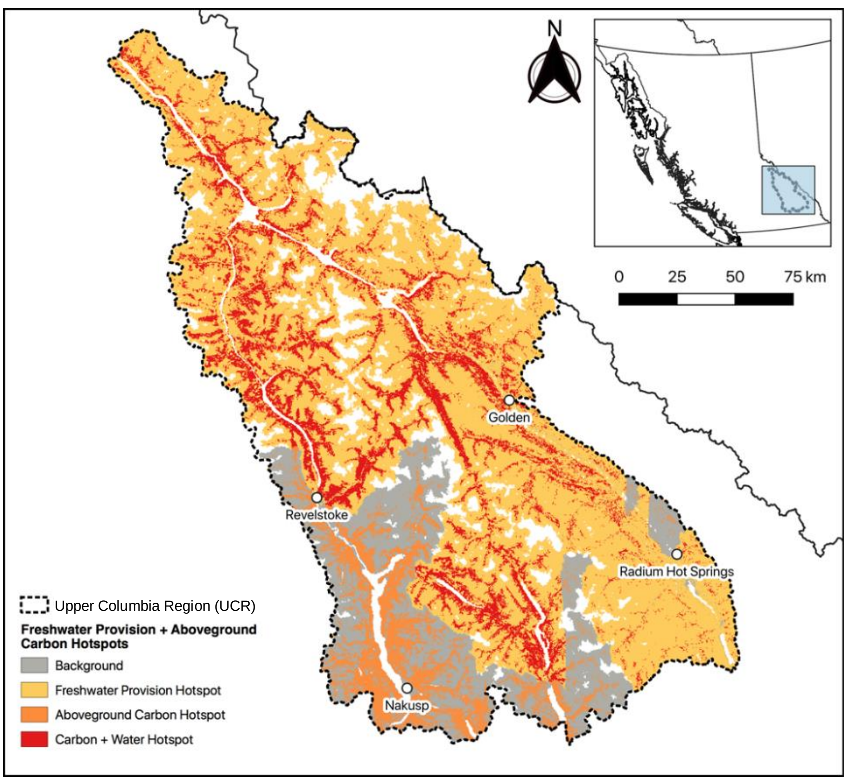
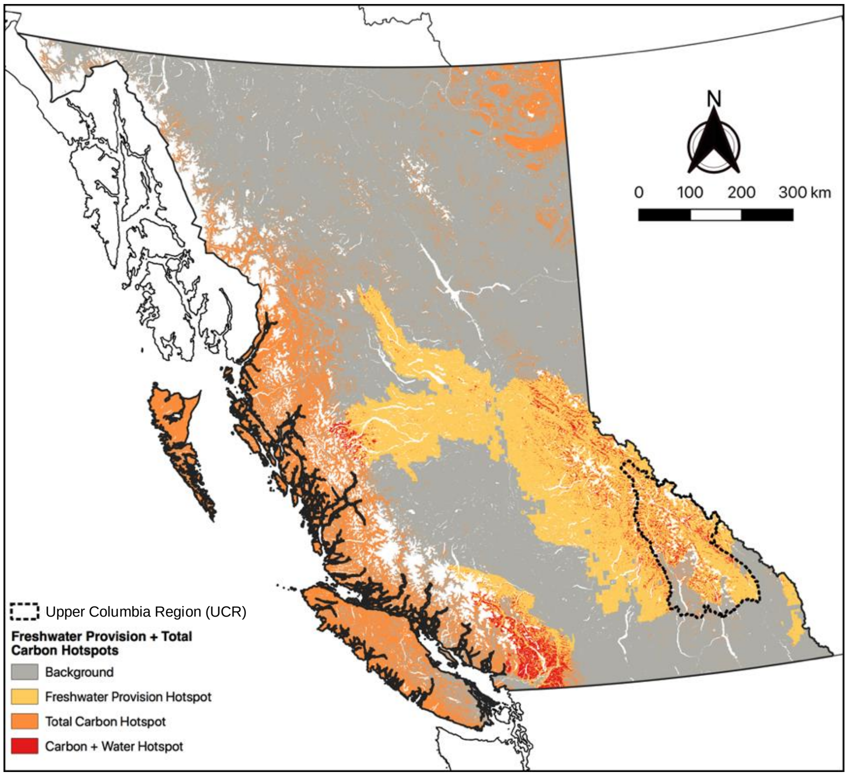


Figure 4-12. Overlap of aboveground carbon and freshwater provision hotspots in British Columbia and the Upper Columbia Region.



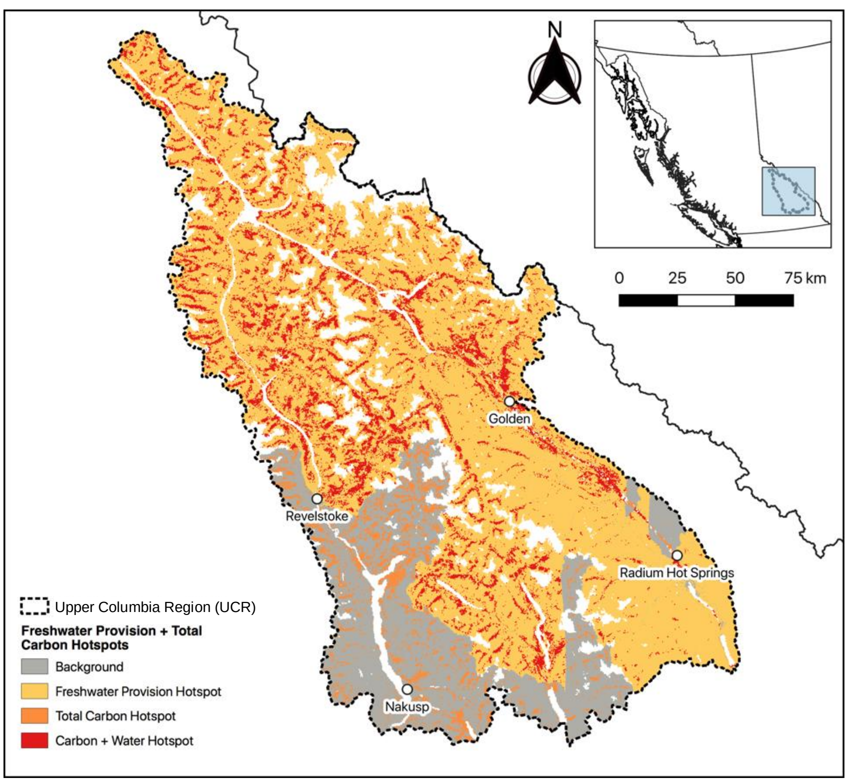


Figure 4-13. Overlap of total carbon and freshwater provision hotspots in British Columbia and the Upper Columbia Region.

4.5 Summary

While the UCR has only average densities of carbon stores and hotspots compared to the rest of BC, it has well above average levels of freshwater provision and a significantly higher density of freshwater provision hotspots than the rest of the province (Table 4-9). In particular, the UCR is one of three key areas in the province where freshwater capacity and provision hotspots overlap. The UCR also is an area where win-win conservation actions that target both carbon and freshwater could be targeted, as it has two to five times the density of overlapping carbon and freshwater provision hotspots as BC overall.

Table 4-9. Summary of ecosystem service hotspot densities in the Upper Columbia Region. *Dark blue* squares indicate values (km^2 hotspot area/100 km^2) less than half of average provincial values, *light blue* half to equal values, *light green* equal to double values, and *dark green* greater than double provincial averages.

	Carbon			Freshwater			Overlap	
	Above	Below	Total	Capacity	Demand	Provision	Above C + Water Prov.	Total C + Water Prov.
Upper Columbia	20.3	12.8	14.5	22.3	17.3	77.1	13.41	10.73

5. Ecosystem Service Provision in British Columbia's Southern Mountain Caribou Local Population Units

5.1 Introduction

We assessed carbon storage and freshwater provision in Southern Mountain Caribou Local Population Units (LPUs) compared to the rest of British Columbia. We focused on three broad groups of LPUs: Northern group (which includes the Chilcotin, Tweedsmuir, Telkwa, Takla, Wolverine, Chase, and Graham LPUs), Central group (Pine River, Quintette, and Narraway LPUs), and Southern group (Hart Ranges, Upper Fraser, Mount Robson, Quesnel Highlands, Wells Gray-Thompson, Revelstoke-Shuswap, Kinbasket, Central Kootenay, South Monashee, Southwest Kootenay, and Southeast Kootenay LPUs). In addition, three specific LPUs of conservation concern in the southern group (Hart Ranges, Revelstoke-Shuswap, and Central Kootenay) were analyzed and compared.

The assessment included estimating carbon stores and densities (amount of carbon per hectare) as well as the total area and density of carbon and freshwater provision hotspots (pixels with the top 20% of values across the province). Densities of hotspots were quantified as km^2 of hotspot area per 100 km^2 of terrestrial area. These hotspot analyses provide a preliminary comparison of caribou LPUs to the rest of the province for the conservation of ecosystem services. We split carbon into aboveground, belowground, and total carbon pools, and split freshwater provision into capacity (amount of runoff), demand (amount of downstream demand by humans), and provision (the overlap of capacity and demand). Finally, to identify areas where win-win conservation actions might be targeted, we assessed the overlap in hotspot/priority areas for carbon and freshwater; first the overlap between hotspot areas for aboveground carbon and water provision and then the overlap in hotspot areas for total carbon and water provision.

5.2 Carbon Storage

The caribou LPUs in BC store 7.3 gigatonnes of carbon (GtC) in total, with 1.5 GtC aboveground (20.1%) and 5.9 GtC (79.9%) belowground (Table 5-1). This equals 23.4% of the total carbon stored in the province. Overall, caribou LPUs in BC have carbon densities very close to provincial averages (Table 5-2). However, the Southern Group LPUs have slightly higher belowground and total carbon densities than the Northern and Central groups as well as provincial average values (Table 5-2, Figure 5-1), with the Hart Ranges having the highest densities out of the three Southern Group LPUs our analysis focused on. Of the total carbon stored in the LPUs, 59.6% is stored within the Southern Group, 28.3% in the Northern Group, and 12.1% in the Central Group. Similarly, aboveground carbon in forest vegetation across all the included LPUs is concentrated in the Southern Group (62.5%), with smaller amounts in the Northern Group (26.2%), and Central Group (11.3%).

Most caribou LPUs in all three groups have lower carbon hotspot densities than the provincial average for belowground, aboveground, and total carbon, as well as overlapping hotspots (Table 5-3, 5-4). The one exception is for the Southern Group and aboveground carbon, where average hotspot densities (28.4 $km^2/100km^2$) are much higher than the provincial average (18.4 $km^2/100km^2$). This is likely due to the fact that the Southern Group LPUs cover highly productive interior rainforests and ecosystems (Fig. 5-2). This high aboveground hotspot density is especially true for the Revelstoke-Shuswap LPU which has the highest density of aboveground carbon hotspots (30.3 $km^2/100km^2$) in our analysis. Overall, carbon hotspot densities in the Southern Group LPUs are significantly higher than those for the Northern and Central Groups (Fig. 5-2, Table 5-3). These same patterns are present for overlapping aboveground and belowground carbon hotspots, with much lower overlapping hotspot densities in the caribou LPUs compared to the provincial average, but higher densities overall in the Southern Group LPUs, and especially in the Hart Ranges, Revelstoke Shuswap and Central Kootenay LPUs.

Table 5-1. Carbon storage in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia. Numbers in parentheses represent proportions within BC.

Caribou LPU	Area (km²)	Aboveground Carbon (GtC)	Belowground Carbon (GtC)	Total Carbon (GtC)
Northern Group	67,463 (7.1%)	0.395 (7.5%)	1.730 (6.6%)	2.124 (6.8%)
Central Group	28,699 (3.0%)	0.170 (3.2%)	0.738 (2.8%)	0.908 (2.9%)
Southern Group	140,013 (14.8%)	0.941 (17.9%)	3.543 (13.6%)	4.481 (14.3%)
Hart Ranges	15,615 (1.6%)	0.094 (1.8%)	0.458 (1.8%)	0.552 (1.8%)
Revelstoke-Shuswap	18,428 (1.9%)	0.120 (2.3%)	0.490 (1.9%)	0.609 (1.9%)
Central Kootenay	12,767 (1.3%)	0.077 (1.5%)	0.349 (1.3%)	0.426 (1.4%)
Total for Caribou LPUs	*231,262 (24.4%)*	*1.480 (28.2%)*	*5.871 (22.5%)*	*7.347 (23.4%)*

Table 5-2. Average carbon densities in British Columbia southern mountain caribou local population units (LPUs).

Caribou LPU	Aboveground Carbon Density (MgC/ha)	Belowground Carbon Density (MgC/ha)	Total Carbon Density (MgC/ha)
Northern Group	58.56	256.46	314.83
Central Group	59.34	257.28	316.54
Southern Group	67.19	253.06	320.06
Hart Ranges	60.39	293.41	353.67
Revelstoke-Shuswap	65.31	265.72	330.75
Central Kootenay	60.29	273.44	333.60
Caribou LPU Mean	***64.02***	***253.85***	***317.69***
British Columbia Mean	*55.34*	*275.66*	*330.74*

Table 5-3. Carbon storage hotspot coverage in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia.

Caribou LPU	**Aboveground Carbon Hotspot Density (km²/100km²)**	**Belowground Carbon Hotspot Density (km²/100km²)**	**Total Carbon Hotspot Density (km²/100km²)**	**Overlapping Above/Below Carbon Hotspot Density (km²/100kms²)**
Northern Group	14.1	7.7	6.7	0.9
Central Group	11.3	5.6	5.1	0.5
Southern Group	28.4	7.6	8.8	1.8
Hart Ranges	21.5	14.3	14.5	2.4
Revelstoke-Shuswap	30.3	11.8	14.2	3.3
Central Kootenay	24.6	11.6	14.6	3.5
Total for Caribou LPUs	***22.3***	***7.2***	***7.6***	***1.4***
British Columbia	*18.4*	*18.2*	*18.3*	*5.5*

Table 5-4. Carbon storage hotspot area in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia. Numbers in parentheses represent proportions within BC.

Region	**Area (km²)**	**Aboveground Hotspots (km²)**	**Belowground Hotspots (km²)**	**Total Carbon Hotspots (km²)**	**Overlapping Above/Below Hotspots (km²)**
Northern Group	67,463 (7.1%)	9,514 (5.4%)	5,209 (3.0%)	4,495 (2.6%)	638 (1.2%)
Central Group	28,699 (3.0%)	3,234 (1.9%)	1,651 (1.0%)	1,468 (0.8%)	157 (0.3%)
Southern Group	140,013 (14.8%)	39,750 (22.8%)	10,573 (6.1%)	12,386 (7.2%)	2,481 (4.7%)
Hart Ranges	15,615 (1.6%)	3,352 (1.9%)	2,236 (1.3%)	2,259 (1.3%)	375 (0.7%)
Revelstoke-Shuswap	18,428 (1.9%)	5,575 (3.2%)	2,173 (1.3%)	2,624 (1.5%)	599 (1.1%)
Central Kootenay	12,767 (1.3%)	3,138 (1.8%)	1,480 (0.9%)	1,863 (1.1%)	447 (0.9%)
Total for Caribou LPUs	*231,262 (24.4%)*	*51,668 (29.6%)*	*16,695 (9.7%)*	*17,669 (10.2%)*	*3,167 (6.0%)*

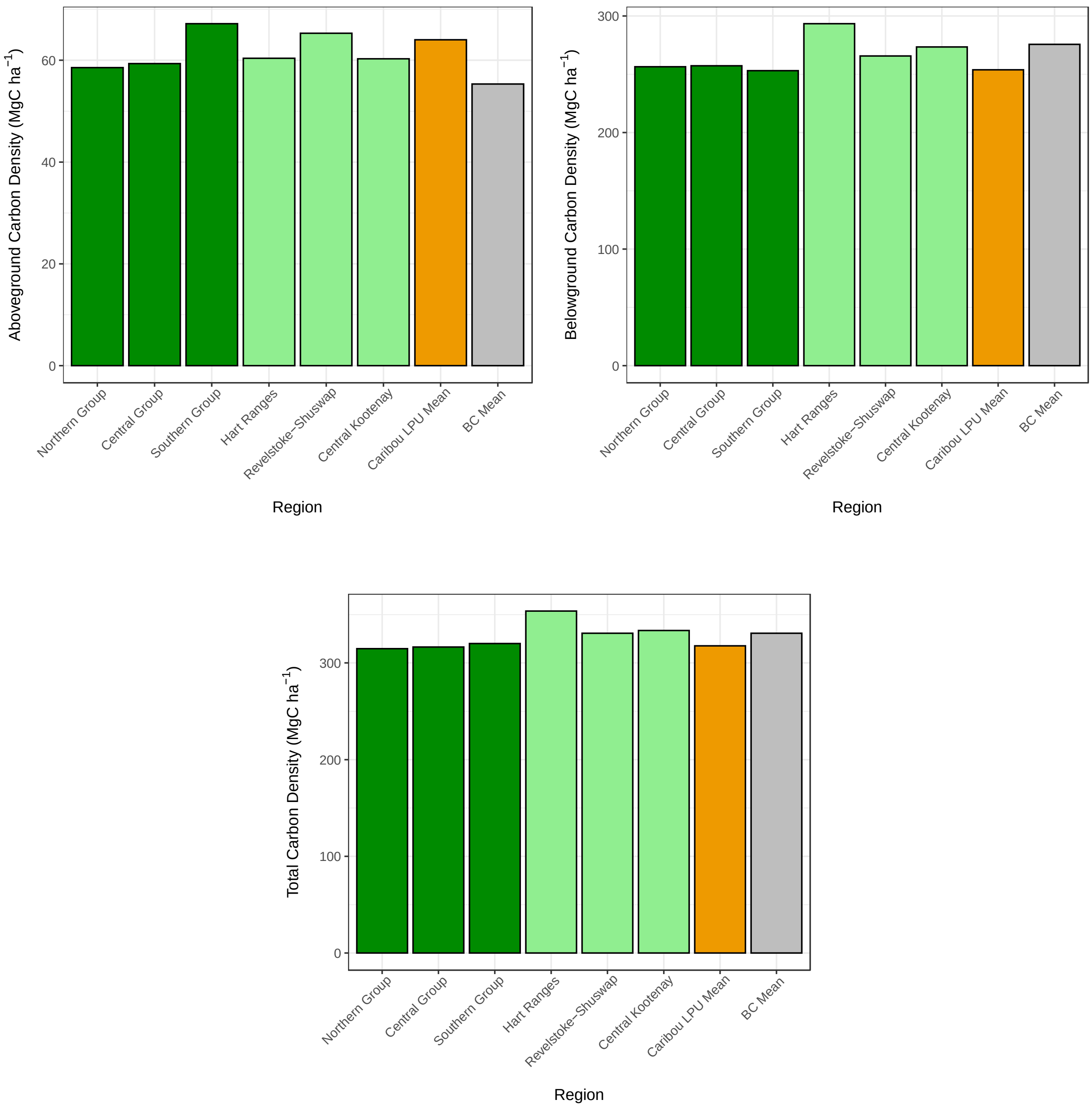


Figure 5-1. Average carbon densities in British Columbia's Southern Mountain Caribou Local Population Units. Dark green columns are broad LPU groups, light green columns specific LPUs of interest within the Southern Group LPUs, orange column identifies the overall average value for all LPUs, grey column is the provincial average.

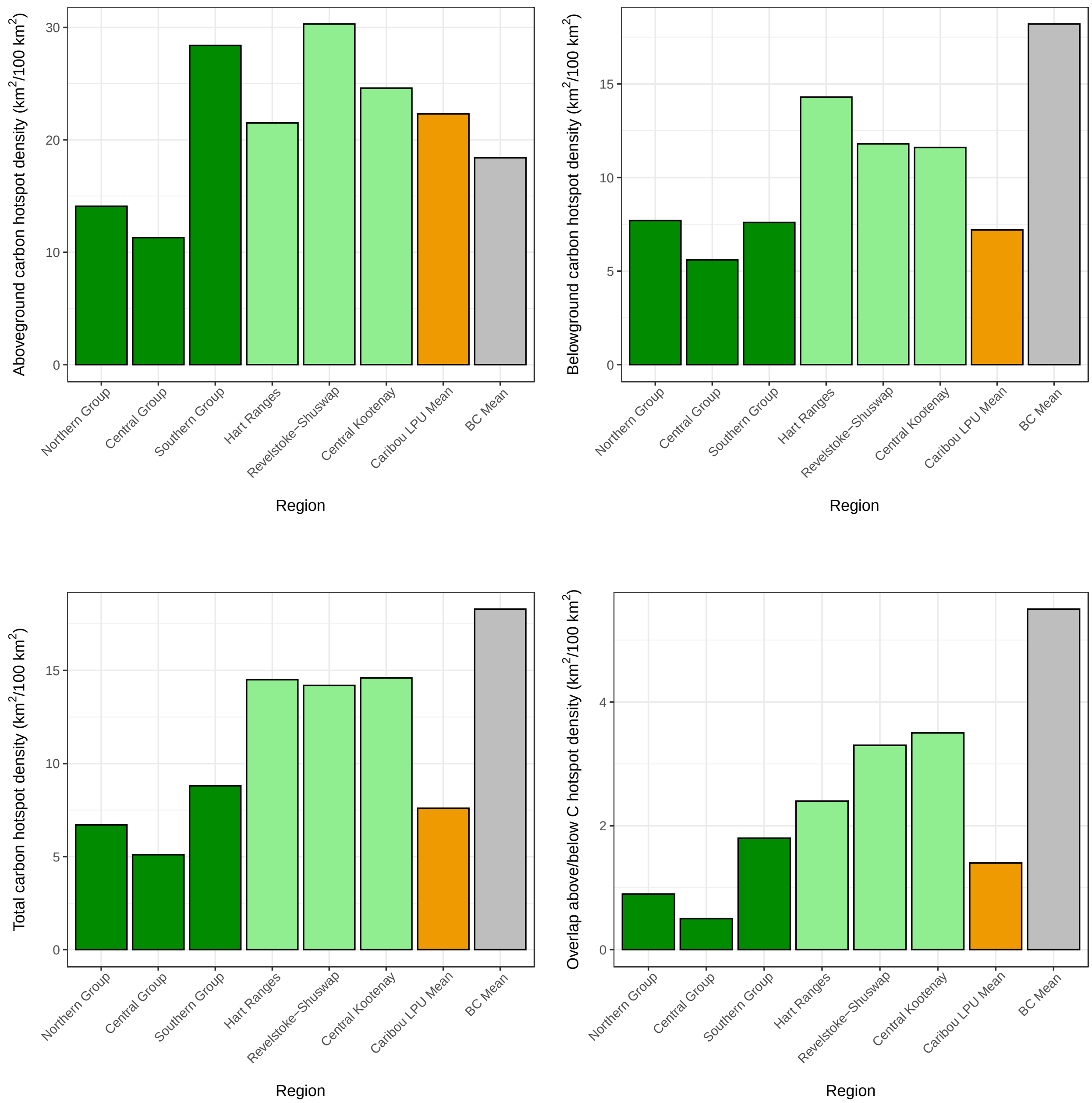


Figure 5-2. Carbon hotspot densities in British Columbia's Southern Mountain Caribou Local Population Units. Dark green columns are broad LPU groups, light green columns specific LPUs of interest within the Southern Group LPUs, orange column identifies the overall average value for all LPUs, grey column is the provincial average.

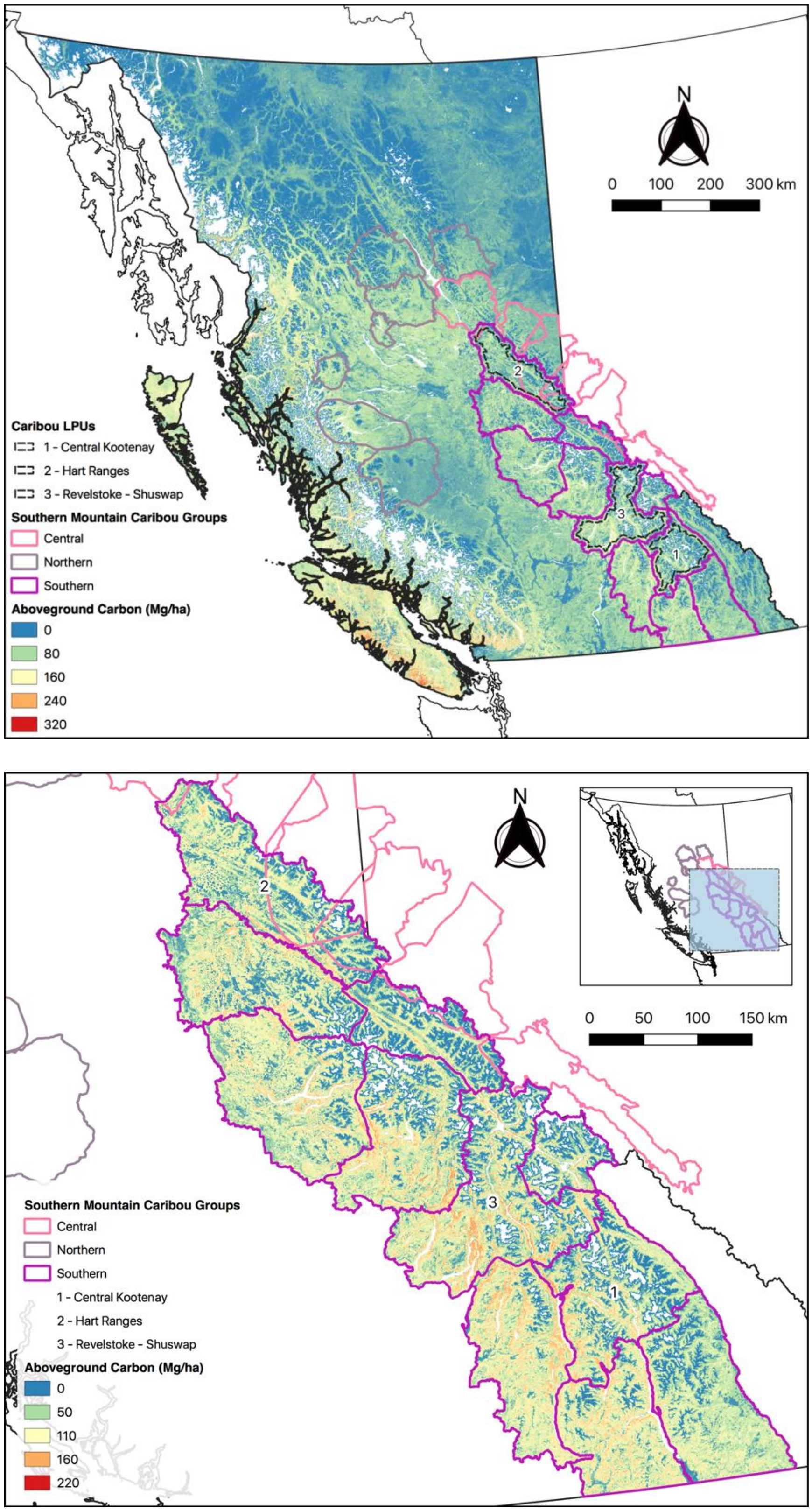


Figure 5-3. Aboveground carbon storage in Mg/ha in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.

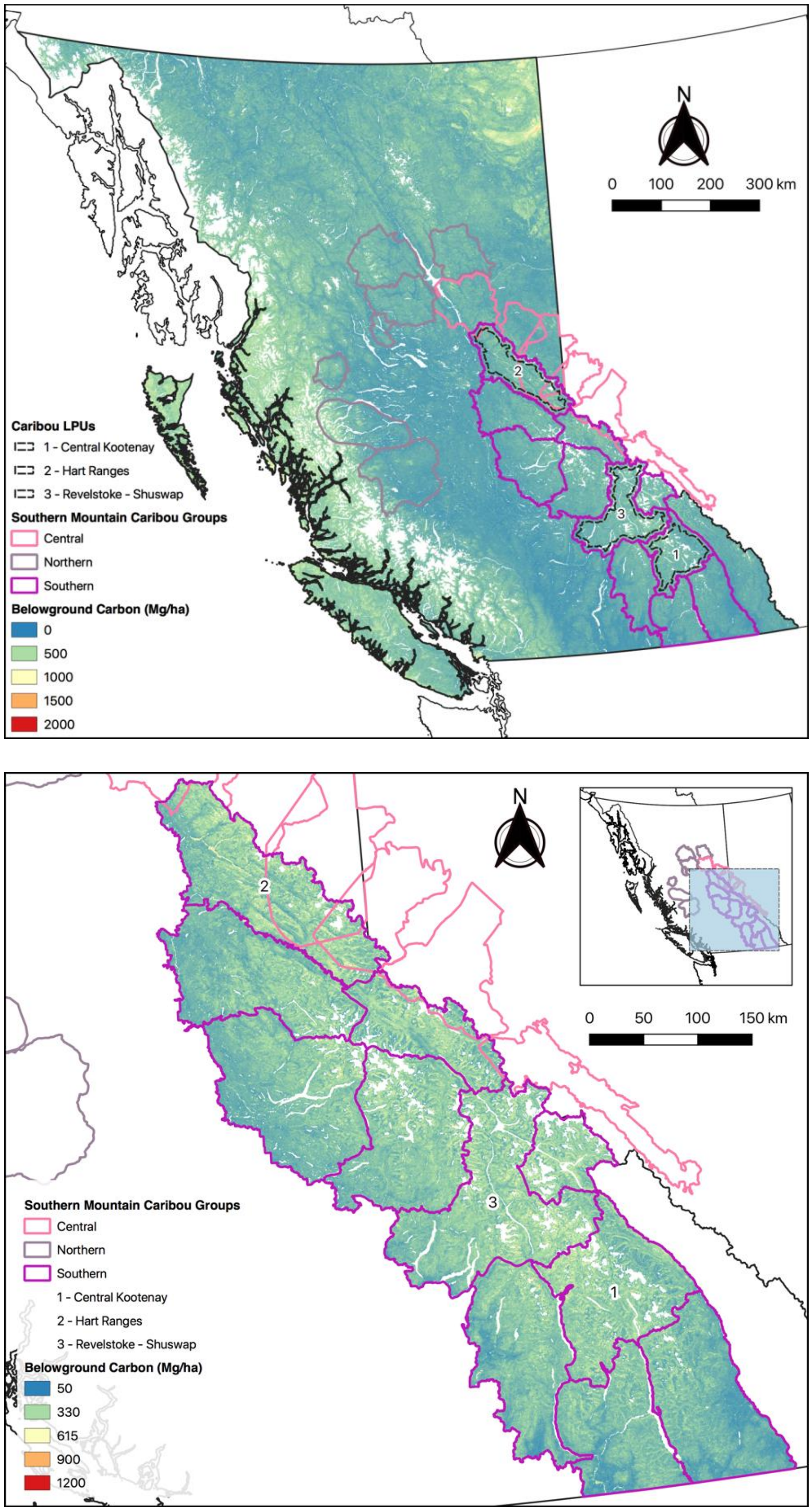


Figure 5-4. Belowground carbon storage in Mg/ha in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.

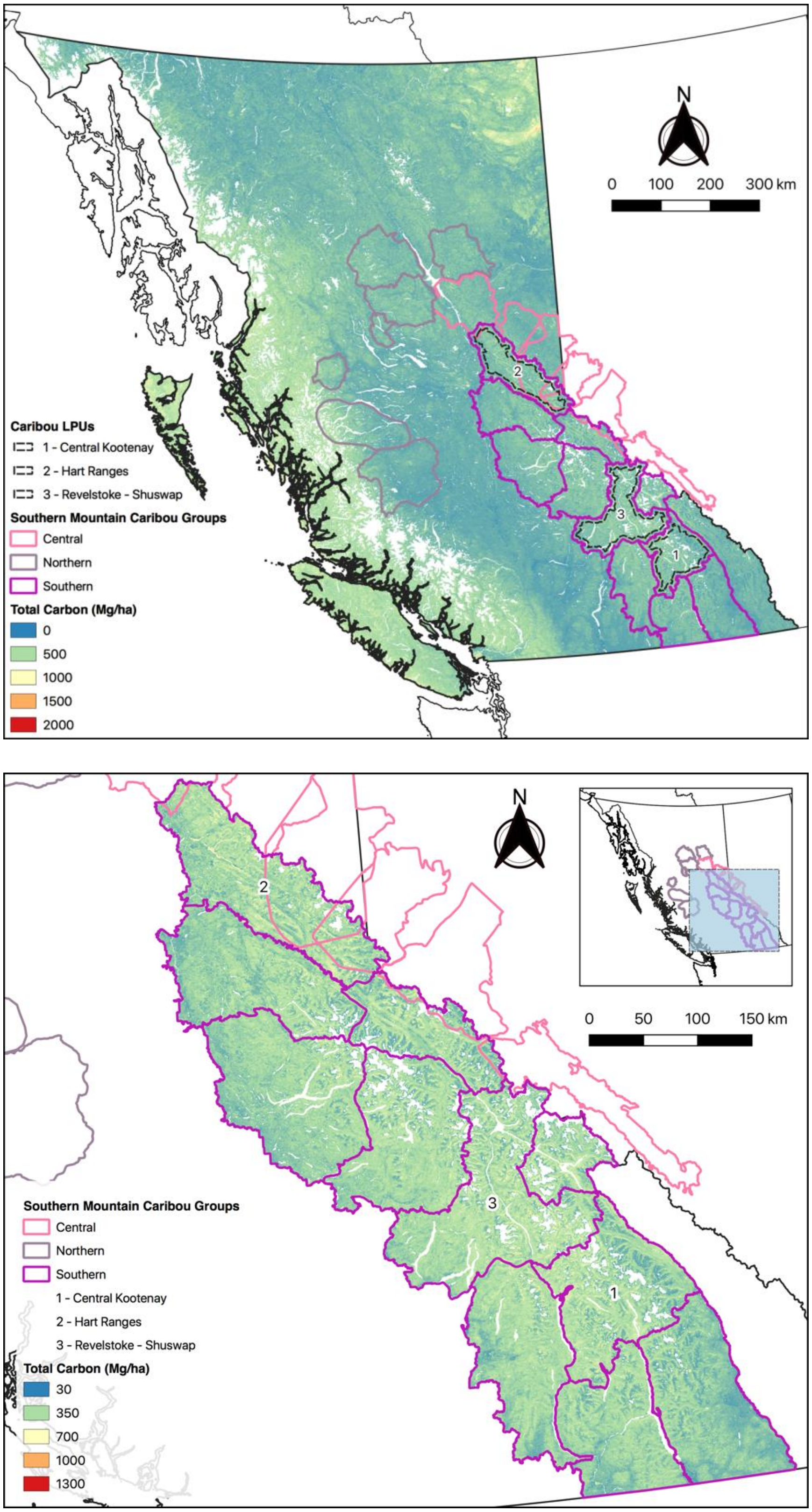


Figure 5-5. Total carbon storage in Mg/ha in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.

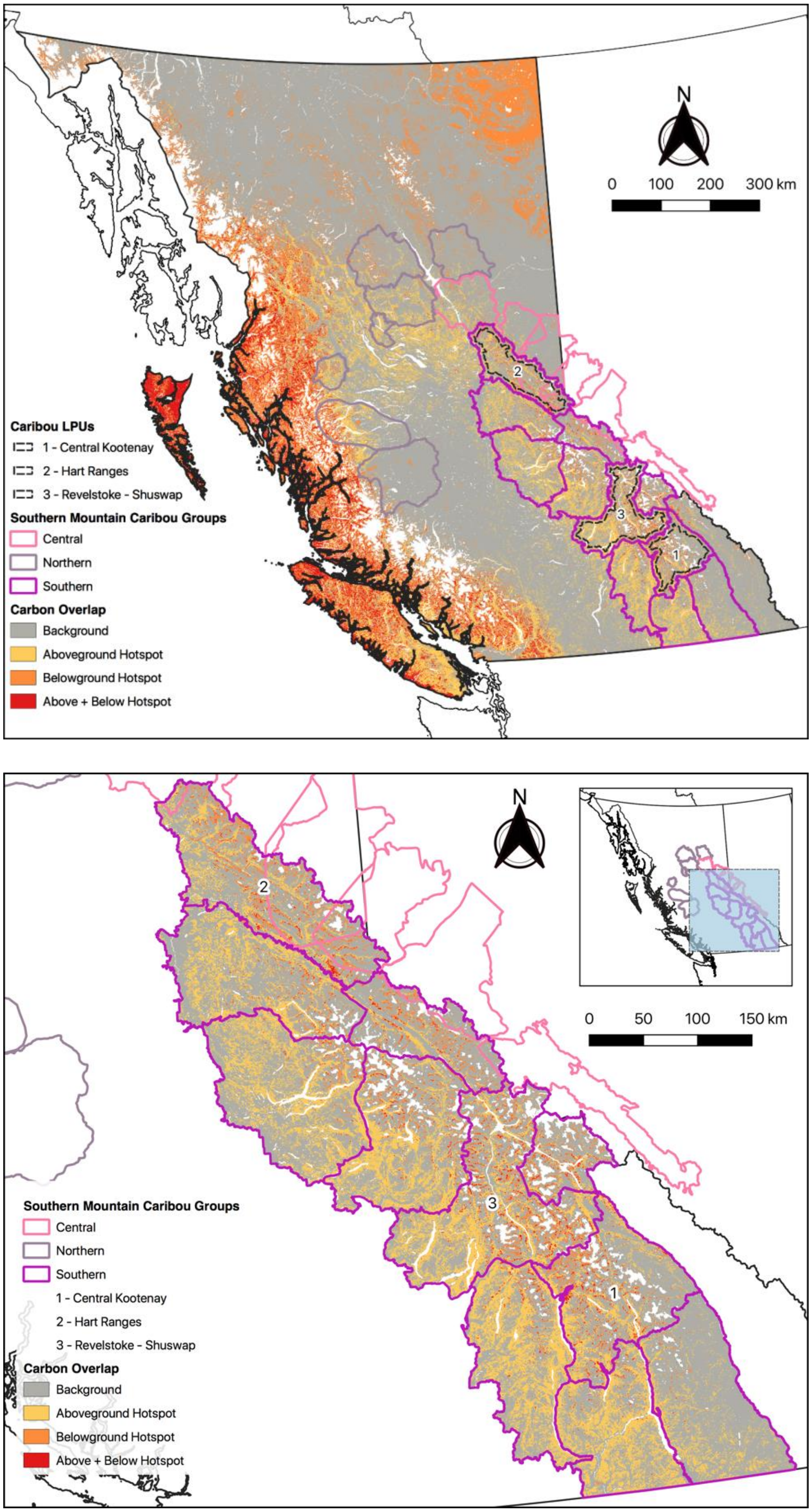


Figure 5-6. Carbon storage hotspots (top 20th percentile of values) and overlap in BC southern mountain caribou local population units (LPUs).

5.3 Freshwater Provision

At the provincial level, BC's southern mountain caribou LPUs encompass very few freshwater capacity hotspots, but a disproportionately large proportion of provincial hotspots for freshwater demand and provision. This is especially true for the Northern and Southern Group LPUs, that have respective densities of 32.2 and 56.1 km^2 of demand hotspots per 100 km^2 area compared to an average of 20.0 km^2 per 100 km^2 provincially; and respective densities of 21.1 and 70.1 km^2 of provision hotspots per 100 km^2 area compared to 20.0 km^2 per km^2 provincially (Table 5-5). In particular, the Southern Group LPUs, which cover just under 15% of BC, encompass over 40% of freshwater demand hotspots and over 50% of freshwater provision hotspots (Table 5-6). Overlapping hotspot densities are highest and greater than provincial averages in the Southern Group LPUs (4.9 versus 3.5 km^2 hotspots per 100 km^2) and in particular in the Revelstoke-Shuswap LPU (30.1 km^2 hotspots per 100 km^2), whose density of overlapping hotspots is almost 18 times the provincial average (Figure 5-7).

Similar patterns also occur for the individual LPUs of interest in the Southern Group, especially for the Revelstoke-Shuswap LPU that has an extremely high density of freshwater provision hotspots (95.7 km^2 hotspots per 100 km^2 area) and covers just 2% of the province but has almost 10% of the freshwater provision hotspots. The Hart Ranges LPU, which covers the headwaters of the Fraser River, also stands out, covering just 1.6% of the province but over 5% of provincial demand and provision hotspots (Table 5-6). The Hart Ranges LPU also has the highest density of demand hotspots (65.1 km^2 of hotspots per 100 km^2 area) of the LPUs analysed. These Southern Group LPUs are located in areas of relatively high rainfall and runoff along the southeast mountain chains of BC, and are connected to significant downstream demand from human settlements, industry, and agriculture in BC and the northwest USA. The estimation of freshwater demand downstream in BC includes demand in the USA from settlements and agriculture, but not dams or industry, and is therefore likely an underestimate of transboundary demand and freshwater provision.

Across all of the caribou LPU regions, over three-quarters of the freshwater hotspots within these regions occur in the Southern Group (capacity: 77.2%, demand: 78.3%, provision: 87.3%) even though this region covers only 60.5% of the total LPU area analyzed here for southern mountain caribou. The remaining proportion of hotspots across the caribou LPUs occur mainly in the Northern Group (12.7-22.8%), with a very small component within the Central Group (0.0-4.5%). Overlapping hotspots of freshwater capacity and provision occur mainly in the Southern Group (6,842 km^2 or 41.6%) and Northern Group (1,280 km^2 or 7.8%) LPUs, while none are found within the Central Group. In particular, the Revelstoke-Shuswap LPU contains a disproportionately high amount of these overlapping hotspots, with 4,439 km^2 (27.0%).

Table 5-5. Freshwater hotspot densities in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia.

Caribou LPU	**Capacity Hotspot Density ($km^2/100km^2$)**	**Demand Hotspot Density ($km^2/100km^2$)**	**Provision Hotspot Density ($km^2/100km^2$)**	**Overlapping Cap/Pro Hotspot Density ($km^2/100km^2$)**
Northern Group	3.6	32.2	21.2	1.9
Central Group	0.0	15.8	15.7	0.0
Southern Group	5.9	56.1	70.1	4.9
Hart Ranges	0.0	65.1	64.8	0.0
Revelstoke-Shuswap	25.4	39.6	95.7	30.1
Central Kootenay	11.7	28.2	62.3	2.3
Total for Caribou LPUs	***4.6***	***43.4***	***48.6***	***3.5***
British Columbia	*20.0*	*20.0*	*20.0*	*1.7*

Table 5-6. Freshwater hotspot coverage in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia. Numbers in parentheses represent proportions within BC.

Region	**Area (km^2)**	**Capacity Hotspots (km^2)**	**Demand Hotspots (km^2)**	**Provision Hotspots (km^2)**	**Overlapping Cap/Pro Hotspots (km^2)**
Northern Group	67,463 (7.1%)	2,453 (1.3%)	21,749 (11.5%)	14,276 (7.5%)	1,280 (7.8%)
Central Group	28,699 (3.0%)	0 (0.0%)	4,530 (2.4%)	4,520 (2.4%)	0 (0.0%)
Southern Group	140,013 (14.8%)	8,291 (4.4%)	78,511 (41.5%)	98,122 (51.8%)	6,842 (41.6%)
Hart Ranges	15,615 (1.6%)	0 (0.0%)	10,158 (5.4%)	10,125 (5.3%)	0 (0.0%)
Revelstoke-Shuswap	18,428 (1.9%)	4,689 (2.5%)	7,296 (3.9%)	17,635 (9.3%)	4,439 (27.0%)
Central Kootenay	12,767 (1.3%)	1,488 (0.8%)	3,601 (1.9%)	7,955 (4.2%)	288 (1.7%)
Total for Caribou LPUs	*231,262 (24.4%)*	*10,744 (5.7%)*	*100,291 (53.0%)*	*112,431 (59.3%)*	*8,122 (49.3%)*

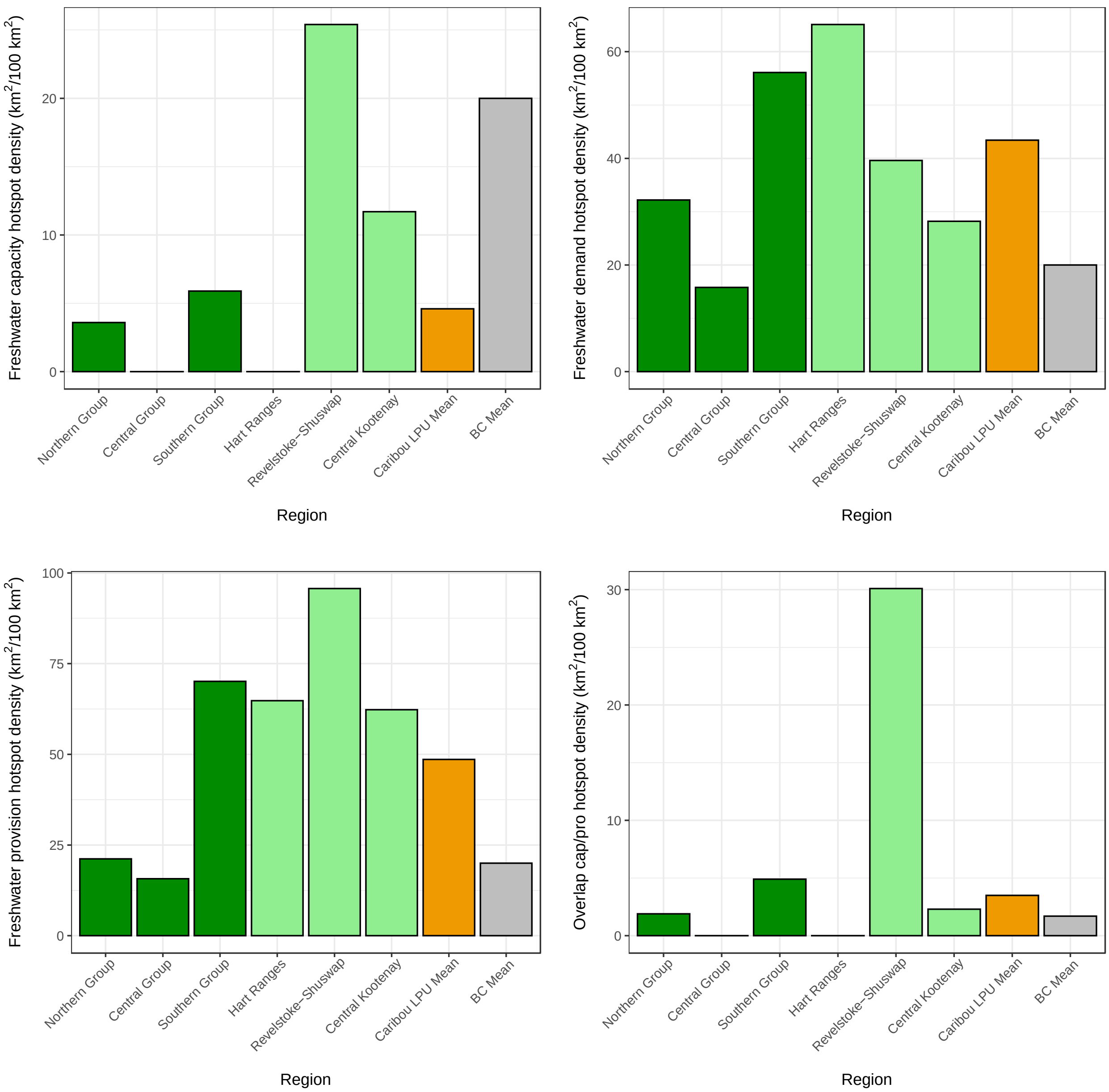


Figure 5-7. Freshwater hotspot densities in British Columbia's Southern Mountain Caribou Local Population Units. Dark green columns are broad LPU groups, light green columns specific LPUs of interest within the Southern Group LPUs, the orange column identifies the overall average value for all LPUs, and the grey column the provincial average. The overlapping hotspot density figure refers to overlapping hotspots for freshwater capacity and provision.

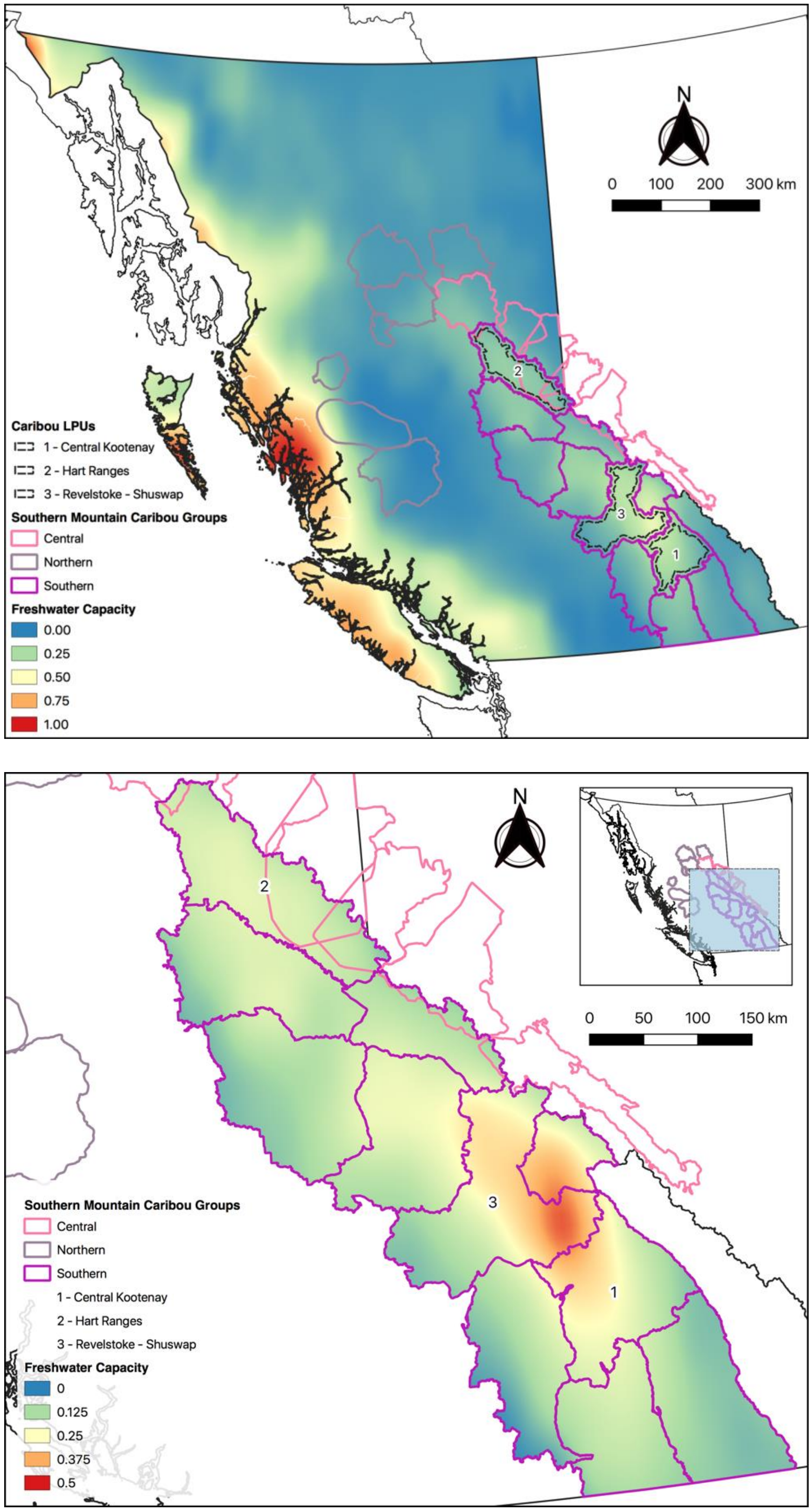


Figure 5-8. Freshwater capacity importance in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.

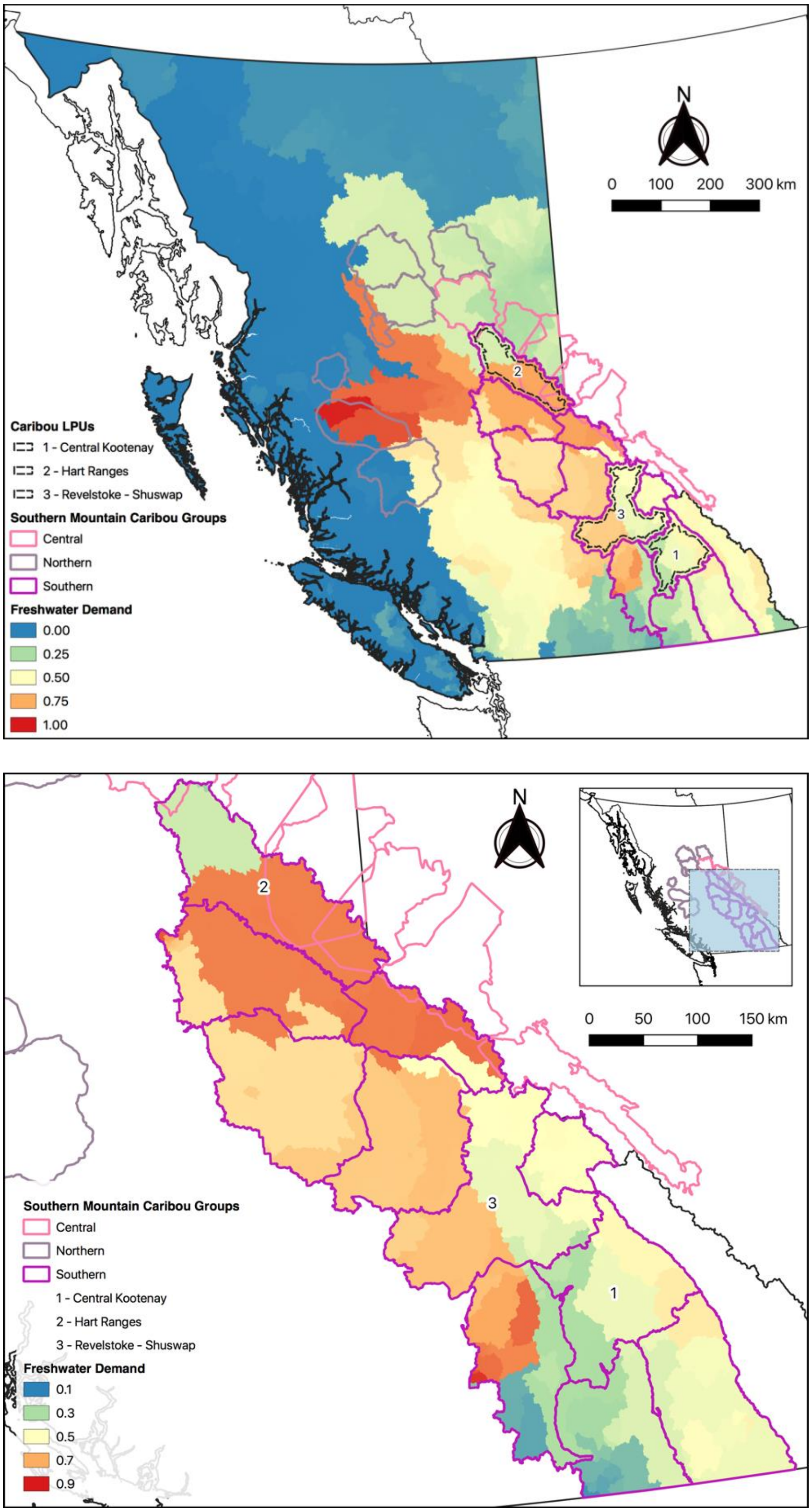


Figure 5-9. Freshwater demand importance in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.

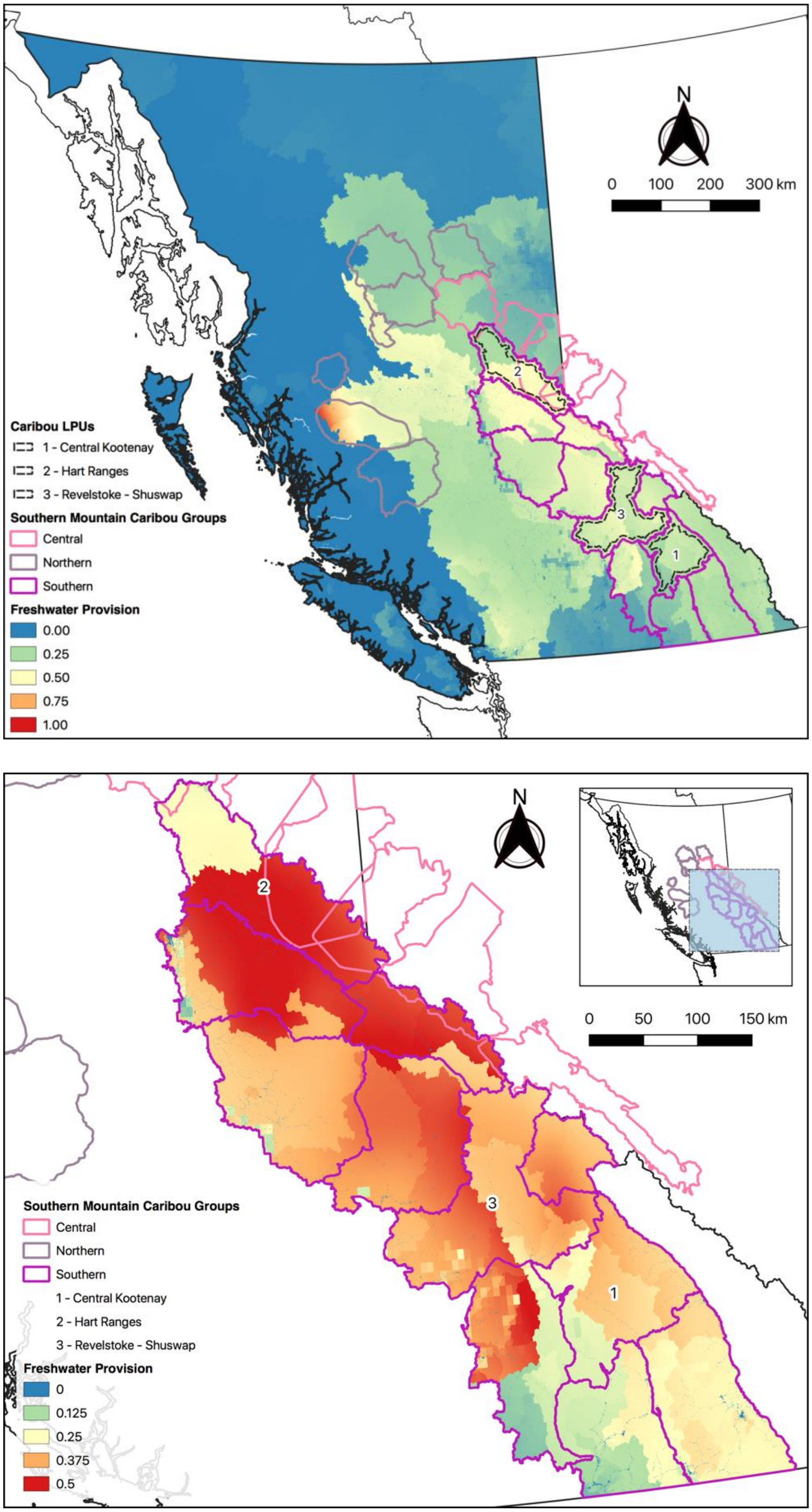
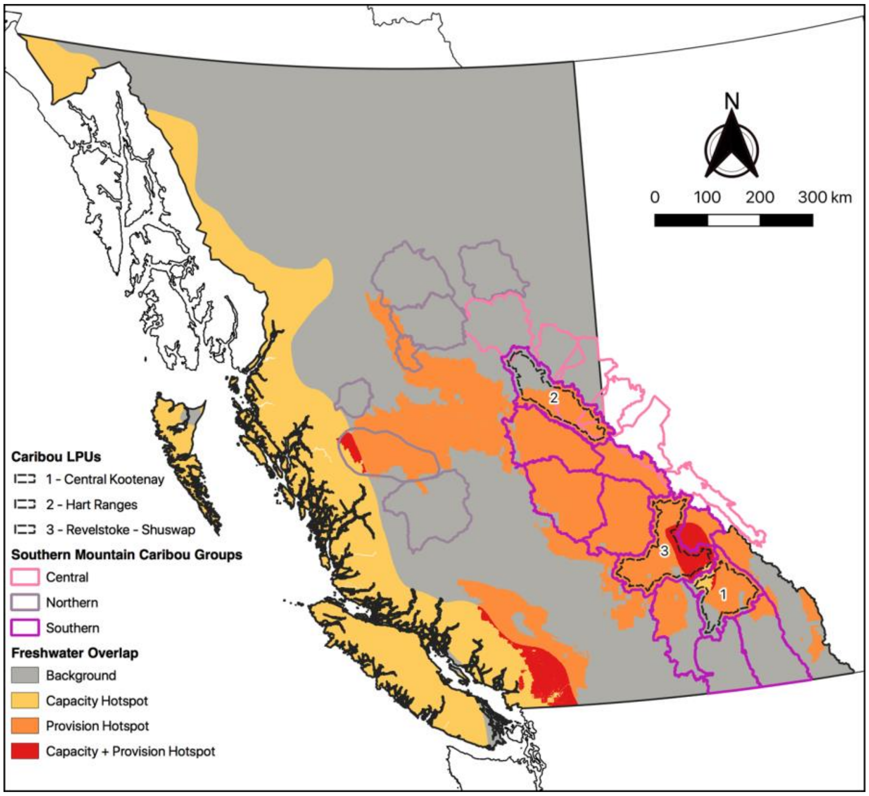


Figure 5-10. Freshwater provision importance in BC southern mountain caribou local population units (LPUs). Note that the legend has been rescaled for the Southern Group map.



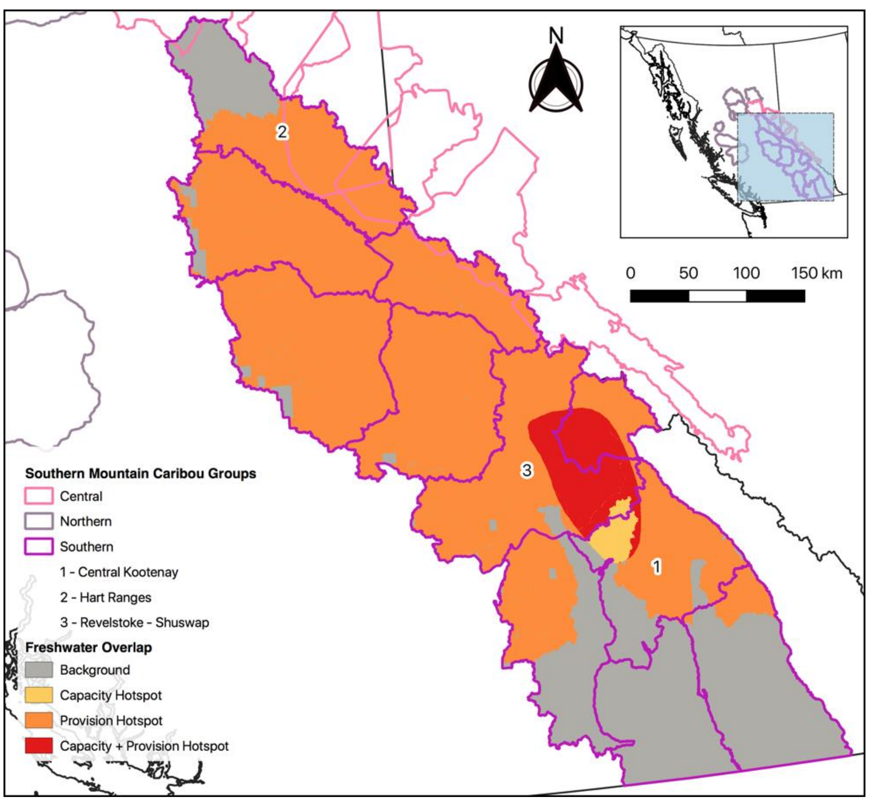


Figure 5-11. Freshwater hotspots (top 20th percentile of values) in BC southern mountain caribou local population units (LPUs).

5.4 Overlapping Ecosystem Service Hotspots

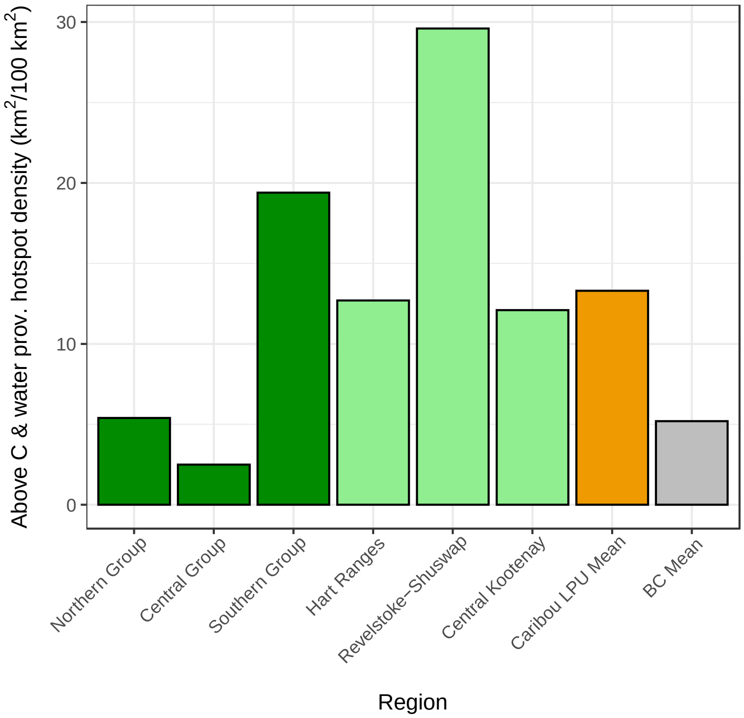
Overall, the Southern Mountain Caribou LPUs in BC cover a disproportionate amount of the overlapping carbon and freshwater provision hotspots in the province. Aboveground carbon and freshwater provision hotspot density across all caribou LPUs is two and a half times the provincial average (13.3 versus 5.2 km^2 hotspots per 100 km^2 area) and 2.3 times the provincial average for total carbon and freshwater provision (4.8 versus 2.1 km^2 hotspots per 100 km^2 area). These densities are highest in the Southern Group LPUs and especially in the Revelstoke-Shuswap LPU (Table 5-7). The Southern Group, while only covering 15% of BC, includes over 55% of the overlapping aboveground carbon and freshwater provision hotspots, and just under 50% of the overlapping total carbon and freshwater provision hotspots (Table 5-8). The Revelstoke-Shuswap and Hart Ranges LPUs have the greatest proportion of these overlapping hotspots. Both cover under 2% of the province, but the Hart Ranges has 8% and the Revelstoke-Shuswap just under 13% of the overlapping total carbon and freshwater provision hotspots.

Table 5-7. Overlapping ecosystem service hotspot density in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia.

Caribou LPU	**Aboveground Carbon and Freshwater Provision Hotspot Density ($km^2/100km^2$)**	**Total Carbon and Freshwater Provision Hotspot Density ($km^2/100km^2$)**
Northern Group	5.4	2.0
Central Group	2.5	2.3
Southern Group	19.4	6.9
Hart Ranges	12.7	9.9
Revelstoke-Shuswap	29.6	13.5
Central Kootenay	12.1	7.1
Total for Caribou LPUs	***13.3***	***4.8***
British Columbia	*5.2*	*2.1*

Table 5-8. Combined ecosystem services hotspot area in southern mountain caribou local population units (LPUs) and percent coverage within British Columbia. Numbers in parentheses represent proportions within BC.

Caribou LPU	Area (km²)	Aboveground Carbon and Freshwater Provision Hotspot Area (km²)	Total Carbon and Freshwater Provision Hotspot Area (km²)
Northern Group	67,463 (7.1%)	3,611 (7.4%)	1,381 (7.1%)
Central Group	28,699 (3.0%)	728 (1.5%)	648 (3.3%)
Southern Group	140,013 (14.8%)	27,228 (55.6%)	9,637 (49.4%)
Hart Ranges	15,615 (1.6%)	1,976 (4.0%)	1,539 (7.9%)
Revelstoke-Shuswap	18,428 (1.9%)	5,449 (11.1%)	2,492 (12.8%)
Central Kootenay	12,767 (1.3%)	1,546 (3.2%)	901 (4.6%)
Total for Caribou LPUs	***231,262 (24.4%)***	***30,839 (62.9%)***	***11,021 (56.5%)***
British Columbia	*947,536*	*49,008*	*19,509*



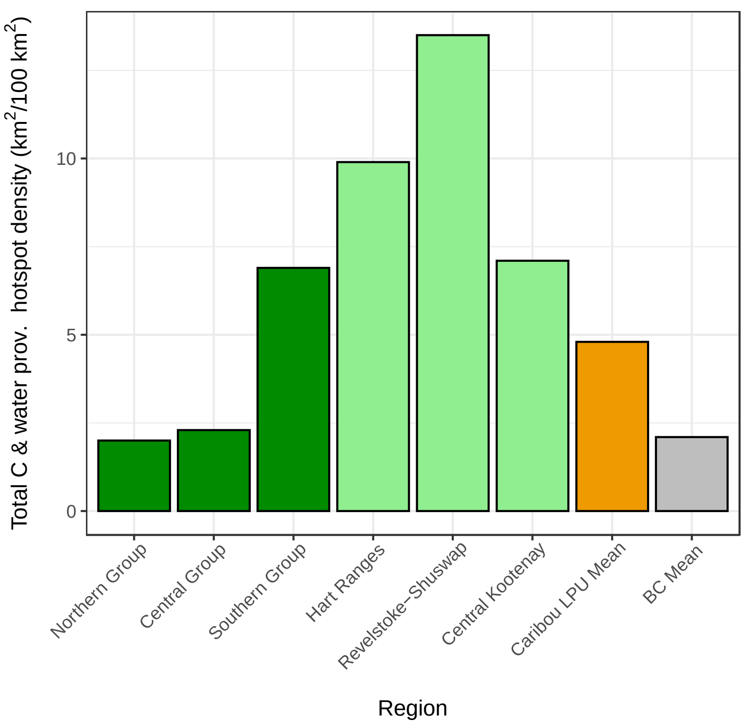


Figure 5-12. Overlapping ecosystem service hotspot densities in British Columbia's Southern Mountain Caribou Local Population Units. Dark green columns are broad LPU groups, light green columns specific LPUs of interest within the Southern Group LPUs, the orange column identifies the overall average value for all LPUs, and the grey column the provincial average.

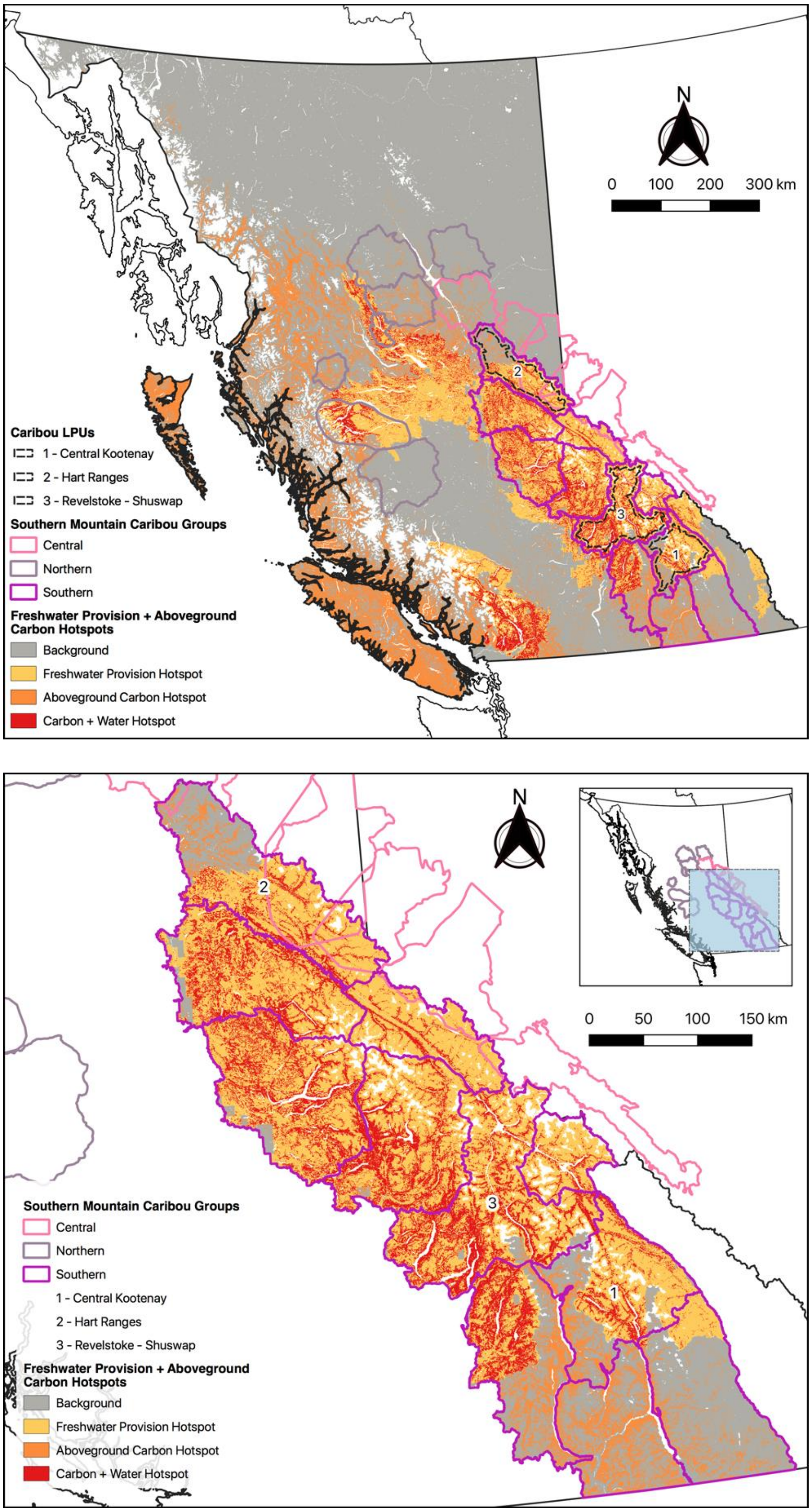
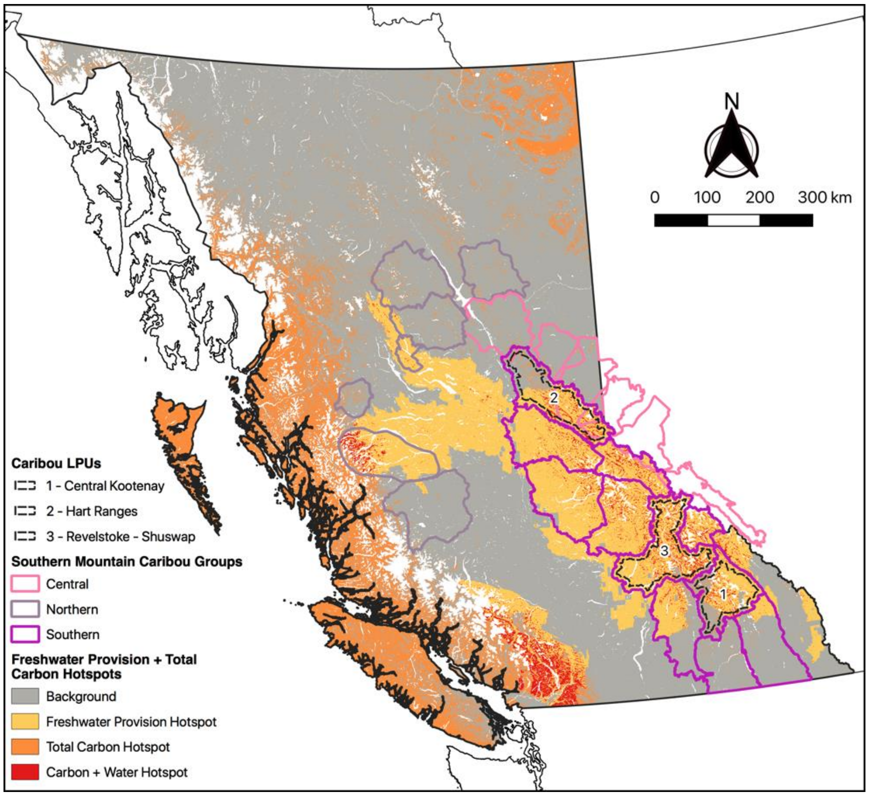


Figure 5-13. Overlap of aboveground carbon and freshwater provision hotspots in British Columbia and the province's Southern Mountain Caribou LPUs.



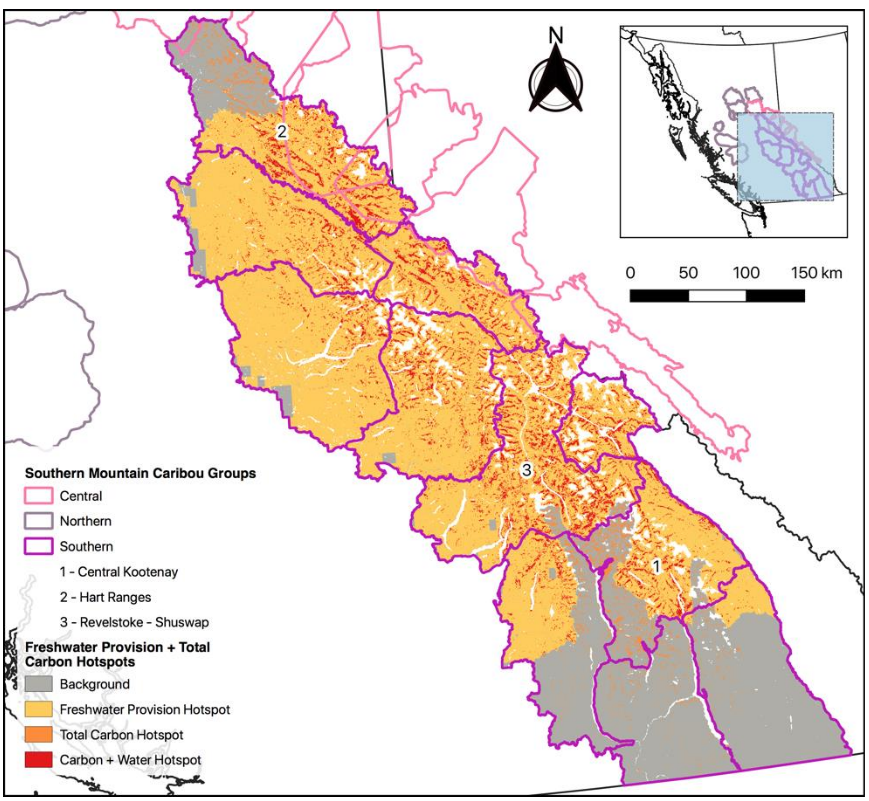


Figure 5-14. Overlap of total carbon and freshwater provision hotspots in British Columbia and the province's Southern Mountain Caribou LPUs.

5.5 Summary

Southern Mountain Caribou LPUs in British Columbia should be a conservation priority for freshwater provision and actions that can target and protect both carbon and freshwater provision (Table 5-9). These trends are primarily driven by the Southern Group LPUs, which have significantly higher densities of freshwater demand and provision hotspots and overlapping carbon and freshwater provision hotspots. In contrast, the Central Group LPUs have below provincial average densities for most ecosystem service components except overlap between total carbon and freshwater provision, while the Northern Group LPUs have above average densities for freshwater demand and provision, and overlapping aboveground carbon and freshwater provision hotspots. Thus, the Southern Group LPUs, and in particular the Revelstoke-Shuswap LPU, represent an important priority for conserving both Southern Mountain Caribou and carbon and freshwater ecosystem services.

Table 5-9. Summary of ecosystem service hotspot densities for Southern Mountain Caribou LPUs. *Dark blue* squares indicate values (km^2 hotspot area/100 km^2) less than half of average provincial values, *light blue* half to equal values, *light green* equal to double values, and *dark green* are greater than double provincial averages.

	Carbon			Freshwater			Overlap	
	Above	Below	Total	Capacity	Demand	Provision	Above C + Water Prov.	Total C + Water Prov.
Northern Group	14.1	7.7	6.7	3.6	32.2	21.2	5.4	2.0
Central Group	11.3	5.6	5.1	0.0	15.8	15.7	2.5	2.3
Southern Group	28.4	7.6	8.8	5.9	56.1	70.1	19.4	6.9
Hart Ranges	21.5	14.3	14.5	0.0	65.1	64.8	12.7	9.9
Revelstoke-Shuswap	30.3	11.8	14.2	25.4	39.6	95.7	29.6	13.5
Central Kootenay	24.6	11.6	14.6	11.7	28.2	62.3	12.1	7.1
All Caribou LPUs	***22.3***	***7.2***	***7.6***	***4.6***	***43.4***	***48.6***	***13.3***	***4.8***

6. References

1. Anderson, B.J., Armsworth, P.R., Eigenbrod, F., Thomas, C.D., Gillings, S., Heinemeyer, A., Roy, D.B. & Gaston, K.J. (2009) Spatial covariance between biodiversity and other ecosystem service priorities. *Journal of Applied Ecology*, **46**, 888–896.
2. Asner, G.P., Powell, G.V.N., Mascaro, J., Knapp, D.E., Clark, J.K., Jacobson, J., Kennedy-Bowdoin, T., Balaji, A., Paez-Acosta, G., Victoria, E., Secada, L., Valqui, M. & Hughes, R.F. (2010) High-resolution forest carbon stocks and emissions in the Amazon. *Proceedings of the National Academy of Sciences*, **107**, 16738–16742.
3. Balk, D.L., Deichmann, U., Yetman, G., Pozzi, F., Hay, S.I. & Nelson, A. (2006) Determining Global Population Distribution: Methods, Applications and Data. *Advances in Parasitology*, **62**, 119–156.
4. Beaudoin, A., Bernier, P.Y., Guindon, L., Villemaire, P., Guo, X.J., Stinson, G., Bergeron, T., Magnussen, S. & Hall, R.J. (2014) Mapping attributes of Canada's forests at moderate resolution through kNN and MODIS imagery. *Canadian Journal of Forest Research*, **44**, 521–532.
5. Brauman, K.A., Daily, G.C., Duarte, T.K. & Mooney, H.A. (2007) The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review Of Environment And Resources*, **32**, 67–98.
6. Canada, S. (2013) Human Activity and the Environment: Measuring Ecosystem Goods and Services in Canada.
7. Convention on Biodiversity. 2020. Zero Draft of the Post-2020 Global Biodiversity Framework. Available at: https://www.cbd.int/doc/c/efb0/1f84/a892b98d2982a829962b6371/wg2020-02-03-en.pdf. Accessed August 2020.
8. CEC. (2017) 2010 Land Cover of North America at 30 meters.
9. Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C. & Daily, G.C. (2006) Conservation planning for ecosystem services. *Plos Biology*, **4**, 2138–2152.
10. CIESIN, IFPRICIAT. (2011) Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Settlement Points.
11. Clark, R.N. & Stankey, G. (1979) The Recreation Opportunity Spectrum: a Framework for Planning, Management, and Research.
12. Costanza, R. (2008) Ecosystem services: multiple classification systems are needed. *Biological Conservation*, **141**, 350–352.
13. Darvill, R. & Lindo, Z. (2014) Quantifying and mapping ecosystem service use across stakeholder groups: Implications for conservation with priorities for cultural values. *Ecosystem Services*, 1–9.
14. Döll, P., Kaspar, F. & Lehner, B. (2003) A global hydrological model for deriving water availability indicators: model tuning and validation. *Journal of Hydrology*, **270**, 105–134.
15. Durán, A.P., Casalegno, S., Marquet, P.A. & Gaston, K.J. (2013) Representation of Ecosystem Services by Terrestrial Protected Areas: Chile as a Case Study (ed EG Lamb). *Plos One*, **8**, e82643.
16. ECCC. (2016) Canadian Environmental Sustainability Indicators: Water Withdrawal and Consumption by Sector. Ottawa.
17. Egoh, B.N., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C. & van Jaarsveld, A.S. (2008) Mapping ecosystem services for planning and management. *Agriculture Ecosystems & Environment*, **127**, 135–140.
18. Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S. & Tordoff, A. (2004) Key Biodiversity Areas as Site Conservation Targets. *BioScience*, **54**, 1110.
19. England, N. (2017) Monitor of Engagement with the Natural Environment Survey. Natural England.
20. GeoFabrik. (2017) Canada OpenStreetMap Data.
21. Gillis, M.D., Omule, A.Y. & Brierley, T. (2005) Monitoring Canada's forests: The National Forest Inventory. *The Forestry Chronicle*, **81**, 214–221.

22. Government of Canada. 2020. Canada Target 1 Challenge. Available at: https://www.canada.ca/en/environment-climate-change/services/nature-legacy/canada-target-one-challenge.html. Accessed August 2020.

23. Hengl, T., Mendes de Jesus, J., Heuvelink, G.B.M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M.N., Geng, X., Bauer-Marschallinger, B., Guevara, M.A., Vargas, R., MacMillan, R.A., Batjes, N.H., Leenaars, J.G.B., Ribeiro, E., Wheeler, I., Mantel, S. & Kempen, B. (2017) SoilGrids250m: Global gridded soil information based on machine learning (ed B Bond-Lamberty). *Plos One*, **12**, e0169748–40.

24. Jensen, F.S. & Koch, N.E. (2010) Twenty-five Years of Forest Recreation Research in Denmark and its Influence on Forest Policy. *Scandinavian Journal of Forest Research*, **19**, 93–102.

25. Joyce, K. & Sutton, S. (2009) A method for automatic generation of the Recreation Opportunity Spectrum in New Zealand. *Applied Geography*, **29**, 409–418.

26. Latifovic, R. & Pouliot, D. (2005) Multitemporal land cover mapping for Canada: methodology and products. *Canadian Journal Of Remote Sensing*, **31**, 347–363.

27. Lehner, B. & Grill, G. (2013) Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, **27**, 2171–2186.

28. Lehner, B., Verdin, K. & Jarvis, A. (2008) New Global Hydrography Derived From Spaceborne Elevation Data. *Eos, Transactions American Geophysical Union*, **89**, 93–94.

29. Luck, G.W., Chan, K.M.A. & Fay, J.P. (2009) Protecting ecosystem services and biodiversity in the world's watersheds. *Conservation Letters*, **2**, 179–188.

30. Mace, G.M., Norris, K. & Fitter, A.H. (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends In Ecology & Evolution*, **27**, 19–26.

31. Meidinger, D., & Pojar, J. 1991. *Ecosystems of British Columbia*. Research Branch, BC Ministry of Forests. Victoria, BC.

32. Mitchell, M.G., Suarez-Castro, A.F., Martinez-Harms, M., Maron, M., McAlpine, C.A., Gaston, K.J., Johansen, K. & Rhodes, J.R. (2015) Reframing landscape fragmentation's effects on ecosystem services. *Trends In Ecology & Evolution*, **30**, 190–198.

33. Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M. & Gascon, C. (2011) Global Biodiversity Conservation: The Critical Role of Hotspots. *Biodiversity Hotspots* pp. 3–22. Springer, Berlin, Heidelberg, Berlin, Heidelberg.

34. NRC. (2002) Digital elevation model of the Canadian Landmass - Canada3D.

35. NRC. (2003) Atlas of Canada 1,000,000 National Frameworks Data, Hydrology - Dams.

36. NRC. (2010) Atlas of Canada 1:1000000 National frameworks Data: Generating Stations, 2007 - Power Source.

37. NRC. (2018) CanVec Hydrological Data - Waterbodies.

38. Ouelle Dallaire, C. (2018) River System Classifications and Cumulative Watershed Perspectives to Inform Sustainable River Basin Management at Global and Regional Scales (ed B Lehner). McGill University, Montreal, QC.

39. Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., Termansen, M., Zandersen, M., Pérez-Soba, M., Scholefield, P.A. & Bidoglio, G. (2014) Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. *Ecological Indicators*, **45**, 371–385.

40. Peña, L., Casado-Arzuaga, I. & Onaindia, M. (2015) Mapping recreation supply and demand using an ecological and a social evaluation approach. *Ecosystem Services*, **13**, 108–118.

41. Prime Ministers Office. 2019. Minister of Environment and Climate Change Mandate Letter. Available at: https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-environment-and-climate-change-mandate-letter. Accessed August 2020.

42. Qiu, J. & Turner, M.G. (2013) Spatial interactions among ecosystem services in an urbanizing agricultural watershed. *Proceedings of the National Academy of Sciences*, **110**, 12149–12154.

43. Ricketts, T.H., Watson, K.B., Koh, I., Ellis, A.M., Nicholson, C.C., Posner, S., Richardson, L.L. & Sonter, L.J. (2016) Disaggregating the evidence linking biodiversity and ecosystem services. *Nature communications*, **7**, 13106.

44. Rose, A.N., McKee, J.J., Urban, M.L. & Bright, E.A. (2018) Landscan 2017.

45. StatCan. (2011) Boundary Files.

46. StatCan. (2015) National Road Network - NRN - GeoBase Series.

47. StatsCan. (2017) Road Network File, 2016.

48. Tallis, H., Mooney, H., Andelman, S., Balvanera, P., Cramer, W., Karp, D., Polasky, S., Reyers, B., Ricketts, T.H. & Running, S. (2012) A global system for monitoring ecosystem service change. *BioScience*, **62**, 977–986.

49. Villamagna, A.M., Angermeier, P.L. & Bennett, E.M. (2013) Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity*, **15**, 114–121.

50. Xu, W., Xiao, Y., Zhang, J., Yang, W., Zhang, L., Hull, V., Wang, Z., Zheng, H., Liu, J., Polasky, S., Jiang, L., Xiao, Y., Shi, X., Rao, E., Lu, F., Wang, X., Daily, G.C. & Ouyang, Z. (2017) Strengthening protected areas for biodiversity and ecosystem services in China. *Proceedings of the National Academy of Sciences of the United States of America*, **114**, 1601–1606.

51. Zulian, G., Paracchini, M.L., Maes, J., C Liquete - Institute for Environment …2013. (2013) *ESTIMAP: Ecosystem Services Mapping at European Scale*. European Commission.