An ecoregional approach to protected area monitoring using satellite remote sensing in British Columbia

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**Abstract:** Protected areas conservation is an effective means of conserving biodiversity and valuable ecosystem services. Currently, many nations and international governments use proportional area protected as a critical metric for assessing progress towards biodiversity conservation. However, these metrics do not assess the effectiveness of protected area networks, nor do they assess how representative PAs are at protecting the ecosystems they aim to protect. Within forest environments, forest structure can be a key indicator of biodiversity. To face these challenges, we examined the protected area network of British Columbia using satellite remote sensing data within British Columbia’s biogeoclimatic ecosystem classification (BEC) system. First, we examined BEC ecosystem and land cover class bias in protected areas by elevation, and harvesting and fire disturbance regimes by latitude. We then examined forest structural attributes in ecosystem subzones, comparing them using the student’s t-test by taking an equal sample of unharvested pixels in each subzone in protected and unprotected areas. We found that forest structural attributes are most often significantly different in protected and unprotected areas (426/496 significant at P < 0.01). We then examined a vector diagram of three structural attributes to determine the subzones with the most different structures in protected and unprotected areas. The results from this analysis will allow parks management to consider forest structure when examining new locations for protected areas in British Columbia, within the provincial ecosystem classification context.

**Keywords:** Protected Areas, Remote Sensing, Forest Structure, Disturbances, Land Cover, Ecological Classifications

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# 1 Introduction

Protected areas (hereafter PAs) are an integral component of biological conservation, designed to preserve ecosystem services and biodiversity both inside the PAs and in some cases the surrounding regions (Chape et al. 2005, Watson et al. 2014). In recent decades, there has been a push to conserve varying portions of the terrestrial area of the globe, with the goals increasing as time has gone on (CBD 2004, 2010). In the 2010’s, the Aichi biodiversity target sought to protect 17% of the entire globe (CBD 2010). Nationwide, the Canadian government has set the goal of protecting 25% of Canada’s terrestrial area by 2025 (ECCC 2021). While increasing proportional ecosystem protection does in turn increase conservation, it does not guarantee that the protected ecosystems are representative of the entire ecosystem, or guarantee that all biodiversity will be conserved.

Many conservation goals, both global and regional, are commonly based on the proportion of area protected due in part to its ease of use and calculation (Chape et al. 2005, CBD 2010). However, while the area protected is a simple metric to report on, it is not always the most effective metric, as it does not convey how effective a given PA is for protecting the inherent ecosystem services or biodiversity in the area (Chape et al. 2005). In fact, many studies do not consider areal percentages to be an effective metric for indicating biodiversity protection (Butchart et al. 2015); the area metric heavily underestimates the global protected area required to adequately protect biodiversity, which research indicates is up to 50% of each ecoregion (Butchart et al. 2015, Dinerstein et al. 2017).

In response to issues associated with simply using protected area size as a metric for conservation, a number of other methodologies have been developed to evaluate the effectiveness of PAs (Parrish et al. 2003, Gaston et al. 2006, 2008, Hansen and Phillips 2018, Bolton et al. 2019). A commonly concept for PA effectiveness is e ecological integrity, defined by Parks Canada as an ecosystem having the expected “living and non-living pieces for the region,” and that ecological processes should occur in the PA at the expected frequency and intensity for the region (Parks Canada 2019). Subsequently, many potential ecological integrity indicator variables have been examined to capture these pieces and processes (Hansen and Phillips 2018). These indicators can then be interpreted manually or automatically, most often through examining temporal trends within the PAs or by comparing the indicators to areas in known healthy reference ecosystems (Woodley 1993).

Remote sensing technologies offer a key approach to deriving and monitoring indicators to assess PA effectiveness for monitoring ecological integrity (Parmenter et al. 2003, Olthof et al. 2006, Nagendra 2008, Fraser et al. 2009, Soverel et al. 2010, Burkhard et al. 2012, Pereira et al. 2013, Bolton et al. 2019) with demonstrated capacity to detect and monitor the pieces and processes found within PAs (Turner et al. 2003, Nagendra et al. 2013). Pieces, or components, of the environment, such as forested area, wetland area, rock and rubble, can be measured from space at broad spatial extents and temporal scales. While it can be difficult to directly monitor biodiversity, an integral “piece” of ecological integrity, using satellite remote sensing (Nagendra 2001, Turner et al. 2003, Gillespie et al. 2008), a number of methods have been developed to indirectly measure biodiversity, namely: canopy species mapping (Nagendra 2001), habitat classification (McDermid et al. 2005, Lucas et al. 2011), examining spectral information (and indices such as NDVI) (Feeley et al. 2005, Gillespie 2005, Nagendra et al. 2010), spectral heterogeneity (Rocchini et al. 2010), ecosystem structure (Cohen and Goward 2004, Goetz et al. 2007, Soverel et al. 2010, Pôças et al. 2011), and function (Skidmore et al. 2021). Processes, such as natural and anthropogenic disturbance regimes, including flooding, fires, harvesting, and insect outbreaks, are frequently monitored from satellite imagery (Kerr and Ostrovsky 2003, Alsdorf et al. 2007, Hermosilla et al. 2015b, Bolton et al. 2019), with biogeochemical cycles being observed throiugh measures of carbon sinks and sources (Myneni et al. 2001), vegetation productivity (Running et al. 2004), and vegetation dynamics (Zhang et al. 2003). While not a panacea for protected area monitoring, remote sensing does offer an important suite of tools for monitoring protected area networks (Nagendra 2001, Nagendra et al. 2013).

Remote sensing also offers a cost-effective method for deriving forest structure across large extents through the use of light detection and ranging (LiDAR). When combined with satellite optical remote sensing, LiDAR data can be imputed across large regions to generate wall-to-wall coverage of forest structural attributes (Wulder et al. 2012b). Diversity in vegetation structure measurements is a strong indicator of biodiversity, providing habitat, influencing food quality, and mediating microclimates (Gao et al. 2014, Guo et al. 2017). The natural variation in vertical and horizontal forest structure has been explored using LiDAR, as well as SAR (synthetic aperture radar) data, however, comparisons between protected and unprotected areas are less frequently drawn using these methods (Nagendra et al. 2013).

In recent years, many studies monitoring ecological integrity or related indicators using remotely sensed data are heavily relying on free and open-source data (Fraser et al. 2009, Soverel et al. 2010, Pôças et al. 2011, Bolton et al. 2019, Skidmore et al. 2021). By leveraging this cost-free data, conservation scientists are able to conduct studies across an entire jurisdiction’s PA network and examine temporal changes in protected areas (Turner et al. 2015, Buchanan et al. 2018). These changes can then be compared to unprotected areas, allowing for researchers and park managers to gauge the effectiveness of a given PA or the entire PA network (Soverel et al. 2010, Turner et al. 2015, Bolton et al. 2019). This methodological framework offers an improvement over using ecoregional (or global) area based approaches, in that it provides a better understanding of the efficacy of protected areas.

As Canada progresses towards the national goal of 25% of terrestrial area protected by 2025, there is a growing need to better understand how PAs compare to unprotected areas with respect to location, ecological classifications, elevations, productivity, and structure. This adds increasing importance for considering protected area conservation goals beyond just proportional coverage. Also relevant to consider, are the biases in PA placement, which have frequently been located in cheaper, low productivity regions both globally (Joppa and Pfaff 2009, Venter et al. 2014, Venter et al. 2018) and regionally, as is the case in British Columbia, Canada (Hamann et al. 2005, Environmental Reporting BC 2016, Wang et al. 2020). By comparing protected and unprotected areas in the province, differences can be shown across varying gradients, including latitude, elevation, and ecological classification.

In this study, we (1) seek to enshrine in peer-reviewed literature the results found of Environmental Reporting BC (2016), in that PAs in British Columbia are biased towards high-elevation, low-productivity regions of the province, and (2) identify gaps in forest structures in PAs in the province. The identified gaps will highlight which additional forest structures are required to be captured within protected areas to ensure equal representation of the various ecozones. To accomplish this, we examined the bias in PA placement by comparing ecoregional PA coverage and land cover classes by elevation, and disturbances by latitude across protected and unprotected areas in British Columbia, Canada. Following this, we calculate representative forest structural attributes for each BEC zone in order to determine the differences between PAs and unprotected areas and then use this information to determine the most and least similar forest structures. Results will allow parks management to better consider forest structure when planning PA acquisitions.

# 2 Methods

## 2.1 Study Area

British Columbia, Canada is 94.4 million hectares, of which approximately 64% is forested (BC Ministry of Forests, 2003), and encapsulates a wide variety of biomes and ecosystems. This diversity of ecosystems are in part due to the its large size as well as variations in topography and climate. The existing Biogeoclimatic Ecosystem Classification (BEC) system disaggregates the ecosystems of BC into zones.. At the broadest level, 16 zone classifications are delineated based on macroclimate, climax vegetation species, and soil (Pojar et al. 1987). Zones are further broken down into subzones, variants, and phases based on microclimate, precipitation, and topography (Pojar et al. 1987, Meidinger and Pojar 1991). As a result BEC zones vary widely in size, as well as number of subzones (Table 2.1).

Table 2.1: Number of subzones, total area, and percent protected by BEC Zone

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Zone Name | # of Subzones | Total Area (ha) | Percent Protected |
| BAFA | Boreal Altai Fescue Alpine | 2 | 6286778.8 | 30.1% |
| BG | Bunchgrass | 2 | 257072.1 | 11.8% |
| BWBS | Boreal White and Black Spruce | 5 | 16404143.0 | 8.6% |
| CDF | Coastal Douglas-fir | 1 | 251232.2 | 4.8% |
| CMA | Coastal Mountain-heather Alpine | 3 | 3574039.1 | 17.9% |
| CWH | Coastal Western Hemlock | 10 | 10795067.4 | 19.5% |
| ESSF | Engelmann Spruce – Subalpine Fir | 43 | 17465113.0 | 17.8% |
| ICH | Interior Cedar – Hemlock | 12 | 5538842.2 | 10.2% |
| IDF | Interior Douglas-fir | 12 | 4488085.9 | 5.9% |
| IMA | Interior Mountain-heather Alpine | 2 | 1257949.1 | 29.2% |
| MH | Mountain Hemlock | 6 | 4059301.2 | 19.8% |
| MS | Montane Spruce | 8 | 2863394.3 | 9.4% |
| PP | Ponderosa Pine | 1 | 294985.3 | 7.1% |
| SBPS | Sub-Boreal Pine – Spruce | 4 | 2265365.8 | 9.5% |
| SBS | Sub-Boreal Spruce | 11 | 10337497.4 | 6.7% |
| SWB | Spruce – Willow – Birch | 6 | 8655855.9 | 23.3% |

The protected area system in British Columbia is designed to serve as areas available for ecological conservation as well as human recreation (BC Parks 2012). The system consists of a network of PAs and PA complexes (multiple nearby PAs which share the same conservation goals), with large variations in size, ranging from 0.02 to 987,899 ha (Figure 2.1). Both the British Columbian (BC Parks 2012) and Canada-wide protected areas mandates (Government of Canada, 2019) commit to conserving ecological integrity across the PA network. Protected areas in the BC network are frequently located in mountainous, high elevation areas, leading to underrepresentation in high productivity ecosystems (Environmental Reporting BC 2016, Wang et al. 2020).

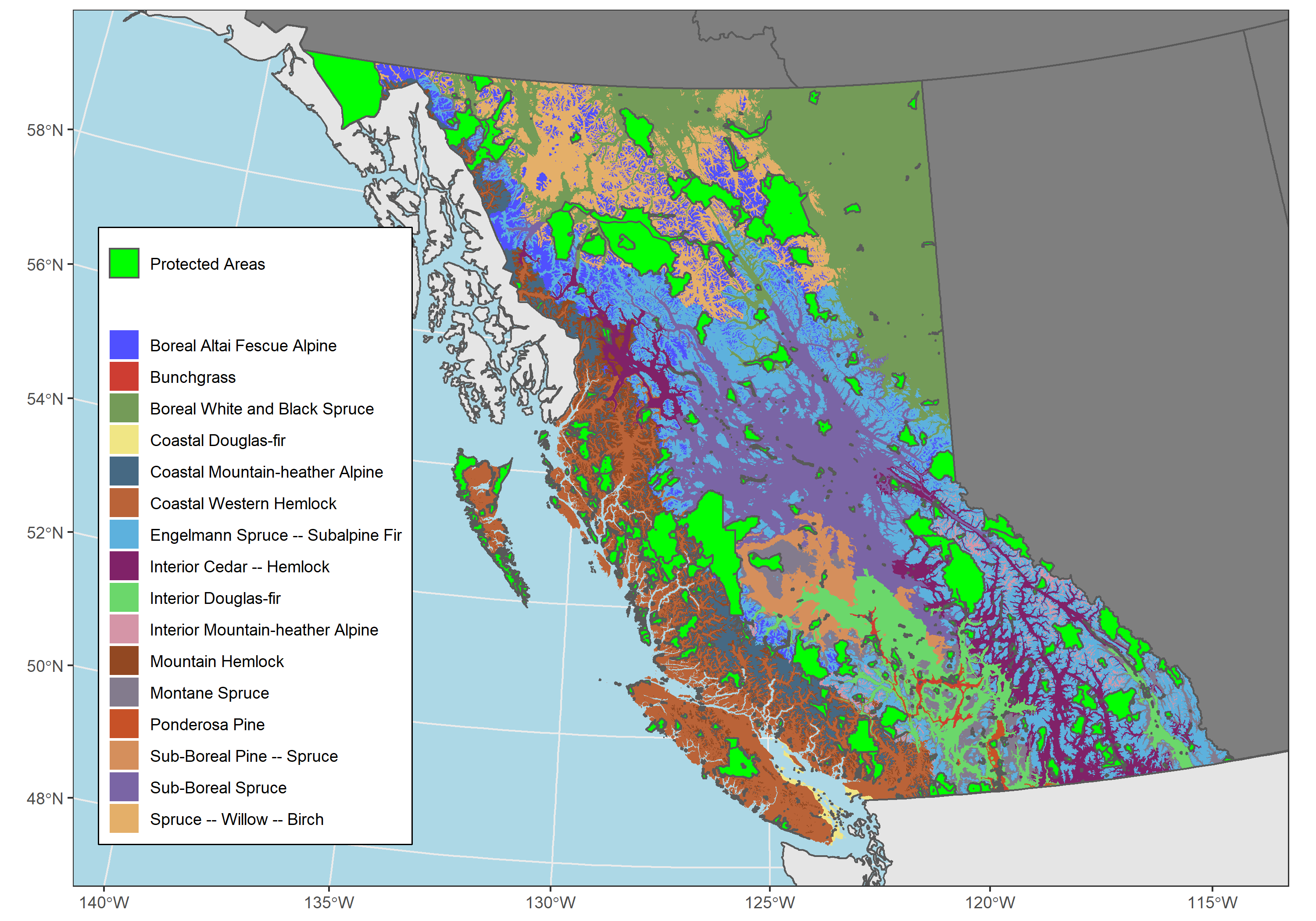


Figure 2.1: Map of terrestrial British Columbia including BEC zones and the location of PAs used in this study.

## 2.2 Data

### 2.2.1 Biogeoclimatic Ecosystem Classification

Boundaries for BEC zones and subzones were acquired using the **bcmaps** R package (Teucher et al. 2021). Two BEC subzones were entirely subsumed by PAs (Boreal White and Black Spruce - Very Wet Cool and Spruce – Willow – Birch - Very Wet Cool Shrub), whereas the Sub-Boreal Pine – Spruce - Moist Cool subzone has no PAs associated with it.

### 2.2.2 Protected Areas

Boundaries for all parks and protected areas in BC were obtained from the Canadian Protected and Conserved Areas Database (available from <https://cws-scf.ca/CPCAD-BDCAPC_Dec2020.gdb.zip>) which contains spatial coverage of all PAs in Canada as of December 2020, and includes the IUCN classification for each PA. Protected areas were selected to be suitable for analysis following the criteria outlined in Bolton et al. (2019). Only parks which belonged to IUCN classes Ia, Ib, II, and IV were selected, as these categories are considered strictly protected. Protected areas smaller than 100ha in size were also excluded from the analysis. After selection, 745 suitable parks managed under various jurisdictions (provincial, federal, NGOs) which comprise 15.4% of the total terrestrial area of British Columbia were studied (Environmental Reporting BC 2016).

### 2.2.3 Digital Elevation Model

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model (GDEM V2, 30m) was used to examine biases in protected area land cover and ecological classification by elevation (Tachikawa et al. 2011).

### 2.2.4 Satellite Imagery

The opening of the Landsat archive in 2008 (Wulder et al. 2012a) has played a significant role in the use of satellite imagery in conservation monitoring (Nagendra 2008, Turner et al. 2015). The availability of the satellite archive since 1972 allows for assessment of temporal trends in satellite derived indicator variables (Nagendra et al. 2013, Hansen and Phillips 2018, Bolton et al. 2019), while the global coverage of many satellite data sources allows for comparisons between similar and differing ecosystems (Nagendra 2008, Wulder et al. 2012a).

With multiple images available for a given region for all portions of the year, a recent development in satellite remote sensing has been to create best-available-pixel (BAP) composites. These composites include the best single observation at each pixel for the catalog of available scenes, within certain temporal bounds such as seasons (White et al. 2014). This allows for the examination of trends on a yearly basis with high quality data, removing most missing data such as clouds, shadows, and sensor errors (White et al. 2014). This method does however have drawbacks: the revisit time of many sensors (e.g. Landsat’s 16 day revisit time) makes it difficult to compare a region intra-annually.

While Landsat provides an excellent dataset for picturing the environment in 2D (e.g. land cover, disturbances), airborne laser scanning allow for very detailed and accurate depictions of the 3D forest structure (Wulder et al. 2012b). One common problem associated with these airborne laser scanning datasets is their often limited spatial and temporal coverages. By combining airborne laser scanning with BAPs generated from the Landsat archive, these structural datasets can be imputed across time and space, providing coverage far beyond the initial spatial coverage of the LiDAR acquisitions (Matasci et al. 2018, Coops et al. 2021). The Landsat archive can now provide researchers and end-users with high quality, value-added datasets, such as land cover (Hermosilla et al. 2018), forest disturbances (Hermosilla et al. 2015b), and 3D forest structure (Matasci et al. 2018). These datasets are openly available online at <http://opendata.nfis.org/mapserver/nfis-change_eng.html>.

#### 2.2.4.1 Land Cover

Land cover information for Canada from 1984-2019 was produced following Hermosilla et al. (2018) using the Virtual Land Cover Engine framework. It includes eleven land cover classes, all of which are present in British Columbia. To accomplish this, an annual BAP surface reflectance image composite was created from Landsat imagery (Hermosilla et al. 2016), taking into consideration the annual forest changes generated while using the Composite 2 Change approach (Hermosilla et al. 2016). To classify the BAP composite, a the random forest algorithm was used, and a Hidden Markov Model was applied to ensure logical land cover transitions between years (Hermosilla et al. 2018).

#### 2.2.4.2 Forest Disturbances

Forest disturbance metrics were generated by Hermosilla et al. (2016) for the period of 1985-2019 using the BAP composites generated by Hermosilla et al. (2016). Forest disturbances were delineated by examining changes in the normalized burn ratio through time (White et al. 2014, Hermosilla et al. 2016). Hermosilla et al. (2016) used breakpoint (temporal) and contextual (spatial) analysis to ensure that changes were detected in the correct year (Hermosilla et al. 2015b). These changes were then classified into a change type (fire, harvesting, road, and non-stand replacing) via the object based image analysis approach described in Hermosilla et al. (2015b).

#### 2.2.4.3 Forest Structural Attributes

Forest structure metrics (lorey’s height, total aboveground biomass, elevation covariance, and canopy cover) were imputed across the forested area of British Columbia following methods utilized in Matasci et al. (2018), on an independant, per year basis. This process utilizes annual Landsat proxy surface reflectance composites across Canada produced following Hermosilla et al. (2015a), the forest disturbance layers produced via Hermosilla et al. (2015b), and LiDAR samples collected across the country (Matasci et al. 2018). Ancillary data such as topography was also used to fit the models. The forest structure metrics were imputed using a k-NN approach, and generated six LiDAR metrics and four forest inventory attributes in total. Accuracy for the forest structural attributes used in this study (lorey’s height, total aboveground biomass, elevation covariance, and canopy cover) were 0.666, 0.699, 0.125, and 0.642, respectively (Matasci et al. 2018).

## 2.3 Analysis

To meet our analysis objectives, our approach was as follows: first, we examined ecozonal and land cover proportions in British Columbia throughout the province, as well as a function of elevation between protected and unprotected areas. Secondly, we examined disturbance rates on a latitudinal gradient across the province. Finally, we examined forest structural attributes at a finer ecosystem classification level, statistically comparing between protected and unprotected areas, and compare forest structural attribute means in ecosystem subzones to determine which structures are missing from the PA network in British Columbia

### 2.3.1 Pre-processing

The raster data (Section 2.2.4) was retrieved in a different format than what is available online, with each raster divided into UTM zones. In order to accommodate the provincial extent of the analysis, the five UTM zones covered by BC (UTM 7-11) were converted into provincial mosaics. Non-overlapping UTM masks were applied to the data before mosaicing, in order to preserve the information with the least deformation at the edges of the UTM projections.

Forest cover classes (deciduous, broadleaf, mixed-wood, and wetland-treed) were used to generate land cover masks to focus the analysis on forested pixels. Pixels harvested within the last 35 years were removed from forest structural attribute rasters in both protected and unprotected areas, in order to compare non-anthropogenically disturbed areas. BEC subzones and PA boundaries were intersected to create protected and unprotected BEC subzone masks for ease of processing. Each BEC subzone mask had tabular data created each input layer for analysis, in order to aggregate land cover, BEC zones, and disturbances by elevation and latitude.

BEC zones and land cover classifications were aggregated to protected and unprotected areas in order to determine the proportion of each zone under the protected classifications. In this paper, zones are used to examine categorical data (land cover and disturbance), while forest structure is compared at the subzone level between PAs and their unprotected counterparts in British Columbia. Subzones with only protected or unprotected areas were excluded from hypothesis testing, but were included in zonal aggregations. Land cover and BEC data were further examined along an elevation gradient, at bin sizes of 50m. Forest disturbances were aggregated along a latitudinal gradient with bin sizes of 1000 pixels. The mean values for protected and unprotected areas forest structural attributes were calculated, in order to examine the differences in their distribution and determine which structures and zones differ between protected and unprotected areas. These were also converted into z-scores in order to determine the greatest standardized vector magnitude when comparing canopy cover, elevation covariance, and forest height between protected and unprotected areas.

### 2.3.2 Statistical Analysis

An equal sample of cells (equal to the total number of pixels in protected or unprotected areas, whichever was lower) was sampled from both protected and unprotected areas for each BEC subzone. For each forest structure variable and BEC subzone pair, a two-tailed T-Test was conducted, comparing protected and unprotected samples, and the Bonferroni correction was applied.

# 3 Results

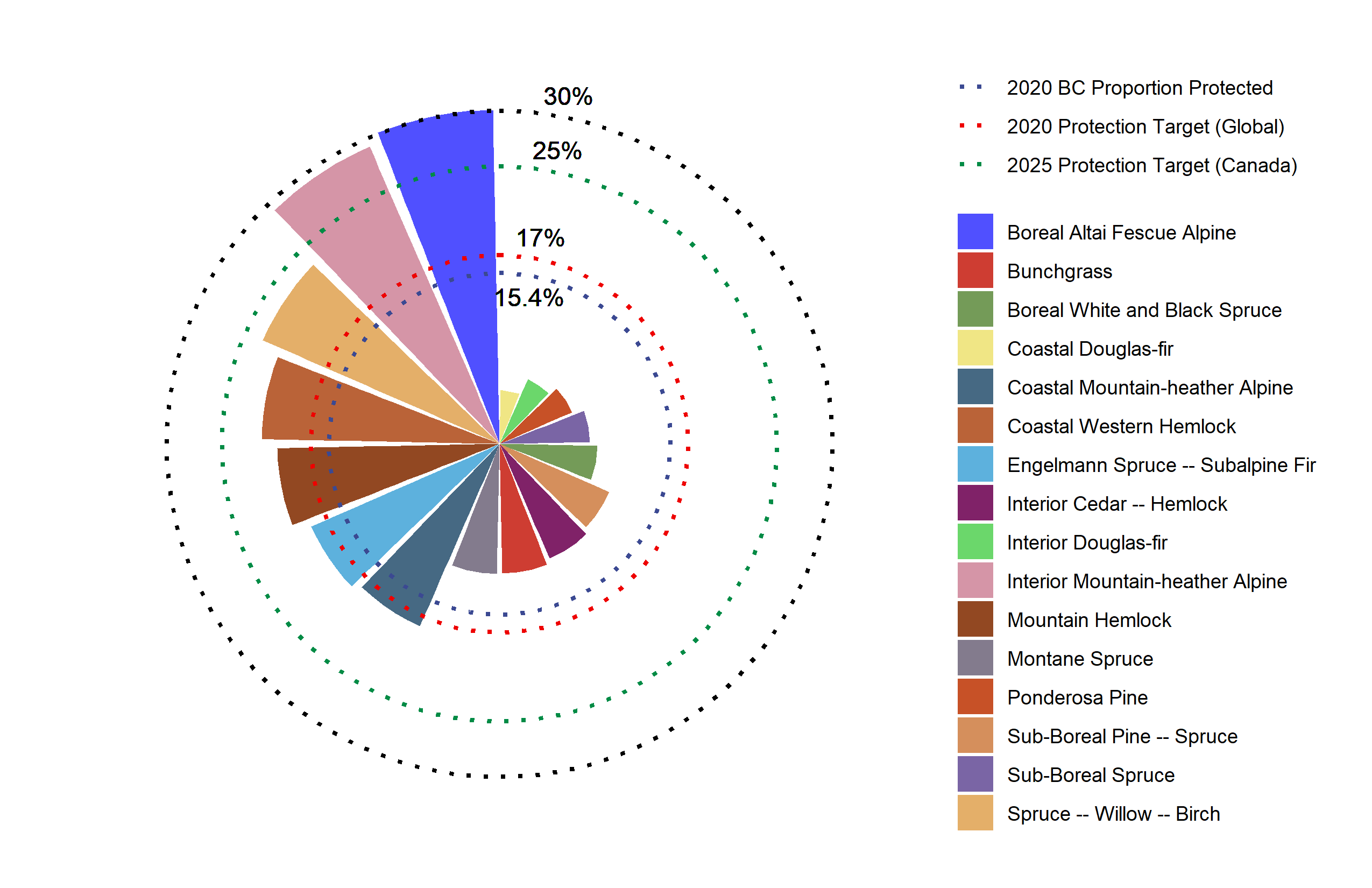


Figure 3.1: Diagram of proportion of the area of each BEC zone protected. Red dotted line indicates 2020 global protected area coverage goal, Blue dotted line indicates 2025 Canadian protected area coverage goal, and the green dotted line indicates the overall proportion of protected areas in British Columbia.

British Columbia’s ecosystems are protected at varying rates in the province (Figure 3.1). Of the 16 ecosystem zones present in British Columbia, seven are protected at rates above the Aichi biodiversity target (10%). Only two zones (Boreal Altai Fescue Alpine and Interior Mountain-heather Alpine) are currently protected at rates above the Canadian 2025 protection targets (25%). Zones with Douglas-fir as a primary component (Coastal Douglas-fir and Interior Douglas-fir) are the least proportionally represented zones in British Columbia, with 4.9% and 6.4% protected, respectively (Figure 3.1).

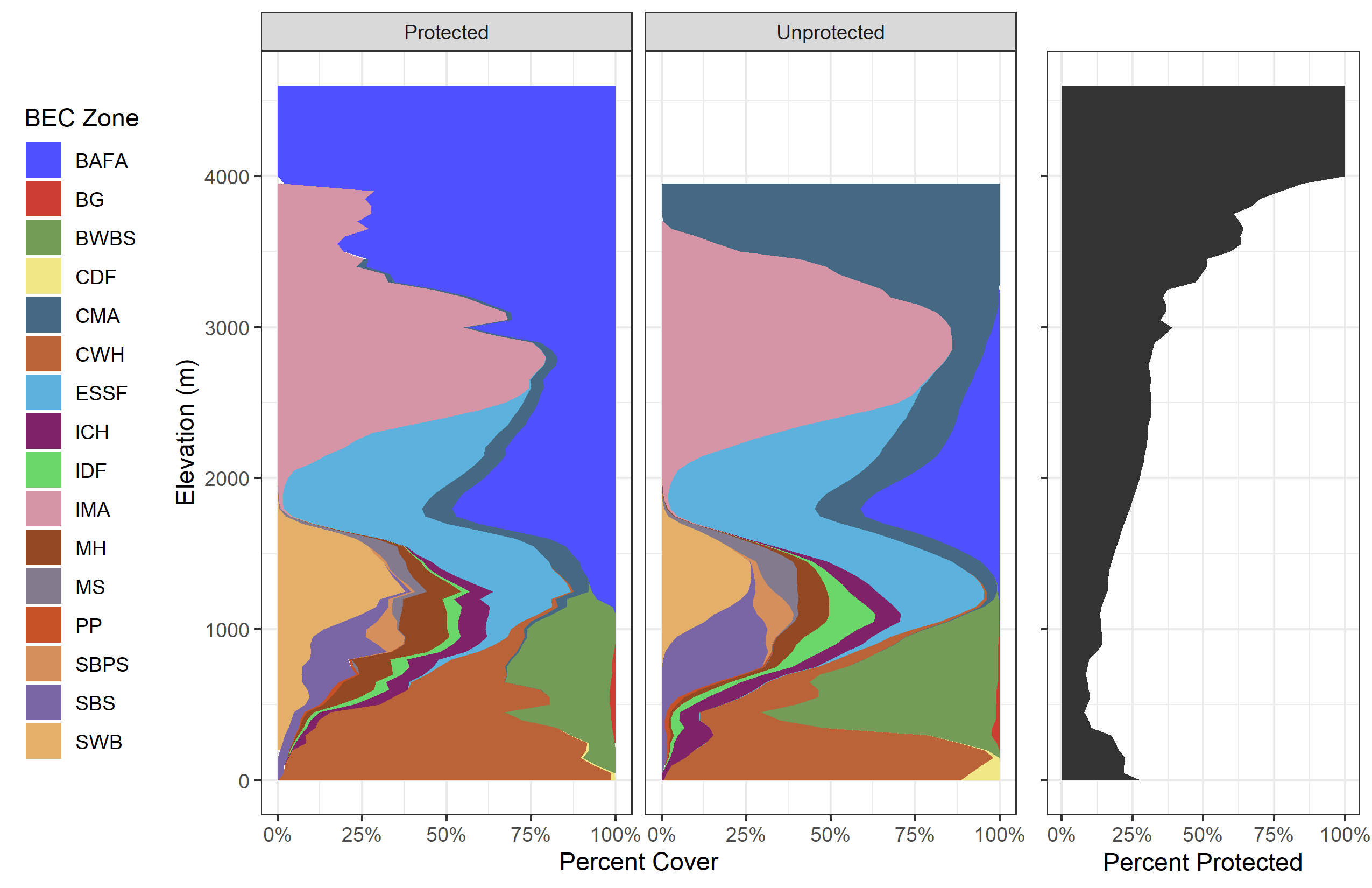


Figure 3.2: Proportion of BEC zone by elevation for both protected areas (left), and unprotected areas (centre). The rightmost figure represents the proportion of terrestrial area that is protected at each elevation.

As elevation increases in British Columbia, increasing terrestrial area is protected until ~4000m, where all terrestrial area in BC is protected (Figure 3.2). When comparing between protected and unprotected areas, zones are protected at differing proportions. Zones commonly found at high elevations, such as the Boreal Altai Fesuce Alpine, are predominantly location in protected areas. Conversely, a greater proportion of the Coastal Western-hemlock ecosystem is protected at low elevations, while Boreal White and Black Spruce shows the opposite; more of this ecosystem is found in unprotected areas. Generally, the remaining ecosystems are found at similar rates in both protected and unprotected areas (Figure 3.2).

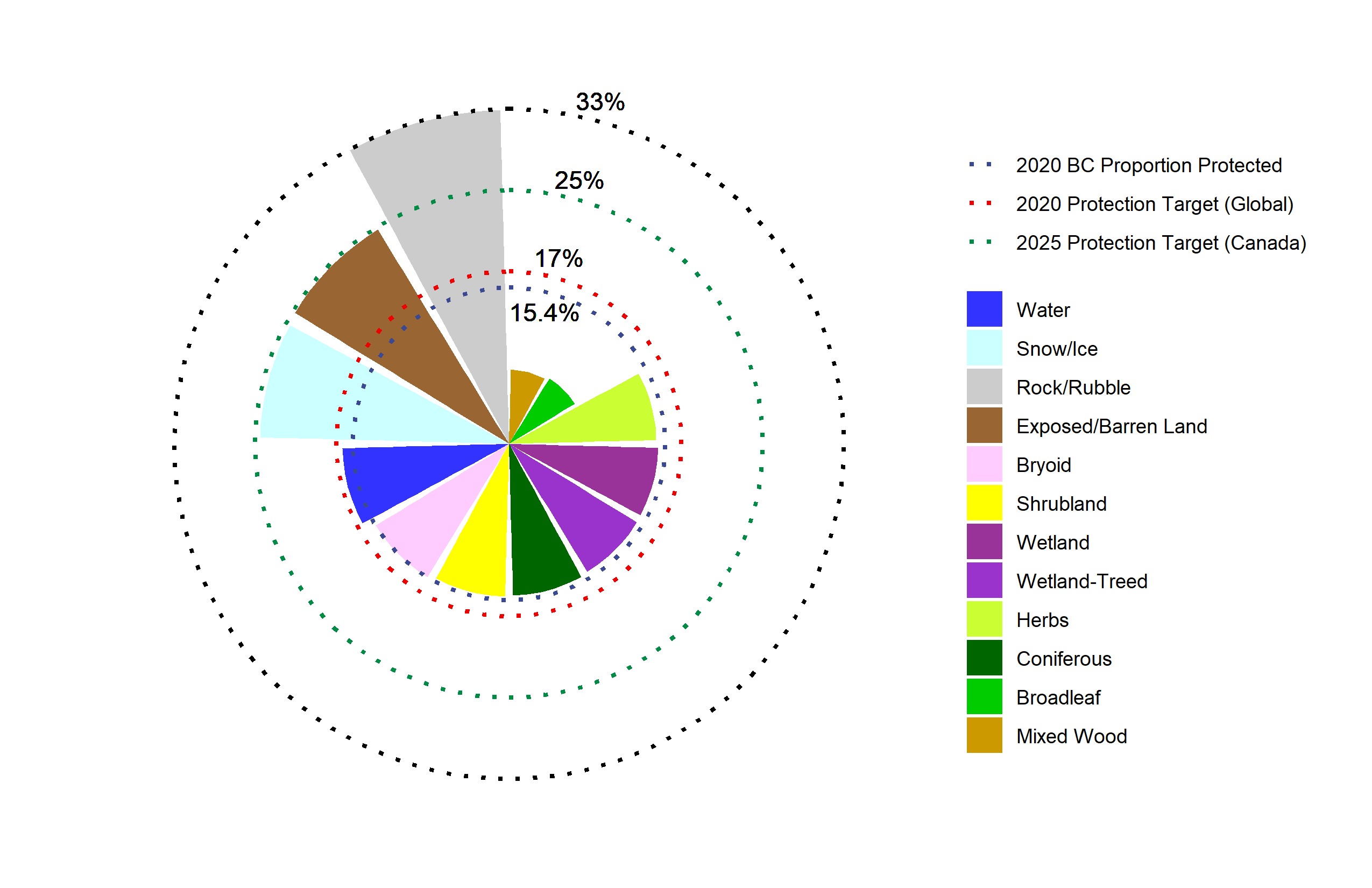


Figure 3.3: Diagram of proportion of the area of each land cover class protected. Red dotted line indicates 2020 global protected area coverage goal, Blue dotted line indicates 2010 ecoregional protected area coverage goal, and the green dotted line indicates the overall proportion of protected areas in British Columbia.

Land cover classes also vary by proportion protected (Figure 3.3). Snow/ice, exposed/barren land, and rock/rubble have higher than average proportions protected. Conversely, mixedwood and broadleaf land cover classes are underrepresented in BC’s PA network. All other classes are found at rates similar to the overall proportion of the province protected (Figure 3.3).

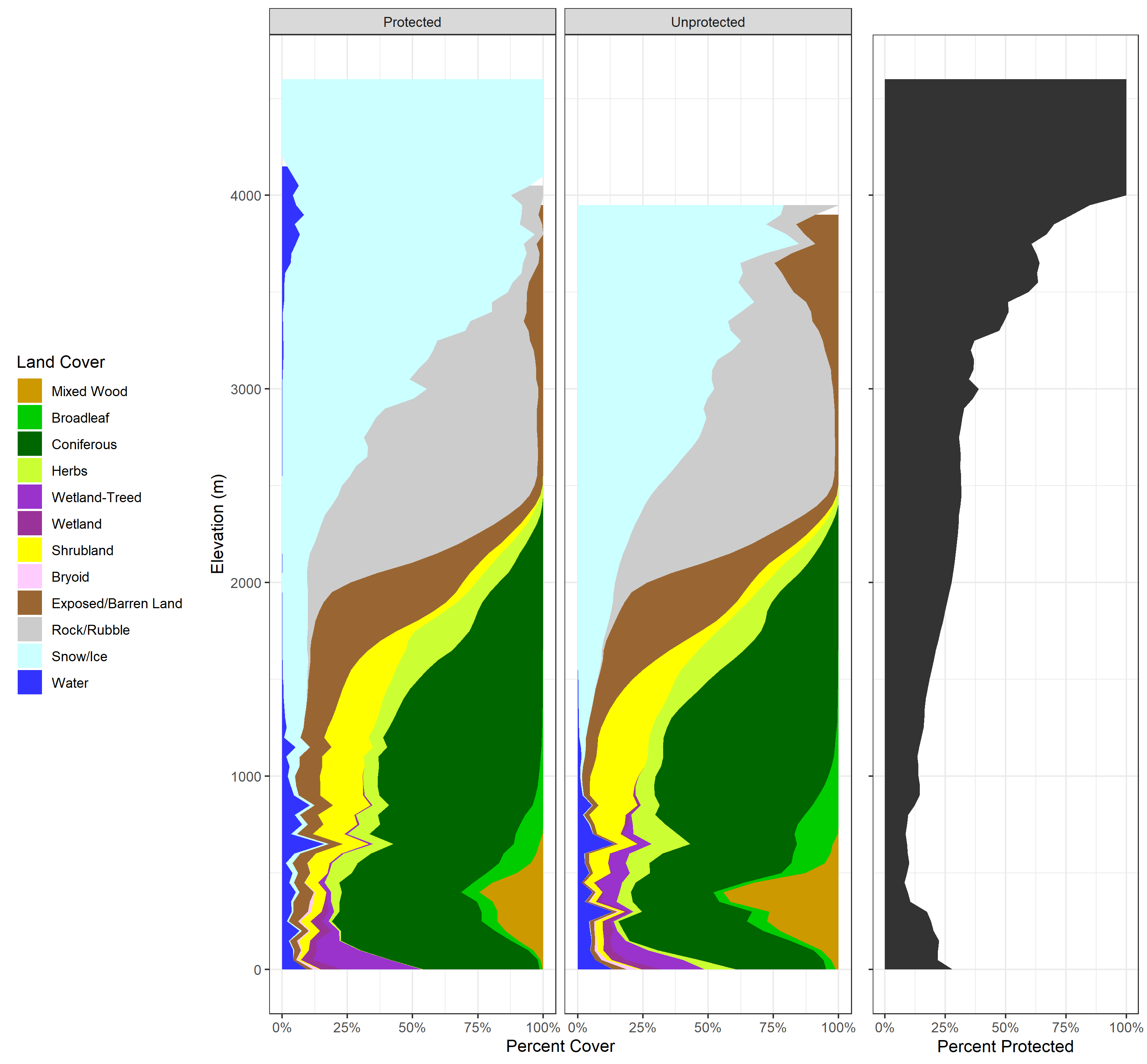


Figure 3.4: Proportion of each land cover class by elevation for both protected areas (left), and unprotected areas (centre). The rightmost figure represents the proportion of terrestrial area that is protected at each elevation.

Similar to BEC zones (Figure 3.2, land cover classes also vary with elevation (Figure 3.4. Expectedly, snow and ice make up a large proportion of PAs at high altitudes. The only water present in high elevations is found in lakes within protected areas, mostly above 3500m. At lower elevations in unprotected areas, mixedwood forest is a more common forest type than in PAs. Wetland classes are found less frequently in the 400-900m range in unprotected areas than in PAs.

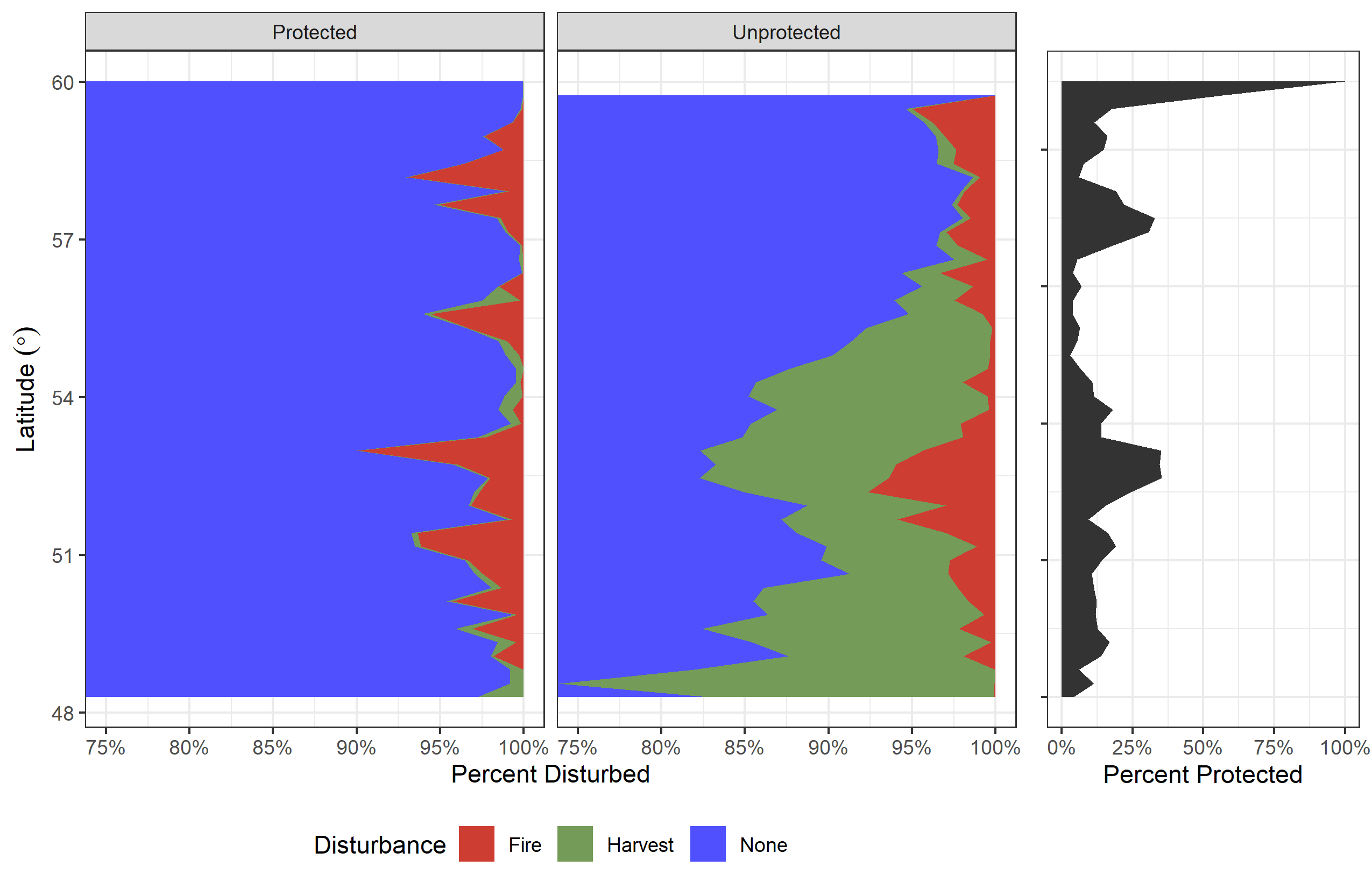


Figure 3.5: Proportion of area disturbed by latitude from 1984 to 2019 in protected areas (left), and unprotected areas (centre). The rightmost figure represents the proportion of terrestrial area that is protected at each latitude.

Fire regimes are similar between protected and unprotected strata at all latitudes indicating a lack of fire suppression inside park boundaries (Figure 3.5. As anticipated by the IUCN designations, harvesting is rare within PAs, and within unprotected areas, harvesting is more common at lower latitudes.

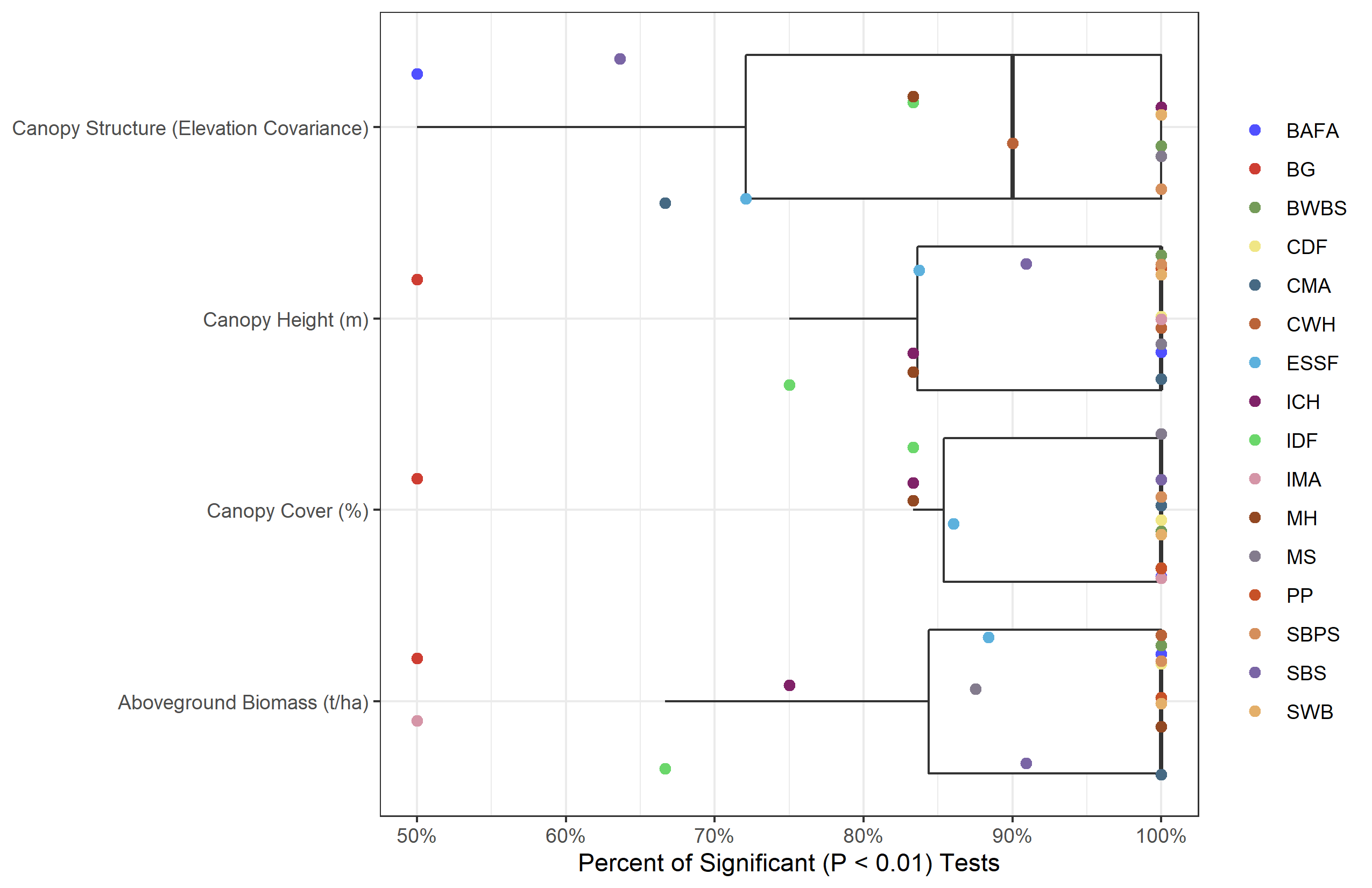


Figure 3.6: Boxplot of proportion of ecosystem subzone which have significant p-values from a two-tailed t-test with the Bonferroni correction (n = 496) applied at a significance level of 0.05.

Figure 3.6 shows the subzonal proportional significance (P < 0.01) by zone of the 496 t-tests by forest structural variable. Higher percentages indicate that a zone has more dissimilar subzones than lower percentages. At least half of all subzones in each zone are significantly different (exception being Ponderosa Pine, which has one subzone that is not significantly different in canopy structure). The median values for canopy height, canopy cover, and aboveground biomass are all 100% significantly different.

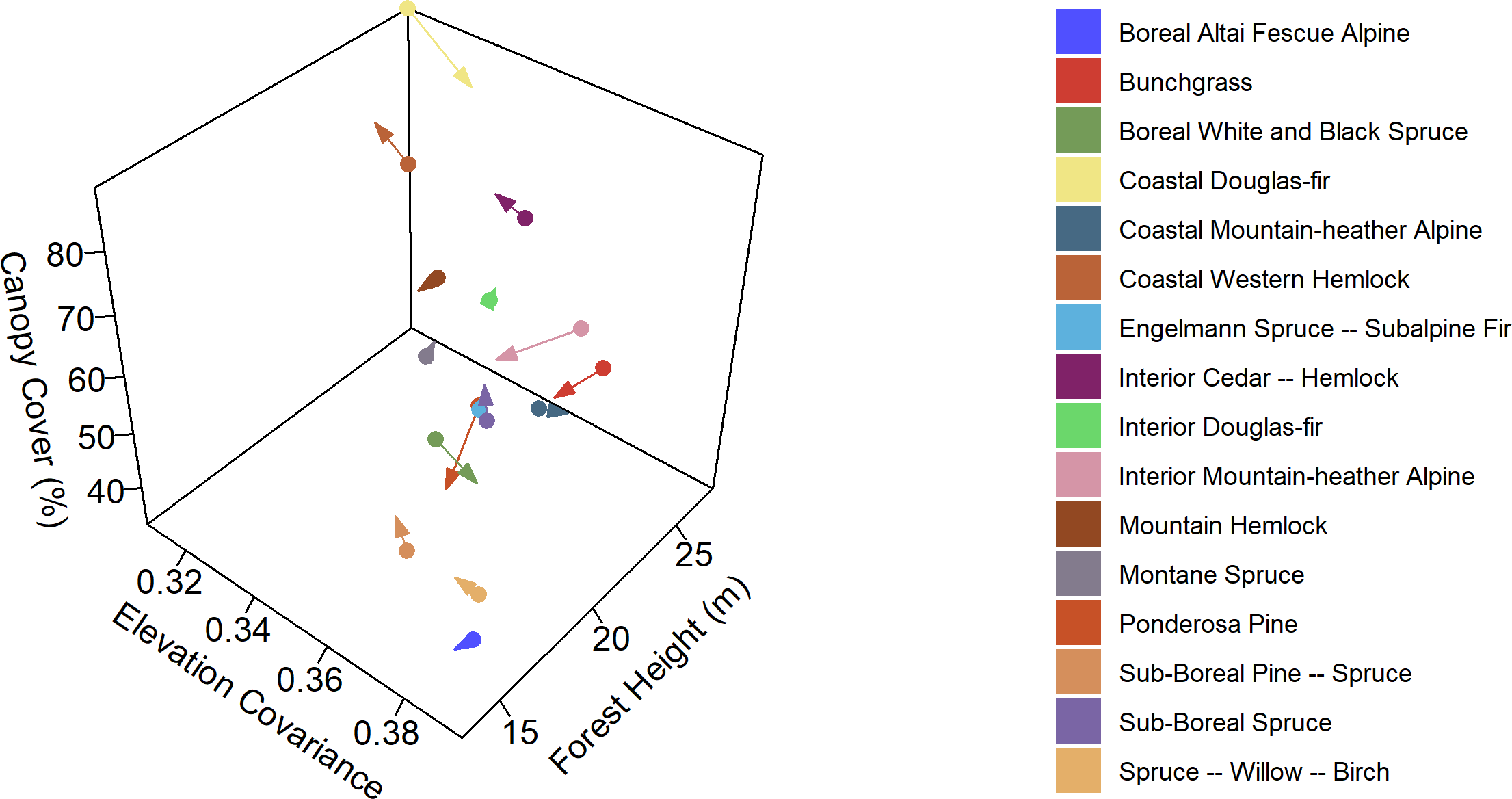


Figure 3.7: 3d vector diagram of BEC zones forest structure attributes across British Columiba. Dots indicate the protected area means, and arrowheads indicate unprotected area means.

Figure 3.7 displays a 3-dimensional vector diagram of the forest structural description (forest height, vertical complexity, and canopy cover) of each zone in both protected (dots) and unprotected areas (arrowheads). Forests are generally taller in PAs (Figure 3.7). Scalar distances of attribute z-scores were also calculated, with the Coastal Douglas-fir zone having the largest difference between protected and unprotected areas.

# 4 Discussion

Recently developed remote sensing datasets are beginning to provide wall to wall coverage of forest structure attributes across entire jurisdictions [SOURCE]. These datasets are allowing researchers to compare PAs to their unprotected counterparts in novels ways. Being able to track forest structure metrics, an indicator of biodiversity (Guo et al. 2017), across wide swaths of land allows for park managersto make informed decisions on the location of new PAs with respect to missing forest structures. By applying this analysis to each ecozone within the province, we can determine not only which ecozones need additional representation (the proportional metric), but what types of forest structures should be represented.

Internationally, biodiversity preservation targets aim to protect a proportion of the total terrestrial area (CBD 2010). Frequently, new protected areas are placed in high-elevation, low-productivity ecosystems both globally (Joppa and Pfaff 2009, Venter et al. 2014, Venter et al. 2018), and in British Columbia (Wang et al. 2020). We found that this was the case in both ecosystems (Figure 3.1) and land cover classes (Figure 3.3) across BC. Alpine ecosystems are more commonly protected, and the land cover classes associated with them (rock/rubble, snow/ice, exposed/barren land). As elevation increases, theses ecosystem and land cover classes continue to become more dominant (Figures 3.2 & 3.4). It is also relevant to note that as elevation increases, proportion protected also increases, up to 100% protected above 4000m.

When examining disturbances, we found similar results to Bolton et al. (2019), in that harvesting is most prevalent at low latitudes in unprotected areas, and that fire regimes are similar between protected and unprotected areas (Figure 3.5). Our results agree with the author’s conclusions that northern areas are less frequently harvested, while fires are similar across PAs and unprotected areas (Bolton et al. 2019).

Our analysis showed that the majority of structural attributes were significantly different in BEC subzones (Figure 3.6). Analyzing the mean structural attributes in tandem showed that many zones’ protected areas were different from their unprotected counterparts. Coastal Douglas-fir, a zone with a single subzone, had the largest variation between protected and unprotected areas in the three forest structural attributes examined. The unprotected forests were significantly less tall, had significantly less canopy cover, and significantly higher elevation covariance (vertical forest structure; Figure 3.7). In addition to this, it was the least protected ecozone by area, with only 4.8% of the total terrestrial area protected. In this specific ecozone, not only does additional area need to be protected to meet national goals, different forest structures need to be included in these new protected areas.

Forests in PAs were generally found to be significantly larger than forests in unprotected areas (Figure 3.6. While forest age can be challenging to determine from remote sensing, forest structure has shown moderate success in the approximation of stand age (Maltamo et al. 2020). Forest height, for example, is a predictor of successional stage. With this, the taller forests found in PAs are likely older forests than those found in unprotected areas. While older forests generally contribute more to ecological services, it is important to protect a range of habitats at differing successional stages in order to conserve the processes and habitants not found in older forest communities (Kuuluvainen and Gauthier 2018).

Monitoring the effectiveness of PAs is a difficult but important task. It is beyond time to move past simple ecosystem proportion metrics for assessing the effectiveness of protected areas. The advent of free and open global datasets can allow for the monitoring of protected area health across the globe (Nagendra et al. 2013). Future research monitoring protected area health using satellite remote sensing could focus on implementing essential biodiversity variables (Pereira et al. 2013) into their monitoring scheme. Advancing research towards these variables would not only benefit PA monitoring projects, but also biodiversity monitoring projects across the globe. Other research avenues include comparing the areas directly outside of PA’s for forest structure using methodologies similar to Bolton et al. (2019) and Soverel et al. (2010). Beyond this, examining post-disturbance forest structural attribute recovery in both PAs and unprotected areas would assess the effectiveness of PAs for promoting regeneration.

# 5 Acknowledgments

Add packages for both R and Python here.

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# (APPENDIX) APPENDIX

# Appendix A – Unused Figures

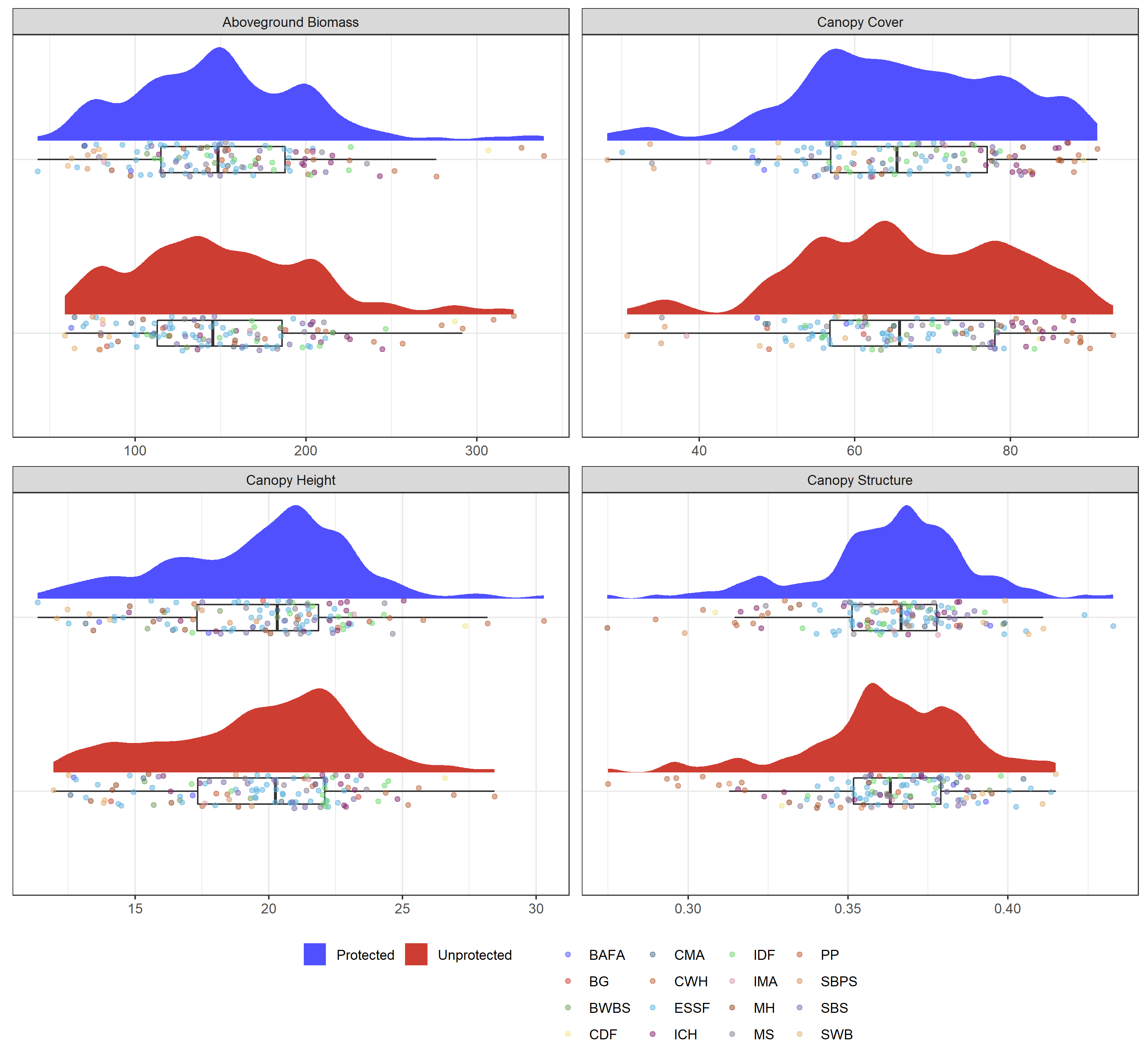


Figure 5.1: Scatterplots of mean BEC subzone forest structure attributes in protected (x-axis), and unprotected (y-axis) areas of British Columbia. Dotted line indicates 1:1 line.

Figure 5.1 shows raincloud plots of various forest structural attributes. These plots show the distribution and boxplots of BEC subzone means by protected areas status for of aboveground biomass, canopy cover, canopy height, and canopy structure in protected and unprotected BEC subzones in British Columbia.

### 5.0.1 Dot Points - intro

* Leverage open data to examine ecological integrity in BC PAs
* Compare these to nPAs (non-protected areas) at multiple scales, using t-test
  + BEC Zone scale for land cover and distrubance
    - Note that these have been previously explored
  + SUbzones for structural attributes
    - to my knowledge not explored yet
* results will
  + inform parks management on which bec zones accurately represent their environments
  + allow parks management to see what types of forest structures are missing from the PA network
  + provide novel information on the status of protected area forest structural attributes

### 5.0.2 Dot Points - methods

* Mosaiced NTEMS data, with edges of UTM zones removed
* Forest masks generated from land cover
* Masked out non-forest pixels from forest structure data using forest masks
* BEC zones and PAs intersected to determine proportions of each bec zone protected
* Intersect turned into masks by BEC subzone and PA status
* Each pixel turned into csv for bec subzone and PA status
  + Includes: elevation, forest structure (canopy cover, lorey’s height, total biomass, canopy structure)  
    land cover, change attribution, change year, latitude, protected status, subzone, and year of data
* mean structure for each variable and bec zone and PA status generated
* equal random sample of forested pixels generated for PA and nPA for forest structure attributes
  + 2 sided t-tests ran; bonferroni correction applied
* Land cover aggregated by protected status and elevation
* BEC coverage aggregated by protected status and elevation
* disturbances aggregated by protected status and LATITUDE

### 5.0.3 dot points - discussion

*###i think this can be in the discussion as sort of limitations*

* While not all aspects of ecological integrity can be effectively monitored from space, those that can provide insight into the effectiveness of PAs when examined spatially (when compared to unprotected areas), or temporally (Woodley 1993).
* Shown representation of proportions for bec zones is off, and also changes with elevation in PAs and nPA. Forest structure also differ in some cases. large samples sizes….
* Agrees with previous literature (Bolton & Soverel notably) about differences in protected area forests from unprotected areas. Follows latitudinal gradient. Additionally adds the elevation aspect and looks at the proportion of zone protection.
* Contributes to discussion about examining forests in protected and unprotected areas
* Real novel findings is that forest structure attributes vary between protected and unprotected areas.
* Future research: temporal, index of forest structure compared to nPA, compare to local envmt (bolton paper) but in forest structure context
* Overall, British Columbia did not meet the Aichi biodiversity target, having protected only 15.4% of the available terrestrial area, rather than 17%.
* Higher average height possibly indicating protection of older forests.
* Land cover classifications follow a similar trend to ecosystem zones, with high elevation (less productive) classes being more prevalent in protected areas
* Rather than using the genetics approach of Wang et al. (2020), we focused on the forest structural attributes that are currently found within the BEC zone framework.
* While elevation can be an important driver for land cover and ecosystem classifications, disturbances generally follow a latitudinal gradient.

# 6 Writing I may use in the future

Insights provided by remote sensing datasets can allow British Columbia to continue to assess the effectiveness of the BEC zones as a strata for PA ecological integrity. Due to the spatial variation in PA locations within BEC zones, it becomes important to consider if the PAs within a given BEC zone actually represent conditions throughout the remainder of the BEC zone, especially considering the tendency of PAs to be placed in lower productivity environments (Environmental Reporting BC 2016).

# 7 Journals

Ecological Applications ([<https://www.resurchify.com/impact/details/20287>](https://www.resurchify.com/impact/details/20287)) - IF 4.248

Ecological Modelling ([<https://www.journals.elsevier.com/ecological-modelling>](https://www.journals.elsevier.com/ecological-modelling)) - IF 2.497