Determining the Accuracy of the Beaver Restoration Assessment Tool for Identifying North American Beaver (*Castor canadensis*) Habitat in the Central Interior Cariboo Region of British Columbia

by

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List of Acronyms

%	percent
°C	degrees Celsius
BC	British Columbia
BCLCS	BC Land Classification Scheme
BDA	beaver dam analogue
beaver	North American beaver (*Castor canadensis*)
BRAT	Beaver Restoration Assessment Tool
cm	centimetre(s)
DAsqm	drainage area (square miles)
dams/km	dams per kilometre
DBH	diameter at breast height
DEM	digital elevation model
DUC	Ducks Unlimited Canada
GIS	geographic information system
HSI	habitat suitability index
km	kilometre(s)
km^2	squared kilometre(s)
LWD	large woody debris
m	metre(s)
m^3	cubic metre(s)
m^3/s	cubic metres(s) per second
mm	millimetre(s)
NA	not applicable
RCP	representative concentration pathway
SD	standard deviation
W/m	watts per metre

Abstract

Perennial watercourses in British Columbia are becoming intermittent from climate change. North American beaver (*Castor canadensis*) dams retain perennial flow while providing other ecosystem services. The Beaver Restoration Assessment Tool (BRAT) estimates a stream's dam capacity by evaluating the vegetative, physical, and hydrological habitat. This research project surveyed 15 streams in the Cariboo region to assess the accuracy of the BRAT's outputs. Climate data were used to model changes in flow. Overall, the BRAT outputs generally correlated with field measurements. However, the non-vegetation outputs contributed minimally to dam capacity, and higher dam capacity did not always indicate higher habitat quality. Climate projections also indicate most streams will lose nival flow by 2041-2071. Therefore, using the BRAT with other models can determine both dam capacity and overall habitat quality to increase successful beaver restoration chances. When vegetation and physical stream conditions are met, higher watershed/channel size may indicate higher-quality habitat.

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1.0 Introduction

Streams and rivers provide ecosystem services such as drinking water, flood protection, irrigation, commercial use, and aquatic and riparian species habitat (Yeakley et al. 2016). Climate change effects on watersheds in British Columbia (BC) have included a reduction in snowpack at low elevations (Pike et al. 2010) and glacial retreat (Walker & Pellatt 2003). The reduction in snowpack has caused changes in river and stream-flow patterns, including low or dry summer flows (BC Ministry of Environment 2016). Low summer river flows impact aquatic habitats by negatively impacting water quality with increased water temperatures (BC Ministry of Environment 2016) and reducing fish-habitat availability. The loss of both perennial flow and glaciers will create water-shortage issues for both aquatic life (Datry et al. 2013) and human consumption (Baggio et al. 2021).

Water retention in the upper portion of watersheds is required to maintain the ecosystem services provided by perennial watercourses. Man-made water structures (i.e., dams and reservoirs) can be difficult and costly to both construct and maintain (ADSO 2016). In addition, timely repairs to dams following damage may not be readily feasible, especially if they are located in more remote upper watersheds. River restoration projects have also been expensive historically (Bernhardt 2005). North American beaver (*Castor canadensis* – “beaver”) are known ecosystem engineers through their construction of beaver dams which modify the physical, biological, and hydrological features of a landscape (Burchsted et al. 2010). These dams provide a wide variety of ecosystem services such as wetland creation, water retention, reduced erosion, improved water quality, improved aquatic habitat complexity, expansion of riparian areas, and creation of new aquatic and riparian habitats for birds, mammals, fish, reptiles, and amphibians (Boyle & Owens 2007; Pollock et al. 2023). Beaver can build dams quickly and efficiently with adequate resources and can quickly repair damages to dams (Arner 1963). By using beaver to construct dams, the monetary costs of manual implementation are removed, and if they persist, beaver also provide year-round maintenance to dams. Therefore, the potential ecosystem benefits provided by beaver create a cost-effective, nature-based solution to managing current and future water retention challenges from climate change and restore some ecosystem services provided by perennial flow.

Prior to the arrival of Europeans in North America, beaver populations were estimated to be 60 – 400 million with a 15-million-squared-kilometre (km^2) geographical range (Naiman et al.

1988). The North American fur trade left beaver nearly extinct by 1900 (Jenkins & Busher 1979). The conversion of wetlands to dry lands has also occurred concurrently with the loss of beaver populations. Conservation organizations estimate that 70 percent (%) of wetlands have been lost in southern areas of Canada, and up to 95% in densely populated areas (Kaumeyer 2022). Beaver populations have been increasing since the fur trade but have not returned to pre-fur-trade numbers (Gibson & Olden 2014).

1.1 Beaver Ecology

Beaver live in colonies with three to nine individuals including adults, yearlings and kits (MELP 2001). Females reach reproductive maturity at two years, and two-year-old juveniles will leave the colony in early spring when they typically colonize new territory, often in adjacent watersheds (MELP 2001). Active beaver systems are not permanent, as after food is exhausted, they abandon their lodges and dams in search of habitat with more food (Case et al. 2003). They prepare for winter by establishing winter food caches within the impoundment, although West Coast populations likely continue to cut accessible vegetation all year (MELP 2001). Beaver are primarily nocturnal (Pollock et al. 2023). Primary beaver dams (i.e., dams that support a lodge) are typically about one metre high but can reach heights above three metres (Gurnell 1998). Beaver build secondary dams to extend their range to forage and harvest building material upstream and/or downstream of a primary dam (Macfarlane et al., 2017). Secondary dams are typically at least 30- to 50-cm in height (Macfarlane et al., 2017). In lower slope/gradient areas, fewer dams are needed to extend their ranges (Macfarlane et al., 2017).

In British Columbia, the most productive beaver colonies are often in newly-occupied stands of poplar (*Populus* spp.) that naturally regenerate in forest clearings created by fire, blowdown, bug-kill or logging and on old sedimentation bars along large rivers (MoE n.d.). Aspen (*Populus* spp.) regrowth may support population expansion eight to ten years after a burn, but will usually take 20 to 30 years to produce aspens at a size that will provide the maximum amount of useable food (MoE n.d.). Beaver generally overuse their food supply, especially aspen. They can be highly selective in their feeding preferences, as a new colony can waste up to 65% of the available food by not using bark on the larger pieces, and can drown food supplies in the rising waters behind their dams (MoE n.d.). A colony can take only two or three years to use up the aspen within safe and efficient foraging distance from the water's edge. However, willow (*Salix* spp.) will often take hold in beaver impoundments with increased moisture and nutrient conditions. It may be only ten years between when a beaver colony is established and when is it abandoned, especially in aspen habitat (MoE n.d.). There is also a risk of beaver spreading non-native riparian vegetation from foraging activities as they are transported to new riparian areas (Gibson & Olden 2014).

1.2 Beaver Habitat Requirements and Preferences

Beaver will build dams in essentially any waterbody where additional water can be retained and thus improve resources for beaver (Pollock et al. 2023). They can survive in a range of suitable locations from the Arctic tundra to the deserts of northern Mexico (Naiman et al. 1988; Andersen & Shafroth 2010). However, beaver do have baseline habitat requirements and preferences to build dams. Two mandatory habitat features are needed for beaver dams. They are (1) sufficient water to maintain underwater entrances to their lodges for protection from predators and (2) sufficient woody and herbaceous plants for food and building material (Müller-Schwarze & Sun 2003). Regardless if these features are present, beaver will most likely avoid building dams in habitat with specific characteristics such as overly high gradient, stream power, stream width, stream depth, valley confinement, grazer presence, and predator presence. Additionally, beaver will migrate to new habitat if it is higher quality than their current habitat (MELP 2001).

1.2.1 Physical and Hydrological Habitat Requirements and Preferences

More importantly than all other factors, beaver require a year-round water source to survive (Pollock et al. 2023). Water is essential and can be from a stream, river, lake, or pond (Pollock et al. 2023). Year-round water supply must be sufficient for access to food resources, protection of lodge and burrow entrances, and general safety from predators (Müller-Schwarze & Sun, 2003). Beaver predominantly occupy perennial systems with a reliable water source (Albert &Trimble 2000). However, they have been occasionally found on intermittent streams and can turn them into perennial systems (Pollock et al. 2003). Dam building is not required in watercourses where water depth is sufficient to provide underwater entrances to their lodges (Macfarlane et al. 2017). In colder climates with winter freeze, approximately 0.6 – 0.9-m of unfrozen water is required to maintain lodge entry points (Government of Manitoba 2022). No studies were found that examined the water depths that North American beaver tend to build lodges without dams. However, Hartman & Törnlöv (2006) found that most (93%) of dams built by *C. fiber* (Eurasian beaver) were built in stream depths < 0.7-m. Additionally, Neumayer et al.

(2020) found that Eurasian beavers build dams most frequently at stream depths (~93%) < 1-m, with ~59% between 0.5 and 1-m, and 34% at < 0.5-m.

Physical habitat characteristics have been found to limit beaver occupation, even when there are preferable biological characteristics. Beier & Barrett (1987) found that poor gradient, width, and depth characteristics contributed most frequently to colony abandonment, and these sites had more preferred vegetation than active sites. Less favourable physical characteristics include overly wide channels (e.g., main river stems too wide to build dams), high stream gradient (> 6%), high stream-power systems, and watercourses located in constrained valleys (Pollock et al. 2023). Dams are typically built in lower-order streams because larger streams with high stream power often remove dams during freshet (Brazier et al. 2020; Mccomb et al., 1990; Perisco & Meyer 2009). Watercourses that are high order or in steep gradients will unlikely have dams, although there are exceptions when population densities are high (Müller-Schwarze & Schulte 1999). Beaver dams have been found in stream orders as high as fourth order (Ronnquist 2021). Neumayer et al. (2020) also found that Eurasian beaver-dam-building occurs most frequently in stream widths between two- to 11-m. Confined watercourses are located in a well-defined valley corridor or where there is possible valley wall contact. Unconfined watercourses are located in a poorly defined valley with limited or no discernible slopes (Credit Valley Conservation 2010). Beaver prefer building dams along channels with a low valley confinement of > 46 m (Dittbrenner et al. 2018). These preferences are presumably so the dams are less likely to wash out during spring freshet (Gurnell 1998). Spreading stream flow across a valley bottom reduces its power, and beaver-dam failure rates (Westbrook et al. 2020). Beaver dams found off-channel and near the valley edge are usually fed by groundwater (Westbrook et al. 2006), and have a higher longevity than dams fed by upstream flow because of a lower and less dynamic discharge pattern (Burchsted & Daniels 2014).

1.2.2 Biological Habitat Requirements and Preferences

Biological preferences include vegetation; beaver prefer deciduous and broadleaf vegetation such as aspen, willow, and cottonwood for harvesting although they will harvest many other tree and shrub species if their preferred species are not available (Baker & Hill 2003; Boyle & Olsen 2007). Northcott (1971) stated that aspen is their favourite food. However, willow is often the most available and most used woody riparian species in their range (Baker & Hill 2003). Conifers are less suitable food but can be used as building material (Beardsley & Doran 2015). Beaver do not prefer coniferous trees because of the tree’s branched-chain tannins, which are a deterrent to the beaver's salivary proteins (Hagerman & Robbins 2011). Their salivary proteins are adapted to digest vegetation with linear condensed tannins found in broadleaf vegetation such as poplar and willow (Hagerman & Robbins 2011). Beaver also prefer stems less than 15 centimetres (cm) diameter at breast height (DBH) because smaller stems have a shorter fell time, which reduces predation risk while foraging (England & Westbrook 2021; Mahoney & Stella 2020). Biological deterrents to beaver colonization include competition with other grazing species like deer (family Cervidae) including elk (*Cervus canadensis*), moose (*Alces americanus*), and livestock (Scamardo & Wohl 2019). High predator density such as cougars (*Puma concolor*), bears (*Ursus* spp.), coyotes (*Canis latrans*), and wolves (*Canis lupus*) is also a deterrent (Stoll 2019).

1.3 Conflicts with Humans

While beaver provide multiple ecological and hydrological benefits, their dam-building activities can create safety conflicts with humans and are sometimes considered a nuisance species (Taylor et al. 2017). Some hazards to human activity include gnawing trees (near people or property) or crops, flooding property through dam building, and degrading or destabilizing banks from burrowing (Taylor et al. 2017). Abandoned dams are at a higher risk of failure as they are no longer maintained (Case et al. 2003). Therefore, individuals with frequent beaver occupancy on their land (e.g., farmers) often have concerns about uphill dam failure and abandonment, as dam failure can also lead to destructive outburst floods (Hillman 1998). Damages from failure can be large-scale. In British Columbia, a beaver dam failure in Chudnuslida Lake was reported to discharge approximately two million cubic metres (m^3) of water and deposit 80,000 m^3 of sediment into the channel (Case et al. 2003). Filled beaver ponds and their downstream reach can also contain Giardiasis – a common disease caused by the enteric parasite *Giardia lamblia* (BC CDC 2012). It is often waterborne and has the common name 'beaver fever' due to the parasite being found in the guts of beaver. However, the name is misleading, as the disease can be found in and spread by many other wild and domestic animals and humans (BC CDC 2012). Given the concerns and potential damages from beaver-dam-building, there is an ongoing perspective that beaver are a risky nature-based solution for water retention (Butler & Malanson 2005).

1.4 Dam Failure and Flooding

There is conflicting evidence that beaver dams increase flood severity. Beaver dams have been shown to help reduce impacts of storm events by reducing peak flows and discharge volume (Noor 2021). Excess water overflows above an active dam can still effectively reduce flow rate due to overflow energy loss (Noor 2021). Westbrook et al. (2020) studied the largest flood recorded in the Canadian Rocky Mountains that occurred during July 2013 and found 42% of impacted beaver dams were intact, and 26% were affected but persisted. In addition, the dams that did fail still delayed floodwater inputs downstream. These findings were observed in a mountainous landscape thought to have a high dam failure rate due to having a narrow and steep valley where multiple channels meet at high flow rates (Westbrook et al. 2020). In between storm events, pond levels can gradually drop through evaporation and dam seepage, which increases storage capacity of water for the next storm event (Noor 2021). A beaver dam's capacity to impound water is a function of the state of its repair. Older and/or abandoned dams tend to have weak points (Gurnell 1998) either at the crest or base (Woo & Waddington 1990). Streamflow becomes concentrated at these weak points which can lead to structural failure when stream discharge exceeds a critical strength threshold (Parker et al. 1985). However, the flood discharge that exceeds the threshold for major damage is not known (Andersen & Shafroth 2010), and probably varies widely based on the condition of a dam and the materials from which it was built (Westbrook et al. 2020). Pond fullness in relation to the magnitude of the water-sediment surge appears to be an important factor that determines if a beaver dam remains or fails (Westbrook et al. 2020). Still, the overall causes of beaver dam to mitigate flood damage or increase flood severity remain difficult to determine (Westbrook et al. 2020).

1.5 Beaver Restoration Assessment Tool

In the past, identifying suitable locations for beaver restoration has included habitat suitability index (HSI) models. Traditional HSI models have predicted habitat that is currently suitable for beaver, but are less able to predict an area's intrinsic potential to become suitable habitat because the models do not account well for a beaver's ability to modify a landscape into suitable habitat (Dittbrenner et al. 2018). In addition, beaver experimental relocation projects that use traditional HSI models have resulted in high rates of emigration from the released beaver (Ellensburg et al. 2015; McKinstry et al. 2001; Woodruff 2016). GIS-based models such as the Beaver Restoration Assessment Tool (BRAT) have been developed with improved capability to quantify beaver capacity.

The BRAT was developed in Utah by the Wheaton Ecogeomorphology & Topographic Analysis Laboratory at Utah State University (Utah State University n.d.). It serves to help resource managers, restoration practitioners, wildlife biologists, and researchers assess the potential for beaver as a stream conservation and restoration agent across landscapes. It is a GIS-based capacity model that predicts where and to what extent beavers can build dams (DUC 2022). The BRAT focuses on dam building capacity of streams rather than general habitat suitability because it is the dam-building activity of beaver that facilitates their ecosystem engineering services (Riverscapes Consortium n.da). The BRAT estimates the maximum capacity of dams a stream can accommodate within a drainage network, measured in dams per kilometre (dams/km). Streams are segmented into 300-m reaches along the drainage network before it can be run (DUC 2022). Each 300-m reach is classified into one of five dam-building capacity categories (Macfarlane et al. 2017):

- None – 0 dams/km, segments not capable of supporting dam building activity;
- Rare – 0-1 dams/km, segments barely capable of supporting dam-building activity. Likely used by dispersing beaver;
- Occasional – 1-4 dams/km, segments that are not ideal, but can support an occasional dam or small colony;
- Frequent – 5-15 dams/km, segments that can support multiple colonies and dam complexes, but may be slightly resource-limited;
- Pervasive – 16-40 dams/km, segments that can support extensive dam complexes and many colonies.

In the BRAT's mapped output, Pervasive stream segments are coloured blue, Frequent are coloured green, Occasional are coloured yellow, Rare are coloured orange, and None are coloured red.

Categorization of the stream reach into one of the five categories is based on seven lines of evidence (Macfarlane et al. 2017):

1. Evidence of a perennial water source;
2. Stream bank vegetation conducive to foraging and dam building;
3. Vegetation within 100 m of the stream edge to support the expansion of dam complexes and maintain large beaver colonies;
4. Likelihood that dams could be built across the channel during low flows;

5. The likelihood that a beaver dam on a river or stream is capable of withstanding typical floods;
6. Evidence of suitable stream gradient that limits or eliminates dam building by beaver;
7. Evidence that the river is too large to allow dams to be built and to persist.

Not all lines of evidence are weighted equally. The primary line of evidence is water, followed by vegetation, which is the primary control of beaver dam density and distribution (Macfarlane et al. 2014). The other lines of evidence are then used to assess how low flows, flood events, gradient, and channel size might limit dam-building activity (Macfarlane et al. 2014; Macfarlane et al. 2017).

The BRAT uses a fuzzy inference system, where the multiple lines of evidence are combined mathematically with simple rule tables to account for uncertainty that arises in categorical data (Openshaw 1996; Zadeh 1996). The BRAT is not a hydrological model, but it uses regional regressions to estimate flow statistics for every 300-m reach. The BRAT is designed to use a two-year peak flow instead of a ten-year peak flow. The model's inputs are a drainage network layer, a historic and existing vegetation raster, a digital elevation model (DEM), and streamflow information (Riverscapes Consortium n.da). The BRAT's outputs include existing dam capacity, historic dam building capacity, existing dam complex, and historic dam complex (DUC 2022). The BRAT's suitability scheme requires a field added to the attribute called VEG_CODE which represents the dam-building material preferability for beaver and is ranked from 0 to 4, with 0 being unsuitable materials and 4 being most preferred materials (Macfarlane et al. 2017).

1.6 Hydrological Modelling

The rationale for hydrological modelling in addition to the BRAT modelling comes from the primary need for beaver habitat – water. Even if sufficient woody building material is present, beaver dams will not be built where there is insufficient water. Using the American National Hydrography dataset, the BRAT was found to accurately classify perennial watercourses, but it also occasionally designated intermittent streams as perennial (Macfarlane et al. 2017). In addition, Rogers' (2023) study in the Gold River watershed in Vancouver Island, BC found that the assessed watershed was more limited by water than vegetation, resulting in the BRAT being a poorer indication of beaver habitat suitability than the Beaver Intrinsic Potential model which analyzes physical habitat characteristics (i.e., stream gradient, channel width, and valley-bottom width) to assess beaver occupancy suitability (Dittbrenner et al. 2018).

Given the increased rates of perennial flow loss from climate change, applying climate change scenarios to flow estimations made by the BRAT would allow resource managers to assess which watercourses would be best from a water availability perspective to prioritize beaver restoration. For example, watercourses could be selected for having the greatest water quantity and thus the greatest chance of beaver occupancy. Alternatively, streams at higher risk of perennial loss in the future could be prioritized for beaver restoration as a preventative measure.

1.7 Research Questions and Project Rationale

Given the BRAT's fundamental purpose to determine the dams per kilometre a stream could hypothetically hold, it does not necessarily predict a stream's overall habitat quality to host beaver for long periods. By applying hydrological modelling at ground-truthed reaches, the accuracy of assessing beaver-habitat quality may be improved.

Therefore, the research questions of this project are 1) can the BRAT be used to accurately determine high- and low-quality beaver habitat, and 2) can hydrological modelling be used to account for any inaccuracies?. The research project's hypothesis is that the BRAT will provide a relatively accurate measurement of the availability of preferred material for dam building in each stream reach and will parse out some physical habitat limitations, if present. However, it will not accurately capture some of the hydrological features of the stream reach that are preferable/not preferable for beaver habitat (e.g., water availability). Accuracy was determined by comparing results of the field assessments to values the BRAT designated for the assessed stream reaches. The research project's purpose is to ideally create an improved method for Ducks Unlimited Canada (DUC) to identify a list of candidate beaver restoration sites that are both ideal for dam building to create wetlands and higher chances of long-term beaver occupancy, rather than just having suitable dam building material but lower chances of long-term occupancy.

2.0 Goals and Objectives

Three goals were chosen for the research project. Each goal had a series of two to five objectives.

Goal 1: Use the BRAT to identify potentially suitable areas to support beaver establishment.

- *Objective 1.1*: Use the BRAT to identify stream reaches with pervasive, frequent, occasional, rare, and no dam-building capacity.
- *Objective 1.2*: Use the BRAT to find streams of each suitability category for ground truthing in the Cariboo Region.
- *Objective 1.3*: Collect the BRAT outputs of the ground-truthed sites to compare against field outputs.

Goal 2: Conduct ground-truthing field assessments at stream reaches classified by the BRAT as having strong and weak potential to support beaver. Ground-truth surveys aimed to evaluate if the BRAT accurately determined areas of high and low dam-building capacity by collecting data on stream morphology, riparian vegetation density and composition, and dam features if present.

- *Objective 2.1*: Complete a habitat quality scorecard at each stream reach.
- *Objective 2.2*: Conduct a riparian vegetation sampling survey at each stream reach to determine species composition, density, and structural stage.
- *Objective 2.3*: Collect instream data to quantify current hydrologic conditions and physical habitat variables, including channel morphology measurements, sediment composition, and large woody debris (LWD) count.
- *Objective 2.4*: If beaver dams are already present in the channel, conduct dam count, collect dam and pond measurements and classify the structural stage of the dam.
- *Objective 2.5*: Compare the ground-truth field results with the BRAT outputs

Goal 3: Use hydrological modelling to determine how accurately the BRAT accounted for hydrological limitations of dam-building capacity.

- *Objective 3.1*: Apply climate data to the BRAT-estimated flows with a regression to examine which climate factors are significantly impacting flow (if any).
- *Objective 3.2*: Run the climate regression results against future projections to determine which climate variables will be negatively impacting flow in the future.
- *Objective 3.3*: Determine if the hydrological modelling results correlate with physical/hydrological habitat scores from the habitat suitability scorecard.

3.0 Research Project Area

Field assessments were conducted within the central interior of the Cariboo Region, BC (Figure 1). The field assessments were conducted within the following major watersheds:

- The San Jose River watershed within and near Williams Lake, BC
- The Thompson River watershed near 70 Mile House, BC
- The Quesnel River watershed near Quesnel, BC
- The Fraser River watershed north of Williams Lake, BC

The Cariboo Region is located within hydrologic zones 14, 15, 16, and 25. DUC has a series of manmade dams located within the Bridge Creek and San Jose River watersheds located near some of the assessed streams.

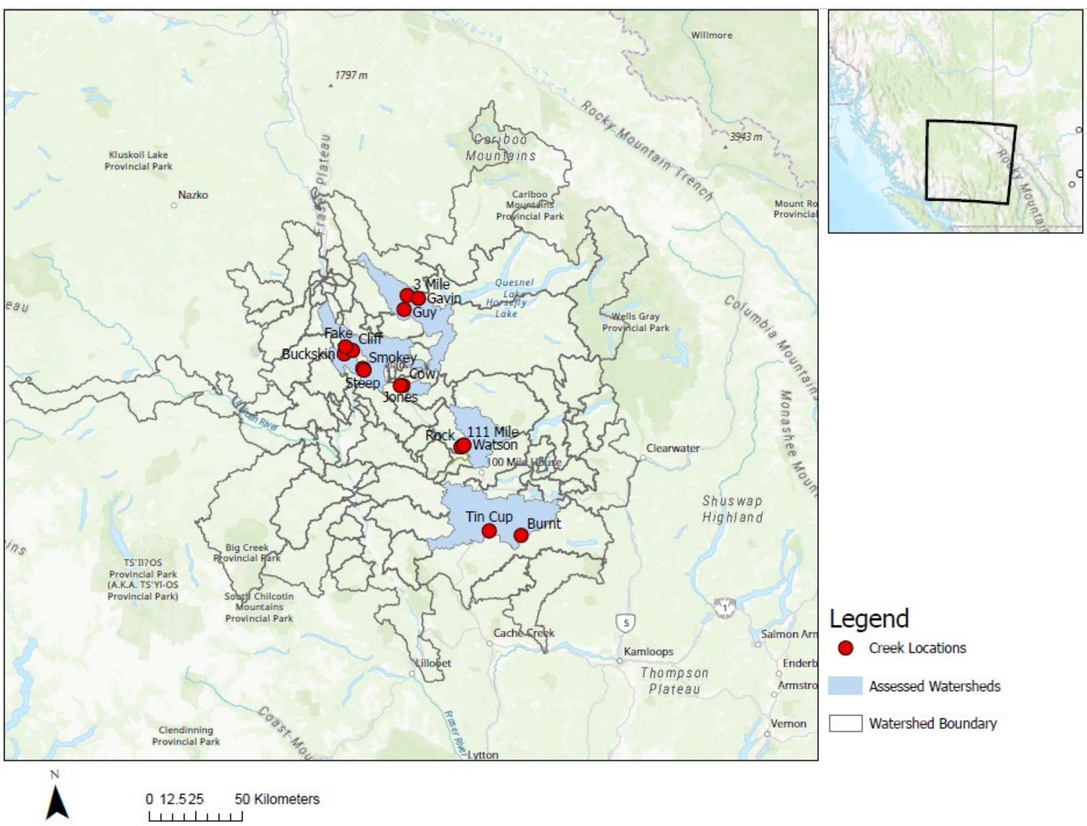

Figure 1. Research project area and location of field sites within the Cariboo region, British Columbia.

4.0 Methods

The research project consisted of three phases. The first phase was to run the BRAT across the Cariboo Region to segment the streams by BRAT suitability prior to field assessments. The second phase was to ground-truth 15 BRAT-classified stream reaches. The third phase was to model impacts to flow in these 15 reaches after field assessments by applying climate data at present and future using a climate change scenario.

4.1 BRAT Modelling

The BRAT was run over all perennial watercourses within 22 watersheds of the Cariboo region (DUC 2022). Although the BRAT is designed to filter out non-perennial streams, streams that were estimated to have a two-year low flow > 0 m are designated as perennial. The BRAT was originally designed to be run with LANDFIRE – a national and publicly available vegetation raster dataset in the United States (Macfarlane et al. 2017). Canada does not have a comparable national dataset to LANDFIRE. Therefore, dataset pre-processing was required to make the datasets compatible with the model's parameters. Datasets were collected from the BC Open Data Catalogue (Table 1).

Table 1. British Columbia datasets used in-place of American datasets required to run the BRAT.

Data Input	British Columbia Data Source	Producer	USA Data Source[6]	Line of Evidence[7]
Digital Elevation Model	Canadian Digital Elevation Data – 1:250,000 dataset[1]	GeoBC	USGS National Elevation Dataset	6
Segmented Drainage Network	Freshwater Atlas[2]	GeoBC	National Hydrography Dataset	1, 4, 7
Historic Vegetation or Land Cover Raster	Land Cover 1984-2019 Version 2[3]	CCFM	LANDFIRE	2, 3
Existing Vegetation or Land Cover Raster	Vegetation Resource Inventory[4]	MFLNRORD	LANDFIRE	2, 3
Hydrological Data for Base and Peak flows	BC Streamflow Inventory[5]	MOECCS	USGS StreamStats or USGS National Streamflow Statistics	5, 7

[1] GeoBC n.d.
[2] GeoBC 2024.
[3] CCFM n.d.
[4] MFLNRORD n.d.

[5] MOECCS n.d.
[6] Riverscapes Consortium n.db
[7] Section 1.5

4.1.1 Historic Land Cover and Existing Vegetation Rasters

The BRAT can use vegetation or land cover rasters interchangeably to estimate woody material availability. This research project used a land cover raster for the historic vegetation raster input, and a vegetation raster for the existing vegetation raster input. The historic land cover raster was numerically coded. Each code defined a different land cover type. Classification of each code to a BRAT suitability score followed the classification scheme used in Rogers (2023 – Table 2). Broadleaf was defined as 'Pervasive' suitability because willow, aspen, cottonwood, maple, and ash trees are the preferred species for beaver (Section 1.2.2). Mixed wood was categorized 'Frequent' because of the presence of both preferred broadleaf trees and less preferred coniferous trees. Wetland and wetland-treed were categorized as 'Frequent' for having preferred riparian vegetation such as willows and birches but at a lower density than forested systems as wetland vegetation as sub-boreal spruce and interior Douglas-fir wetlands also consist of cattails grasses, bulrushes (interior Douglas-fir), and sedges (sub-boreal spruce and interior Douglas-fir – MoF 1998; MoF n.d.). Coniferous and shrubs were categorized as 'Occasional' for having vegetation present for dam building, but with less-preferred conifers. Water, rock/rubble, and exposed barren land were categorized as 'None' for not having dam-building vegetation present.

Table 2. Historic Land Cover data codes from raster datasets of 1984 and designated BRAT suitability categorization to run the historic vegetation layer. Adapted from Rogers (2023).

Land Cover Data Code	Meaning	BRAT Suitability and Score
220	Broadleaf	Pervasive – 4
230	Mixed Wood	Frequent – 3
80	Wetland	Frequent – 3
81	Wetland – Treed	Frequent – 3
210	Coniferous	Occasional – 2
50	Shrubs	Occasional – 2
20	Water	None – 0
32	Rock/Rubble	None – 0
33	Exposed Barren Land	None – 0

The existing vegetation dataset was converted from a polygon feature class into a raster before being used. Five fields from the BC Land Classification Scheme (BCLCS) in the attribute table correspond to vegetation types in the polygons. BCLCS level 1 classifies the presence and absence of vegetation in the polygon boundaries. BCLCS level 2 classifies the land cover type within the polygon boundaries. BCLCS level 3 classifies the polygon location relative to drainage and elevation. BCLCS level 4 classifies vegetation types and non-vegetation cover types, and was selected for the BRAT classification scheme since it determines the dominant vegetation cover type. The BRAT categorization for BCLCS level 4 followed the categorization scheme used in Rogers (2023 – Table 3).

Table 3. BCLCS codes levels 1-4 with their code meanings and designated BRAT suitability categories to run the existing vegetation layer. Adapted from Rogers (2023).

BCLSS Level	Code	Meaning	BRAT Suitability and Score
BCLSS_LEVEL_1	V	Vegetated	N/A
	N	Non-vegetated	N/A
	U	Unreported	N/A
BCLCS_LEVEL_2	T	Treed	N/A
	N	Non-Treed	N/A
	L	Land	N/A
	W	Water	N/A
BCLCS_LEVEL_3	W	Wetland	N/A
	U	Upland	N/A
	A	Alpine	N/A
BCLCS_LEVEL_4	TB	Treed-Broadleaf	Pervasive – 4
	TM	Treed-Mixed	Frequent – 3
	ST	Shrub Tall	Frequent – 3
	TC	Treed-Coniferous	Occasional – 2
	SL	Shrub Low	Occasional – 2
	HE	Herb	Rare – 1
	HF	Herb-Forbs	Rare – 1
	HG	Herb-Graminoids	Rare – 1
	BY	Bryoid	None – 0
	SI	Snow/Ice	None – 0
	RO	Rock/Rubble	None – 0
	EL	Exposed Land	None – 0

For the existing vegetation classification types, treed-broadleaf, treed-mixed, treed-coniferous, shrub low, snow/ice, rock/rubble, and exposed land categories follow the categorizations used in the historic classification. Shrub tall was categorized ‘Frequent’ for having woody material of broadleaf plants. Herb layers were classified as ‘Rare’ for having vegetation that is mostly non-woody stem. Bryoids were classified as ‘None’ for not having useable vegetation for beaver.

BCLCS level 5 classifies level 4 vegetation layers into density classifications. The BCLCS level 5 classes were also given a BRAT vegetation suitability score based on the vegetation density within the polygon (Table 4). The BRAT vegetation suitability classes were derived from the density definition of the BCLCS values (MFLNRO 2019). All non-vegetation layers were classified as 'None' for not having vegetation. Closed was classified 'Rare' as it is defined as the polygon being covered in > 50% of the polygon. Sparse was classified as 'Occasional' for the polygon being covered between 10% and 25% treed polygons, or cover is between 20% and 25% shrub or herb polygons. Open was classified 'Frequent' as it is defined as tree, shrub, or herb cover is between 26% and 60% of the polygon. Dense was classified as 'Pervasive' as it is defined as tree, shrub, or herb cover between 61% and 100% of the polygon. Using the existing vegetation layer, the BCLCS level 5 inputs were also run in the Cariboo Region.

Table 4. BCLCS level 5 codes with code meanings and designated BRAT suitability classifications to run the existing vegetation density layer.

BC Land Classification Scheme Level 5	Meaning	BRAT Vegetation Suitability
DE	Dense	Pervasive – 4
OP	Open	Frequent – 3
SP	Sparse	Occasional – 2
CL	Closed	Rare – 1
GL	Glacier	None – 0
PN	Snow Cover	None – 0
BR	Bedrock	None – 0
TA	Talus	None – 0
BI	Blockfield	None – 0
MZ	Rubbly Mine Spoils	None – 0
LB	Lava Bed	None – 0
RS	River Sediments	None – 0
ES	Exposed Soil	None – 0
LS	Pond or Lake Sediments	None – 0
RM	Reservoir Margin	None – 0
BE	Beach	None – 0
LL	Landing	None – 0
BU	Burned Area	None – 0
RZ	Road Surface	None – 0
MU	Mudflat	None – 0
CB	Cutbank	None – 0
MN	Moraine	None – 0
GP	Gravel Pit	None – 0
TZ	Tailings	None – 0
RN	Railway Surface	None – 0
UR	Urban	None – 0
AP	Airport	None – 0
MI	Open Pit Mine	None – 0
OT	Other	None – 0
LA	Lake	None – 0
RE	Reservoir	None – 0
RI	River/Stream	None – 0
OC	Ocean	None – 0

4.1.2 Streamflow Information

The BRAT makes determinations if a beaver can or cannot build dams based on physical barriers and/or hydrological restrictions based on known deterrents to beaver (Section 1.2.1). Macfarlane et al. (2014) ran the BRAT over 2,852 beaver dam locations in Utah and found some sparse dams between 17 and 23% gradient, but none above 23% gradient. Thus, stream gradients above 23% were classified as 'None' for building potential. Gradients between 15 -23% were designated as can probably build a dam, 0.5 -15% as can build dam, and 0-0.5% as really flat. Macfarlane et al. (2017) determined low flow stream power that beavers can build dams as between 0 – 175 watts per metre (W/m) (Pervasive), can probably build dams between 176 – 190 W/m (Frequent), and cannot build dams as > 190 W/m (None). Two-year flood stream power that dams can persist through was designated between 0-1000 W/m (pervasive dam presence), 1000-1200 W/m as an occasional breach (frequent dam presence), 1200 – 2000 W/m as an occasional blowout (rare dam presence), and > 2,000 W/m as a blowout (no dam presence). Drainage areas that beaver can build dams in were designated as 0-10,000 km^2 and drainage areas that beaver cannot build dams in were designated as > 10,000 km^2.

Gradient was estimated from differencing the top and bottom elevations of the segment and dividing by reach segment length. The Valley Bottom Extraction Tool of the BRAT was used to estimate valley-bottom width. Drainage areas were converted from square kilometres to square miles and flow values were converted from cubic metres to cubic feet. The conversion to imperial was to ensure the BRAT interpreted and calculated the data correctly. Regional regressions were based on the hydrologic zones determined by the BC Streamflow Inventory. Data for the regressions used flow data from gauged streams within Hydrologic Zones 14 and 15 where the field sites for ground truthing were located (Section 5.1). Hydrologic zones are defined as areas where runoff characteristics are homogeneous and where data collected in the region can be reasonably extrapolated to estimate characteristics at ungauged sites to an acceptable degree of accuracy (Ahmed 2017). They are considered a practical approach to estimate streamflow characteristics at ungauged sites (Ahmed 2017). One regression was created for each hydrologic zone. Regression equations were calculated for low flow and peak flow. Low flow was calculated as the discharge that exceeded 80% of the time for the month with the lowest runoff. Low flow equations used the drainage area, along with ten-year and seven-day annual low flow values from the BC Streamflow Inventory. Given the BRAT is designed to use a two-year peak flow instead of a ten-year peak flow, two two-year peak flow equations were created by using two graphs which show the relationship between the instantaneous peak flow interval of two years and the drainage area.

The low flow and peak flow formulae for Hydrologic Zones 14 and 15 were:

Hydrologic Region 14

Low flow: $y = 0.172995049(DAsqm)^{1.035568336}$

Peak flow: $y = 819.3296487(DAsqm)^{0.044719065}$

Hydrologic Region 15

Low flow: $y = 0.013545976(DAsqm)^{1.115656437}$

Peak flow: $y = 0.7182211519(DAsqm)^{0.899632024}$

Where DAsqm is drainage area in square miles.

4.1.2 BRAT Outputs

BRAT outputs of the assessed streams are the gradient, drainage area, 30-m and 100-m existing vegetation, two-year low flow and peak flow, two-year low and peak flow stream power, and dam capacity. All streams not designated as ‘None’ capacity were considered perennial (Section 1.5), thus they would not be limited by water availability according to the BRAT. Vegetation scores between whole numbers represent an average between the differing vegetation classifications of adjacent polygons that the reach intercepts. Likewise, dam densities between whole numbers represent the average between differently-classified vegetation polygons combined with the physical and hydrological outputs. Dam capacity determines the reach’s classification into one of five BRAT categories (Section 1.5).

4.2 Field Assessments – Site Selection

A three-hundred-metre-long reach of the stream was assessed based on the BRAT’s 300-m stream reach segmentation (Section 1.5). Fifteen sites were selected for ground-truthing, consisting of three sites of each of the five BRAT suitability categories (Section 1.5). The equal distribution of sites samples by BRAT suitability was to control for results being impacted by differing levels of effort between suitability categories. All sites were surveyed between June and September (one site was surveyed in late May but re-visited in June) to assess the stream’s hydrological features during the June to September low-flow period of the Cariboo Region

(Ahmed 2017). Separate watercourses were selected instead of differently-classified reaches of the same watercourse to minimize spatial autocorrelation of results. Best efforts were made to avoid reaches that intersected through, or were within 100-m of, active roads and within 100-m of buildings to avoid anthropogenic impacts that could artificially deter beaver occupancy. One-hundred metres was chosen as the exclusion cut-off distance for reach selection because it is the maximum distance beaver will forage from their lodges (Allen 1983). Final site selection was limited by vehicle accessibility and land ownership status and agreements.

4.3 Field Assessments – Data Collection

Data were input using a digital map created by the DUC GIS team on the FieldMaps app created by the Environmental Systems Research Institute (2023). Four forms on the FieldMapps were used to collect stream reach data: (1) Dam Monitoring Form, (2) Instream Assessment, (3) Vegetation Assessment, and (4) Habitat Quality Scorecard. The entire length of each 300-m reach was walked and/or waded in-between data collection points and plots.

4.3.1 Dam Monitoring Form and Beaver Presence

If encountered, dams were counted and measured. Measurements of beaver dams were adapted from methods used in Woo & Waddington (1990 – Table 5).

Table 5. Dam parameters with their descriptions and units of measurement to measure beaver dams encountered during field assessments of the Cariboo Region, 2023.

Parameter	Description	Units
Dam Height	Height of the dam from the water surface to top of woody material.	Metre
Dam Length	Length of the woody material of the dam across stream.	Metre
Dam Status	Determination if the dam has signs of activity or is inactive.	Categorical (active, inactive)
Pond Depth	Depth of pond formed upstream from the beaver dam.	Metre
Dam Flow	Determination of how water enters and leaves beaver dam.	Categorical (overflow, gap-flow, underflow, through-flow)
Upstream Water Level	The depth of the stream upstream of the beaver pond that is unimpacted from the dam.	Metre
Downstream Water Level	Depth of stream downstream of the beaver dam.	Metre
Water Level Distance	Depth difference between upstream and downstream water levels.	Metre

Beaver Encounters and/or Signs of Presence	Recording of beavers encountered and signs of beaver presence within the reach.	Count and Observation

Dam height, pond depth, and water levels were measured using a wooden collapsible 2-m ruler. Dam length was measured using a 50-m Eslon open-reel measuring tape. If the dam length and height was too large and determined unsafe to measure with the measuring tape, the height was visually estimated, and the length was estimated using the measure tool on the FieldMaps app. Dam flow was categorized as either overflow, gap flow, through flow, or under flow. If beaver were encountered, they were counted and identified as an adult or kit. The beaver activity and/or behaviour at time of identification was also recorded. Signs of beaver presence included fresh mud and/or vegetation on dams and/or lodges, beaver tracks, scat, beaver trails to the stream, gnawed trees and stumps, and beaver-felled trees.

4.3.2 Instream Assessments

Prior to collecting instream data, two random numbers were generated using The Random Number Generator app on an iPhone to determine where stream data was collected at each reach. The first number was generated between 1 and 150 m, and the second was generated between 151 and 300 m. The two points were separated to capture possible variation within the reach (e.g., breaks, microsite changes) and reduce measurements in one microsite while also maintaining some sampling randomization. If the stream reach ended before the second instream could be surveyed, only one instream point was used to represent the reach. Bankfull area was estimated by multiplying the average measured bankfull width by the segment length (i.e., 300 or 150). Wetted volume was estimated by multiplying the segment length by average wetted width and average wetted depth. The instream field measurements were recorded to compare habitat features that the BRAT estimates (e.g., gradient). Data parameters selected for instream assessments (Table 6) were largely based on data parameters collected for the Fish Habitat Assessment Procedure (Johnston & Slaney 1996).

Table 6. Data parameters with their description and units of measurement used to measure instream habitat features during field assessments of the Cariboo Region, 2023.

Parameter	Description	Units
Dewatered Status	Visual determination if stream was or was not dewatered.	Categorical (yes or no)
Channel Depth	Average depth of stream calculated from depth measurements taken at ¼, ½, and ¾ distance from the left bank.	Metre
Wetted Width	Width of stream with flow at time of assessment.	Metre
Channel Width	Width of stream from left bank to right bank.	Metre
Bankfull Depth	Depth of stream when experiencing highest flow periods (e.g., spring freshet).	Metre
Stream Gradient	Average gradient of stream in section assessed.	Percent
Bed Material	Predominant and subdominant substrate materials instream.	Categorical (fines/clays/silts/sand, gravels, cobbles, boulders, bedrock)
Bank Material	Predominant and subdominant composition materials of the left bank and right	Categorical (organics, fines, sand, gravels, cobbles, boulders, bedrock)
Anthropogenic features	Observations of anthropogenic features found within stream reach.	Observational
Riparian Crown Closure	Vegetated canopy cover over stream at time of assessment.	Percent
Habitat Morphology	Visual estimation of riffle, glide, pool, and cascade habitat.	Percent
Disturbance Indicators	Observations of natural and/or anthropogenic disturbance to stream reach.	Observational
Off-channel habitat	Presence of channel braids or tributaries from main stem.	Categorical (yes, no)
Valley Confinement	Gradient from stream bottom to top of left and right valley side and estimation of valley height.	Percent and Metre

Channel depths and smaller (< 2-m) channel widths were measured with a collapsible 2-m wooden ruler. Larger (> 2-m) channel widths were measured using a 50-m Eslon open-reel measuring tape. Stream gradient was measured with a clinometer instream and having the field crew partner walk 15 m upstream and downstream from the sampling point as the point of measurement. Then average of both points was the representative gradient. If the stream meandered or the crew partner was not visible from the stream, the gradient was measured from the stream bank. Valley confinement was measured using a clinometer from instream to the bottom of a landmark on the top of the valley (e.g., tree or boulder) and estimating the height of the canyon. Stream substrate was determined by visual estimation and grabbing substrate samples instream. Bank material was determined by visual estimation and grabbing samples of bank material. All other parameters were visually estimated.

4.3.3 Vegetation Assessments

At the instream assessment points, two random numbers were generated using the same iPhone app as per the instream assessment to determine the riparian vegetation plots. The first number was generated between 1-30 for the preferred range (in metres) for beaver to forage for woody material and retreat to their lodges to avoid predators (Barnes and Mallik 2001; Jenkins 1979). The second number was generated between 31-100. The second number was selected for the range (in metres) that beaver will forage if required (Allen 1983). If the stream reach ended before the second instream point could be reached, only one pair of vegetation plots was used to represent the reach. A 10-m x 10-m tree plot was placed at each randomly generated distance from the bank to measure trees. The selected stream bank for the vegetation assessment was the bank with the greater number of trees and/or the presence of preferred species. The selection for the higher-quality bank was to measure the vegetation that would be available for beaver if present. Tree plots were placed using four pieces of 10-m rope. Vegetation was considered a tree if it had a woody stem and was ≥ 2-m in height. The input data layers to run the vegetation raster for BRAT cannot determine the DBH of trees that are best for beaver felling (< 15-cm DBH – Section 1.2.2). Thus, the total number of coniferous and deciduous trees of each stream reach were analyzed to compare the BRAT outputs to the field assessments. Counted trees (except willow) were categorized by DBH using diameter tape. The separation by DBH was used to determine the number of trees present in the plot that were the preferred size class for beaver forage. If tree trunks were forked at/near the bottom (i.e., > one stem), they were counted as separate trees, as beaver could forage them for material separately. Trees were identified to species when possible, and genus when not possible. Beaver cutting of sprouting woody species is analogous to coppicing – where trees are cut close to the ground to produce basal sprouts rather than growth from seed (Baker et al. 2003;). Most of the willow bases showed signs of a coppiced response to browsing (Appendix C; Photo 1, 2) and the number of individual stems were not counted. Instead, willows were counted by the base. To measure shrubs, a nested 5-m x 5-m shrub plot was placed in the middle of the tree plot. The shrub plot was made from four pieces of 5-m rope. Vegetation was considered a shrub if it had a woody stem and was between ≥ 15 cm and < 2 m in height (Table 7). Shrub cover was visually estimated, and not taxonomically identified.

Table 7. Data parameters with their description and units of measurement for vegetation measurements during field assessments of the Cariboo Region, 2023.

Parameter	Description	Units
Cover Class	Majority type of vegetation cover within 100 m^2 plot.	Categorical (treed-broad leaf, treed-mixed, treed-coniferous, shrub tall, shrub low, herb, other).
Structural Stage	Visually estimated age of stand within 100 m^2 plot.	Categorical (initial, shrub, pole-sapling, young forest, mature forest, old-growth forest).
Number of Trees $\leq$ 15 cm DBH	Number of stems for conifers, alder, aspen, cottonwood, and other deciduous trees with DBH $\leq$ 15 cm within 100 m^2 plot.	Count and species identification.
Number of Trees > 15 cm DBH	Number of stems for conifers, alder, aspen, cottonwood, and other deciduous trees with DBH > 15 cm within 100 m^2 plot.	Count and species identification.
Willow Presence	Number of bases with willow within 100 m^2 plot.	Count.
Suitable BDA Material	Estimation if there is adequate material to make BDAs within 100 m^2 plot.	Categorical (yes, no)
Shrub Cover	Estimation of shrub cover within 25 m^2 plot.	Percent
Herbivory	Chance-find observations of herbivory within or near plot. If possible, include if beaver, rodent, or ungulate herbivory.	Observational

4.3.4 Habitat Scorecard

The habitat scorecard was completed after the other field assessments, and after the reach was walked/waded. The scorecard was originally developed by the Methow Beaver Project to determine what sites will best support newly released beavers and dam building (Lundquist & Dolman 2018). The scorecard rates release site suitability with a point system based on factors deemed relevant from the Methow Beaver Project's past monitoring studies (Lundquist & Dolman 2018). The scorecard received an update from the Lands Council of Washington State (Lundquist & Dolman 2018 – Appendix A). Both versions of the form were completed with some amendments, but only the updated version was used in subsequent analysis and included in this report. The springtime stream flow section was discarded from the assessment, as it requires flow assessments during both high flow and low flow periods. Since field surveys were conducted during summer low flows, the months surveyed between some sites were different, and sites were not re-visited, the stream flow category was not completed. Therefore, the updated score for a bad release site was changed to 0-39 points from 0-44 points, and the good release site to 40-90 points from 45-95 points. If the answer to a scorecard category was unknown, it was given a “0” in the assessment. Since only a 300-m reach length or less was assessed (Section 4.3), the Habitat Unit Size score was determined by multiplying the average channel width by the length of the assessed reach. If the channel was observed to continue from the end of the survey location, one extra point was given to the Habitat Unit Size. Due to the literature indicating that beaver prefer building dams in less than one-metre-deep channels (Section 1.2.1), and the scorecard having a negative score for stream depths over waist depth (approximately one metre for this report’s author), stream depths exceeding one metre were determined negative for dam construction.

The scores of each stream were based on the relative habitat quality of each stream, not as an objective measure of the stream’s suitability to habituate released beaver. After the field surveys were completed, some parameters of the scorecards were re-assessed to better reflect the differences among sites. The re-assessment was completed because (1) the experience and skill to accurately assess a site increased with each successive site completed, and (2) re-assessment with numerical data (e.g., tree counts and stream size) allowed for more quantitative, objective assessments.

To see if the BRAT dam capacity outputs relates mostly to vegetation availability and not other beaver habitat characteristics, the habitat scorecard was separated into vegetation and physical/hydrological parameters to determine if the BRAT’s lack of habitat-quality estimation was more indicative from the vegetation score parameters or from physical/hydrological parameters.

The habitat scorecard parameters considered vegetation parameters were:

- Woody food
- Herbaceous food
- Lodge and dam building materials
- Large woody debris presence instream
- Browsing/grazing impacts
- Recent fire (from bonus)

The habitat scorecard parameters considered physical/hydrological parameters were:

- Stream gradient
- Year-round flow prediction
- Average stream depth

- Habitat unit size
- Floodplain width
- Predominant stream substrate
- Number of pools presence

The total weight of the vegetation scorecard parameters is 50% (45/90) and the total weight of the physical/hydrological scorecard parameters is approximately 39% (35/90). Other parameters (the remaining approximate 11%) such as historical beaver use and proximity to beaver colony were excluded from the sub-categorization because changes to the stream from beaver activities are already accounted for in the other physical and hydrological parameters, and vegetation impacts are already accounted for in the browsing/grazing impacts parameter. Damages from flooding and other bonus point parameters were excluded because these parameters measure the site's restoration feasibility considering anthropogenic factors, not inherent habitat quality.

4.4 BRAT Outputs and Field Assessment Comparisons

Scatter plots were used to compare the BRAT outputs with field assessment results (Table 8) and determine if correlations were present. The correlations would indicate that the BRAT was or was not accurately estimating a specific ground-truthed variable. The two-year low flow was compared against the wetted volume to determine if lower to higher low flow estimates correlated with lower to higher measured wetted volumes found during the low-flow period, respectively. Likewise, the two-year peak flow was compared against the bankfull volume to determine if lower to higher peak flow estimates generally correlated with lower to higher bankfull measurements. Since measurements were conducted during the summer low-flow period, no field measurements were correlated with BRAT stream power outputs.

BCLCS level 4 vegetation outputs were compared to the average all tree counts, coniferous tree counts, and deciduous tree counts to determine if there was a correlation between the BRAT outputs and the average number of all trees; and if the correlation changes when comparing with deciduous/broadleaf trees only and coniferous trees only. BCLCS Level 5 vegetation outputs were compared to average total tree counts to determine if the BRAT accurately estimated sites with relatively higher tree counts than others. Sites not classified as treed were excluded from the BCLCS level 5 analysis because they did not have trees present but still had max vegetation density (4) outputs due to the land cover being predominated by tall herbaceous vegetation (Appendix C; Photo 3). No sites were classified as shrubbed; thus, no shrub density analysis was conducted. Average tree count was used instead of total tree count as three sites had only one 30-m and 100-m sampling plot due to being approximately 150-m segments while the other twelve 300-m sites had two 30-m and 100-m plots (Section 5.1).

Table 8. BRAT Output Correlations with Field Measurements.

	Gradient (%)	Drainage Area (km^2)	Veg Score 100 m (0-4)	Veg Score 30 m (0-4)	Two-year Low flow (m^3/s)	Two-year Peak Flow (m^3/s)	Dam Capacity (dams/km)
BRAT Outputs ↕ **Field Measurements**	Field Gradient (%)	Bankfull Area (km^2)	Tree Count 31-100-m	Tree Count 1-30-m	Wetted Volume (m^3)	Bankfull Volume (m^3)	Habitat Scorecard (0-90)

4.5 Hydrological Modelling

The ground-truthed sites were segmented into the smallest sub-watersheds available using Freshwater Atlas watershed layers (GeoBC 2024). Seasonal climate data that overlapped these watersheds was collected from the 2022 ClimateBC database, and the 2041 and 2071 projections using the representative concentration pathway (RCP) 8.5 estimate. ClimateBC extracts and downscales gridded (4 x 4 km) monthly climate data from PRISM (Wang et al. 2016). The future climate projections were selected from the General Circulation Models of the Coupled Model Intercomparison Project that was included in the Intergovernmental Panel on Climate Change sixth assessment report (Mahoney et al. 2022). RCP 8.5 was recommended over 4.5 for being a more realistic projection of global emissions (Darin Brooks personal communications 2024). Twelve seasonal variables and one constant variable (13 total) in 2022, 2041, and 2071 were selected to analyze which seasons are affecting flow and may need consideration for beaver occupation and restoration. The selected variables were:

- Elevation in metres;
- Average winter, spring, summer, and autumn temperature in degrees Celsius (Tave_wt, Tave_sp, Tave_sm_Tave_at);

- Precipitation as snow in millimetres (PAS_wt, PAS_sp, PAS_sm, PAS_at).
- Hargreaves reference evaporation in winter, spring, summer, and autumn in millimetres (Eref_wt, Eref_sp, Eref_sm, Eref_at).

Precipitation as snow was selected over total precipitation to examine the changes in flow from a reduced snowpack. While the Cariboo region is expected to have increased precipitation in spring and autumn, this does not necessarily indicate increased streamflow. As part of the Interior Plateau, the Cariboo has a nival (snowmelt-dominated) streamflow (Eaton & Moore 2010). Higher snowpack helps maintain perennial flows as higher snowpack stores more water for flow later in the season than lower snowpacks (Eaton & Moore 2010). Rainfall is not stored on land as long as snow and flows downstream earlier (Eaton & Moore 2010). The Cariboo region is projected to have warmer annual temperature with wetter winters with more rain and less snow, wetter springs and falls, and drier summers (Daust n.d.; MFLNRO 2016). Peak flows are expected to change, with a smaller spring snowpack, earlier spring freshet, and lower summer low flows (MFLNRO 2016). Therefore, examining flow changes from snowfall can provide a better indication of perennial flow changes than total precipitation.

The sub-watersheds were mapped on ArcGIS Pro, and the climate data points overlapping each sub-watershed were tabulated. The two-year low flow and peak flow estimates by the BRAT (Section 4.1.2) were used as current flow estimations, and the average of each climate variable was used in calculations. Once the climate data were tabulated and averaged, a stepwise regression was run for each sub-watershed under 2022 conditions to determine which climate factors were significantly impacting flow using R version 4.2.2 ($\alpha = 0.05$). Autumn seasonal variables were excluded from the low flow regression and summer seasonal variables were excluded from the peak flow regression as they are not expected to influence these flow periods respectively. After running the regressions, the estimates were applied as coefficients to the 2022, 2041, and 2071 climate values to assess the impact to stream flow. The climate data were first normalized to have a uniform scale, and the results were de-normalized to compare the BRAT-estimated flows with and without applying climate data. Change in flow was calculated as:

$$\Delta Q_L \text{ or } \Delta Q_p = Intercept \pm \sum[coefficient\ (Elevation) \pm [coefficient(Tave)] \pm [coefficient(PAS)] \pm [coefficent\ (Eref)]$$

Where Tave is the average temperature of each season, PAS is the precipitation as snowfall of each season, and Eref is the Hargreaves reference evaporation of each season.

4.6 Statistical Analyses for Correlation Tests

Spearman's rank correlation tests were run for all correlation tests using R version 4.2.2. Spearman's rank correlation test was selected because the data were non-parametric. The correlation test determined if positive or negative relationships between variables existed, and if the relationship was significant. The Spearman's rho (r coefficient) indicates the relationship strength. Ninety-five percent confidence intervals were selected; thus, p is significant at < 0.05. Correlation tests were run by site, and as an average of each of the three sites BRAT suitability grouping (i.e., Pervasive, Frequent, Occasional, Rare, and None). Since the BCLCS level 5 was not used to determine the stream's BRAT suitability, no BRAT-averaged analysis was completed for vegetation density.

4.7 Figure Naming Conventions

The first letter of the BRAT suitability category was used to display the category in the scatter plot (e.g., Pervasive = P). Assessed stream site names were given the following abbreviations on the scatterplots:

- 3 Mile Creek = 3MC
- Watson Creek = WC
- Guy Creek = GC
- Rock Creek = RC
- 111 Mile Creek = 111MC
- Tin Cup Creek = TCC
- Gavin Lake Creek = GLC
- Fake Creek = FC
- Buckskin Creek = BskC
- Jones Creek = JC
- Cow Creek = CowC
- Burnt Creek = BrnC
- Smoky Creek = SmC
- Steep Creek = StC
- Cliff Creek = ClC

5.0 Results – BRAT Outputs and Field Observations

5.1 Site Selection for Ground Truthing

Fifteen reaches (three of each BRAT suitability category) were examined for their potential to support beaver dams (Table 9). Three reaches were in Hydrological Zone 14 – North Columbia Mountains (3 Mile Creek, Guy Creek, and Gavin Lake Creek) while the remaining 12 sites were in Hydrologic Zone 15 – Fraser Plateau.

Table 9. Summary information of field-assessed sites in the Cariboo Region, 2023.

Site Name	Watershed	BEC Zone	BRAT Suitability	Assessment Date(s) (YYYY-MM-DD)	Length Surveyed (m)	Coordinates (Lat/Long)
3 Mile Creek	Quesnel River	SBSdw1	Pervasive	2023-07-09	300	52.515627, -121.801030
Watson Creek	San Jose River	IDFdk3	Pervasive	2023-06-04; 2023-06-06	300	51.775661, -121.428019
Guy Creek	Quesnel River	SBSdw1	Pervasive	2023-07-10	300	52.448818, -121.832694
Rock Creek	San Jose River	IDFdk3	Frequent	2023-05-29; 2023-06-04; 2023-06-06	300	51.768116, -121.451474
111 Mile Creek	San Jose River	IDFdk3	Frequent	2023-06-04; 2023-06-06	300	51.776079, -121.429205
Tin Cup Creek	Thompson River	IDFdk3	Frequent	2023-07-01	300	51.354322, -121.274229
Gavin Lake Creek*	Quesnel River	ICHmk3	Occasional	2023-07-03	300	52.497641, -121.713007
Fake Creek*	Fraser River	IDFdk3	Occasional	2023-06-05	150	52.283846, -122.312474
Buckskin Creek	Fraser River	IDFdk3	Occasional	2023-07-08	300	52.250281, -122.325810
Jones Creek	San Jose River	IDFxm	Rare	2023-07-07	300	52.081710, -121.896406
Cow Creek*	San Jose River	IDFdk3	Rare	2023-07-07	150	52.081802, -121.876746
Burnt Creek*	Thompson River	IDFdk3	Rare	2023-09-24	300	51.321975, -121.029286
Smoky Creek*	San Jose River	IDFxm	None	2023-07-11	300	52.175549, -122.166085
Steep Creek*	San Jose River	IDFxm	None	2023-07-11	150	52.166683, -122.175460
Cliff Creek*	Fraser River	IDFxm	None	2023-06-05	300	52.264700, -122.259346

*Watercourse name is not official and made by author for reader convenience.

5.2 BRAT Outputs

No streams were limited by an excessively large drainage area or high two-year flood stream power (Table 10). The ‘None’ streams were not designated by vegetation limitation, and instead by gradient. Most streams fell within the 0.5 – 15% gradient category. Vegetation scores were the biggest differentiator between suitability designations, as lower vegetation scores always correlated with lower dam density scores, except for the ‘None’ creeks as they exceeded the gradient limit. Watson Creek received the maximum dam capacity score (40 dams/km).

Table 10. Summary of BRAT Outputs for the 15 field-assessed streams in the Cariboo Region, 2023.

Site	Gradient (%)	Drainage Area (km^2)	Veg Score 100 m (0-4)	Veg Score 30 m (0-4)	Two-year Low flow (m^3/s)	Two-year Peak Flow (m^3/s)	Two-year Low flow Stream Power (W/m)	Two-year Peak Stream Power (W/m)	Dam Capacity (dams/km)
3 Mile Creek	5.0	8.43	2.74	3.43	6.2×10^{-3}	0.10	0.09	1.42	**23.7**
Watson Creek	1.7	248.87	3.87	4	0.02	0.52	0.10	2.42	**40**
Guy Creek	4.9	4.156	3.15	3.46	3.0×10^{-3}	0.06	0.04	0.73	**24.3**
Rock Creek	2.0	113.68	1.60	2.38	9.1×10^{-3}	0.26	0.05	1.43	**10.7**
111 Mile Creek	0.07	640.83	2.56	2.21	0.06	1.2	0.02	0.34	**7.2**
Tin Cup Creek	0.85	31.93	2.05	2.62	2.2×10^{-3}	0.08	5.2×10^{-3}	0.19	**11.8**
Gavin Lake Creek	9.1	0.51	2	2	3.4×10^{-4}	7.9×10^{-3}	8.6×10^{-3}	0.20	**3.6**
Fake Creek	14.1	2.91	2	2	1.5×10^{-4}	9.5×10^{-3}	5.9×10^{-3}	0.37	**3.6**
Buckskin Creek	0.41	54.73	1.97	1.77	4.0×10^{-3}	0.13	4.5×10^{-3}	0.15	**3.6**
Jones Creek	0.37	97.25	1	1	7.6×10^{-3}	0.22	7.8×10^{-3}	0.23	**0.57**
Cow Creek	4.1	4.11	1	1	2.2×10^{-4}	0.01	2.5×10^{-3}	0.15	**0.57**
Burnt Creek	0.30	4.27	1	1	2.3×10^{-4}	0.01	1.9×10^{-4}	0.01	**0.57**
Smoky Creek	24.4	1.45	2.09	2	6.9×10^{-5}	5.1×10^{-3}	4.7×10^{-3}	0.34	**0**
Steep Creek	29.4	0.64	1.93	1.94	2.8×10^{-5}	2.4×10^{-3}	2.3×10^{-3}	0.20	**0**
Cliff Creek	25.1	2.48	1.89	1.88	1.3×10^{-4}	8.3×10^{-3}	8.8×10^{-3}	0.58	**0**

5.3 Field Assessments – Beaver Presence

Dams were found only in two streams: 111 Mile Creek and Watson Creek which is a tributary of 111 Mile Creek (Table 11). Both streams are located within privately owned farmland at the 108 Mile Ranch. Fish were observed upstream and downstream of both dams in Watson Creek. One Pervasive stream had signs of beaver presence, all three Frequent streams had signs of beaver presence, and one Occasional stream had a beaver sighting downstream of the assessment area in a constructed wetland built by a DUC-managed dam (Table 12).

Table 11. Summary of observed beaver dams with their dimensions and upstream and downstream water levels from field assessments in the Cariboo Region, 2023.

Dam Location	Dam Status	Dam Flow	Dam Height (m)	Dam Length (m)	Pond Depth (m)	Upstream Water Level (m)	Downstream Water Level (m)
Watson Creek Upstream	Inactive	Through-flow	0.35	4.8	0.23	0.29	0.20
Watson Creek Downstream	Active	Underflow	0.25	4.1	0.53	0.32	0.23
111 Mile Creek Upstream	Inactive	Through-flow	0.35	3.1	0.60	0.50	0.40
111 Mile Creek Downstream	Active	Through-flow	0.4	19	0.95	0.67	0.45

Table 12. Summary of other signs of beaver presence in assessed streams during field assessments in the Cariboo Region, 2023.

Stream	Date of Observation	Beaver Observed	Sign(s) of Presence	Presence Comment
Rock Creek	2023-05-29	0	Gnawed trees	Some gnawed tree trunks adjacent to stream.
Watson Creek	2023-06-04	0	Gnawed trees	Abundant gnawed tree trunks adjacent to vegetation plots.
111 Mile Creek	2023-06-04	0	Gnawed trees	Abundant gnawed tree trunks adjacent to vegetation plots.
Tin Cup Creek	2023-07-01	0	Gnawed trees; Scat	Multiple gnawed tree trunks < 3 m from stream; Unconfirmed scat.
Buckskin Creek	2023-07-08	1 Adult	Coppiced willow stems	Single beaver seen swimming in Buckskin Marsh; Coppiced willow stems indicate beaver clipping.

5.4 Field Assessments – Instream

Although stream power was not measured in the field, it is assumed that all streams lacked sufficient stream power to prevent beaver-dam-building. This assumption is based on 111 Mile Creek having the highest stream power (from feeling when wading through the stream) and was one of the only two streams to have dams present at the time of assessment (and the largest dams – Table 11). Additionally, Watson Creek had the highest estimated two-year peak flow stream power by the BRAT (Table 10), and was the only other stream to have beaver dams present (Table 11). Therefore, it is assumed that the BRAT correctly estimated that none of the assessed streams were limited by stream power.

The average bankfull depth of all streams was 0.30 m. Bankfull depth variation across all sites was relatively low (SD = 0.181) and all sites were below 1 m. Average estimated BRAT low flow and peak flows between all sites was 7.8 x 10^{-3} m^3/s and 0.18 m^3/s respectively, and both had low variation among sites (SD = 0.02; 0.32 respectively). 111 Mile Creek had the greatest bankfull width and bankfull depth, though this depth is likely influenced by the active beaver dams.

5.5 Field Assessments – Vegetation

Aspen were found on all plots that had deciduous trees (12 of 15 sites). Plots with no aspen also had no other deciduous trees. All aspen found during the project were trembling aspen (*Populus tremuloides*). Willows were the next most common deciduous species, found at 7 of the 15 sites. Mountain alder (*Alnus incana*) were only found at the two sites in the SBSdw1 zone (3 Mile Creek and Guy Creek). Other deciduous trees were found at three sites and included black cottonwood (*Populus trichocarpa*) and paper birch (*Betula papyrifera*) at Guy Creek. Saskatoon berry (*Amelanchier alnifolia*) was found at Smoky Creek. The other deciduous trees found in Burnt Creek could not be identified due to the fire.

Coniferous tree species richness was relatively consistent across sites within the same BEC zone. Coniferous species found at 3 Mile Creek and Guy Creek (the SBSdw1 sites) included western hemlock (*Tsuga heterophylla*), hybrid white spruce (*Picea engelmannii* x *glauca*) with lodgepole pine (*Pinus contorta*) found in 3-Mile Creek only. The single ICHmk3 site (Gavin Lake Creek) had lodgepole pine, Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*) present. Of the IDFxm sites that had trees (Cliff Creek, Steep Creek, Smoky Creek), Steep Creek and Smoky Creek only had Douglas-fir. Cliff Creek had both Douglas-fir and common juniper (*Juniperus communis*). Lodgepole pine, hybrid white spruce, and Douglas-fir were found at most sites of the IDFdk3 sites (all other sites).

6.0 Results – BRAT Comparisons to Field Results

6.1 BRAT Stream Feature Outputs and Instream Assessments

Despite the BRAT filtering for perennial watercourses (Section 1.5), five field sites were dry at time of assessment, and all five had nearly zero BRAT-estimated two-year low flow and peak flows (Figure 2 a, b). There is a positive correlation between BRAT-estimated two-year low flow and average wetted volume that is significant (r = 0.76, $p = 9.2 \times 10^{-4}$). Correlation between BRAT-estimated two-year peak flow and average bankfull volume was weaker but significant (r = 0.58, $p = 0.02$). When averaging by BRAT suitability, there was a positive correlation between low flow and wetted volume and between peak flow and bankfull volume that was not significant (r = 0.7 for both; $p = 0.19$ for both – Figure 2 c, d).

Overall, a weaker positive correlation was found between BRAT-estimated drainage area and average bankfull area that was significant (r = 0.57, p = 0.03 – Figure 3 a). The average bankfull area of the assessed sites was 1.37 km^2. While only three streams had a bankfull area > 1 km^2, variation among the streams was high (SD = 1.55). Average BRAT-estimated drainage area was 81.1 km^2 with high variation among sites (SD = 169). There was high variation among bankfull areas of some sites with similar BRAT drainage area estimations. Jones Creek and 111 Mile Creek have the same bankfull area despite different BRAT drainage areas. Burnt Creek had the highest bankfull area despite one of the lowest BRAT drainage areas. When averaging by BRAT suitability, there was a weaker correlation between average drainage area and average bankfull area that was not significant (r = 0.5; p = 0.39 – Figure 3 c). Larger drainage areas did not indicate a higher BRAT suitability, as Pervasive sites bankfull areas were smaller than all sites except None sites. Rare were the largest, and much larger relative to drainage area estimations.

Smoky Creek had a lower measured gradient than modeled, and Fake Creek had a higher than modeled gradient, above the 23% gradient limit (Figure 3 b). All other streams not designated as ‘None’ were correctly estimated below the 15% gradient limit that might limit dam building (Section 4.1.2). Overall, there is a high correlation between the BRAT outputs and the measured gradient (r = 0.87), and this correlation is highly significant ($p = 2.1 \times 10^{-5}$). When averaging by BRAT suitability, the correlation is high and significant (r = 0.9; p = 0.04 – Figure 3 d). Since all streams not designated ‘None’ except Fake Creek were correctly estimated below 15%, the BRAT correctly did not use gradient as a physical limitation or prevention to estimate dam capacity, and did use it as a physical prevention for the None streams all above 23% except Smoky Creek.

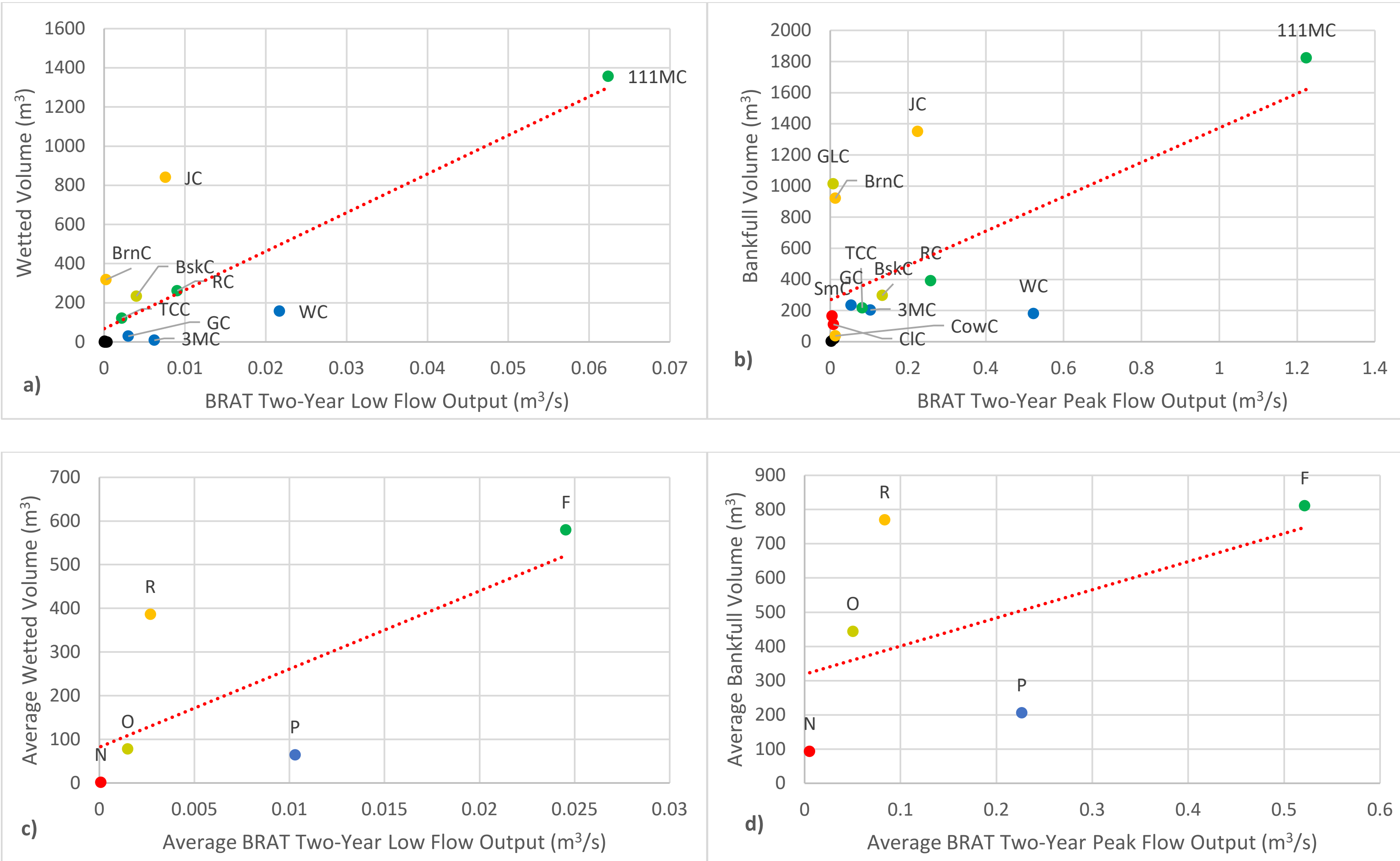

Figure 2. Scatter plots showing relationship between (a) BRAT two-year low flow outputs and wetted volume; (b) BRAT two-year peak flow outputs and bankfull volume; (c) average BRAT two-year low flow outputs and average wetted volume averaged by BRAT suitability; (d) average BRAT two-year peak flow and average bankfull volume averaged by BRAT suitability. Data points colour correspond to the site's BRAT suitability category (Section 1.5). Black dot clusters in Figures (a) and (b) represent all sites at or near zero. Section 4.7 describes the naming scheme for data points.

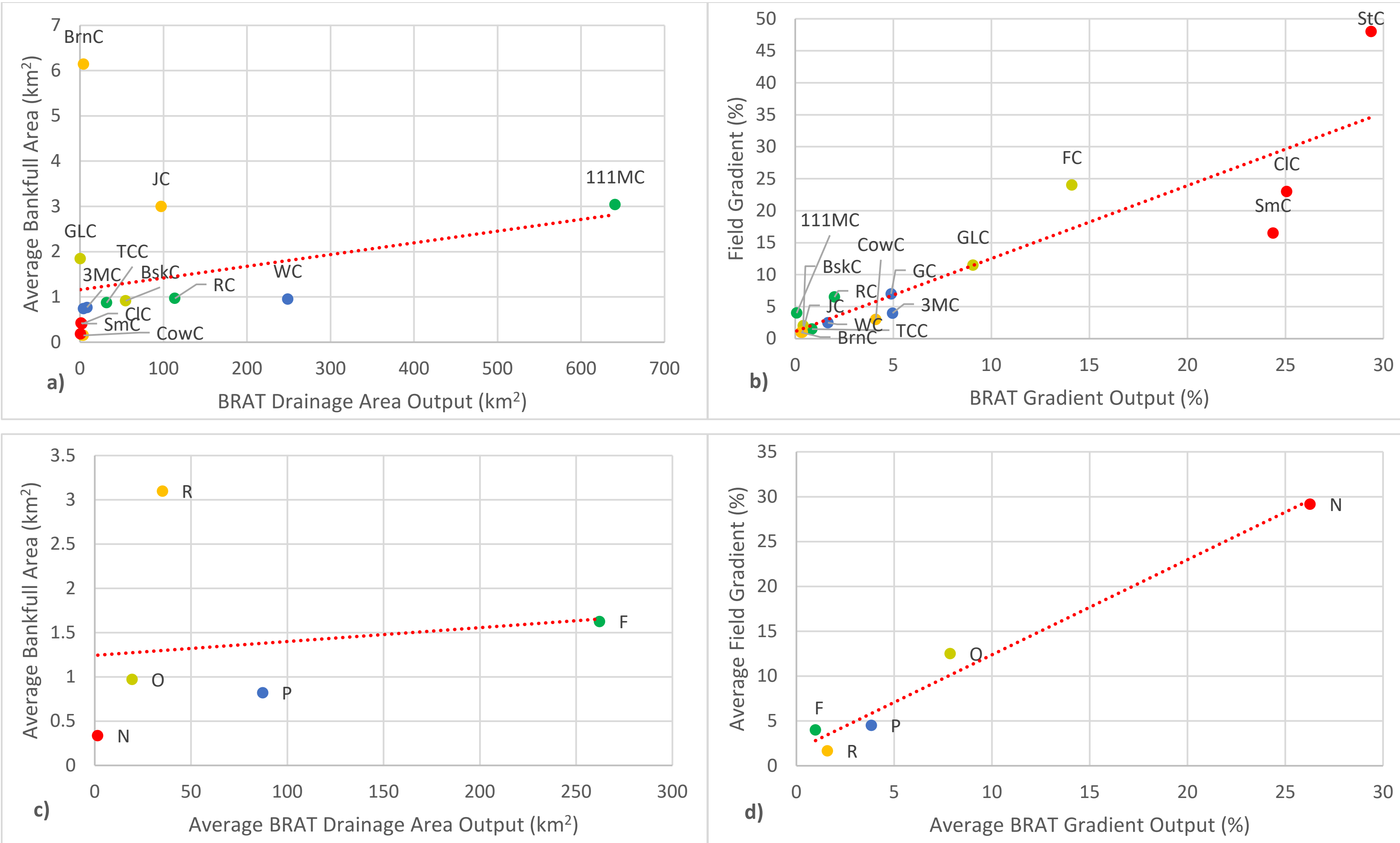

Figure 3. Scatter plots showing the correlation between (a) BRAT drainage area outputs and average bankfull area of assessed sites; (b) BRAT gradient outputs and field-measured gradient of assessed sites; (c) BRAT-estimated drainage area and bankfull area averaged by BRAT suitability; and (d) the average BRAT gradient outputs and field-measured gradients averaged by BRAT suitability.

6.2 BRAT Vegetation Outputs and Field Vegetation Assessments

A higher BRAT vegetation output should indicate greater deciduous vegetation based on the vegetation classification system used (Section 4.1.1). However, for coniferous vegetation, a higher BRAT vegetation output should not indicate greater coniferous vegetation because coniferous forests were given an Occasional score (2), and mixed forests were given a Frequent score (3) for being less-preferred vegetation (Section 4.1.1).

6.2.1 All Trees

There was little correlation found when comparing the within 30-m tree counts with the 30-m vegetation BRAT output and was not significant (r = 0.27; *p* = 0.32 – Figure 4 a). However, a significant positive correlation was found with vegetation between 31-100 m (r = 0.76, *p* = 9.2 x 10^{-4} – Figure 4 b). When the BRAT output scores and field tree counts were averaged by BRAT suitability, little positive correlation was found within 30 m (r = 0.1; *p* = 0.87 – Figure 4 c). Within 100-m, the average BRAT vegetation output had a high positive correlation with the number of trees, but was not significant (r = 0.8; *p* = 0.10 – Figure 4 d).

When analyzing only preferred-size trees ($\leq$ 15-cm DBH), the overall same relationships were seen within 30-m and between 31-100-m with some minor variations. Within 30-m, the positive correlation was similar to all tree sizes and was not significant (r = 0.26; *p* = 0.37 – Figure 5 a). Between 31-100-m, the positive correlation was similar to all tree sizes and significant (r = 0.75; *p* = 1.0 x 10^{-3} – Figure 5 b). When averaging by BRAT suitability, the overall trend was nearly identical to the assessment of all tree sizes, except that Occasional and None creeks had a similar field average at 30-m. At 100-m, the correlation was high and significant (r = 0.9; *p* = 0.04) (Figure 5 d). However, at 30-m, the correlation was lower and less significant (r = 0.87, *p* = 0.05) (Figure 5 c).

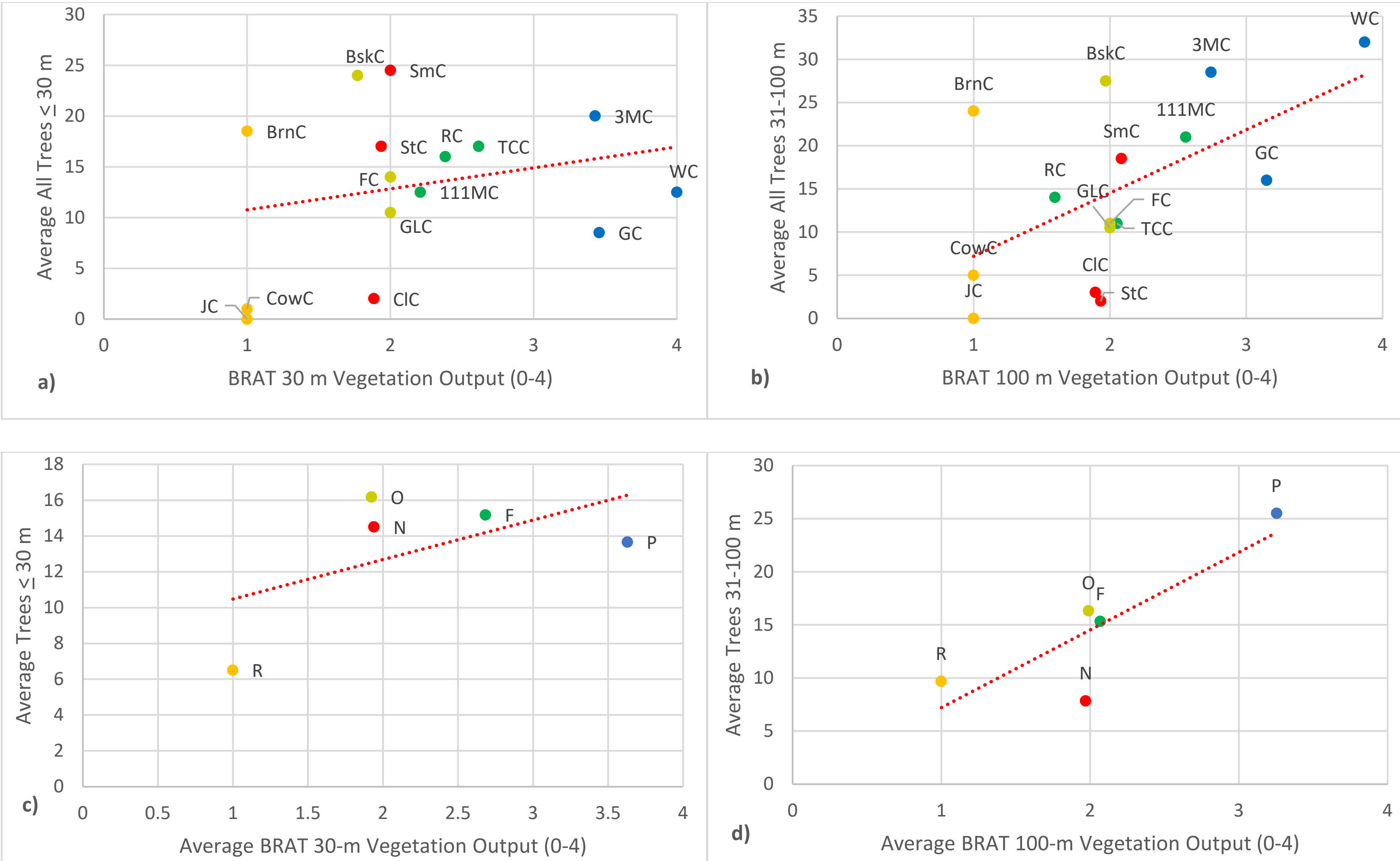

Figure 4. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation output average tree count within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and average tree count between 31-100 m of the stream; (c) relationship between the average BRAT 30-m vegetation output and the average tree count by each BRAT suitability within 30 m of the stream; (d) relationship between the average BRAT 100-m vegetation output and the average tree count between 31-100 m by each BRAT suitability.

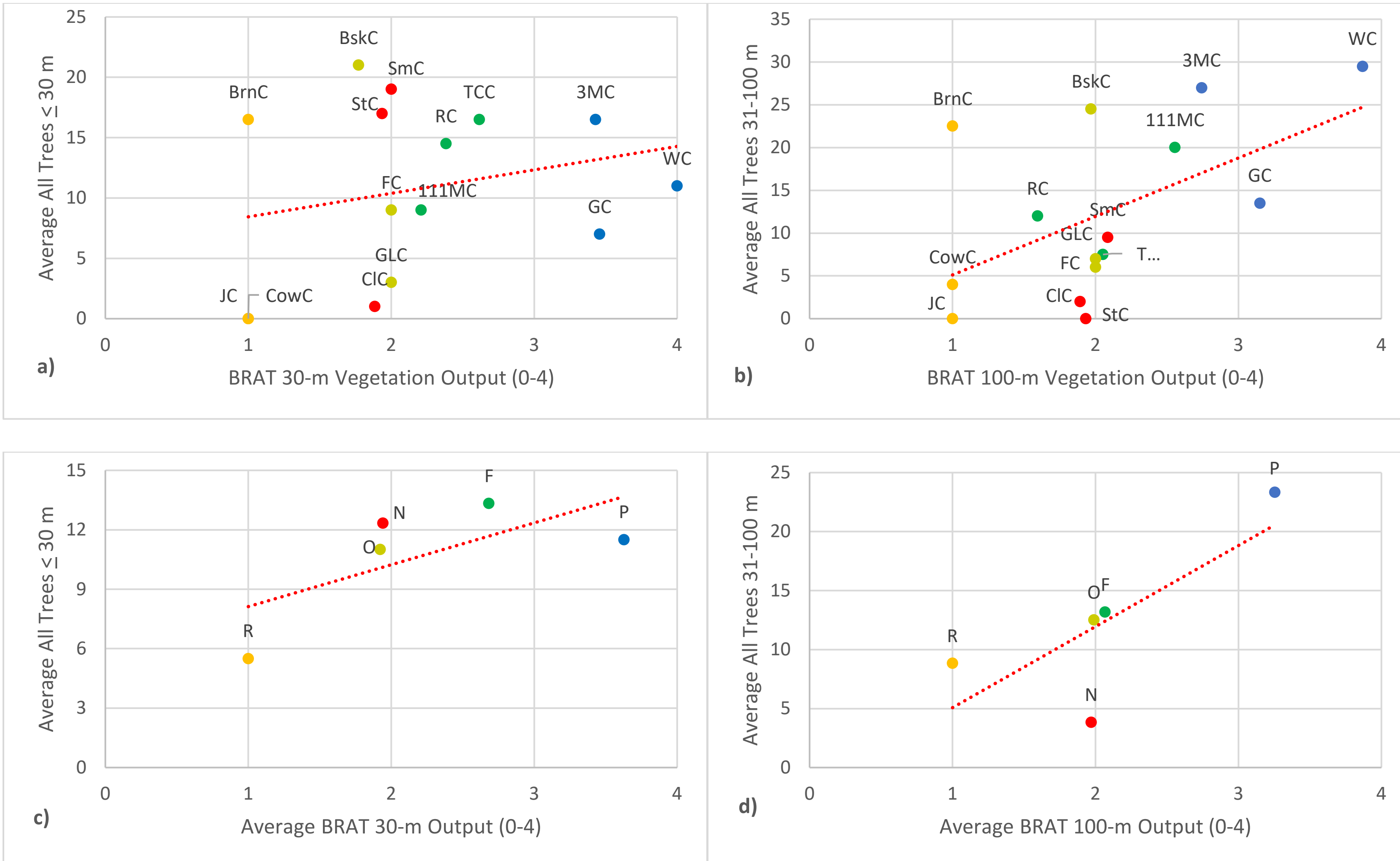

Figure 5. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation output and the average 5-15 cm DBH trees within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and the average 5-15 cm DBH trees between 31-100 m of stream; (c) relationship between the average BRAT 30-m vegetation output and the average 5-15 cm DBH trees within 30 m of the stream by dam capacity; (d) relationship between the average BRAT 100-m vegetation output and the average 5-15 cm DBH trees between 31-100 m of stream by dam capacity.

6.2.2 Coniferous Trees

Correlation was lower between BRAT vegetation outputs and average coniferous tree counts compared to the all trees and deciduous trees analysis (Figure 6 a, b). Both 30-m and 100-m vegetation zones had a low correlation (r = 0.01; 0.29 respectively) and neither correlation was significant (p = 0.96; 0.29 respectively). The highest counts of coniferous trees were generally around BRAT output scores near two (Figure 6 c, d) which was the score designated for coniferous forests (Section 4.1.1). Rare creeks outputs were less than two and had fewer conifers than all other sites. Pervasive creeks scored higher than two and had fewer conifers than sites that scored closer to two (except for None creeks at 100 m), but more than Rare creeks. Within 30 m, Frequent sites scored above two and had fewer conifers. Between 31-100 m, Frequent sites scored closer to two and had high conifer abundances. At both distance ranges, Occasional creeks scored close to two and had the highest conifer abundances. None creeks had a high number of conifers relative to the BRAT output within 30 m, but had far fewer conifers relative to the vegetation output between 31-100 m. The correlation between average BRAT vegetation outputs and number of conifers within 30 m was low and not significant (r = 0.10, p = 0.87). At the 100 m vegetation zone, the correlation was slightly positive but not significant. (r = 0.60, p = 0.28).

When analyzing preferred-size coniferous trees, a similar overall trend was observed. Both 30-m and 100-m vegetation correlations were low and not significant (r = 0.14, p = 0.61; r = 0.30, p = 0.28), respectively (Figure 7 a, b). Likewise, averaging the outputs and assessed trees by BRAT suitability followed a similar trend. Correlation between the average BRAT vegetation outputs and average number of conifers $\leq$ 15 cm DBH counted within 30 m is low and not significant (r = 0.2; p = 0.75 – Figure 7 c). Between 31-100 m, the correlation is slightly positive and not significant (r = 0.5; p = 0.39 – Figure 7 d).

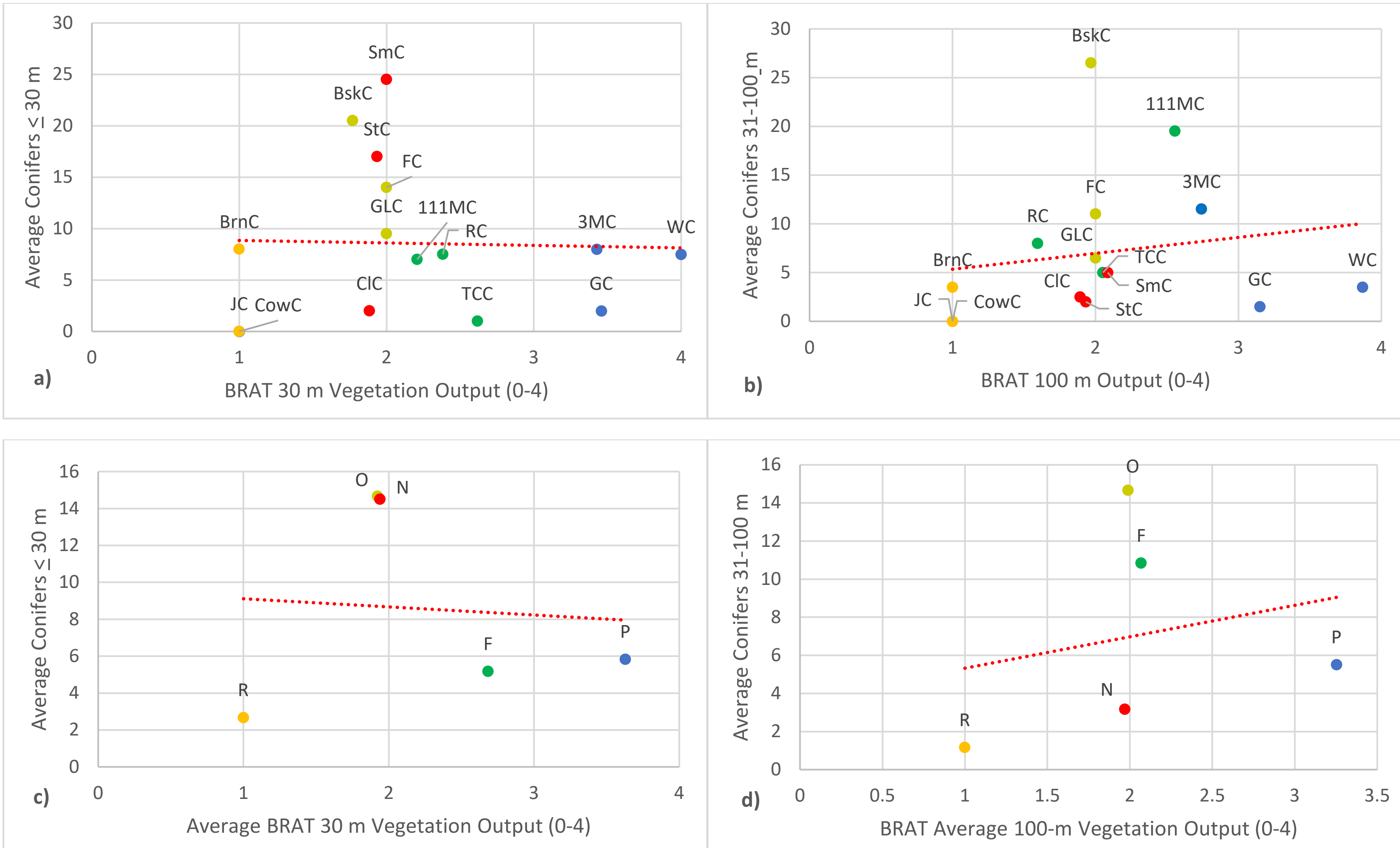

Figure 6. Scatter plots displaying the (a) relationship between the BRAT 300-m vegetation output and the average conifer count within 30 m of the stream; (b) relationship between the BRAT 100-m vegetation output and the average conifer count between 31-100 m of the stream; (c) relationship between the average BRAT 30-m vegetation output and the average conifer count within 30 m of the stream for each BRAT suitability category; (d) relationship between the average BRAT 100-m vegetation output and the average conifer count between 31-100 m of the stream for each BRAT suitability category.

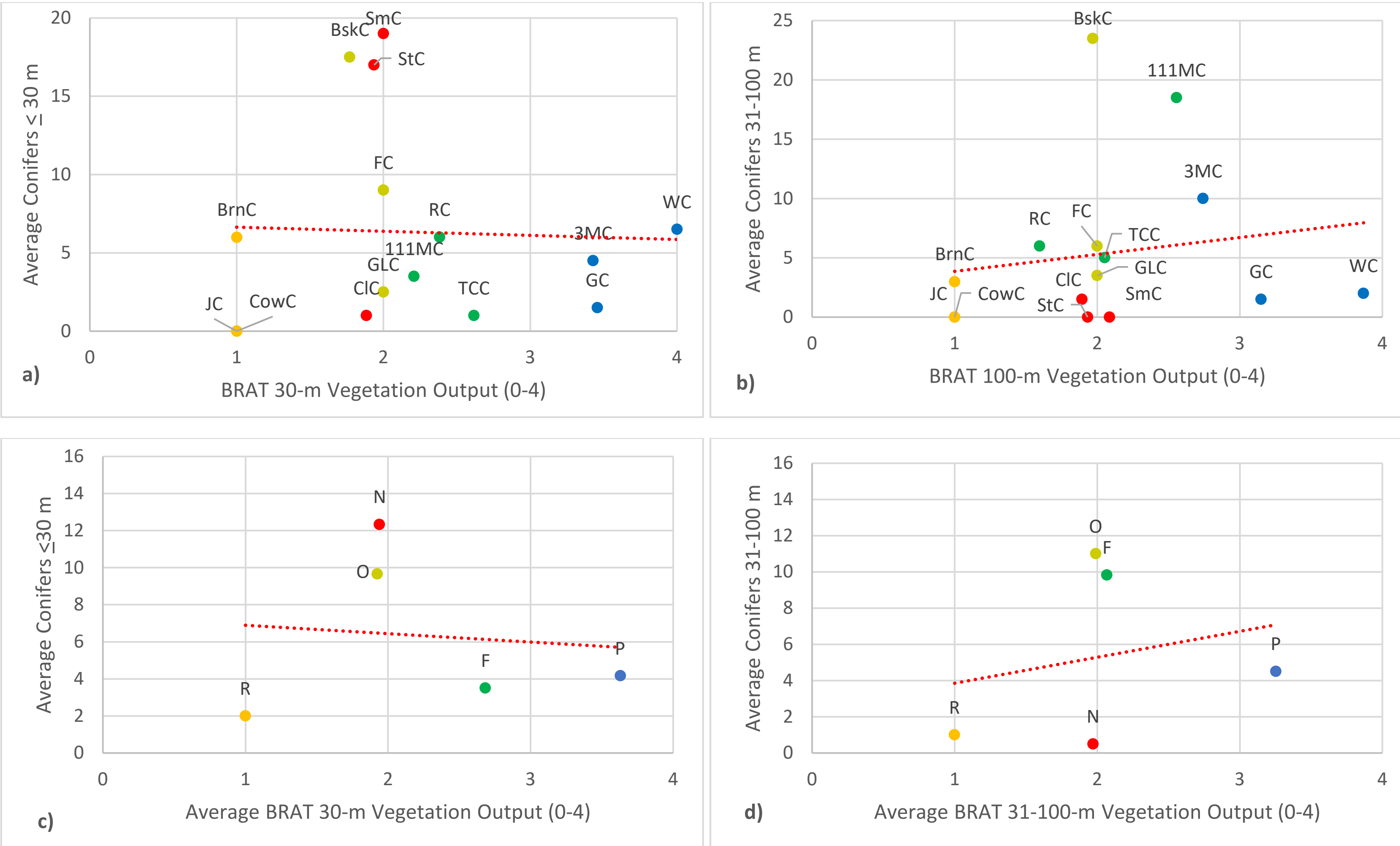

Figure 7. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation output and the average ≤ 15-cm DBH conifer count within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and the average ≤ 15-cm DBH conifer count between 31-100 m of the stream; (c) relationship between the average BRAT 30-m vegetation output and the average ≤ 15-cm DBH conifer count within 30 m of the stream for each BRAT suitability category; (d) relationship between the average BRAT 100-m vegetation output and the ≤ 15-cm DBH average conifer count between 31-100 m of the stream for each BRAT suitability category.

6.2.3 Deciduous Trees

Unlike the coniferous-tree analysis, there was an overall positive correlation between the BRAT 30-m and 100-m vegetation output and the number of deciduous trees measured within 30 m and between 31-100 m (r = 0.72; 0.68 respectively) that was significant ($p = 2.0 \times 10^{-3}$; 5.0×10^{-3} respectively – Figure 8 a, b). Within 30 m, the BRAT was quite accurate as all sites with outputs less than two had lower deciduous tree counts than all sites with outputs greater than two, except for Burnt Creek. Between 31-100 m, the average number of deciduous trees increased – particularly with Pervasive creeks where the tree counts were more representative of the BRAT output. When averaging 30-m and 100-m correlations by BRAT suitability, the correlations were weaker (r = 0.5; 0.1), respectively, and not significant (p = 0.39; 0.87), respectively (Figure 8 c, d). Frequent site deciduous trees decreased from the within 30-m and between 31-100-m plots, and this decrease was captured by the lower BRAT outputs. Occasional and None sites had an average BRAT vegetation output near two at both distances, and correctly had few deciduous trees being primarily coniferous forests. Pervasive sites had lower average deciduous trees compared to Frequent sites within 30 m despite a higher average BRAT output. However, their average deciduous tree counts nearly tripled between 31-100 m despite a slightly lower BRAT output compared to within 30 m.

When analyzing preferred-size deciduous trees only, the correlation between 30-m BRAT vegetation outputs and within 30-m deciduous trees 5-15-cm DBH was greater and more significant than the analysis of all tree sizes (r = 0.76; $p = 9.6 \times 10^{-4}$ – Figure 9 a). Between 31-100 m, the correlation between the 100-m BRAT vegetation output and 31-100-m deciduous trees 5-15-cm DBH was lower than all tree sizes (r = 0.64; p = 0.01 – Figure 9 b). When averaging by BRAT suitability, the correlation between the 30-m BRAT vegetation output and the number of deciduous trees 5-15-cm DBH was the same as the by-site analysis and not significant (r = 0.5; p = 0.39 – Figure 9 c). Between 31-100 m, the correlation between the 100-m BRAT vegetation output and the number of deciduous trees 5-15-cm DBH was slightly higher than the analysis of all tree sizes and not significant (r = 0.21; p = 0.74 – Figure 9 d). Average deciduous tree counts overall did not reduce greatly when including only $\leq$ 15 cm DBH.

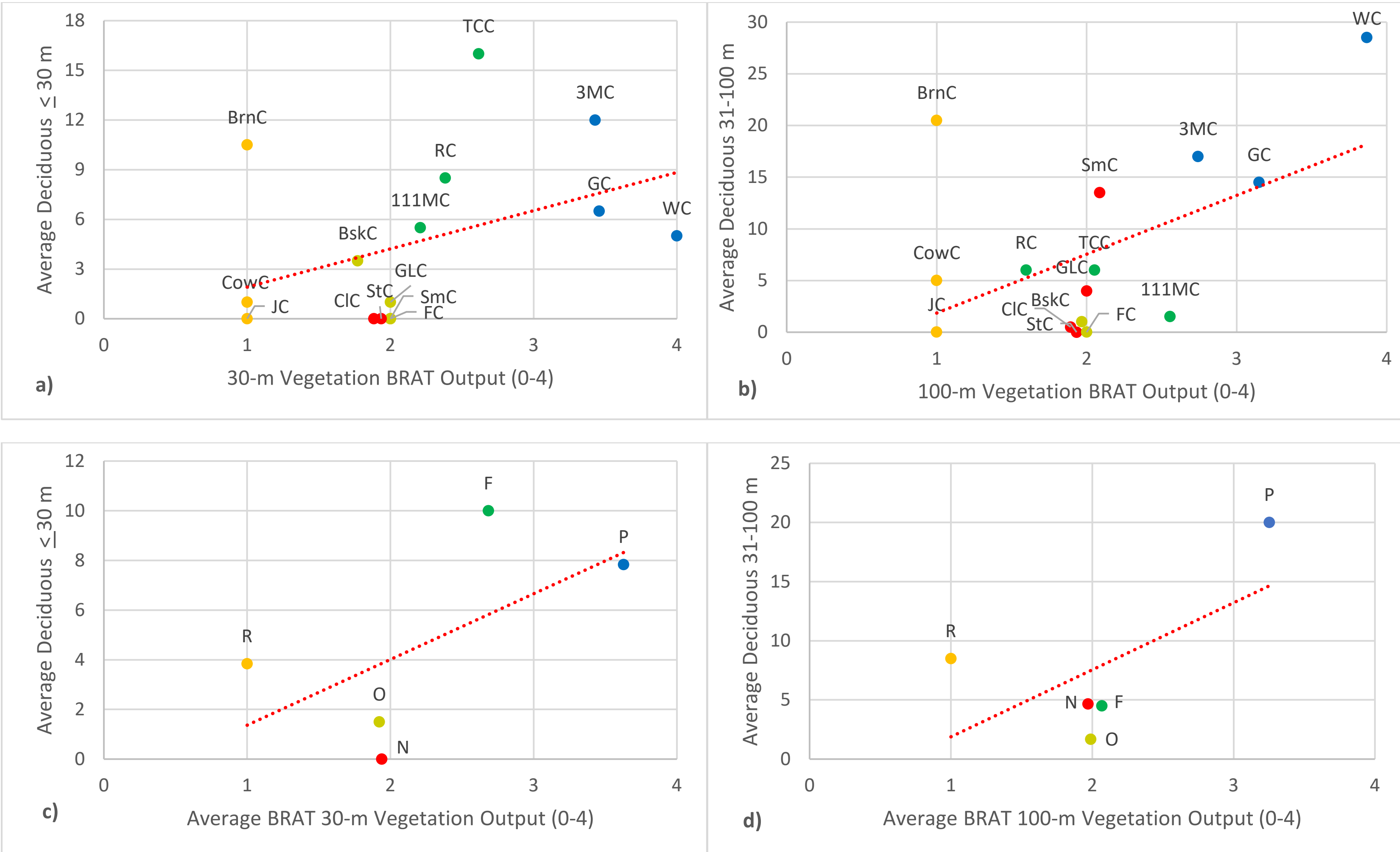

Figure 8. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation output and the average deciduous count within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and the average deciduous count between 31-100 m of the stream; (c) relationship between the average BRAT 30 m vegetation output and the average deciduous count within 30 m of the stream by BRAT suitability; (d) relationship between the average BRAT 100-m vegetation output and the average deciduous count between 31-100 m of the stream by BRAT suitability.

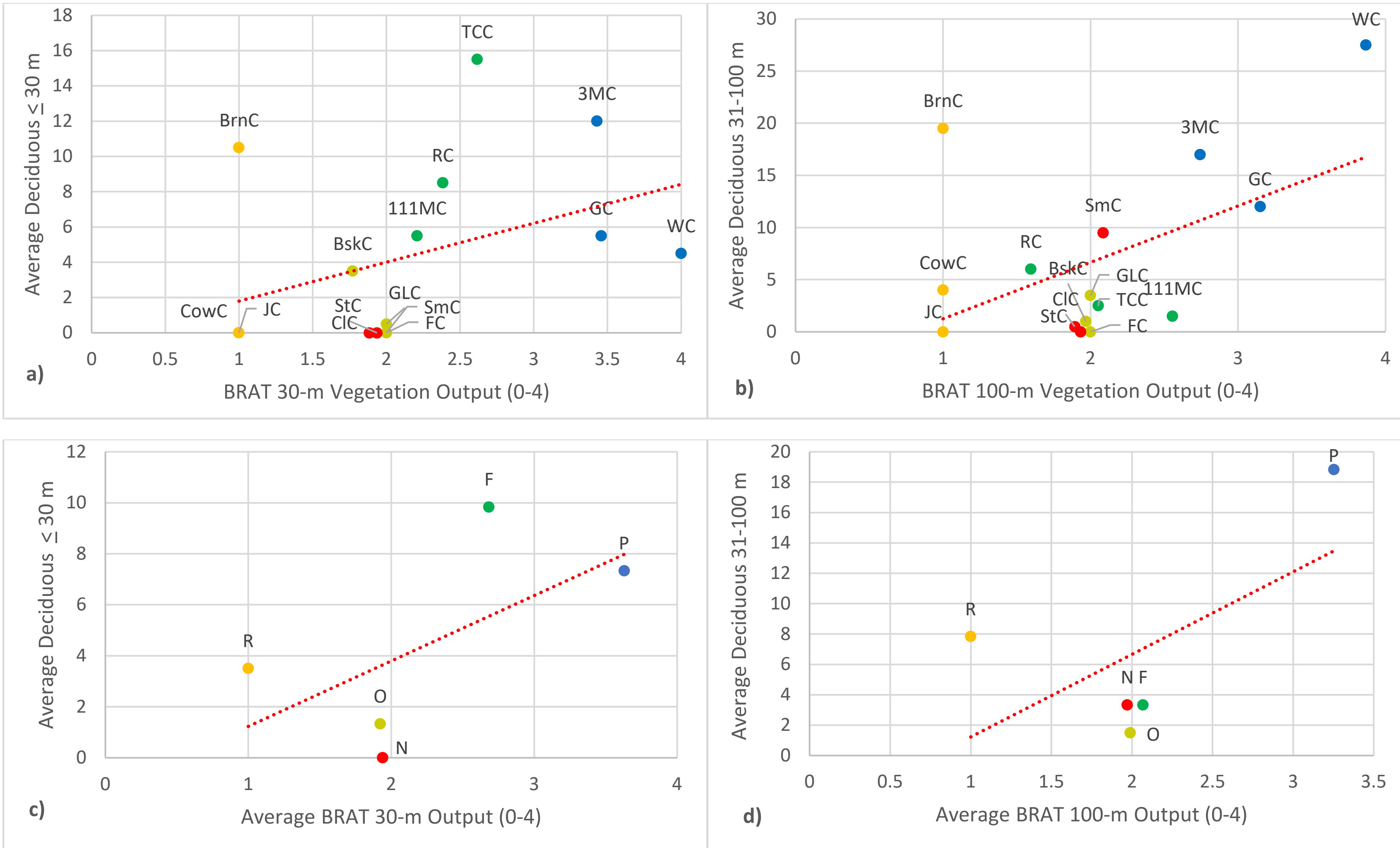

Figure 9. Scatter plots displaying the (a) relationship between the BRAT 30 m vegetation output and the average ≤ 15-cm DBH deciduous count within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and the average ≤ 15-cm DBH deciduous count between 31-100 m of the stream; (c) relationship between the average BRAT 30-m vegetation output and the average ≤ 15-cm DBH deciduous count within 30 m of the stream by BRAT suitability; (d) relationship between the average BRAT 100-m vegetation output and the ≤ 15-cm DBH average deciduous count between 31-100 m of the stream by BRAT suitability.

6.2.4 Shrub Cover

Within 30 m, there was a weak positive correlation between the BRAT 30-m vegetation output and the average percent shrub cover that was not significant (r = 0.43; *p* = 0.10 – Figure 10 a). Between 31-100m, there was a stronger positive correlation between the BRAT 100-m vegetation output and the average percent shrub cover that was significant (r = 0.66; $p = 8.0 \times 10^{-3}$ – Figure 10 b).

When averaging by BRAT suitability within 30 m, there was a strong positive correlation between average BRAT 30-m vegetation output and average shrub cover that was not significant (r = 0.80; *p* = 0.10 – Figure 10 c). Between 31-100 m, there was a weak positive correlation between the average BRAT 100-m vegetation output and the average percent shrub cover that was not significant (r = 0.40; *p* = 0.50 – Figure 10 d).

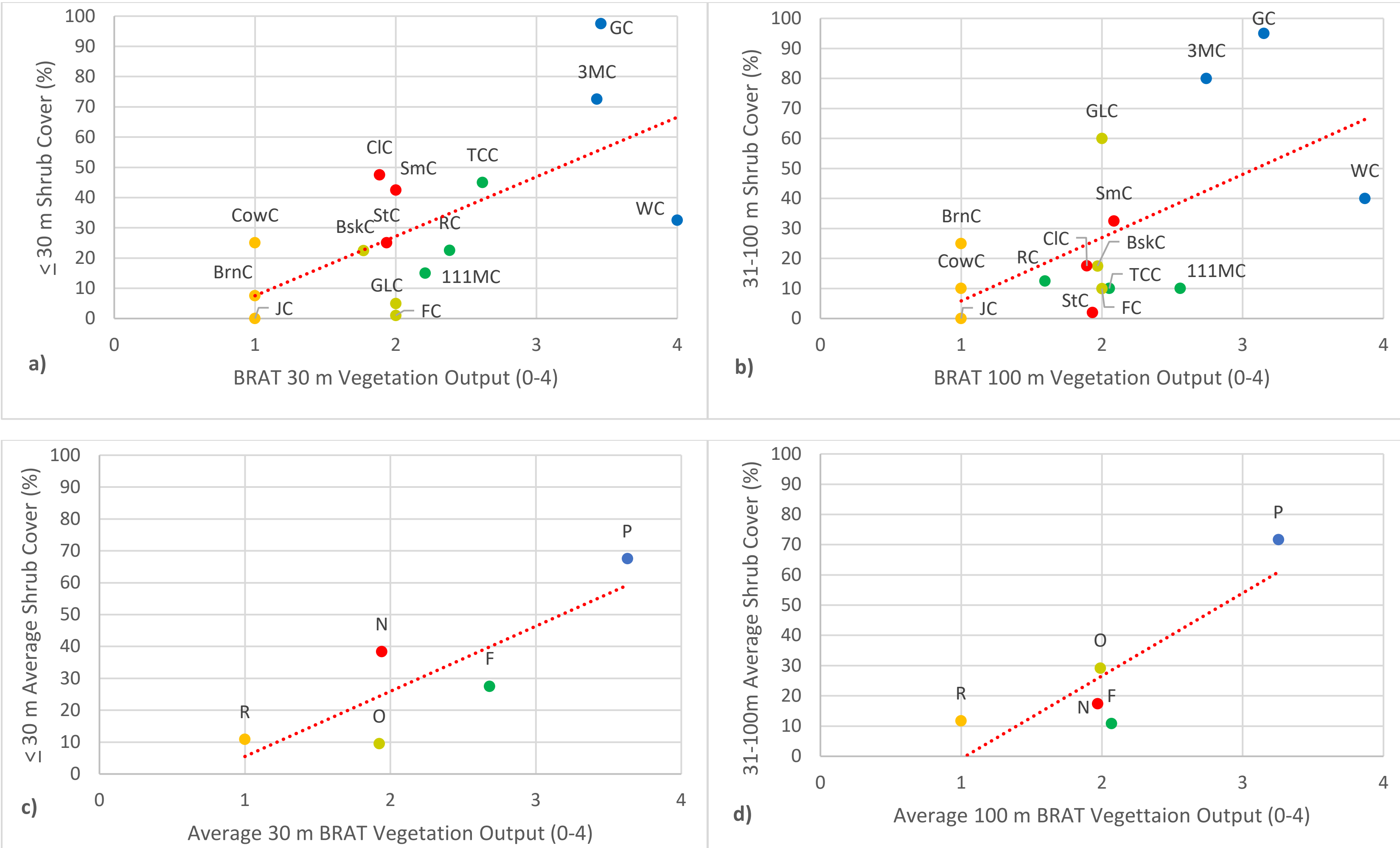

Figure 10. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation output and the average shrub cover within 30 m of stream; (b) relationship between the BRAT 100-m vegetation output and the average shrub cover between 31-100 m of the stream; (c) relationship between the average BRAT 30-m vegetation output and the average shrub cover within 30 m of the stream by BRAT suitability; (d) relationship between the average BRAT 100-m vegetation output and the average shrub cover between 31-100 m of the stream by BRAT suitability.

6.2.5 Tree Density

Burnt Creek, Jones Creek, and Cow Creek (all Rare sites) were classified as herbaceous sites and thus excluded from the tree density analysis. Within 30 m, a weak positive correlation was found (Figure 11 a) that was not significant between the BRAT 30-m output and the average number of all trees (r = 0.47; *p* = 0.12). Between 31-100 m, no correlation was found (Figure 11 b) (r = -0.05; *p* = 0.87). A high variation in the tree counts within 30 m (SD = 6.40) and between 31-100 m (SD = 9.65) was found despite a low variation between the BRAT outputs within 30 m (SD = 0.33) and between 31-100 m (SD = 0.34),

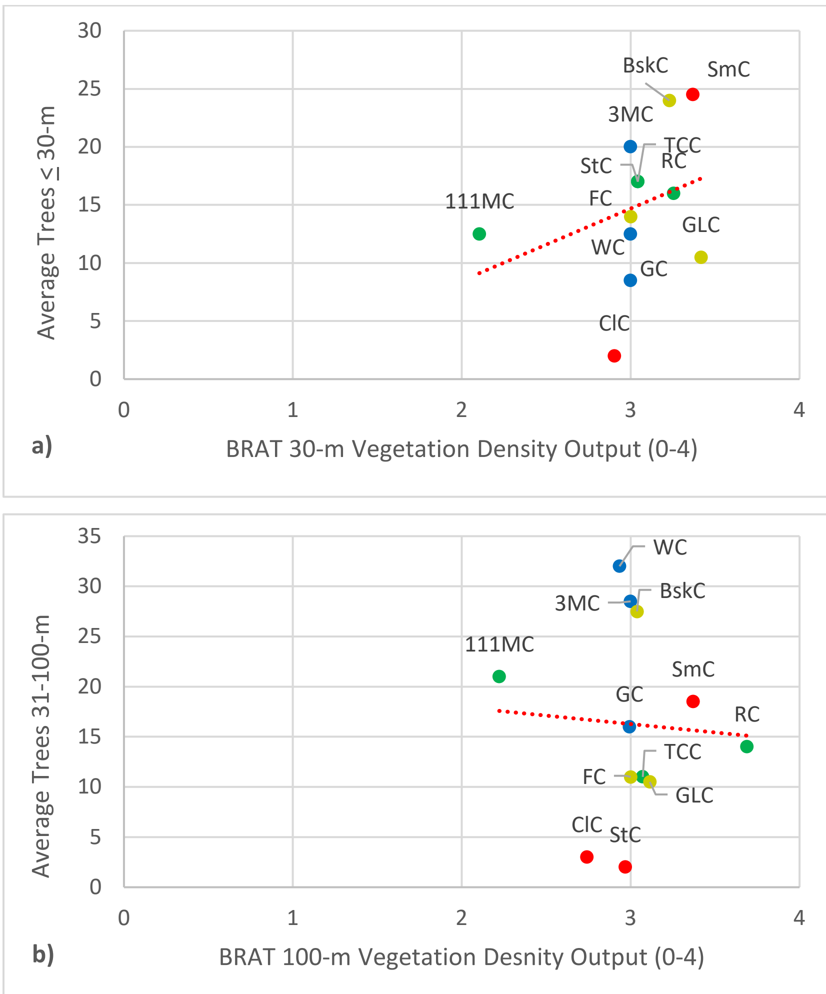

Figure 11. Scatter plots displaying the (a) relationship between the BRAT 30-m vegetation density output and the average number of trees within 30 m; (b) relationship between the BRAT 100-m vegetation density output and the average number of trees between 31-100 m.

6.3 Habitat Scorecard Compared to BRAT Suitability

Five streams received good beaver release site scores ($\geq$ 40), while the other ten received bad scores (< 40) (Appendix B). Of the five good release sites, one was Pervasive, two were Frequent, one was Occasional, and one was Rare (Figure 12 a). There was an overall weak positive correlation between total scores and predicted dams/km that was significant ($r = 0.54$; $p = 0.04$). Watson Creek received the highest habitat total score as well as the highest dams/km output. None creeks generally corresponded with the lowest scores and dams/km output, except for Fake Creek, which scored similarly to the None sites. Otherwise, there was no discernable pattern between habitat scores and the dams/km output (Figure 12 b). When averaging by BRAT suitability, there was a strong positive correlation between dam capacity outputs and habitat scores that was also significant ($r = 0.90$; $p = 0.04$). Pervasive and Frequent creeks had a similar average habitat score despite a greater than three times difference in dam capacity score. Rare creeks on average had a nearly 50% greater habitat score than Occasional creeks despite having an approximately six times lower average dam capacity.

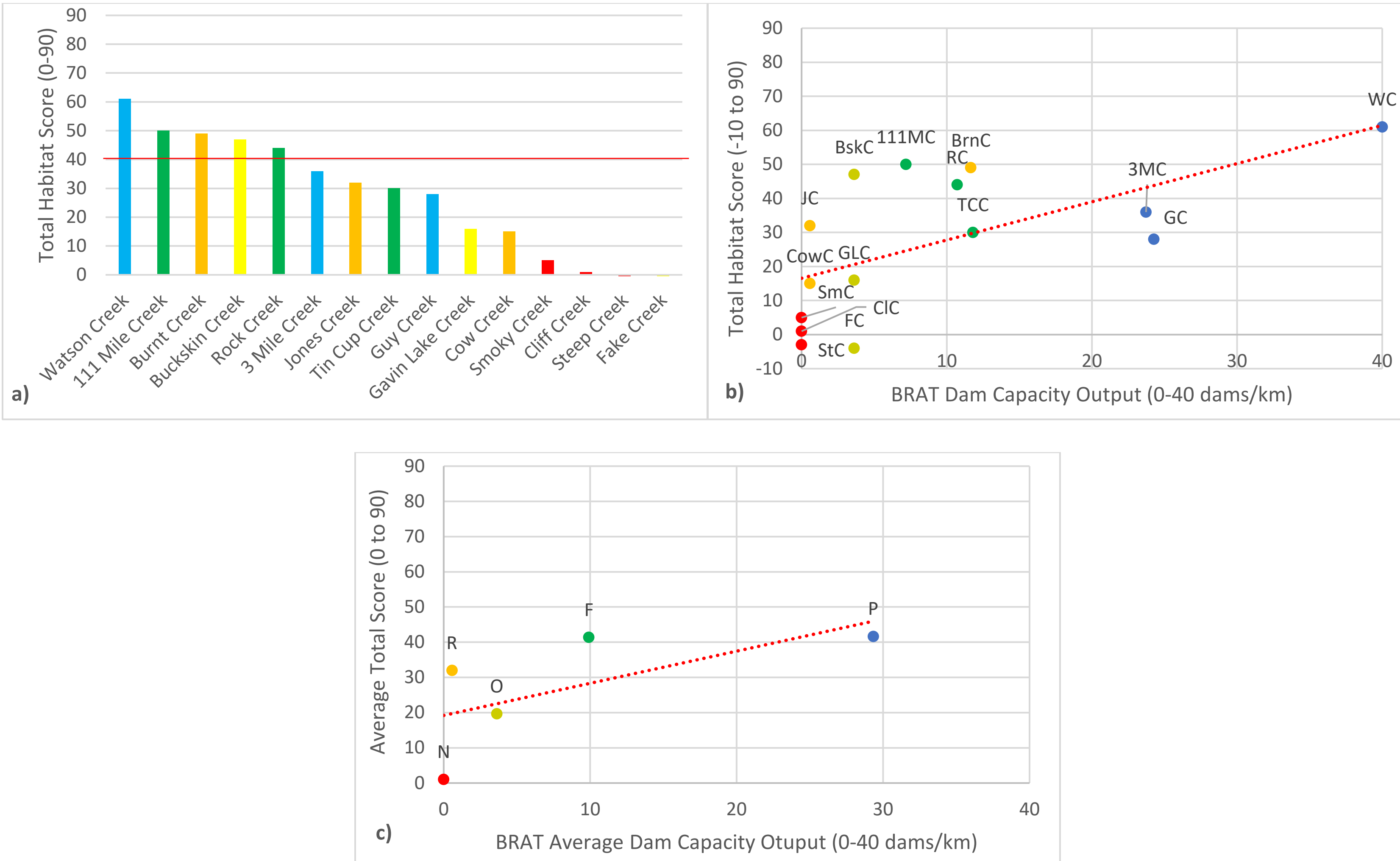

Figure 12. Total habitat quality scorecard results by (a) stream reach ordered by highest to lowest total score; (b) scatter plot showing the correlation between total habitat-quality scores of each site compared to BRAT dams/km output; (c) scatter plot showing the correlation between total habitat-quality scores of each site compared to BRAT dams/km output averaged by BRAT suitability. The red line in figure (a) indicates the cutoff where below 40 is considered a "bad" release site and above 40 is a "good" release site. Colour coding follows BRAT classifications (Section 1.5).

When analyzing only the vegetation parameters from the scorecard (Section 4.3.4), the correlation between the BRAT dam capacity output and the scores of the vegetation habitat parameters was slightly higher and slightly more significant than the correlation between the dam capacity output and total habitat score ($r = 0.60$; $p = 0.02$ – Figure 13 a). Variation between the vegetation habitat scores of all sites was lower than the physical/hydrological scores (SD = 9.8 < 13.9). When averaging by BRAT suitability, there is a perfect positive correlation between the BRAT dam capacity outputs and vegetation habitat scores that is highly significant ($r = 1$; $p < 2.2 \times 10^{-16}$ – Figure 13 b). There was an overall strong discernible trend between increasing BRAT suitability and increasing vegetation habitat quality.

The correlation between the BRAT dam capacity output and the score of the physical/hydrological habitat parameters is lower than the vegetation score correlation and not significant ($r = 0.47$; $p = 0.08$ – Figure 13 c). Variation between the physical/hydrological score of all sites was higher than the vegetation scores (SD = 13.9 > 9.8). Six sites scored less than zero (one Pervasive site, two Occasional sites, all three None sites), and one site scored zero (a Rare site). When averaging by BRAT suitability, there is a weak positive correlation between dam capacity and physical/hydrological habitat scores that is not significant ($r = 0.5$; $p = 0.39$ – Figure 13 d). The correlation is largely driven by None creeks having consistently low scores (SD = 2.6). Otherwise, there is no discernible trend between increasing BRAT suitability categories and increasing physical/hydrological habitat quality.

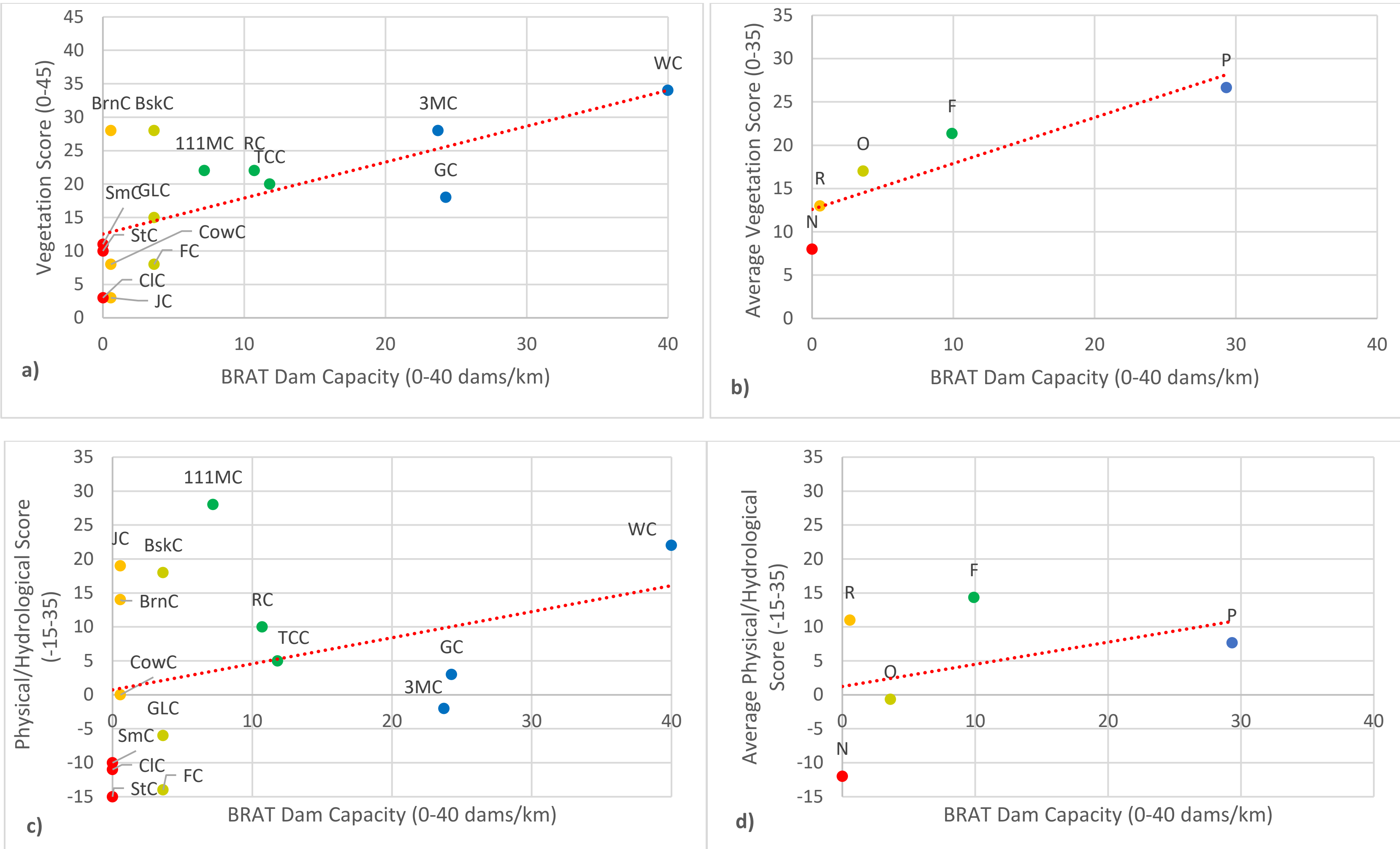

Figure 13. Scatter plots displaying the (a) correlation between vegetation habitat parameters and the BRAT dam capacity outputs; (b) correlation between vegetation habitat parameters and the BRAT dam capacity outputs averaged by BRAT suitability; (c) correlation between physical/hydrological habitat parameters and the BRAT dam capacity outputs; (d) correlation between physical/hydrological habitat parameters and the BRAT dam capacity outputs averaged by BRAT suitability.

7.0 Results – Hydrological Modelling

The smallest sub-watersheds that could be found with publicly available data overlapping the ground-truthed stream reach were selected. Each ground-truthed site was within its own unique sub-watershed (Table 13).

Table 13. Sub-watersheds and Overlapping Climate Data Points of Field Sites.

Sub-Watershed[1]	Sub-Watershed Area (km^2)	Climate Data Points (n)
3 Mile Creek	3.15	13
Watson Creek	1.02	6
Guy Creek	1.71	6
Rock Creek	18.24	74
111 Mile Creek	5.22	21
Tin Cup Creek	3.99	16
Gavin Lake Creek	1.63	7
Buckskin Creek	1.29	6
Fake Creek	2.56	9
Jones Creek	1.69	6
Cow Creek	1.28	5
Burnt Creek	1.63	6
Steep Creek	1.98	9
Smoky Creek	1.22	5
Cliff Creek	2.99	13

[1]GeoBC (2024).

7.1 Current Climatic Condition Regressions

For the low flow stepwise regression, average winter temperature, summer snowfall, spring snowfall, and spring evaporation were found to have the strongest effect on flow (Table 14). Winter temperature had a non-significant positive effect, summer snowfall had a significant positive effect, spring snowfall had a significant negative effect, and spring evaporation had a significant negative effect. The stepwise regression overall was significant (p = 0.03).

Table 14. 2022 Low Flow Stepwise Regression Summary.

Climate Variable[1]	Estimate	Standard Error	t value	Pr
Intercept (Q_L)	1.89	0.99	1.91	0.08
Tave_wt	0.44	0.21	2.07	0.06
PAS_sm	1.09	0.29	3.74	3.9×10^{-3}
PAS_sp	-2.95	1.01	-2.94	0.01
Eref_sp	-2.33	1.01	-2.31	0.04
Residual standard error: 0.19 on 10 degrees of freedom				
Multiple R-squared: 0.62, Adjusted R-squared: 0.46				
F-statistic: 4.00 on 4 and 10 DF, p-value: 0.03				

[1]Acronyms described in Section 4.5

For the peak flow stepwise regression, a greater number of variables were found to impact peak flow (Table 15). Elevation had a non-significant negative impact, average winter temperature had a significant positive impact, average autumn temperature had a significant negative impact, winter snowfall had a significant positive impact, spring snowfall had a non-significant negative impact, autumn snowfall had a negative non-significant impact, and autumn evaporation had a non-significant negative impact. Overall, the stepwise regression was not significant ($p = 0.14$).

Table 15. 2022 Peak Flow Stepwise Regression Summary.

Climate Variable[1]	Estimate	Standard Error	t value	Pr
Intercept (Q_P)	8.05	3.97	2.03	0.08
Elevation	-4.42	2.66	-1.67	0.14
Tave_wt	2.24	0.70	3.21	0.01
Tave_at	-8.51	2.72	-3.13	0.02
PAS_wt	4.62	1.83	2.52	0.04
PAS_sp	-5.72	2.86	-2.00	0.09
PAS_at	-3.69	1.93	-1.91	0.10
Eref_at	-3.10	2.80	-1.11	0.30
Residual standard error: 0.20 on 7 degrees of freedom				
Multiple R-squared: 0.70, Adjusted R-squared: 0.40				
F-statistic: 2.35 on 7 and 7 DF, p-value: 0.14				

7.2 RCP 8.5 Scenario Projection Conditions

On average between all sites, average temperatures were projected to increase in all seasons (Table 16). Winter temperatures were projected to almost reach above freezing by 2071. Snowfall is projected to decrease greatly. Winter evaporation is expected to occur by 2071, likely from the increased temperatures and decreased snowfall. Spring temperatures are projected to increase greatly and are coupled with the greatest evaporation and temperature increases. Summer is projected to have a substantial increase in temperature and evaporation. Autumn follows similar changes to other seasons, but to lesser extremes.

Table 16. 2022, 2041, and 2071 Climate Variables and their changes between 2022-2041 and 2022-2071.

Climate	2022	2041	2022-2041	2071	2022-2071
Tave_wt (°C)	-7.5	-3.7	+3.8	-1.8	+5.7
Tave_sp (°C)	3.7	7.6	+3.9	9.7	+6.0
Tave_sm (°C)	16.0	18.7	+2.7	21.3	+5.3
Tave_at (°C)	4.7	8.0	+3.3	10.2	+5.5
PAS_wt (mm)	161	93	-68	67	-94
PAS_sp (mm)	36	9	-27	3	-33
PAS_sm (mm)	1	0	-1	0	-1
PAS_at (mm)	37	13	-24	7	-30
Eref_wt (mm)	0	0	0	17	+17
Eref_sp (mm)	170	216	+39	233	+63
Eref_sm (mm)	377	388	+11	409	+32
Eref_at (mm)	113	116	+3	127	+14

When applying climate change data to streams flows in 2022, the data generally indicated a slight increase in low flow from the BRAT estimates (Table 17). However, five streams estimated lower flows, with three of the five estimating a dry channel (negative values are interpreted as zero flow). All three of these channels were also dry during the field assessments (Gavin Lake Creek, Fake Creek, and Cow Creek). Peak flows also generally show an increase, except for sites with larger BRAT-estimated flows (Watson Creek and 111 Mile Creek). Fake Creek and Cow Creek remained dry. However, 3 Mile Creek, Burnt Creek, and Smoky Creek are estimated to have negative peak flows despite having positive low flows and had flow present during field assessments.

Table 17. 2022 Climate Change Impacts to Low Flow and Peak Flow by Field Site.

Field Site	Q_L BRAT	Climate Q_L	Q_P BRAT	Climate Q_P[1]
3 Mile Creek	6.2×10^{-3}	8.2×10^{-3}	0.10	-0.01
Watson Creek	0.02	0.04	0.52	0.49
Guy Creek	3.0×10^{-3}	5.6×10^{-3}	0.06	0.16
Rock Creek	9.1×10^{-3}	0.02	0.26	0.44
111 Mile Creek	0.06	0.03	1.2	0.81
Tin Cup Creek	2.2×10^{-3}	3.4×10^{-3}	0.08	0.32
Gavin Lake Creek	3.4×10^{-4}	-4.0×10^{-3} (Dry)	7.9×10^{-3}	0.08
Fake Creek	1.5×10^{-4}	-1.1×10^{-3} (Dry)	9.5×10^{-3}	-0.18 (Dry)
Buckskin Creek	4.0×10^{-3}	3.1×10^{-3}	0.13	0.19
Jones Creek	7.6×10^{-3}	6.1×10^{-3}	0.22	0.32
Cow Creek	2.2×10^{-4}	-8.8×10^{-3} (Dry)	0.01	-0.04 (Dry)
Burnt Creek	2.3×10^{-4}	4.1×10^{-4}	0.01	-0.11
Smoky Creek	6.9×10^{-5}	7.5×10^{-3}	5.1×10^{-3}	-0.12
Steep Creek	2.8×10^{-5}	2.2×10^{-3}	2.4×10^{-3}	0.06
Cliff Creek	1.3×10^{-4}	3.9×10^{-3}	8.3×10^{-3}	0.25

[1]Red highlights indicate errors in peak value estimations when low flow estimates are positive.

RCP 8.5 climate change projections for 2041 and 2071 indicated that the streams will run dry (Figure 14 a). Smoky Creek was projected to maintain low flow into 2071, and Cliff Creek maintained flow until 2041 (though it was found dry during field assessments). Peak flow projections also follow similar trends, with most streams projecting to be dry (Figure 14 b). Guy Creek and Smoky Creek were projected to have increased peak flows. It is important to note that these results do not include winter evaporation effects, as winter evaporation is not projected to occur until 2071.

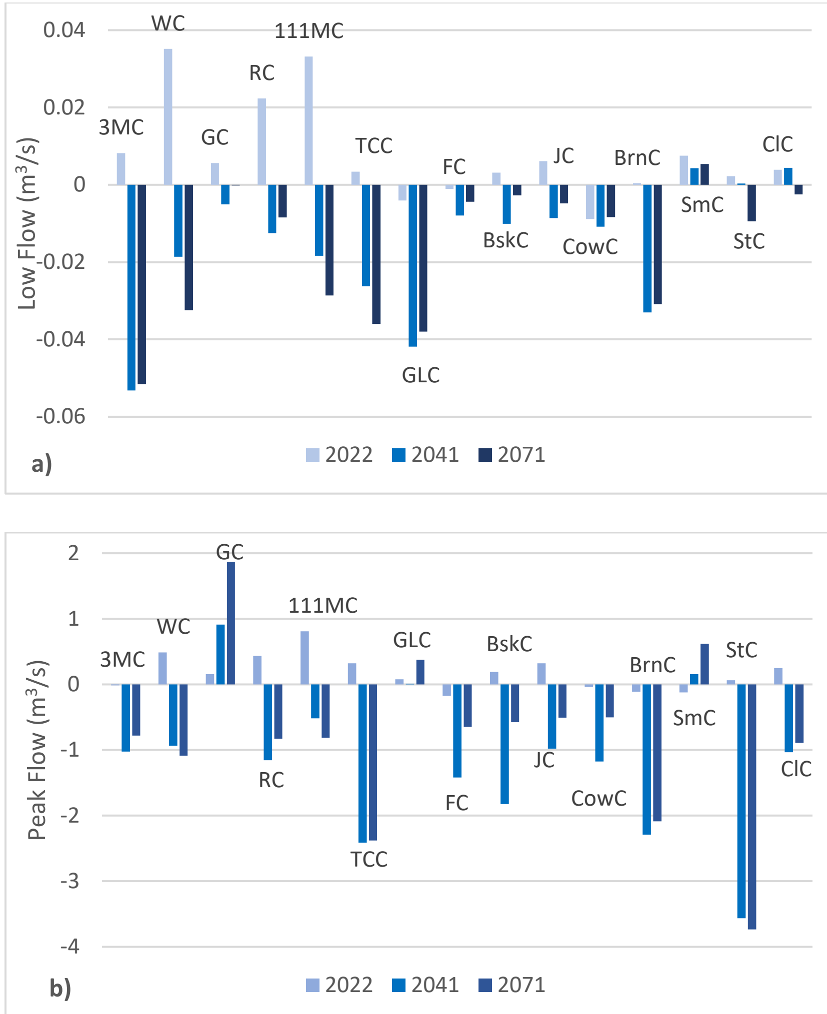

Figure 14. Bar charts of the 15 field sites showing (a) 2022 estimated low flows with climate data and 2041 and 2071 projected low flows by field site; (b) 2022 estimated peak flows with climate data and 2041 and 2071 projected peak flows by field site. Site codes shown in Section 4.7.

8.0 Discussion

8.1 BRAT vs Field Physical and Field Hydrological Results

Based on the strong results of wetted volume versus low flow analysis, there is some evidence that the BRAT can provide an indication of a stream's relative water availability. However, it is important to note that this analysis was based on one season of data collection, and may not be representative of typical low-flow periods. Likewise, the five dry channels at the time of field observation did not necessarily indicate that the streams are not normally perennial, and could be a result of unusually low precipitation and high temperatures (Roden 2024) at the time of assessment. However, channels like Gavin Lake Creek had bio-indicators of a non-perennial channel, with non-aquatic vegetation growing in the channel (Appendix C; Photo 4). Additionally, the BRAT has historically overestimated perennial water flow in both American (Macfarlane et al. 2017) and BC (Rogers 2023) applications.

Although the BRAT estimates of low flow correlated strongly with wetted volume, there was no evidence that increasing water availability correlated with increased BRAT suitability, given how Pervasive creeks on average had much less water than estimated, and Rare and Frequent creeks had much more. Occasional creeks also had slightly more water than Pervasive. Therefore, it appears that the BRAT's weight for the perennial water source line of evidence is binary where if two-year low flow estimations are greater than zero, the site passes the first line of evidence and is then measured based on the other lines of evidence, no matter how low the flow. This apparent binary makes no consideration for water quantity, despite the fact that water quantity will affect a beaver's preference to dam a stream (Section 1.2.1). This observation supports the project's hypothesis that combining hydrological modelling with the BRAT may give natural resource managers an improved approach to select the best sites for beaver restoration by considering the water availability estimated by the hydrological modelling and the vegetation availability estimated by the BRAT.

The drainage area results indicated that the BRAT's drainage area output may give some indication of channel size, but it is not overly reliable. The variation between BRAT suitability categories and channel widths indicated that the BRAT's weight of certain physical habitat characteristics like channel size are also a binary – that is, unless the stream is too large for dam construction (Section 4.1.2), the stream is considered suitable. Similar to the flow outputs, the drainage area results indicate that the BRAT does emphasize the drainage area when classifying the stream segment with no indication of increased suitability for larger drainage areas before reaching the threshold (Section 4.1.2). However, wider streams often result in larger riparian areas due to the larger dams built, as was shown in 111 Mile Creek – the only stream with multiple deep side channels.

Gradient results indicated that the BRAT estimated the stream's gradient accurately and correctly sets reductions or restrictions to beaver-dam-building based on gradient. While Steep Creek had a greater gradient than estimated by BRAT, it is ultimately irrelevant from a dam-building perspective as the stream was correctly classified as None. While the BRAT underestimated the gradient at Fake Creek, this is likely an error in the base data of that segment, as the adjacent downstream segment of Fake Creek was classified as None due to a high gradient (Appendix C; Photo 5), which is a more accurate classification for Fake Creek given its similarly low overall habitat quality score compared to the other None streams. Therefore, outliers in a stream's majority segment classification (especially with a change in more than one classification level – e.g., None to Occasional) should be treated with high skepticism before considering the classification as accurate.

8.2 BRAT vs Field Vegetation Results

The overall significant increase in total and deciduous trees from the field vegetation results compared to the BRAT suitability results supports the hypothesis that the BRAT is a fairly accurate predictor of a stream's riparian vegetation capacity to support beaver-dam-building. While the same trend was observed for total and deciduous trees of preferred size, the same conclusion cannot be made because the positive trend could be a result of the region coincidentally consisting of younger-forest systems, or deciduous trees like trembling aspen generally having thinner trunks than conifers like Douglas-fir and western hemlock. Additionally, there are no baseline data inputs for the BRAT (at least in the Canadian datasets) that estimate tree DBH. Regardless, the similar correlation results found in the preferred-size trees analyses indicated that the area of the Cariboo Region surveyed consists of many trees that are preferred for beaver felling, making the region ideal for dam building from a vegetation availability perspective.

The greatest declining difference in the number of deciduous trees between the BRAT classifications (Pervasive to None) also indicated that the BRAT accurately classifies sites that have a greater quantity of preferred species, especially with the Pervasive and Frequent streams having a much greater quantity compared to the other sites, and Pervasive having an appreciably higher quantity than Frequent. However, some caution should be exercised when using the BRAT to identify for vegetation availability. While Guy Creek and 3 Mile Creek had higher deciduous tree quantities compared to most other low-ranked sites, they had far fewer total deciduous trees compared to Watson Creek (though greater amounts within 30 m). The 300-m segment assessed at Guy Creek and 3 Mile Creek was a single Pervasive segment, with the rest of the reach consisting of Frequent segments in both streams. Comparatively, Watson Creek's entire channel was classified Pervasive (Appendix C; Photos 6-8). These results indicated that it is possible a stream segment's tree quantity will be lower if the upstream and/or downstream connecting segments have a lower classification. Therefore, the best channels for vegetation availability should be Pervasive along the entire or majority of the length.

Unlike with deciduous vegetation, the lack of a significant correlation between the BRAT vegetation output and coniferous tree counts provides more evidence that the BRAT accurately categorizes streams based on their vegetation composition because coniferous forests were given a lower output score (Occasional – 2) than broadleaf forests (Pervasive – 4; Section 4.1.1). Additionally, the Occasional and Frequent streams having the greatest and second greatest number of conifers, respectively, further indicated that the BRAT accurately categorizes streams based on the relative density of each vegetation type, since mixed forests were given a higher score than coniferous forests, but lower than broadleaf forests (Frequent – 3; Section 4.1.1). Mixed forests being classified as Frequent also explains the smaller difference in total and average of all trees found between Pervasive and Frequent sites compared to the difference in deciduous trees only. The similar trends from the preferred-size conifer analysis indicates that the Cariboo Region also consists of a significant proportion of preferred-size conifers for beaver use, although a comparatively smaller proportion than deciduous. Smaller preferred-size conifer proportions should be of less concern for resource managers, as mixed and broadleaf forests should be selected over coniferous as preferred species for beaver.

The overall decreasing number of total trees between BRAT suitability sites (Pervasive to None) is somewhat expected. Rare sites were classified as such for having the lowest vegetation availability but passed the other lines of evidence. BRAT correctly estimated the vegetation availability of these sites with the exception of Burnt Creek. However, None creeks were given a lower dam capacity output because of their gradient limitations rather than vegetation. Additionally, the difference between Occasional, Frequent, and Pervasive sites is based on the proportion of coniferous and deciduous trees, but not necessarily total trees. The weak and insignificant results of the tree density analysis also indicated that the BRAT does not reliably estimate dam capacity based on total vegetation density.

A significant correlation between BRAT vegetation outputs and shrub cover was neither expected nor unexpected. Shrub Low and Shrub High sites were expected to have higher relative covers than sites with lower outputs. However, sites classified as forests could also have high shrub cover in the understory. Therefore, shrub cover could have been high in a variety of different BRAT outputs, which may explain why a significant correlation was not found within 30 m of the stream, but was found between 31-100 m.

8.3 BRAT vs Habitat Quality Scorecard Results

The average BRAT dam capacity output vs the average habitat quality score correlation indicated that the BRAT can accurately determine unsuitable beaver habitat when a creek is designated ‘None’ due to gradient. However, once a stream is designated suitable, the BRAT dam capacity results do not necessarily indicate the site’s overall habitat quality. While a weak yet significant correlation was found between the total habitat score and the dam capacity output, this correlation was driven by the BRAT’s vegetation estimations, and not other habitat factors. The stronger significant correlation found between the vegetation habitat score and dam capacity compared to the weaker insignificant correlation between the physical/hydrological score and dam capacity indicated that the BRAT’s classification of ‘high quality habitat’ is largely driven by vegetation factors and less by physical and hydrological factors.

8.4 BRAT Considerations with Fire – The Case of Burnt Creek

Burnt Creek was a consistent outlier in the data for a number of correlation tests. It had a large measured bankfull volume despite a near-zero two-year peak flow output, the largest measured bankfull area of all sites despite one of the smallest drainage area outputs, and a deciduous tree count that exceeded most of the other sites despite being classified as Rare. It was also the only site to have visible signs of a recent burning (Appendix C; Photo 9). A desktop review after field assessments found a historic fire that burned on July 6, 2017 through the area (Fire K20637 – BC Gov 2024). The fire may have been the reason Burnt Creek is classified as a herbaceous site instead of shrub or forested. Fires can generate new stands of aspen and cottonwood that beaver can colonize within eight-ten years after the burn (Halter & Beal 2003). However, if beaver already occur within the landscape, re-colonization rates after fire have been found to be lower than their pre-fire populations up to 12 years after the burn (Hood et al. 2007).

Assuming this fire was the most recent, the field vegetation results indicate that the site has regenerated appropriate vegetation for dam building despite its BRAT output. While this finding was observed at only one site, it does suggest that historic fire locations and their date of burn might need to be considered alongside the BRAT's vegetation outputs before rejecting them as a candidate site.

8.5 Hydrological Modelling

Applying climate data to the 2022 low flow of the field sites found three field sites to have zero low flow, all of which were dry during summer low-flow periods. While the climate data did not find zero flow for the other two dry creeks (Steep Creek and Cliff Creek), this was likely due to the estimates not accounting for the high gradient and resulting high runoff of these sites. The watercourses that had summer flow present also generally had higher low flow estimates when applying the climate data than BRAT estimated, with the exception of 111 Mile Creek, Jones Creek, and Buckskin Creek. 111 Mile Creek and Jones Creek had relatively wider and deeper channels, thus more resistance to water loss from surface evaporation that the climate-based estimations do not account for. The reasons for the estimated flow reduction in Buckskin Creek are not known. Overall, these findings indicated that streams with negative low flows when climate data are applied have a high chance of being intermittent, and incorrectly estimated as perennial by the BRAT. Conversely, streams with a higher than-BRAT-estimated low flow when climate data are applied have a high chance of perennial flow.

The hydrological modelling generally estimated peak flows higher than BRAT estimated, except for Watson Creek and 111 Mile Creek which had higher BRAT estimates. Cow Creek and Fake Creek had zero peak flow estimates with climate data. However, field surveys were not completed in spring to validate these findings, thus it is more difficult to hypothesize why these reduced flow estimations occurred. 3 Mile Creek, Burnt Creek, and Smoky Creek had negative peak flow estimations despite having perennial flow present and positive low flow estimations. These results are possibly from each of these sites having the highest normalized value of a climate variable with a negative coefficient in the regression (Table 15), which automatically gave the site a normalized value of one. 3 Mile Creek had the highest spring snowfall, Burnt Creek had the highest elevation, and Smoky Creek had the highest autumn evaporation. Therefore, data interpretation and comparison with low flow estimations is required before using peak flow estimations in any management application, as the negative impacts to peak flow could be overestimated at sites with higher relative climatic variables.

While the climate projections make it appear that most streams will be dry by 2041 and continue to be dry into 2071, these projections are making estimations based on snow loss solely, and not rainfall. Rainfall in the Central Interior is projected to increase from December to February as winter precipitation shifts to more rain from snow from higher temperatures (Daust n.d.; MFLNRO 2016). Therefore, it is unlikely that all field-assessed streams will become dry, and instead shift from a nival regime to a pluvial (rainfall-predominated) regime. These streams will likely have earlier and stronger spring freshet flows, and many streams will shift from perennial to intermittent (MFLNRO 2016). This finding reaffirms the importance of using beavers to retain water in the upper sections of the watershed to reduce spring freshet flows and maintain a consistent water-source year-round. Guy Creek is expected to have large increases in peak flow by 2071, likely from a relatively high average winter temperature and winter snowfall which have a positive coefficient in the regression and low spring snowfall which has a negative coefficient (Table 15). Gavin Lake Creek follows a similar trend, though it has a large autumn snowfall normalized value which has a negative coefficient and thus smaller estimated increase. It is not clear in the data why Smoky Creek is estimated to maintain low flow through 2071, and see an overall increase in peak flows by 2071 (from an incorrect 2022 dry estimate). It is possible that this site is an anomaly in the regression, or an error in the baseline climate data at this location.

8.6 Limitations and Opportunities for Further Research

The habitat quality scorecard is a subjective assessment method that will vary based on experience of the surveyor(s), and the biogeoclimatic factors of the locations surveyed. It is not a definitive measure of suitable beaver habitat. Instead, it is better served as a comparative assessment method between candidate sites (Beardsley & Doran 2015). The grazing impacts factor of the habitat quality scorecard is a highly qualitative category that is subject to varied results from differing surveyors. Lundquist & Dolman (2018) also found that the grazing impacts of the scorecard need to be updated to become more quantitative.

This project assessed 300-m channel segments based on the BRAT's channel segmentation. Ideally, in a real habitat assessment for beaver introduction/re-introduction, at least one kilometre of stream would be surveyed as this represents a typical beaver home range (Petro et al. 2015).

Using absence as a proxy for lack of suitability is not necessarily a reasonable explanation for determining useable beaver habitat. Absence could be a result of increased predation or hunting (Baldwin 2013). Additionally, the site could have adequate habitat that is less preferred to other nearby habitat, but would facilitate a beaver colony once the population density increased (Müller-Schwarze & Schulte 1999). The current reduction in beaver populations from historic fur trapping and other management effects (Naiman 1988) could also explain the absence of beaver in some higher-quality sites. Signs of beaver presence also does not necessarily indicate suitable dam-building habitat.

The results from Burnt Creek suggest an opportunity for a separate study that ground-truths BRAT results in post-fire locations of different dates. The study could help address the possible error of the BRAT incorrectly estimating the vegetation availability of sites post-fire after sufficient time for regeneration has passed.

Selecting sites for beaver dam construction needs to carefully consider the potential for beaver-human conflict and scale before initiating beaver relocation. This research project did not run the BRAT's human conflict model as it was beyond the project scope. However, running the conflict model and surveying for sources of human conflict should be completed prior to any active beaver restoration efforts. While a site may appear high quality, it may have to be excluded from consideration if it can cause flooding or other damage to the stakeholder(s). Safety must be the first priority when initiating any beaver restoration activities.

Typically, a water balance equation at a watershed scale is defined as:

$$R = P - E - G \pm \Delta S$$

where R is streamflow, P is precipitation, E is evaporation, G is groundwater storage loss, and ΔS is change in watershed storage (Winkler et al. 2010). As climate changes, species ranges will change, including vegetation (Haman & Wang 2006). The change in species composition from current locations will impact the water balance as different species will alter groundwater storage through changes in rain interception, transpiration, and infiltration (Winkler et al. 2010). This research project's assessment of changes in flow from climate change do not incorporate the changes in vegetation composition that will follow the projected climate changes. A future study could incorporate projected tree distribution changes with climate change (e.g., increasing or decreasing aspen in upper elevations) to examine which sites might lose preferred vegetation for beaver, and should introduce beaver sooner to mitigate/prevent these changes.

While this research project did not build a field-verified hydrological model to make estimations of changes in flow based on the topography, it did use local climate data and flow estimations based on watershed drainage area and local gauged systems as proxies to find degrees of impact to a stream from climate change. Similarly, estimating surface-water storage for beaver dam wetlands for hydrological modelling would ideally remove the need for time-intensive topographic surveys, and be more practical for modelling varying scales and locations (Karran et al. 2017). Past studies have avoided such surveys by using statistical relationships between wetland surface area and volume, which has been successful for modelling entire watersheds (Gleason et al. 2017), but less useful for estimating individual wetlands because depth and morphometry are not considered (Karran et al. 2017). Combining the climate-based hydrological modelling with past methods use to model water storage for beaver dams could give resource managers a strategy to determine which streams could potentially provide the greatest ponds for uses such as water retention and/or waterfowl habitat creation.

8.7 Recommendations

Since this research project changed the datasets that the BRAT was originally intended for and created a new vegetation classification, results from this research project should not be considered outside of BC before first identifying the public data available in the user's region and conversions required before running.

While the BRAT appears to have fairly accurate estimations of vegetation, other factors such as fire intensity, severity, and time for regeneration may also need to be considered before concluding the vegetation outputs as accurate.

To account for flows that are essentially zero and would be functionally unusable for dam building, perhaps the BRAT should be adjusted so streams designated with low flows < 0.01 m^3/s instead of < 0 m^3/s are not perennial. Especially with projected losses in precipitation and increases in temperature and evapotranspiration, streams with nearly zero estimated flow have a high likelihood to become intermittent in the near-future (if not already) and would not make the best candidate streams for beaver-dam-building, even with suitable vegetation. These sites should especially be treated with skepticism if the climate data estimate zero low flow.

Alternatively, focusing on Frequent and Pervasive sites with higher drainage areas could result in higher dam building success rates. Wider streams would provide larger wetlands and deeper beaver ponds with more complex channel habitat such as 111 Mile Creek. Watson Creek and 111 Mile Creek drainage areas were more than double the drainage areas of other streams and were the only sites with beaver dams. Additionally, BRAT-estimated drainage areas highly positively correlated with total habitat scores from the habitat scorecard ($r = 0.84$; $p = 9.1 \times 10^{-5}$). Drainage area estimations also highly positively correlated with BRAT-estimated low flows ($r = 0.90$; $p = 6.1 \times 10^{-6}$) and peak flows ($r = 0.98$; $p = 8.2 \times 10^{-11}$), indicating that streams with larger drainage areas may have higher quality habitat and water availability than smaller drainage areas. In theory, larger drainage areas equal larger channels with more water that are deeper and have expanded riparian areas with more vegetation. These observations could be verified by assessing more sites specifically by high and low drainage area output and comparing their habitat quality scores. Higher elevation sites located in upper reaches of the watershed should also be prioritized as they will help retain water to maintain perennial flow for longer stream channel sections, which will be particularly important given the projected losses of stream flow associated with snowmelt.

Rogers (2023) used the Beaver Intrinsic Potential model with a bankfull channel polygon tool, the valley bottom extraction tool, a DEM, and a stream network layer to determine the channel geomorphology. These inputs provided three score criteria using stream slope, stream width, and valley width. The Beaver Intrinsic Potential model was an overall better indicator of habitat suitability than the BRAT (Rogers 2023). Given the scoring criteria that the Beaver Intrinsic Potential model uses to determine habitat quality, there is more evidence that drainage area size (and by extension channel size) are the most important indicators of higher-quality beaver habitat. Five sites in Rogers (2023) study were also dry during field assessments. This research project and Rogers (2023) study were the only applications of the BRAT found in BC, and both found water as a limiting factor to beaver-habitat quality. Applying the BRAT for vegetation, the Beaver Intrinsic Potential model for channel size, and hydrological modelling for flow estimations may be an improved method to model the best candidate beaver sites before committing field crews to survey the reach.

One potential benefit of reduced peak flows is that some high-stream-power channels may no longer have stream power rates that cause beaver dam washout. If these channels have adequate vegetation capacity, they could be candidate sites for beaver dam analogues (BDAs). BDAs typically make use of local woody materials and sediment for construction, and are most effective when built in complexes (Shahverdian et al. 2019). Building BDAs in a channel/watershed may incentivize beaver occupancy. However, manual seasonal maintenance and monitoring are required if beaver do not occupy them, and monitoring should always be completed (Shahverdian et al. 2019).

9.0 Conclusion

Overall, the BRAT made accurate estimations of deciduous and coniferous vegetation. Site vegetation classifications generally correlated well with field site findings. The successful vegetation estimations were also found for preferred-size trees, indicating that the areas of the Cariboo region sampled currently have a large proportion of trees that are appropriate for beaver felling. From a vegetation perspective, the BRAT effectively differentiates site quality, as found by the high correlations of the habitat scores with the vegetation outputs. The BRAT also accurately identified streams with gradient barriers to dam building.

While weaker than its vegetation estimations, low flow estimations generally correlated with wetted volume measured during the low flow season, and peak flow estimations generally correlated with bankfull volume measurements. Drainage area estimations also generally correlated with wider channels. While the BRAT did estimate these physical and hydrological habitat components decently, they did not factor into the BRAT's dam capacity outputs so long as they were within the pre-determined value thresholds. This finding was supported by the lack of correlation between the physical/hydrological parameters of the habitat suitability scorecard compared to the vegetation parameters. Additionally, one-third of the streams assessed in the field were dry during the summer, an error that has occurred with the BRAT in other applications. Given the BRAT's fundamental purpose is to determine the dam-building potential of a stream, it is not surprising that it did not consider the lower water availability and smaller channels as lower-quality habitat. However, water is critical for beaver occupancy, and it must be considered when selecting the best sites for beaver restoration.

The BRAT does not make estimations based on future climatic conditions. Hydrological modelling helped indicate that the streams estimated to have low flow by BRAT are at a high risk of becoming intermittent or dry. Increased temperature, increased evaporation, and decreased snowfall is projected to have negative impacts to low flow and peak flows at all the assessed creeks. Loss of snow is expected to have a negative effect on flows, as less snow reduces the amount of water stored in the watershed, and instead begins flow earlier in the season, leaving less water by summer. This finding further supports the need to have beaver present in the upper reaches of watersheds to maintain perennial flow for ecosystems and human use.

References

Ahmed, A. (2017). Inventory of Streamflow in the Cariboo Region. Knowledge Management Branch, British Columbia Ministry of Environment and Climate Change Strategy, Victoria, B.C. Retrieved from: https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=52707. Accessed October 2023.

Allen, A. W. (1983). Habitat suitability index models: beaver. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, US Department of the Interior.

Albert, S., & Trimble, T. (2000). Beavers are partners in riparian restoration on the Zuni Indian Reservation. *Ecological Restoration*, *18*(2), 87-92.

Andersen, D. C., & Shafroth, P. B. (2010). Beaver dams, hydrological thresholds, and controlled floods as a management tool in a desert riverine ecosystem, Bill Williams River, Arizona. *Ecohydrology*, *3*(3), 325-338.

Arner, D. H. (1963). Production of duck food in beaver ponds. *The Journal of Wildlife Management*, *27*(1), 76-81.

Association of State Dam Safety Officials (ADSO). (2016). The Cost of Rehabilitating Our Nation's Dams – 2016 Update. Retrieved from: https://damsafety.org/sites/default/files/Cost%20of%20Rehab%20Report-2016%20Update_1.pdf. Accessed August 2023.

Atun, A., Filiz, Z., & Iscen, F, C. (2008). Assessment of Seasonal Variations of Surface Water Quality Characteristics for Porsuk Stream*. Environ Monit Assess, 158*, 51–65.

Baker, B. W., E. P. Hill. (2003). Beaver (*Castor canadensis*). Pages 288-310 in G. A. Feldhamer, B. C. Thompson, and J. A. Chapman [editors]. *Wild Mammals of North America: Biology, Management, and Conservation. Second Edition*. The Johns Hopkins University Press, Baltimore, Maryland, USA.

Baker, B. W., Ducharme, H. C., Mitchell, D. C., Stanley, T. R., & Peinetti, H. R. (2005). Interaction of beaver and elk herbivory reduces standing crop of willow. *Ecological Applications, 15(*1), 110-118.

Baggio, G., Qadir, M., & Smakhtin, V. (2021). Freshwater availability status across countries for human and ecosystem needs. *Science of The Total Environment, 792*, 148230-148230.

Barnes, D. M., & A. U. Mallik. (2001). Effects of Beaver, *Castor canadensis*, herbivory on streamside vegetation in a northern Ontario watershed. Canadian Field-Naturalist *115*(1), 9-21.

Beardsley, M. & Doran, J. (2015). Beaver Restoration on Thirty-nine-Mile Mountain: An experiment in restoring wetland and watershed functions on headwater streams in the Upper South Platte. Retrieved from: http://cusp.ws/wp-content/uploads/2014/05/2015-Thirtynine-Mile-Beaver-Wetland-Report.pdf. Accessed August 2023.

Beier, P., & Barrett, R. H. (1987). Beaver Habitat Use and Impact in Truckee River Basin, California. *The Journal of Wildlife Management*, *51*(4), 794–799.

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G. M., Lake, P. S., … Sudduth, E. (2005). Synthesizing U.S. River Restoration Efforts. *Science (American Association for the Advancement of Science)*, *308*(5722), 636–637.

Boyle, S. & Owens, S. (2007). North American Beaver (*Castor canadensis*): A Technical Conservation Assessment. USDA Forest Service, Rocky Mountain Region. Available: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5181919.pdf. Accessed November 2023.

Brazier, R. E., Puttock, A., Graham, H. A., Auster, R. E., Davies, K. H., & Brown, C. M. (2021). Beaver: Nature's ecosystem engineers. *Wiley Interdisciplinary Reviews: Water, 8*(1), e1494.

British Columbia Centre for Disease Control (BC CDC). (2012). Giardiasis. Retrieved from: http://www.bccdc.ca/health-info/diseases-conditions/giardiasis#:~:text=Drinking%20inadequately%20treated%20water%20contaminated,rivers%2C%20lakes%20or%20shallow%20wells. Accessed June 2023.

BC Ministry of Environment. (2016). Indicators of Climate Change for British Columbia 2016 Update. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/reporting/envreportbc/archived-reports/climate-change/climatechangeindicators-13sept2016_final.pdf. Accessed November 2023.

Burchsted, D., & Daniels, M. D. (2014). Classification of the alterations of beaver dams to headwater streams in northeastern Connecticut, USA. *Geomorphology*, *205*, 36-50.

Burchsted, D., Daniels, M., Thorson, R., & Vokoun, J. (2010). The river discontinuum: applying beaver modifications to baseline conditions for restoration of forested headwaters. *BioScience*, *60*(11), 908-922.

Butler, D. R., & Malanson, G. P. (2005). The geomorphic influences of beaver dams and failures of beaver dams. *Geomorphology*, *71*(1-2), 48-60.

Canadian Council of Forest Ministers (CCFM). (n.d.). National Terrestrial Ecosystem Monitoring System for Canada. [Data set]. Retrieved from: https://opendata.nfis.org/mapserver/nfis-change_eng.html. Accessed October 2023.

Case, B., Egyir, P., & Geertsema, M. (2003). Catastrophic beaver dam failure at Chudnuslida Lake, Northeastern British Columbia. 10.13140/2.1.4497.8249.

Credit Valley Conservation. (2010). Fluvial Geomorphic Guidelines. Fact Sheet I: Geomorphological Hazards – Confined and Unconfined Watercourses. Retrieved from: https://files.cvc.ca/cvc/uploads/2011/09/022-F1-Confined-and-Unconfined-Valleys.pdf. Accessed October 2024.

Datry, T., Larned, S. T., Fritz, K. M., Bogan, M. T., Wood, P. J., Meyer, E. I., & Santos, A. N. (2014). Broad-scale patterns of invertebrate richness and community composition in temporary rivers: Effects of flow intermittence. *Ecography, 37*(1), 94-104.

Daust, D. (n.d). Climate Change in BC. Chapter 2a in *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests*. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/applied-science/2a_va_bc-climate-change-final-aug30.pdf. Accessed March 2024.

Dittbrenner, B. J., Pollock, M. M., Schilling, J. W., Olden, J. D., Lawler, J. J., & Torgersen, C. E. (2018). Modeling intrinsic potential for beaver (Castor canadensis) habitat to inform restoration and climate change adaptation. *PloS one*, *13*(2), e0192538.

Ducks Unlimited Canada (DUC). (2022). British Columbia Beaver Restoration Assessment. Retrieved from: https://storymaps.arcgis.com/stories/85396260f742451aada8b69ef6cc59e7. Accessed June 2023.

Eaton, B., & Moore, R.D. (2010). Regional Hydrology. Chapter 4 in the *Compendium of forest hydrology and geomorphology in British Columbia,* 85-110. B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Manag. Handb. 66.

Ellensburg, W., Babik, M., & Meyer, W. (2015). Yakima basin beaver reintroduction project: 2011-2015 progress report. Washington Department of Fish and Wildlife, Ellensburg, USA.

England, K., & Westbrook, C. J. (2021). Comparison of beaver density and foraging preferences between urban and rural riparian forests along the South Saskatchewan River, Canada. *Journal of Urban Ecology*, *7*(1), 1-10.

Environmental Systems Research Institute. (2023). ArcGIS Field Maps. Retrieved from: https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/resources. Accessed June 2023.

GeoBC. (n.d). Digital Elevation Model. [Data set]. Retrieved from: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/elevation/digital-elevation-model. Accessed October 2023.

GeoBC. (2024). Freshwater Atlas. [Data set]. Retrieved from: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/freshwater. Accessed October 2023.

Gleason, K. E., Nolin, A. W., & Roth, T. R. (2017). Developing a representative snow-monitoring network in a forested mountain watershed. *Hydrology and Earth System Sciences*, *21*(2), 1137-1147.

Government of British Columbia (BC Gov). (2023). Freshwater Atlas Visualization. [Data set]. Retrieved from: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/freshwater#Visualization. Accessed June 2023.

BC Gov. 2024. iMapBC. [Data set]. Retrieved from: www2.gov.bc.ca/gov/content/data/geographic-data-services/web-based-mapping/imapbc. Accessed March 2024.

BC Gov. (n.d). British Columbia Regional Streamflow Inventory Reports. [Data set]. Retrieved from: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/provincial-hydrology-program/resources/streamflow-inventory#:~:text=What%20are%20hydrologic%20zones%3F,an%20acceptable%20degree%20of%20accuracy. Accessed June 2023.

Gibson, P. P., & Olden, J. D. (2014). Ecology, management, and conservation implications of North American beaver (*Castor canadensis*) in dryland streams. *Aquatic Conservation: Marine and Freshwater Ecosystems, 24*(3), 391-409.

Government of Canada (GOC). (2023). Real-Time Hydrometric Data Map Search. [Data set]. Retrieved from: https://wateroffice.ec.gc.ca/map/index_e.html?type=real_time. Accessed October 2023.

Government of Manitoba. (2022). Coexisting with Beavers – Wildlife Smart. Retrieved from: https://www.gov.mb.ca/nrnd/fish-wildlife/pubs/fish_wildlife/coexisting_beaver.pdf. Accessed October 2023.

Gurnell, A. M. (1998). The Hydrogeomorphological effects of beaver dam-building activity. *Progress in Physical Geography*, *22*(2), 167-189.

Hagerman, A.E., & Robbins, C.T. (2011). Specificity of tannin-binding salivary proteins relative to diet selection by mammals. *Canadian Journal of Zoology*, *71*(3): 628-633.

Halter, D. F., & Beal, A. M. M. (2003). Beaver (*Castor canadensis*). Prepared for Furbearer Management Guidelines, Government of British Columbia, Victoria, British Columbia.

Hamann, A., & Wang, T. (2006). Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology*, *87*(11), 2773-2786.

Hartman, G., & Törnlöv S. (2006). Influence of watercourse depth and width on dam building behaviour by Eurasian beaver (*Castor fiber*). *Journal of Zoology*, *268*,127–131.

Hillman, G. R. (1998). Flood wave attenuation by a wetland following a beaver dam failure on a second order boreal stream. *Wetlands*, *18*, 21-34.

Hood, G. A., Bayley, S. E., & Olson, W. (2007). Effects of prescribed fire on habitat of beaver (*Castor canadensis*) in Elk Island National Park, Canada. *Forest Ecology and Management, 239*(1), 200-209.

Jenkins, S, H., & Busher, P, E. (1979). *Castor canadensis. Mamm. Species 120*,1–9.

Johnston, N. T., & Slaney, P. A. (1996). Fish habitat assessment procedures (p. 102). British Columbia, Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests.

Karran, D. J., Westbrook, C. J., Wheaton, J. M., Johnston, C. A., & Bedard-Haughn, A. (2017). Rapid surface-water volume estimations in beaver ponds. *Hydrology and Earth System Sciences*, *21*(2), 1039–1050.

Kaumeyer, L. (2022). What's Happening to Canada's Vanishing Wetlands? Without a Proper Inventory, we won't Truly Know. Ducks Unlimited Canada. *Story* / *Wetlands*. Retrieved from: https://www.ducks.ca/stories/wetlands/whats-happening-to-canadas-vanishing-wetlands/. Accessed August 2023.

Kimball, B. A., & Perry, K. R. (2008). Manipulating beaver (Castor canadensis) feeding responses to invasive tamarisk (*Tamarix* spp.). *Journal of chemical ecology*, *34*, 1050-1056.

Lundquist K., & Dolman, B. (2018). Beaver restoration feasibility assessment for the North Fork Kern River drainage. Prepared for California Trout, San Francisco, California. Retrieved from: https://oaec.org/wp-content/uploads/2018/08/NF-Kern-River-Beaver-Restoration-Feasibility-Assessment-Final-Report-FINAL.pdf. Accessed November 2023.

Macfarlane, W, W., Wheaton, M, J., & Jensen, L, M. (2014). The Utah Beaver Restoration Assessment Tool: A Decision Support & Planning Tool. Ecogeomorphology and Topographic Analysis Lab, Utah State University. Prepared for Utah Division of Wildlife Resources, Logan, Utah.

Macfarlane, W. W., Wheaton, J. M., Bouwes, N., Jensen, M. L., Gilbert, J. T., Hough-Snee, N., & Shivik, J. A. (2017). Modeling the capacity of riverscapes to support beaver dams. *Geomorphology*, *277*, 72-99.

Mahony, C.R., Wang, T., Hamann, A., & Cannon, A.J. (2022). A CMIP6 ensemble for downscaled monthly climate normals over North America. *International Journal of Climatology 42 (11)*, 5871-5891.

Mahoney, M. J., & Stella, J. C. (2020). Stem size selectivity is stronger than species preferences for beaver, a central place forager. *Forest Ecology and Management*, *475*, 118331.

McComb, W. C., Sedell, J. R., & Buchholz, T. D. (1990). Dam-site selection by beavers in an eastern Oregon basin. *The Great Basin Naturalist*, 273-281.

McKinstry, M. C., Caffrey, P., & Anderson, S. H. (2001). The Importance of Beaver to Wetland Habitat and Waterfowl in Wyoming 1. *Jawra Journal of the American Water Resources Association*, *37*(6), 1571-1577.

Ministry of Forests, Lands and Natural Resource Operations (MFLNRO). (2016). Adapting natural resource management to climate change in the Cariboo Region: Considerations for practitioners and Government staff. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/regional-extension-notes/caribooen160222.pdf. Accessed March 2024.

MFLNRO. (2019). Vegetation Resources Inventory, Photo Interpretation Procedures Manual. Retrieved from: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/data-management/standards/vegcomp_poly_rank1_data_dictionaryv5_2019.pdf. Accessed August 2023.

Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD). (n.d.). VRI – Historical Vegetation Resource Inventory (2002 – 2021). [Data set]. Retrieved from: https://open.canada.ca/data/en/dataset/02dba161-fdb7-48ae-a4bb-bd6ef017c36d. Accessed October 2023.

Ministry of Environment and Climate Change Strategy (MOECCS). (n.d.). British Columbia Regional Streamflow Inventory Reports. [Data set]. Retrieved from: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/provincial-hydrology-program/resources/streamflow-inventory. Accessed October 2023.

Ministry of Environment, Lands and Parks (MELP) Vancouver Island Region. (2001). Beaver Management Guidelines Version 1 DRAFT. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/best-management-practices/beaver-guide.pdf. Accessed August 2023.

Ministry of Environment (MoE) Wildlife Branch. (n.d). Management Guidelines in British Columbia: Beaver. Retrieved from: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/best-management-practices/beaver_mgt.pdf. Accessed August 2023.

Ministry of Forests (MoF). (1998). The Ecology of the Sub-Boreal Spruce Zone. Retrieved from: https://www.for.gov.bc.ca/hfd/pubs/docs/bro/bro53.pdf. Accessed August 2023.

MoF. (n.d). The Ecology of the Interior Douglas-fir Zone. Retrieved from: https://www.for.gov.bc.ca/hfd/pubs/docs/bro/bro47.pdf. Accessed August 2023.

Müller-Schwarze, D., & Schulte, B. A. (1999). Behavioral and ecological characteristics of a “climax” population of beaver (*Castor canadensis*). In *Beaver protection, management, and utilization in Europe and North America* (pp. 161-177). Boston, MA: Springer US.

Müller-Schwarze, D., & Sun, L. (2003). The Beaver: Natural History of a Wetlands Engineer. Cornell University Press, Ithaca, New York. 190 pp.

Naiman, R. J., Johnston, C. A., & Kelley, J. C. (1988). Alteration of North American streams by beaver. *BioScience*, *38*(11), 753-762.

Neumayer, M., Teschemacher, S., Schloemer, S., Zahner, V., & Rieger, W. (2020). Hydraulic modeling of beaver dams and evaluation of their impacts on flood events. *Water, 12*(1), 300.

Noor, M, S. (2021). Hydrological Impact of Beaver Habitat Restoration in the Milwaukee River Watershed. *Theses and Dissertations*, 2707. University of Wisconsin-Milwaukee, Wisconsin, Milwaukee. 105 pp. Retrieved from: https://dc.uwm.edu/etd/2707. Accessed October 2023.

Northcott, T. H. (1971). Feeding habits of beaver in Newfoundland. *Oikos*, 407-410.

Openshaw, S. (1996). Fuzzy logic as a new scientific paradigm for doing geography. *Environment and Planning A*, *28*, 761-768.

Parker, M., Wood, F. J., Smith, B. H., & Elder, R. G. (1985). Erosional downcutting in lower order riparian ecosystems: have historical changes been caused by removal of beaver. In *Tech. Records. Riparian ecosystems and their management: reconciling conflicting uses. 1st N. American Riparian Conf* (pp. 16-18).

Persico, L., & Meyer, G. (2009). Holocene beaver damming, fluvial geomorphology, and climate in Yellowstone National Park, Wyoming. *Quaternary Research*, *71*(3), 340-353.

Petro, V, M., Taylor, J, D., & Sanchez, D, M. (2015). Evaluating landowner-based beaver relocation as a tool to restore salmon habitat. *Global Ecology and Conservation, 3*, 477-486

Pike, R. G., Bennett, K. E., Redding, T. E., Werner, A. T., Spittlehouse, D. L., Moore, R. D., & Tschaplinski, P. J. (2010). Climate Change Effects on Watershed Processes in British Columbia. Chapter 19 in *Compendium of forest hydrology and geomorphology in British Columbia*, 699-747. B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Manag. Handb. 66.

Pollock, M. M., Heim, M., & Werner, D. (2003). Hydrologic and geomorphic effects of beaver dams and their influence on fishes. *American Fisheries Society Symposium*, *37,* 213-233.

Pollock, M.M., G.M. Lewallen, K. Woodruff, C.E. Jordan and J.M. Castro. (2023). The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Version 2.02. United States Fish and Wildlife Service, Portland, Oregon. 189 pp.

Riverscapes Consortium. (n.da). BRAT – About. Retrieved from: https://brat.riverscapes.net/. Accessed November 2023.

Riverscapes Consortium. (n.db). BRAT Ste 1 – Input Data. Retrieved from: https://brat.riverscapes.net/Documentation/Tutorials/1-InputData. Accessed October 2023.

Roden, B. (2024). 2023 was hottest year ever in B.C., and one of the driest. The Ashcroft-Cache Creek Journal. Retrieved from: https://www.ashcroftcachecreekjournal.com/local-news/2023-was-hottest-year-ever-in-bc-and-one-of-the-driest-7295072.

Rogers, J. (2023). Assessing the Potential to Partner with Beavers (*Castor canadensis*) to Restore River and Riparian Habitat in the Gold River Watershed on Vancouver Island, British Columbia. [Unpublished masters research project]. Simon Fraser University & British Columbia Institute of Technology, Burnaby, British Columbia. 72 pp.

Ronnquist, A, L. (2021). Dam Different! How the Physical Properties of Beaver Dams Influence Water Storage Dynamics [Doctoral dissertation]. University of Saskatchewan, Saskatoon, Saskatchewan. 81 pp. Retrieved from: https://harvest.usask.ca/items/4b01ab3c-e23d-475a-a920-81e4cdba7cce. Accessed October 2023.

Scamardo, J. E., Marshall, S., & Wohl, E. (2022). Estimating widespread beaver dam loss: Habitat decline and surface storage loss at a regional scale. *Ecosphere*, *13*(3), e3962.

Shahverdian, S.M., Wheaton, J.M., Bennett, S.N., Bouwes, N., Camp, R., Jordan, C.E., Portugal, E., & Weber, N. (2019). Chapter 4 – Mimicking and promoting wood accumulation and beaver dam activity with post-assisted log structures and beaver dam analogues. Pages 1-66 In: Wheaton, J.M., Bennett, S.N., Bouwes, N., Maestas, J.D., & Shahverdian, S.M. (eds) *Low-tech process-based restoration of riverscapes: design manual*. Utah State University Restoration Consortium, Logan, Utah.

Taylor, J, D., Yarrow, G, K., & Miller, J, E., (2017). "Beavers". Wildlife Damage Management Technical Series. 11. Retrieved from: https://digitalcommons.unl.edu/nwrcwdmts/11. Accessed November 2023

Utah State University. (n.d.). Wheaton Ecogeomorphology & Topographic Analysis Laboratory. Retrieved from: http://etal.joewheaton.org/. Accessed October 2023.

Walker, I. R., & Pellatt, M. G. (2003). Climate change in coastal British Columbia—a paleoenvironmental perspective. *Canadian Water Resources Journal/Revue canadienne des ressources hydriques, 28*(4), 531-566.

Wang, T., Hamann, A., Spittlehouse, & D., Carroll, C. (2016). Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. *PLoS ONE 11(6)*: e0156720.

Watt, W.E., Lathem, K.W., Neil, C.R., Richards, T.L., & Rousselle, J. (1989). Hydrology of Floods in Canada – A Guide to Planning and Design. *National Research Council of Canada*, Ottawa, Ontario.

Westbrook, C. J., Cooper, D. J., & Baker, B. W. (2006). Beaver dams and overbank floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. *Water resources research*, *42*(6).

Westbrook, C. J., Ronnquist, A., & Bedard-Haughn, A. (2020). Hydrological functioning of a beaver dam sequence and regional dam persistence during an extreme rainstorm. *Hydrological Processes*, 34(18), 3726–3737.

Winkler, R.D., Moore, R.D., Redding, T.E., Spittlehouse, D.L., Carlyle-Moses, D.E., Smerdon, B.D. (2010). Hydrologic Processes and Watershed Response. Chapter 6 in *Compendium of forest hydrology and geomorphology in British Columbia,* 133-177. B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Manag. Handb. 66.

Woo, M. K., & Waddington, J. M. (1990). Effects of beaver dams on subarctic wetland hydrology. *Arctic*, *43*(3), 223-230.

Woodruff, K. (2016). Methow Beaver Project: Accomplishments 2015. *Methow Salmon Recovery Foundation: Twisp, WA, USA*. Retrieved from: https://www.regulations.gov/comment/APHIS-2023-0082-0017. Accessed March 2024.

Yeakley, A., J., Ervin, D., Chang, H., Granek, E. F., Dujon, V., Shandas, V., & Brown, D. (2016). Ecosystem services of streams and rivers. *River science: research and management for the 21st century*, 335-352.

Zadeh, L. A. (1996). Fuzzy logic computing with words. *IEEE transactions on fuzzy systems*, *4*(2), 103-111.

Appendices

Appendix A Methow Project Habitat Suitability Scorecard

The Lands Council Washington State Habitat Suitability Scorecard

Used with permission

Release Site Score Card #_______ Date____________________ Observer______________________

Site ID (Creek)_________________________________ Subwatershed__________________________________

GPS Coordinates-UTM (NAD 83)____

Location Description ____

Please circle answers, then fill in the points

1. **Stream Gradient of the defined habitat unit**

________ **5.** ≤3% **3**. 4-6% **1**. 7-9% **0.** ≥9%

2. **Spring Time Stream Flow**

________ **5.** Fire hose **1**. Garden hose **-3.** Unwadeable

3. **Do you predict there will be year-round stream flow?**

________ **5**. Yes **0**. Unsure **-5**. No

4. **Average Stream Depth**

________ **5.** Over knee-high boots **1**. Over sneaker **-3**. Over waist

5. **Habitat Unit Size** (linear stream length)

________ **5.** ≥6 acres of riparian vegetation **1.** Small isolated pocket less than 1 acre

6. **Woody Food**
   a. **3.** Aspen, Cottonwood, Willow **2**. Alder **1.** Other hardwoods
   b. **3**. Within 10 meters **2**. Within 30 meters **1**. Within 100 meters
   c. **3**. Large amount (thousands of stems) **2.** Some (hundreds of stems) **1.** Little (dozens)

_________ Woody food score = multiply a x b x c

7. **Herbaceous Food**

_________ **5.** Aquatic vegetation (Nuphar, Sagitaria) **3**.Diverse Grass/Forbs Present **0.** Minimal Grass/Forbs Present=

8. **Floodplain Width**

_________ **5.** Adjacent floodplain **0.** Narrow V Channel

9. **Dominant Stream Substrate**

_________ **5.** Silt/Clay/Mud **2.**Sand **1.** Gravel **0**. Cobble -**1**. Boulders -**3**. Bedrock

10. **Historic Beaver use**

_________ **5.** Old structures present **3.** Some old indications (chews) **0.** No indication of previous occupancy

11. **Lodge and dam building materials**

_________ **5**. Variety of 1-6" diameter woody vegetation avail. **-5.** No building material present

12. **Are there any roads, culverts, or other damage situations that may result from flooding? (If yes, please expound on below. i.e., how far away is a culvert)**

_________ **0.** No **-3.** Yes.

13. **Are there multiple pools greater than 3 feet in depth present?**

_________ **5.** Yes. **-10.** No

14. **Is there woody debris present in stream (large wood defined as >6 inches at 20 feet from base or a jam)?**

_________ **3.** Yes. **0.** No

15. **Active or Proximity to Active Beaver Colony**

5. >1mile **-5.** <1 mile

____

16. **Browsing/ Grazing impacts**

5. No impact or obvious presence of browsers/ grazers **-3. Heavy browsing/ grazing impacts**

____

17. **Bonus**: (5 points each) a. Easy Access from a road b. Recent fire c. Enthusiastic landowner and neighbors

____

_______ **Total Score** **Good Release site 45-95pts** **Bad Release Site 0-44pts**

Other notes, notes are good! (best place to access, added advantages/disadvantages, land ownership/access/permission):

Appendix B Habitat Suitability Site Score Summary

Table B1. Habitat Quality Scorecard Results by Assessed Stream Reach in Cariboo Region During Summer 2023.

Stream Reach	Gradient Score (0-5)	Predicted Perennial Flow score (-5 to 5)	Average Stream Depth Score (-3 to 5)	Habitat Unit Size Score (1-5)	Woody Food Score (1-27)	Herbaceous Food Score (0-5)	Floodplain Width Score (0-5)	Predominant Substrate Score (-3 to 5)	Historic Beaver Use Score (0-5)	Dam Materials Score (-5 to 5)	Potential Flooding Damage Score (0-3)	LWD score (0-3)	Pool Habitat Score (-10 to 5)	Active or Near Active Colony Score (-5 to 5)	Browsing/ Grazing Score (-3 to 5)	Bonus Scores (5 each)	TOTAL SCORE
3 Mile Creek	3	0	3	1	18	2	0	0	0	4	0	3	-9	5	1	5	**36**
Watson Creek	5	5	2	2	18	3	4	2	5	5	0	3	2	-5	5	5	**61**
Guy Creek	1	3	4	1	8	3	2	1	0	0	-3	2	-9	5	5	5	**28**
Rock Creek	2	5	5	1	12	2	1	1	3	0	-1	3	-5	5	5	5	**44**
111 Mile Creek	3	5	5	5	18	3	5	0	5	2	0	2	5	-5	-3	0	**50**
Tin Cup Creek	5	-5	3	1	18	3	5	5	3	1	-3	1	-9	0	-3	5	**30**
Gavin Lake Creek	0	-5	5	3	6	3	1	0	0	-2	-3	3	-10	5	5	5	**16**

Fake Creek	0	-5	1	0	4	3	0	0	0	1	-3	3	-10	5	-3	0	**-4**
Buckskin Creek	5	5	4	3	9	3	2	5	3	5	-2	3	-6	-5	3	10	**47**
Jones Creek	5	5	5	5	0	3	4	5	0	-5	0	0	-10	5	5	5	**32**
Cow Creek	5	-5	3	0	3	3	2	5	0	-3	-3	3	-10	5	2	5	**15**
Burnt Creek	4	5	1	5	12	3	4	5	0	5	-3	1	-10	5	2	10	**49**
Smoky Creek	0	-5	4	1	3	2	0	0	0	3	-1	2	-10	5	1	0	**5**
Steep Creek	0	-5	0	0	4	0	0	0	0	0	-3	1	-10	5	5	0	**-3**
Cliff Creek	0	-5	3	1	1	1	0	0	0	-4	-1	0	-10	5	5	5	**1**

Appendix C Photo Log

	
Photo 1: Beaver browsing resembling coppicing.	**Photo 2:** Willow growth response to coppice-like browsing. Multiple stems growing from base.
	
Photo 3: Herbaceous vegetation in high density at a Rare creek (Jones Creek).	**Photo 4**: Facing downstream in Gavin Lake Creek channel. Instream bottom covered in non-aquatic vegetation.

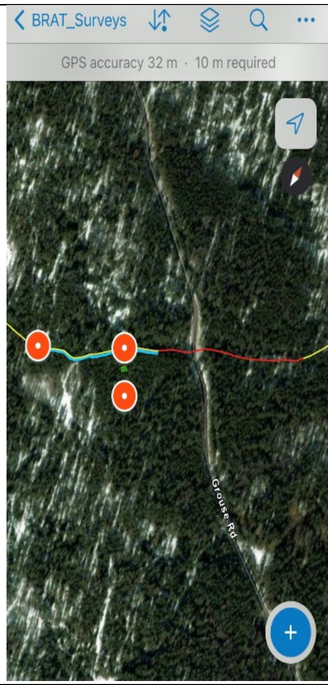

Photo 5: Adjacent downstream segment of Fake Creek classified None (red line).

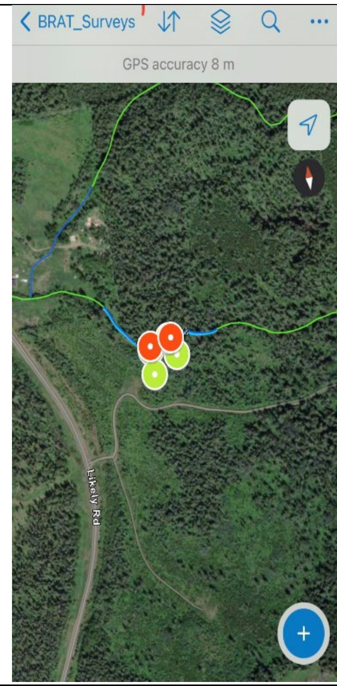

Photo 6: 3 Mile Creek (creek line with data collection points) with upstream and downstream reaches classified Frequent (green line).

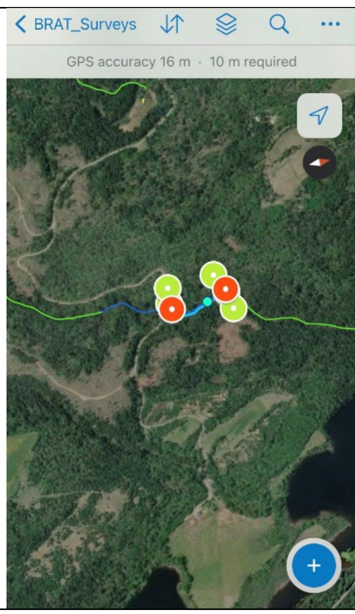

Photo 7: Guy Creek upstream and downstream reaches classified Frequent (green line).

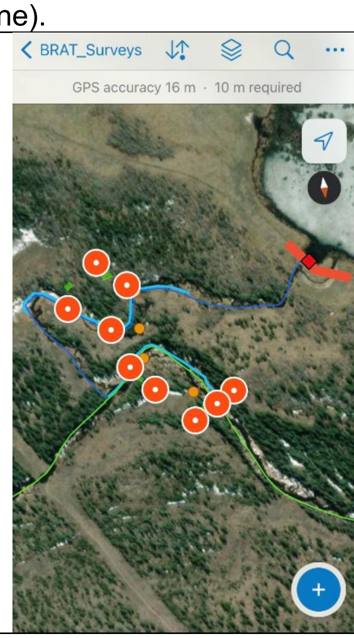

Photo 8: Watson Creek entire channel classified Pervasive (dark blue line). 111 Mile Creek shown as Frequent (green line). Light blue indicates stream segment that was field-surveyed.

Photo 9: Signs of past fire in Burnt Creek with regenerating stand of young trembling aspen.