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ENVIRONMENTAL FOOTPRINT ANALYSIS:
IN SUPPORT OF THE BC HYDRO INTEGRATED RESOURCE PLAN


Photo by Noah Buscher

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SFU is on unceded Coast Salish Territory; the traditional territories of the Musqueam, Squamish, and Tsleil-Waututh Nations

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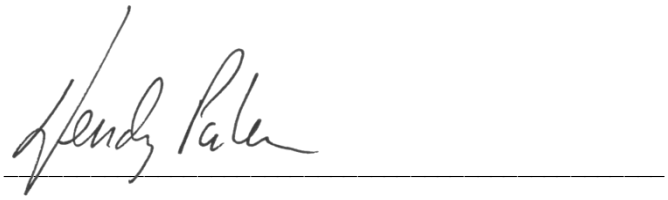
I certify that the data and analysis presented in this report are the original and independent work of the authors listed above, and I declare no conflicts of interest.



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2 INTRODUCTION

BC Hydro's (BCH) Integrated Resource Plan (IRP) is a 20-year plan of how to best meet the province's projected energy and capacity needs. The resource options considered in the IRP include demand-side measures and rates, renewing electricity purchase agreements, enhancing BCH facilities and acquiring power through new clean and renewable sources. BCH determines the best resource portfolio by considering the trade-offs of multiple objectives, such as portfolio costs, rate increases, and environmental impacts. This work supports the IRP by providing a methodology to estimate and compare the environmental footprints[1] of resource portfolios in the IRP. The environmental footprint analysis focuses on estimating the potential environmental impacts of new clean and renewable resources[2]. In addition to providing the environmental footprint for various resource portfolios, this analysis can also be used to help

- improve portfolios of projects;
- make comparisons among projects to highlight key trade-offs; and
- identify key red flags for post-IRP work, such as siting, permitting and early consultation with Indigenous Peoples on issues that are of concern to them, such as cumulative effects.

The scope of work was defined to consider direct (e.g., physical) environmental footprints of resources only, using the best available provincial-scale geospatial data, with input and guidance from BCH on the list of environmental attributes included in the analysis. The scope of work specifically excluded assessing project-level environmental impacts, supply chains, manufacturing or transportation of materials, pollution prevention, GHG emissions, or socio-economic values relating to employment. Also excluded from the scope of work was a comprehensive assessment of cumulative effects. As such, cumulative effects have not been explicitly assessed as part of the methodology developed here, but the analysis includes data relevant to discussions around this topic, particularly in terms of the potential environmental footprints of new resources compared to aggregate existing disturbances from forestry, mining, agriculture, urbanization, and other forms of industrial development (see "Undisturbed Layer" in Appendix 7.1).

The methodology described here is consistent with three of the four objectives stated in BC Hydro's Environment Strategy (2019): 1) achieve environmental compliance; 2) minimize habitat loss and fragmentation; and 3) create environmental benefits. The fourth objective - support climate action and targets - is being addressed directly by BC Hydro, and is excluded from this analysis, as described above.

The methodological approach draws on existing tools from the fields of conservation planning and strategic environmental assessment to account for environmental priorities while planning for utility-scale renewable energy development distributed. Spatial conservation planning is a form of assessment that relies on mathematical algorithms to identify priorities for conservation or environmental planning problems, and to support informed decision-making (Margules and Pressey 2000, Margules and Sarkar 2007). When applied to problems that consider alternative land uses or future development projects (Moilanen et al. 2011), this approach allows for a distinction between areas better suited for biodiversity conservation or environmental protection and areas better suited for development, with the latter being illustrated by locations with high value for potential energy development that have small environmental footprints occurring in areas of lower conservation value. Setting conservation priorities is a value-laden

[1] Environmental footprint is used as a proxy for environmental impact.
[2] It is assumed that upgrades to existing BCH facilities do not substantively alter the environmental footprint of those facilities.

process based on societal desires and available policy instruments (e.g., species at risk and protected areas policies), making the process of evaluating trade-offs between environmental protection and development an exercise of alternative scenario planning (Bryan et al. 2011). Thus, the framework we outline here is rooted in spatial conservation planning principles and can accommodate social, cultural, and economic values as needed, along with environmental ones, and provide a roundtable for enabling informed decision-making regarding energy development prior to development decisions.

Systematic conservation planning principles have been applied to many biodiversity conservation issues, ranging from species to ecosystems and scales from localized jurisdictions to continents. Examples of energy development assessment and prioritization in the context of biodiversity conservation exist from other jurisdictions, such as California (Kreitler et al. 2015), USA's Northern Great Plains (Fargione et al. 2012) or the Appalachian Mountains (Evans et al. 2014), as well as British Columbia (Popescu et al. 2020). Our framework builds on these principles and takes a flexible portfolio-based approach to simultaneously evaluate potential terrestrial, freshwater, and marine biodiversity impacts from a range of renewable energy resources.

Below, we focus on methods to calculate the individual and aggregate (i.e., portfolio) environmental footprint of potential development resources that were determined and provided by BCH, using a suite of spatial attributes agreed to through consultation with BCH. We offer our scientific opinion regarding the assumptions and limitations inherent in using specific layers as proxies for specific environmental considerations below (Appendix 7.1) and acknowledge the limitations of this approach in terms of forecasting potential environmental footprints in advance of more specific site-level information (Section 5.2).

3 METHODS

Overview. We used a systematic conservation planning framework (see Section 3.2) to identify conservation priorities in BC. We evaluated terrestrial, freshwater and marine conservation priorities separately based on sets of environmental attributes specific to each environment (see Appendix 7.1). We then quantified the overlap between energy project infrastructure (At-The-Gate footprint[3], transmission lines and roads) and terrestrial, freshwater, and marine conservation priorities, and calculated environmental footprint scores for each individual project. These scores provide an indication of potential environmental impacts for each individual project, with the caveat that the actual impact of projects can only be evaluated using field-based observations and monitoring before, during, and after project construction. We then ranked the projects to identify the lowest (and highest) environmental footprint and compared two hypothetical portfolios to illustrate the utility of this approach for energy planning and portfolio optimization in BC.

3.1 DATA LAYERS

Potential Development Projects – Geospatial information on the location of potential energy projects, their linear infrastructure (transmission lines, roads), and approximate spatial extent was provided by BCH. Potential development projects include energy production facilities (e.g., wind power, pumped storage, hydropower, etc.) as well as new supporting infrastructure (i.e., transmission lines). BC Hydro provided a list of 137 potential development projects for this analysis. The project list includes nine major transmission lines, fourteen biomass, eight geothermal, seventy-three onshore wind, eight pumped

[3] At-The-Gate footprint refers to the areal footprint (ha) of potential physical infrastructure excluding roads and powerlines connecting the project to the existing electrical grid and road network.

storage, three run-of-river hydropower, five solar, sixteen small storage hydropower, and one battery storage project (Appendix Table 4). The projects analysed here are a subset of all projects in the Resource Options Report database and were selected by BCH and organized into hypothetical portfolios as described below (see Section 3.3).

Environmental attributes were selected based on the following criteria:

I) Available data are science-based, quantitative, and publicly available.

II) Data are relevant and applicable to species and ecosystem conservation or protection.

III) Data are available at required scales and have sufficient coverage across the province.

IV) Data sources span the range of habitats, geography, and regulatory extent relevant to energy development scenarios in the IRP.

Through an iterative consultation process with BCH, a total of seventy-one terrestrial, twenty-four freshwater, and eight marine environmental attribute layers were selected for analysis. For purposes of our analysis, a data layer is the spatial file in which environmental attribute data is stored and displayed. Appendix 7.1 lists all the data layers, how they were used as inputs, as well as their assumptions and limitations.

All data were rasterized at 400 m x 400 m resolution (a minimum mapping unit, MMU, of 16 ha) and set to the provincial spatial extent for this analysis. Unless otherwise stated in the description (Appendix 7.1), layers were converted to binary presence (1) or absence (0) categories. A few layers retained continuous attributes (e.g., counts of ecological features). Note that many datasets used in the models described below include features that are more detailed than the smallest pixel size and therefore some spatial details were lost during rasterization. The rasterization algorithm assigns presence values (1) to a cell if a feature overlaps the cell by at least 50%.

In addition to the terrestrial, freshwater and marine environmental attributes, we also considered protected areas. Based on a review of Regulatory protection and Environmental Assessment guidance, BCH identified nine designations (five federal [F] and four provincial [P]) included in the protected areas layer:

- National Park [F]
- National Wildlife Area [F]
- Migratory Bird Sanctuary [F]
- Marine Protected Area [F]
- National Marine Conservation Area [F]
- Provincial Park [P]
- Ecological Reserve [P]
- Conservancy [P]
- Recreation Area [P]

3.2 SPATIAL CONSERVATION PRIORITIZATION USING ZONATION

We used the Zonation (v4) spatial conservation planning framework (Moilanen et al. 2009, Lehtomäki and Moilanen 2013) to identify conservation priorities in British Columbia for terrestrial, freshwater, and marine environmental layers. Zonation produces a complementarity-based and balanced ranking of biodiversity priorities across the entire landscape (Moilanen et al. 2005). Zonation has been applied to

many conservation planning problems, including reserve design for terrestrial, freshwater, and marine systems (e.g., (Kremen et al. 2008, Leathwick et al. 2008, Moilanen et al. 2008), assessing the resiliency of protected areas to climate change (e.g., Carroll et al. 2010), and examining the trade-offs between biodiversity conservation and distributed energy development (Popescu et al. 2020). Zonation can accommodate multiple types of data in the calculation of priorities, ranging from presence-only data to presence-absence, categorical, and continuous variables, and hence it is suitable for the range of data types considered in this study.

The iterative Zonation meta-algorithm[4] follows the approach by Moilanen et al. (2009). Zonation calculates a rank order value of each cell in the landscape (e.g., study extent) based on conservation priority (distributed between 0 = low conservation priority, and 1 = high conservation priority). The algorithm first identifies the areas of lowest conservation value (e.g., fewest environmental layers overlapping, common co-occurrences of layers, where layers with the smallest distributional extent are given higher importance) and assigns values to each cell starting with the value 0. The algorithm continues to assess cells in the landscape until it reaches the highest value cell for conservation (with the highest value being 1). The resulting output is a raster map with a unique Zonation value (ranging between 0-1) for each individual pixel in the study extent.

We used the additive-benefit function of Zonation with an exponent (z = 0.25), in which conservation value is additive across biodiversity features, and individual feature representation is converted via a concave power function, similar to the species-area relationship (Arponen et al. 2005). This results in areas with the highest species/environmental attribute richness (while accounting for co-occurrence or complementarity in spatial extent of environmental attributes) being considered as top conservation priorities. We implemented separate prioritizations for terrestrial, freshwater, and marine environmental attributes. All environmental attribute layers were weighted equally within their respective habitat-types (terrestrial, freshwater, and marine), with the exception of protected areas. The protected areas layer is considered to have the highest conservation value for biodiversity in BC. Hence, protected areas were considered separately in the prioritization, and assigned the highest conservation rank regardless of the underlying environmental attributes (termed a 'hierarchical removal mask' in systematic conservation planning).

Zonation values follow a uniform distribution; for example, cells with values between 0.60 and 0.70 cover 10% of the study area, cells with values between 0.60 and 0.61 cover 1% of the study area. Because BC's protected areas were considered the highest conservation priority (see section 3.1), and they accounted for 16% of the study area, protected areas received values between 1 and 0.84; thus, the highest conservation-value areas based on the terrestrial or freshwater environmental attributes were given a maximum value of 0.84.

While no At-The-Gate footprints of projects were located within protected areas, linear infrastructure associated with some projects could intersect protected areas. In such cases, projects will be penalized because they would cross the highest conservation-ranked areas of BC. It is likely that in real-world situations, overlap between linear infrastructure and protected areas could be avoided by re-routing transmission lines and roads, or issuing permits for right-of-ways.

[4] For technical details of the Zonation algorithm, visit https://www.syke.fi/en-US/Research__Development/Nature/Specialist_work/Zonation_in_Finland/Zonation_software.

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3.3 CALCULATION OF ZONATION-BASED SCORES FOR POTENTIAL DEVELOPMENT PROJECTS

Outputs from the Zonation-based models are maps where cells have a value ranging between 0 and 1, and values across all grid cells follow a uniform distribution (i.e., no cells have identical values). Scores for each project were calculated separately for each habitat-type (terrestrial, freshwater, and marine). Higher Zonation scores for individual projects, as well as major transmission lines not associated with particular energy projects, can indicate that the spatial extent of the project overlaps with more or more highly weighted environmental attributes, that the spatial extent of the project (ATG and/or linear features) is larger, and/or combinations of the above. Higher Zonation scores are therefore expected to scale with the potential for environmental impact (Popescu et al. 2020). We have taken the following steps to calculate Zonation scores for each potential development project provided by BCH as part of the IRP (Appendix 7.2):

1) Extract Zonation values for At-The-Gate and linear infrastructure footprint - The first step to calculating the scores for the three groups of layers (terrestrial, freshwater, marine) was to extract the Zonation values (range = 0-1, where 1 denotes high conservation value) for each grid cell where the infrastructure of each potential project is estimated to occur. This includes the project At-The-Gate (ATG) location (vector data provided by BCH or calculated as a buffer of equal size with the estimated at-gate footprint, see below), as well as all supporting roads and transmission lines, called linear infrastructure, as well as the major transmission lines that are not associated with individual projects. For the linear infrastructure, we directly extracted Zonation values for all grid cells intersected by roads and transmission lines. As the Zonation pixel size (400 x 400 m) is larger than any potential road or transmission line buffer (including for major transmission lines not associated with particular energy projects), the type of road or transmission line did not affect how the Zonation values were extracted. We extracted Zonation values for all grid cells intersected by the ATG footprint of each project, employing several approaches to accommodate differences in methodology used by BCH to identify potential project locations. These methods varied by energy type and are detailed below:

a. Wind

   i. Wind projects on plateaus – BCH provided large polygons indicating the general spatial footprint of wind projects located on plateaus (Global Energy Concepts, 2009). However, these polygons were often much larger than the ATG footprints. To address this issue, Zonation scores were extracted from randomly generated points within the polygon, corresponding to the number of turbines estimated for each project, and assuming a 34 m buffer around each turbine, based on turbine size. Points were randomly generated 100 times for each project, and the mean value of the weighted sum Zonation score was used as the final ATG environmental footprint for wind plateau projects.

   ii. Wind projects on ridgelines – Similarly for ridgeline wind projects, points were generated along the provided project ridgelines (polylines generated around ridgelines to represent potential turbine areas) with equal spacing. As with plateau wind projects, the number of points generated corresponds to the number of turbines within the project, buffered by turbine size.

b. Solar, Run-of-River, and Geothermal projects – ATG footprints were provided by BCH without explicit spatial extents. We estimated the spatial extent of the ATG footprint for these projects by

applying a circular buffer equal to the ATG footprint centered around each project point location (Kerr Wood Leidal, 2015). We extracted Zonation scores for all cells within these circular buffers.

c. Pump Storage projects – ATG footprints were provided by the Resource Options Report Update Lower Mainland / Vancouver Island Pumped Storage and Resource Options Report Update North Coast Pumped Storage reports (Knight Piesold, 2013). These reports provide the ATG footprints for several individual categories (e.g., lower dam, staging, spoil footprints, etc.). For the purposes of estimating the spatial extent of the ATG footprint of each project, we partitioned the ATG footprint into 'upper reservoir' and 'non-upper reservoir' footprints. 'Upper reservoir' footprints were delineated as a polygon representing an area around the upper reservoir, while the 'non-upper reservoir' footprint polygon (equal to the total ATG area minus the upper reservoir area) was created by generating a rectangular polygon spanning the distance between the upper reservoir and the approximate entrance to the lower reservoir.

d. Small Storage Hydro projects –ATG footprint sizes were based on the reservoir surface area reported in the Small Storage Hydroelectric Resource Options Study Report (Knight Piesold, 2018). The estimated spatial locations of small storage hydro reservoirs were derived from a 15 m Digital Elevation Model (DEM), and located upriver from each project point location. Determination of these spatial locations was done in consultation with BC Hydro.

2) Zonation-derived metrics for each project

We calculated four different metrics for each potential development project included in this analysis. We explain each below.

a) **Sum of Zonation values**– We extracted the sum of all the Zonation pixel values that overlapped with the linear infrastructure and ATG of each project.

b) **Weighted Sum of Zonation Values** – We calculated the sum of Zonation values for each cell included in the project footprint (linear infrastructure, ATG). We multiplied the Zonation values for each cell in the province by a weight that varied between 1 and 10 (Table 1), thus emphasizing areas of high conservation value. As such, the higher the weighted sum, the higher the environmental footprint. We calculated these scores separately for terrestrial, freshwater, and marine habitat-types.

The logic behind this weighting approach is that by simply summing the Zonation values, different projects can achieve a similar summed Zonation score in multiple ways. For example, a 10 km powerline through very low conservation value areas (i.e., low Zonation values for terrestrial or freshwater prioritizations) may have the same summed Zonation score as a project with a 1 km powerline passing through protected areas or caribou habitat. By multiplying the values of individual cells with weights proportional to their conservation value (Table 1), shorter but potentially more impactful infrastructure is penalized and may yield a higher weighted score (thus higher estimated environmental footprint) compared to longer but lower-impact infrastructure (i.e., brownfield development). In a nutshell, a summed weighted Zonation score better incorporates both the magnitude of the footprint and the overlap with high conservation value areas.

Table 1. Weighting classifications applied to the raw Zonation value of each cell in the province.

Zonation Score	Weight
0-0.1	1
0.11-0.2	2
0.21-0.3	3
0.31-0.4	4
0.41-0.5	5
0.51-0.6	6
0.61-0.7	7
0.71-0.8	8
0.81-0.9	9
0.91-1	10

c) **Scaled Zonation Score** – Because the summed weighted scores are dimensionless and cannot be directly compared between terrestrial, freshwater, and marine prioritizations, we scaled the weighted sum of Zonation scores across all energy projects to range from 0-1, with 1 being the project with the largest potential environmental footprint and 0 being the project with the smallest potential environmental footprint. Zonation scores were scaled separately for terrestrial, freshwater, and marine habitats, so that projects can be evaluated based on the relative contribution of terrestrial, freshwater, and marine potential impacts. Importantly, this calculation excluded the major transmission lines not associated with individual energy projects. The reasoning for doing so was that major transmission lines would have a disproportionate effect on the scaled value due to their large footprint, making the comparison of footprint by energy types and portfolio difficult. As such, the calculation of scaled Zonation scores for major transmission lines used the maximum and minimum of all energy production facilities which does not include transmission lines themselves. As a result, the scaled Zonation scores for some major transmission lines are greater than one.

$$Scaled\ Zonation\ score = \frac{x - \min(x)}{\max(x) - \min(x)}$$

where x is the weighted summed Zonation score for each project, and max(x) and min(x) are the maximum and minimum weighted summed Zonation scores among all projects.

d) **Combined Terrestrial and Freshwater summed weighted Zonation score** – Because most of the potential energy projects and major transmission lines considered in this analysis have infrastructure that is predicted to overlap with both terrestrial and freshwater habitat-types, we also summed these scores to create a single metric that showcases the environmental footprint when considering both terrestrial and freshwater habitat-types simultaneously. Note, the

maximum possible value of these combined scores is two (i.e., if a project has the highest score among all projects for both terrestrial and freshwater prioritizations, as described above). However, as the major transmission lines were scaled using the maximum and minimum of energy production facilities (see above) some have a combined score of greater than two.

We were unable to include the marine habitat-type in these combined scores because only six potential development projects and one transmission line had a value greater than zero in marine environments. In the future, including marine scores in a combined metric would be useful, especially if most (or all) projects are expected to have at least some overlap with marine habitats.

3.4 AGGREGATE ZONATION SCORES BY PORTFOLIO

The Zonation scores we provide in this report can be useful at several different scales. While Zonation scores can be used to compare individual projects directly (e.g. comparing different energy types or different geographies), the scores can also be summed for groups of projects to estimate a cumulative or aggregate environmental footprint. These aggregate scores allow for a straightforward comparison of the environmental performance among a suite of portfolios, whereby the lower the aggregate score, the lower the potential for impact to the environmental attributes we evaluated. Because only five potential development projects and one transmission line were determined to have overlap with attributes in the Marine habitat-type, we focus on the terrestrial and freshwater Zonation scores for the remainder of this report. Marine scores are included in the final data shared with BCH.

To illustrate the use of aggregate zonation scores to compare the potential environmental footprint of different portfolios of energy projects, we used two hypothetical future energy portfolios provided by BCH: a mid-range reference portfolio that consists of fourteen potential development projects (Portfolio R), and a portfolio to support electrification of the natural gas industry in BC (Portfolio X), consisting of sixty-six potential development projects, including all twelve potential energy projects used in Portfolio R (Appendix 7.2 Table 4). For each portfolio, we investigated the distribution of terrestrial and freshwater Zonation-based scores for each potential energy project and major transmission lines and identified infrastructure that have a disproportionate influence on the overall aggregate portfolio score. For instance, a small number of projects within a portfolio that have high overlap with high-value conservation cells may disproportionately contribute to a high aggregate Zonation score for a portfolio. Identifying such outliers provides an opportunity to restructure portfolios by removing such projects to lower the aggregate portfolio environmental footprint.

4 RESULTS

4.1 ZONATION RESULTS BY HABITAT

Spatial conservation priority maps were produced for terrestrial (Figure 1), freshwater (Figure 2), and marine (Figure 3) environmental layers using Zonation. Each Zonation raster map is composed of cells ranging between 0 and 1 with no identical values. The values follow a uniform distribution; for example, areas with scores between 0.9 and 1 make up 10% of the province by area, 0.8 to 0.9 another 10% and so forth. Because we set protected areas as the highest conservation value areas of BC (see Section 3.1), and they cover ~16% of BC by area, cells overlapping with protected areas have the highest Zonation scores in all three habitat-types (~85th percentile).

4.1.1 TERRESTRIAL

The Zonation prioritization using terrestrial species and habitat attributes (n = 71) revealed high conservation value for the southern half of the province as well as the Rocky Mountains (Figure 1). Southern British Columbia has the highest biodiversity and includes much of the critical habitat for BC blue and red-listed species. While the terrestrial habitat attributes interact in multiple ways within the Zonation prioritization (based on overlap and complementarity between the seventy-one layers, the spatial extent of the layers, etc.), the Rockies emerge as having high conservation value due to the presence of a diverse large mammal assemblage (grizzly bear, mountain goat, big horn sheep, caribou, fisher) and low disturbance. Northeastern BC emerges as important due to the overlap with caribou distribution and critical habitat. It is important to note that due to the different spatial extents of the layers used in this analysis (e.g., large mammal distribution layer and disturbance layers are province-wide, while critical habitat and old-growth forests have a small spatial extent and are very localized), the resulting prioritization map is very fragmented. As such, the infrastructure of any given project may overlap with a wide range of zonation scores, which may not be evident at the scale of the entire Province or at the resolution of Figure 1.

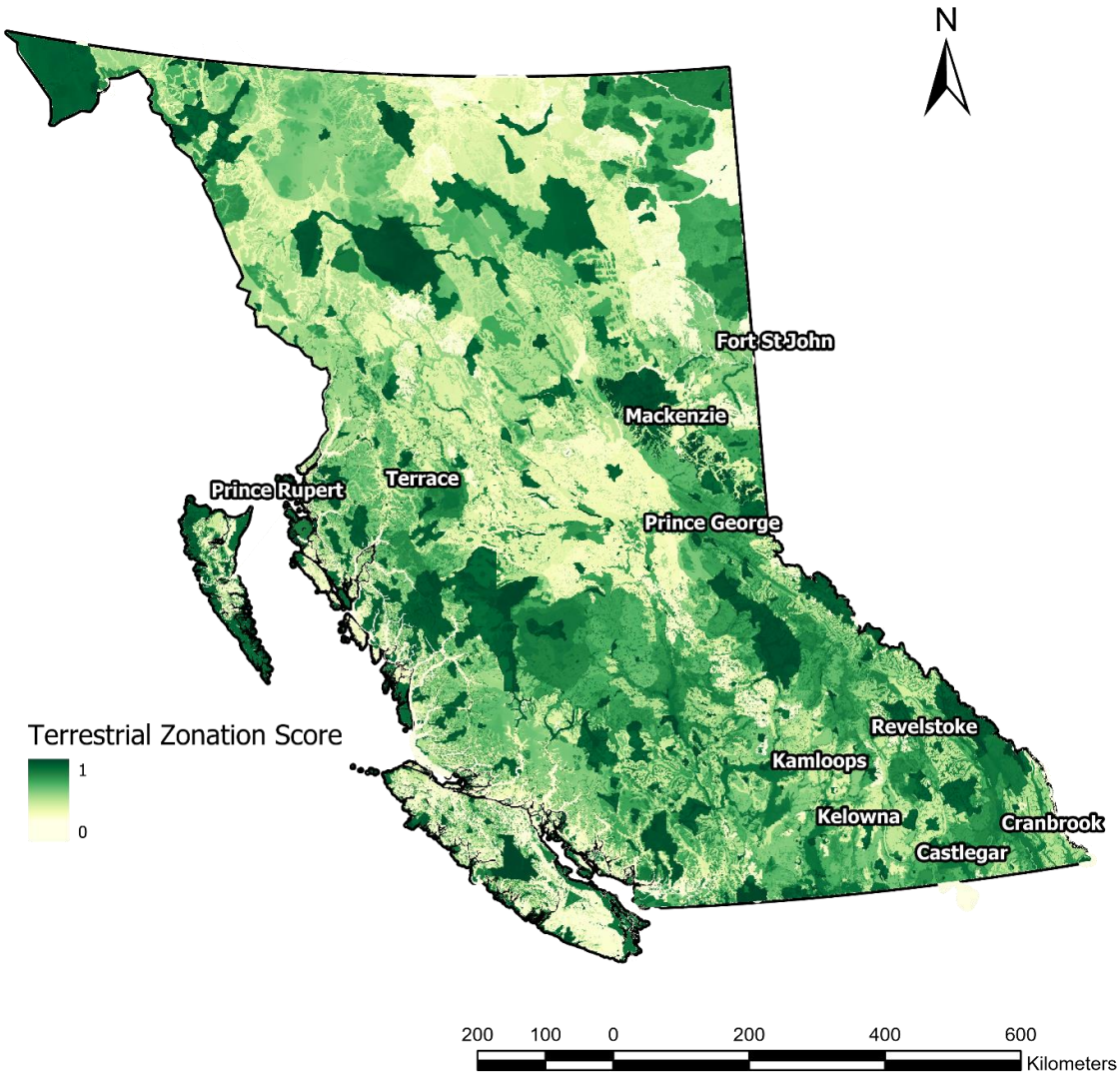

Figure 1. Spatial distribution of conservation priorities (Zonation values, between 0 and 1) for terrestrial attributes (n=71 layers), where areas with higher conservation value are indicated by darker colours. Note that the highest conservation values are given to protected areas.

4.1.2 FRESHWATER

The Zonation prioritization for freshwater attributes (n = 24) revealed a more continuous pattern compared to the terrestrial results (Figure 2). As expected, the largest concentration of high conservation values occurs in Coastal BC, especially along river networks that include anadromous salmon species, and the larger Salmon Conservation Areas. However, salmonid habitat extends into Central BC and, to a lesser extent, the Rockies. Hence, some watersheds in these regions also have relatively high conservation importance. In comparison, Northeastern BC has lower freshwater conservation values, largely due to the lack of anadromous salmonid occurrence.

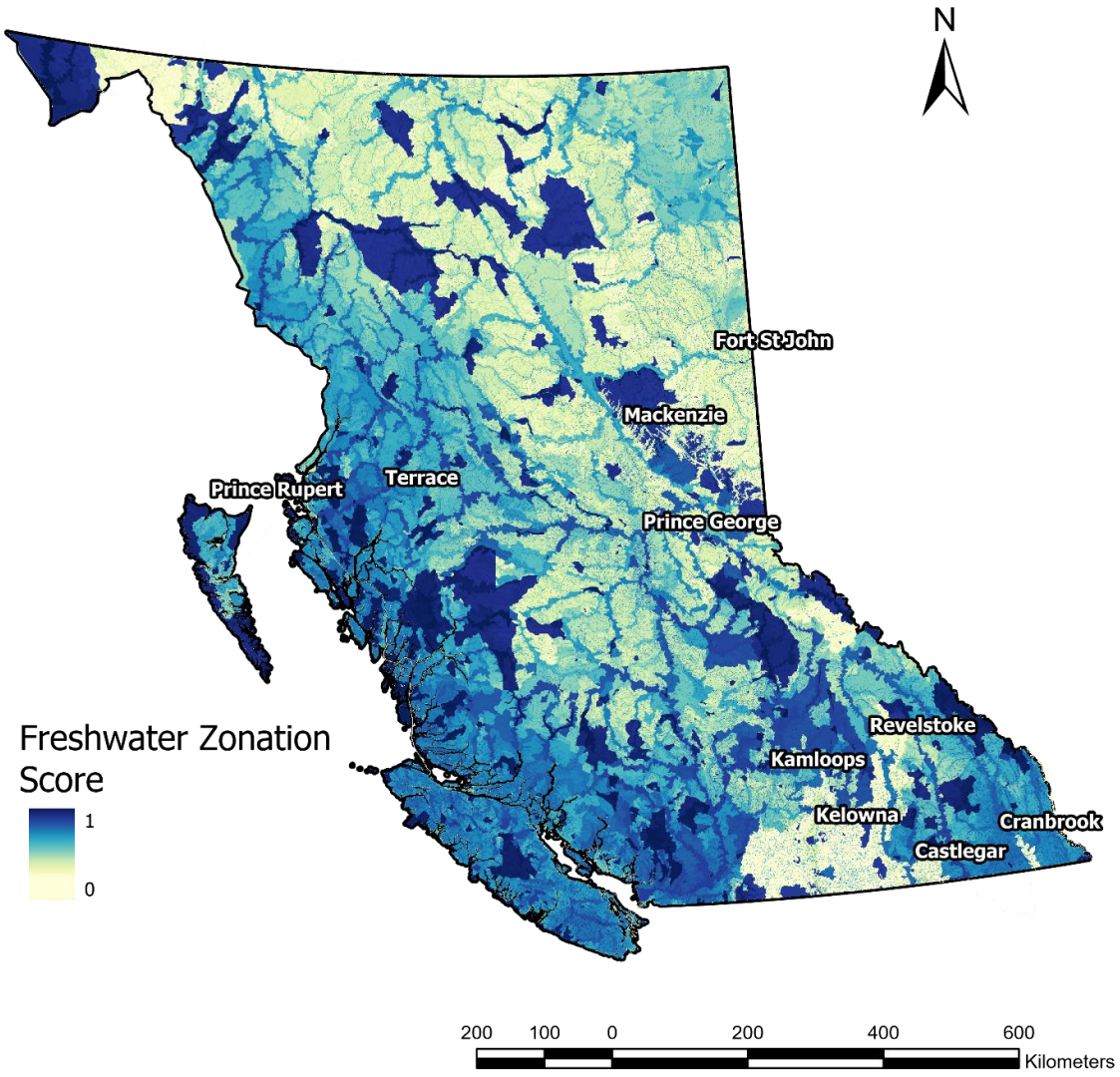

Figure 2. Spatial distribution of conservation priorities (Zonation values, between 0 and 1) for freshwater attributes (n=24 layers), where areas with higher conservation value are indicated by darker colours. Note that the highest conservation values are given to protected areas.

4.1.3 MARINE

The Zonation prioritization of marine attributes (n = 6) indicates that the highest marine conservation values occur along the coastlines of Haida Gwaii, Vancouver Island, and the mainland, where species diversity is generally higher than areas further offshore (Figure 3).

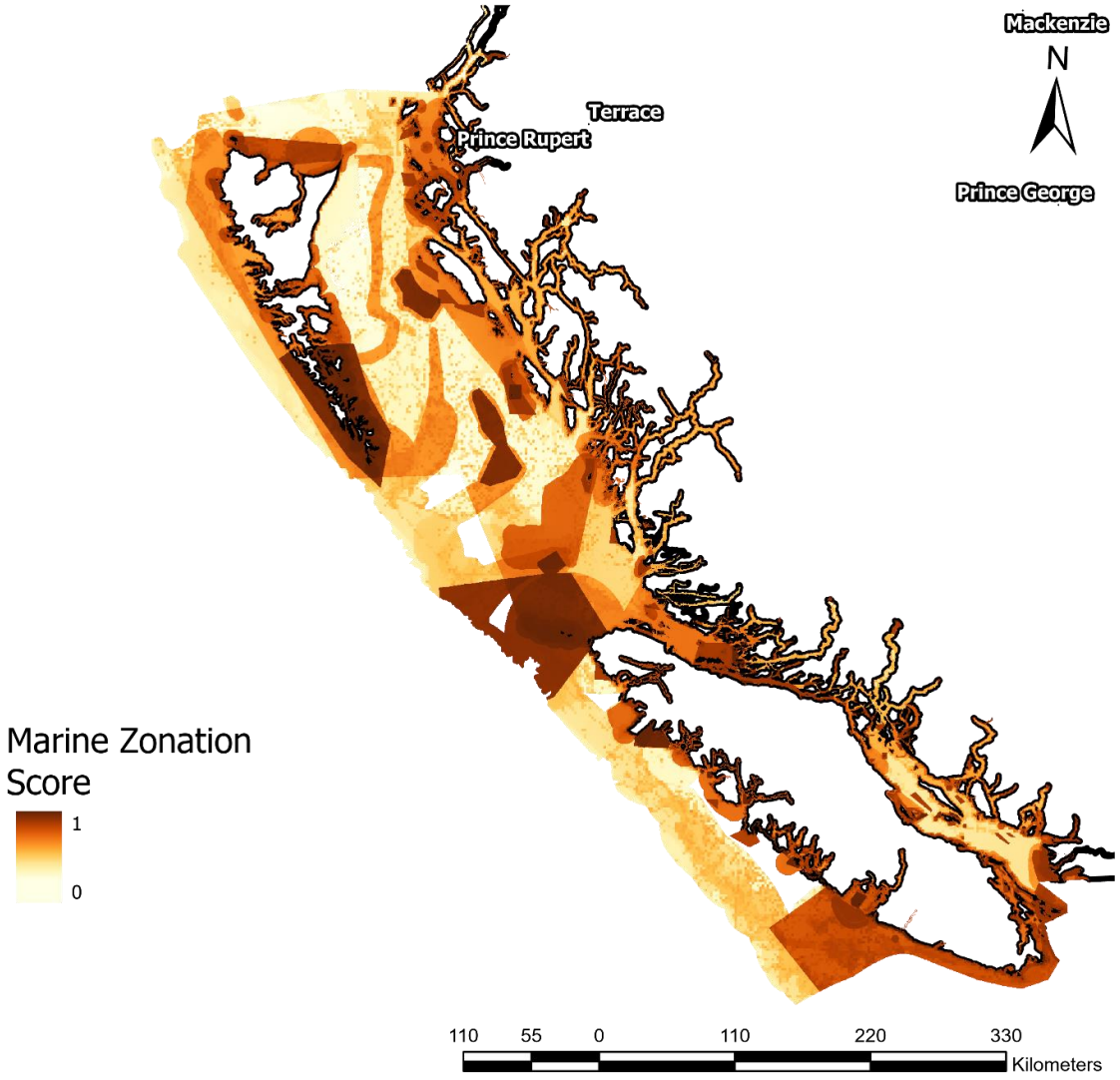

Figure 3. Spatial distribution of conservation priorities (Zonation values, between 0 and 1) for marine attributes (n=6 layers), where areas with higher conservation value are indicated by darker colours.

4.2 SCALED ZONATION SCORES BY PROJECT AND PORTFOLIO

Although weighted Zonation scores were developed for the terrestrial, freshwater, and marine environments, in this report we focus on presenting the results from terrestrial and freshwater environments, as only five of the one hundred twenty-eight potential development projects included in this analysis (NC01, NC02, VI05, V09, and T_2L129) overlapped with the marine environment. Figure 4 shows the combined terrestrial and freshwater scaled Zonation scores for all the potential development projects (energy projects and major transmission lines) included in the analysis (n = 137, Appendix

Table 4). Potential development projects with the lowest overlap with freshwater or terrestrial conservation priorities include projects that make use of existing infrastructure (such as battery storage and some biomass projects) as well as some onshore wind, small storage hydro, run-of-river and geothermal projects.

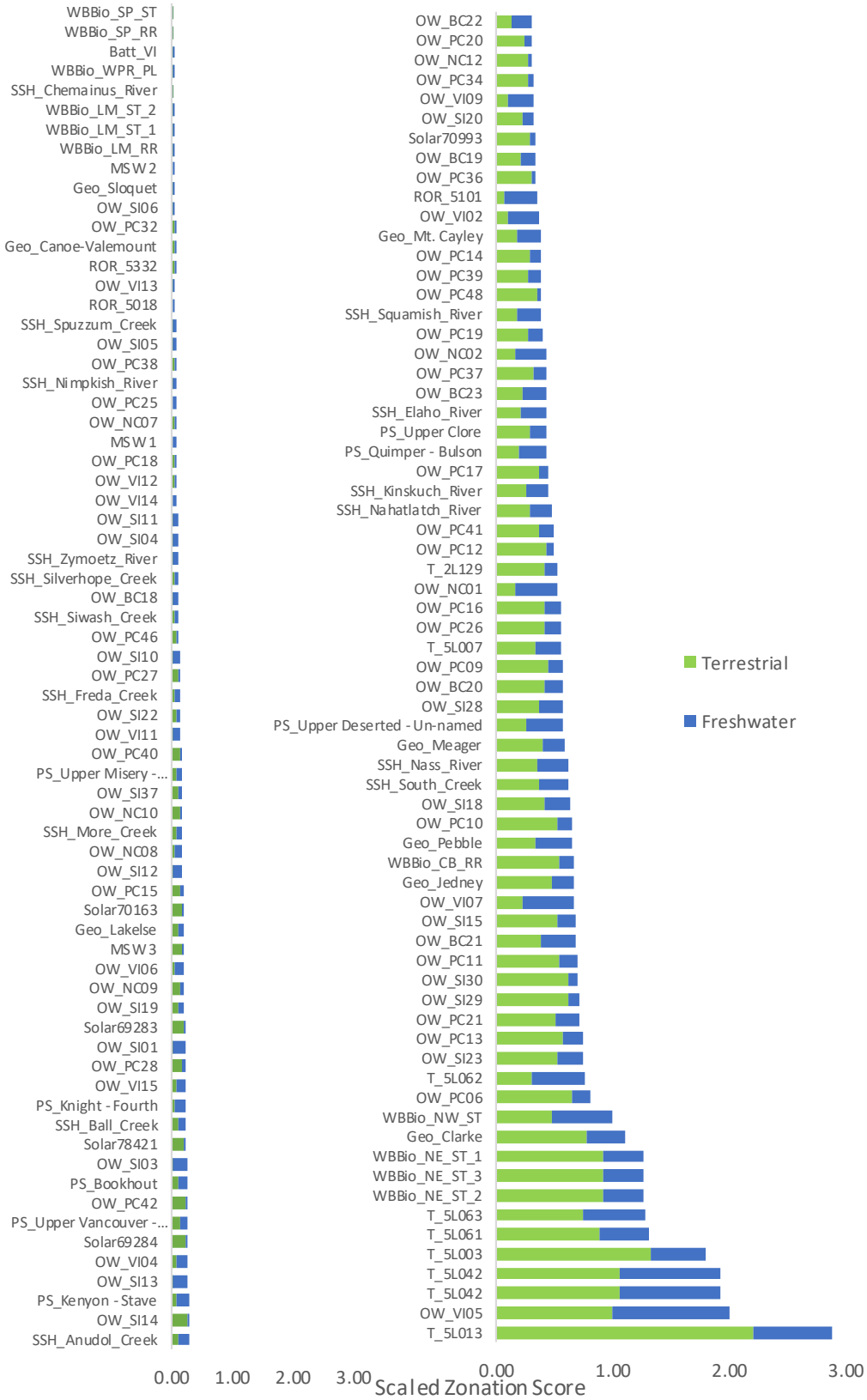

Figure 4. Scaled Zonation scores (T+FW) for terrestrial (green) and freshwater (blue) habitat types shown for all potential development projects, listed in ranked order.

Regardless of energy type, projects with low combined terrestrial and freshwater Zonation scores were generally characterized by having limited linear infrastructure (e.g., new roads and powerlines), even though the size of the At-The-Gate (ATG) footprints of these projects were more variable. The highest scores were calculated for projects with substantial new linear infrastructure and high overlap with areas of high conservation value. The major transmission lines had some of the highest scaled Zonation scores due to their length and overlap with terrestrial and freshwater high conservation value areas.

Development projects with the highest combined Zonation scores for terrestrial and freshwater attributes were primarily major transmission lines (Figure 4

), although one onshore wind project (VI05) received the maximum score of 2 (it included a 303-km powerline, crossing areas of high terrestrial and freshwater conservation value, see Appendix **Error! Reference source not found.**). The project with the highest footprint score is the major transmission line 5L013 which epitomizes the generally high environmental footprint of large transmission lines spanning hundreds to thousands of kilometers. High-score onshore wind projects (combined Zonation score > 0.5, equal to project scores in the 75th percentile or above) often occur on mountaintops in the Peace River watershed as well as on plateaus in the Kelly-Nicola region and on Vancouver Island. Three biomass projects in the Peace River region (score = 1.27 for WBBio_NE_ST_1, WBBio_NE_ST_2, WBBio_NE_ST_3) and one in the North Coast regions (score = 1 for WBBio_NW_ST) also received very high scores, along with a geothermal project in the Peace River (score = 1.11 for Clarke Lake); the high scores for these energy projects are typically due to long linear infrastructure and/or the combination of long linear infrastructure and ATG overlap with high conservation value areas (e.g., conservation lands, caribou habitat, critical habitat for listed species).

For many projects with combined scores > 0.5, the overlap of linear infrastructure with terrestrial attributes contributed more to the overall score than overlap with freshwater attributes (Figure 4). While infrastructure for projects with high combined terrestrial and freshwater Zonation scores can overlap with a wide range of Zonation scores, the weighting scheme we applied (see Section 3.3) ensures that substantial overlap with sensitive species and habitats (e.g., caribou and other large mammal habitat, critical habitat for listed species, or conservation lands [including the West Moberly agreement region]) results in an elevated overall project score. For major transmission lines, this was compounded by their considerable length (100's of km).

The two portfolios considered here illustrate different patterns regarding combined Zonation scores for the projects included in each portfolio. Portfolio R includes only a small number of projects (n = 12), dominated by onshore wind, and where most of the wind projects (7 out of 8) received high summed terrestrial and freshwater Zonation scores (>0.5) for both terrestrial and freshwater attributes (highest, PC10 = 0.66) (Figure 5). The major transmission line (T_5L042) part of portfolio R had the greatest overall Zonation score. For Portfolio X, which included a larger number of projects among a diversity of energy types (n = 64), the projects with the lowest scores included several from Portfolio R (Chemainus, Nimpkish, Batt_VI), and several other low footprint onshore wind (SI05, NC07, VI12, SI11, PC25), hydropower (Spuzum, Zymoetz, Silverhope), and geothermal projects (Canoe Creek-Valemount) (Figure 6**Error! Reference source not found.**). The ten highest scoring projects in Portfolio X include six onshore wind projects, two geothermal projects (Meager Creek and Pebble Creek), one small storage hydropower project (South Creek), and one transmission line (TO-23/T_5L042).

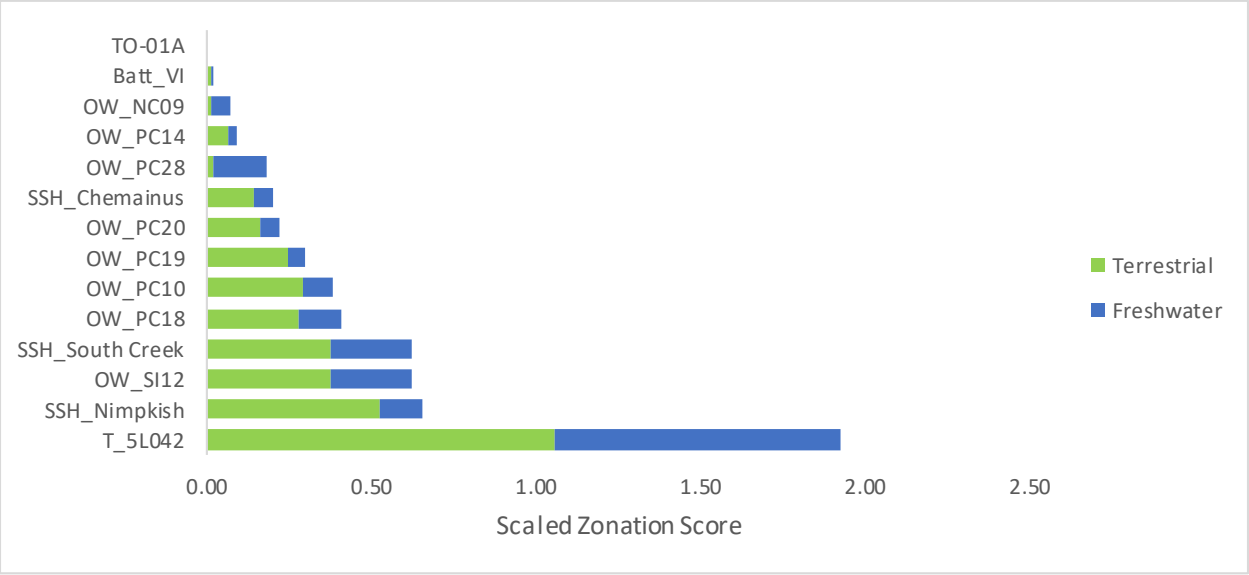

Figure 5: Scaled Zonation scores (T+FW) for terrestrial (green) and freshwater (blue) habitat types shown for development projects included in Portfolio R. Ranked from highest overall footprint to lowest.

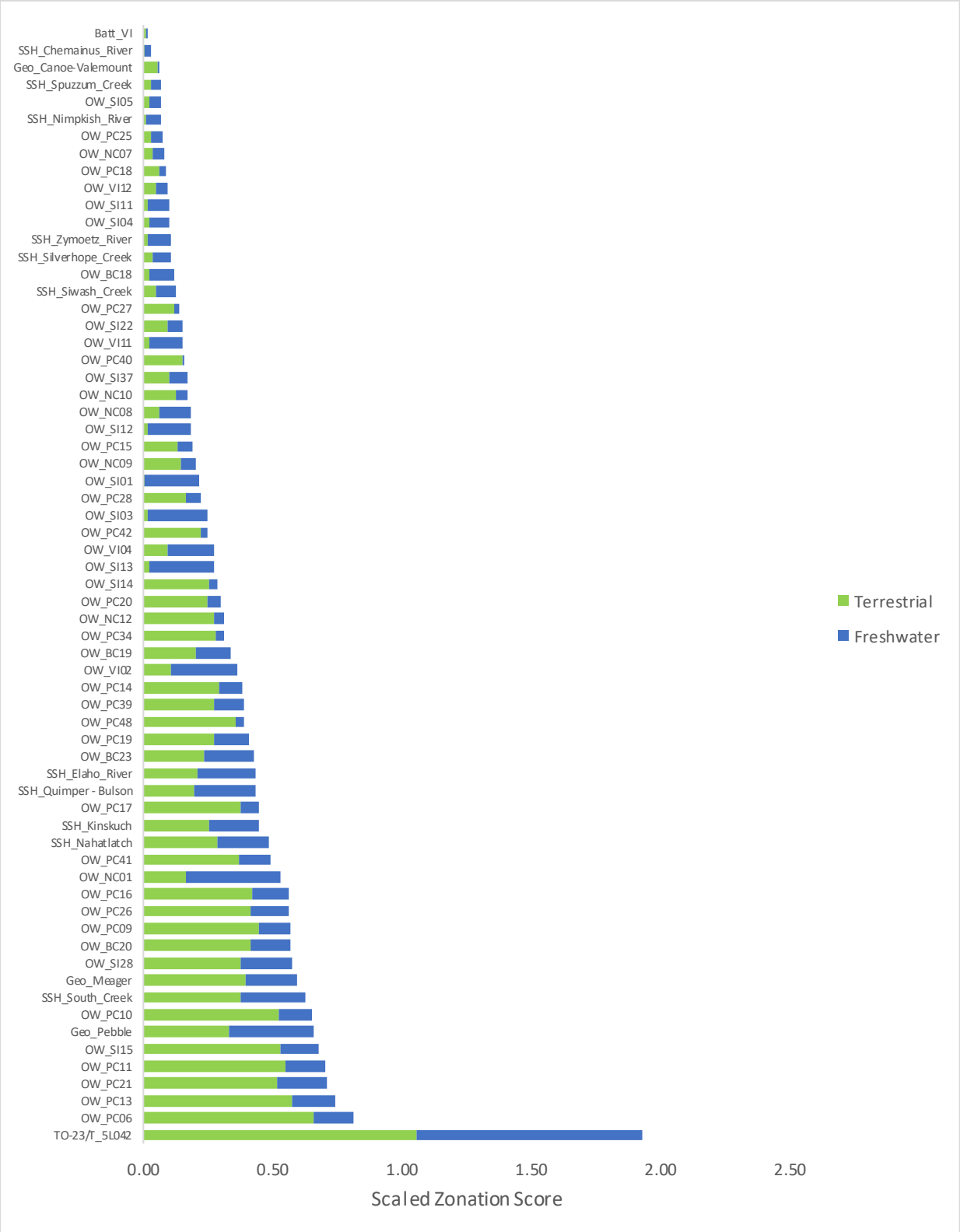

Figure 6: Scaled Zonation scores (T+FW) for terrestrial (green) and freshwater (blue) habitat types shown for development projects in Portfolio X. Ranked from highest overall footprint to lowest

4.3 SCALED ZONATION SCORES BY PROJECT TYPE

Overall, the major transmission lines had the largest scaled Zonation scores for terrestrial and freshwater prioritization, and made up six out of top seven development projects considered here (Figure 4). When comparing the terrestrial and freshwater scaled Zonation scores across energy types for potential energy projects considered in this analysis, we found that the infrastructure of geothermal and onshore wind is predicted to have the highest, as well as the largest range of scores (excluding major transmission lines Figure 4

). In contrast, biomass and battery storage have the lowest scores, with other types of projects (pumped storage, solar, run-of-river, and small storage hydropower) having intermediate scores. Battery storage projects have the lowest scores because they are associated with existing development and no new linear infrastructure.

However, when investigating the distribution of scores across different portfolios, a different picture emerges. For Portfolio R, which includes battery storage, onshore wind, and small storage hydro resources, small storage hydro has a low environmental footprint compared to onshore wind (Figure 7). For Portfolio X, which includes battery storage, geothermal, onshore wind and small storage hydro, the highest scores are for onshore wind, with geothermal and battery storage providing the lowest potential environmental footprint (Figure 6). However, for both portfolios, there are onshore wind projects with low scores (Figures 5 and 6). Thus, these results suggest that optimizing portfolios for low environmental footprints can be accomplished via multiple energy types.

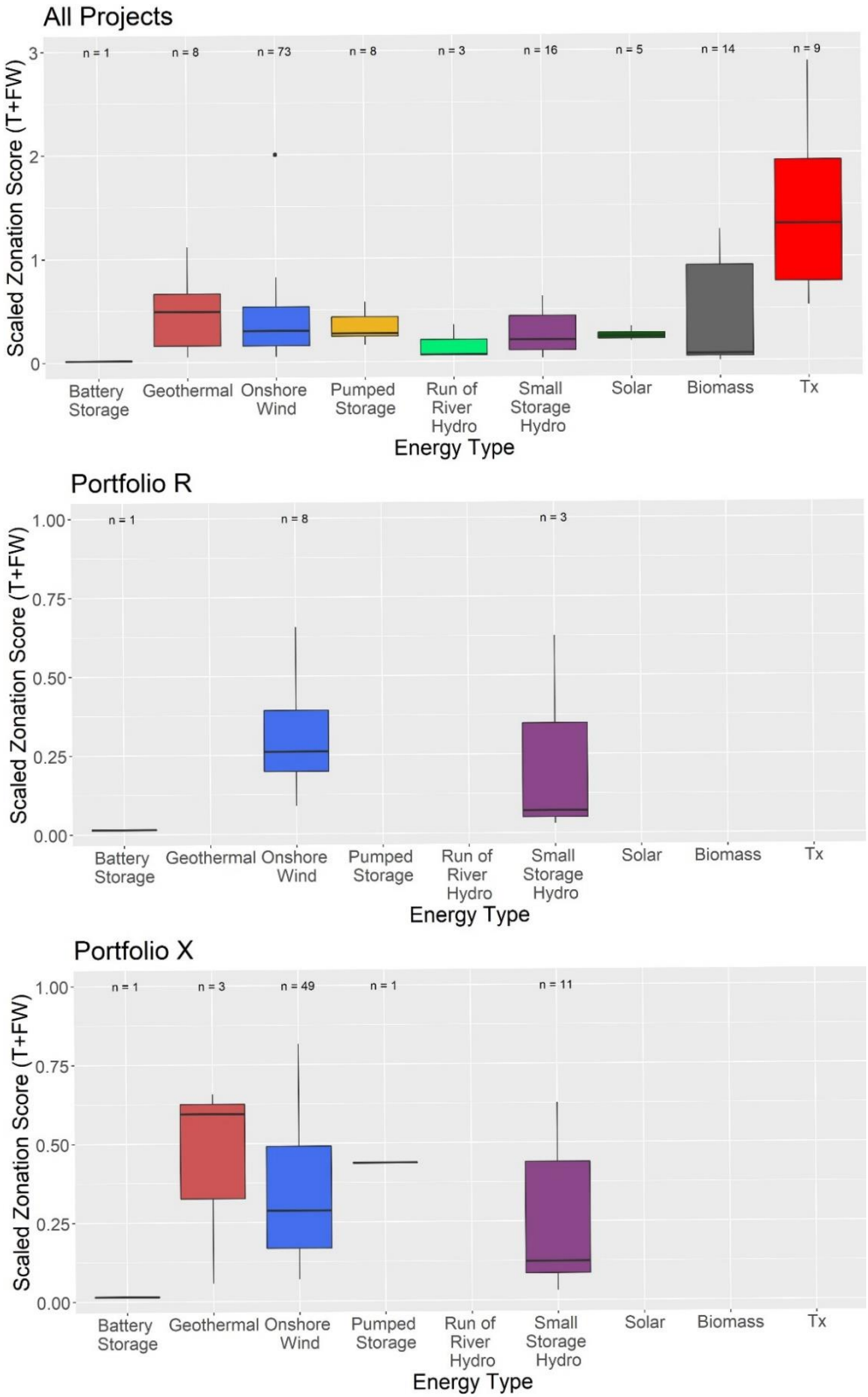

Figure 7: Boxplots of the Scaled Zonation Score (T+FW) across all energy types. Shown for all projects, Portfolio R, and Portfolio X. Major transmission lines were only included for all projects.

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4.4 AGGREGATE ZONATION SCORES BY PORTFOLIO

To compare the environmental footprint scores among alternative portfolios, we summed the combined terrestrial and freshwater scores across all projects included in Portfolio R and Portfolio X, except the major transmission lines. We did not include major transmission lines in the comparison because their scaled Zonation score was calculated after scaling the individual energy project scores (see section 3.3) and their high Zonation scores had a disproportionate contribution to aggregate portfolio scores.

Portfolio X, which included sixty-six potential projects with a total installed capacity of 8,683 MW (aggregated score = 20.83) had a 6.35 times higher aggregated terrestrial and freshwater footprint compared to Portfolio R (aggregated score = 3.28), which contained twelve potential energy development projects for a total installed capacity of 1,750 MW (Table 2 and 3). This resulted in an average score per project of 0.27 for Portfolio R and 0.32 for Portfolio X. Overall, the potential environmental footprint is greater for Portfolio X, cumulatively (overall aggregate score) and per project (score/project).

Table 2. Summary of aggregate environmental footprint for Portfolio R using scaled Zonation score (T+FW). Total MW reflects estimated installed capacity.

Energy Type	# Projects	Installed Capacity (MW)	Footprint (T+FW)
Battery storage	1	50	0.015
Geothermal	-	-	-
Onshore Wind	8	1525	2.82
Pumped Storage	-	-	-
Run of River Hydro	-	-	-
Solar	-	-	-
Small Storage Hydro	3	175	1.48
Transmission line projects	2	-	-
TOTAL	**14**	**1750**	**3.78**

Table 3. Summary of aggregate environmental footprint for Portfolio X using scaled Zonation score (T+FW). Total MW reflects estimated installed capacity.

Energy Type	# Projects	Total MW	Footprint (T+FW)
Battery storage	1	50	0.015
Geothermal	3	256	1.31
Onshore Wind	49	7302	16.44
Pumped Storage	1	500	0.44
Run of River Hydro	-	-	-
Solar	-	-	-
Small Storage Hydro	11	575	2.64
Transmission line projects	1	-	-
TOTAL	**65**	**8683**	**20.83**

4.5 EXAMPLE ZONATION SCORES AND PROJECT OVERLAP WITH ENVIRONMENTAL ATTRIBUTES[5]

In this section, we further examine four example development projects, spanning a range of Zonation-based scores in different regions of BC to illustrate the relationship between Zonation scores and project overlap with environmental attributes (Section 3**Error! Reference source not found.**, and see Appendix 7.4.1).

[5] Additional methods exploring the correlation between Zonation-based project scores and a subset of environmental attributes is provided for interested readers in Appendix 7.4.1.

Example 1: Low Terrestrial & Low Freshwater Score – PC15 (Figure 8) is an onshore wind ridgeline project with an ATG footprint of 24 ha, linear footprint of 61 km, and installed capacity of 75 MW. Despite its mid-range ATG footprint size, PC15 has relatively low scaled Zonation scores of 0.13 (T) and 0.05 (FW). When overlaid on the terrestrial and freshwater Zonation maps (Figure 8), it is apparent that the low Zonation scores emerge from little overlap with high Zonation score areas for both terrestrial and freshwater attributes. PC15 overlaps several large extent layers including large mammal, grizzly bear conservation, and undisturbed layers, and limited overlap with smaller extent layers such as caribou critical habitat and old growth extent, including a few pixels of overlap with protected areas and the West Moberly region. Similarly, in terms of freshwater attributes, PC15 has limited overlap with a few environmental layers: Arctic grayling and bull trout ranges, and some riparian areas and wetlands. In summary, PC15 is a medium sized project with a low Zonation score that is reflected in the low amount of environmental layer overlap.

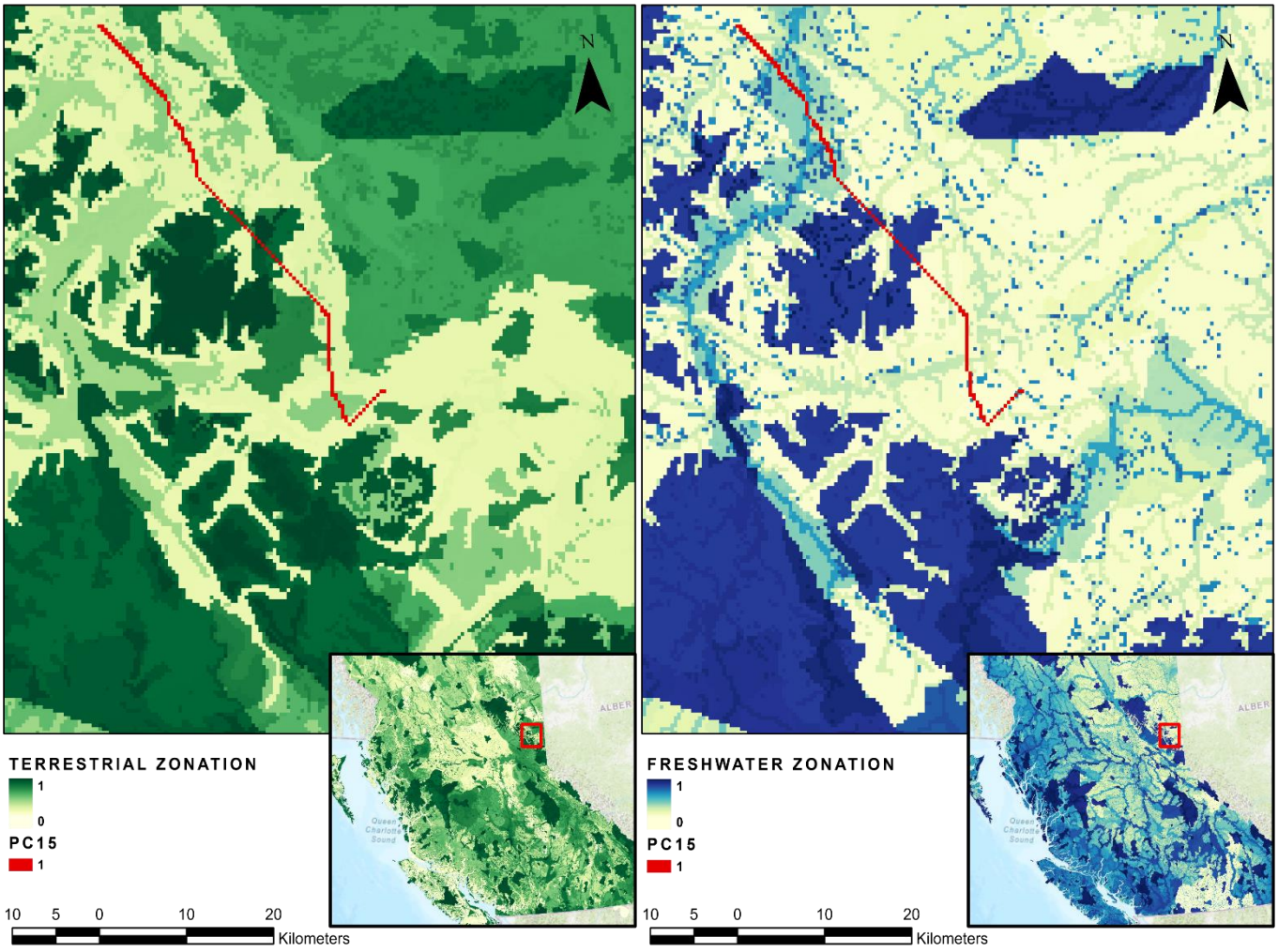

Figure 8: Project footprint of PC15, including ATG and linear infrastructure, overlaid on raw Zonation raster map.

Example 2: High T & Medium FW Score - PC21 (Figure 9) is an onshore wind ridgeline project with an ATG footprint of 22 ha, linear footprint of 50 km, and installed capacity of 95 MW. PC21 has relatively high scaled Zonation scores of 0.52 and 0.2 (terrestrial and freshwater respectively). PC21 has similar levels of overlap when compared with PC15, (e.g. large mammal, grizzly bear conservation, undisturbed, old growth), but also has high levels of overlap with many of the layers that PC15 does not, including ungulate winter range (UWR) and caribou range. More importantly, PC21 has even higher overlap with protected areas and the West Moberly region, leading to higher overall Zonation scores. In terms of freshwater attributes, PC21 has limited overlap with a few environmental layers: bull trout range, Arctic grayling range, and some riparian and wetlands. As with the terrestrial scores, freshwater scores are also higher because of the increased overlap with protected areas when compared to PC15.

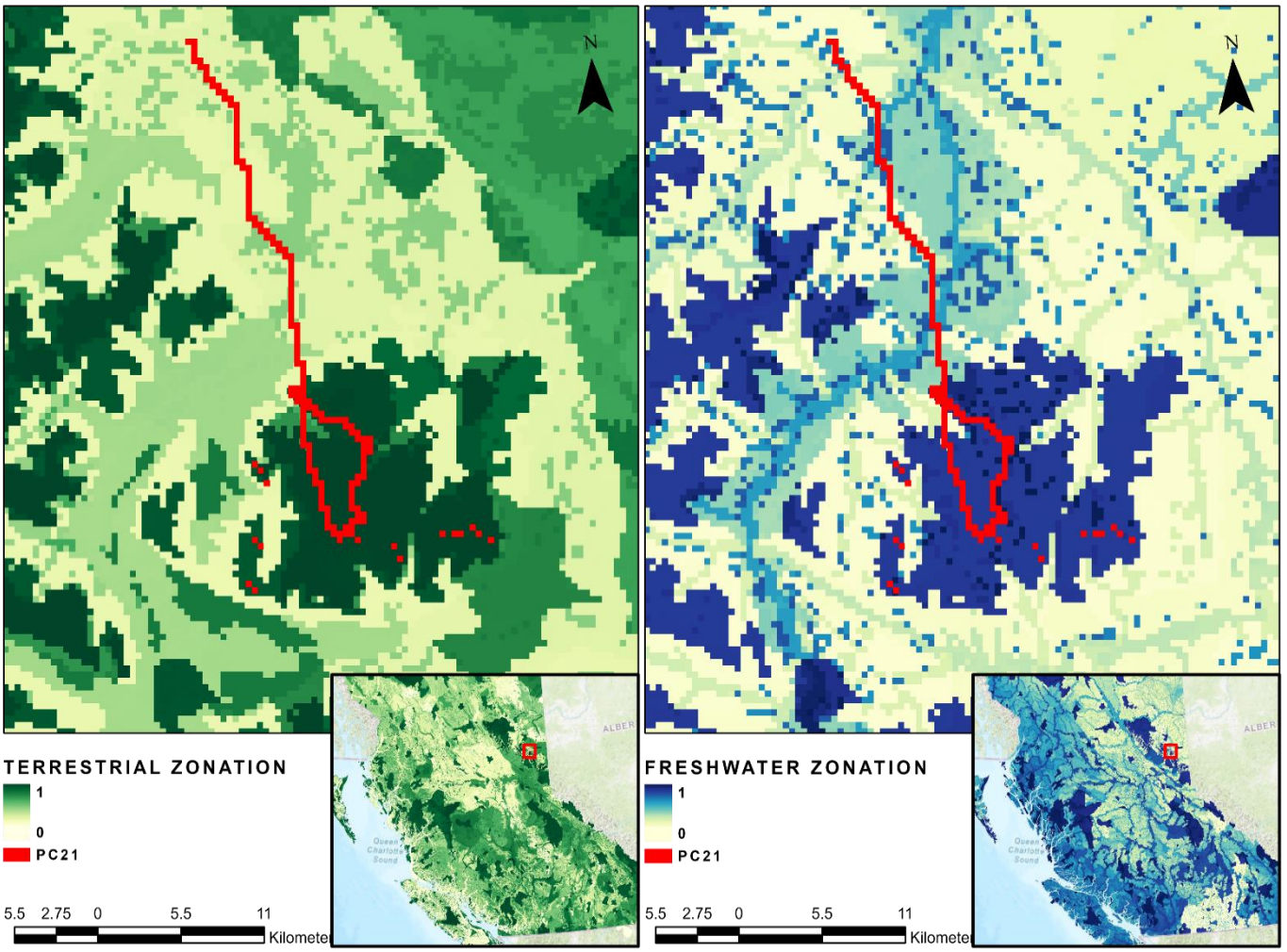

Figure 9: Project footprint of PC21, including ATG and linear infrastructure, overlaid on raw Zonation raster map.

Example 3: High Terrestrial and Low Freshwater Score - SI30 (Figure 10) is an onshore wind plateau project with an ATG footprint of 55 ha, linear footprint of 107 km, and installed capacity of 140 MW. SI30 has a high terrestrial and low freshwater Zonation score of 0.63 and 0.08 respectively. In terms of terrestrial attributes, SI30 overlaps to some degree with nearly every single layer with the exception of conservation lands and caribou range, and West Moberly). The terrestrial aspect of SI30 is a good example of a project where Zonation scores are high both because of the large linear footprint and high overlap with environmental attributes. In terms of freshwater attributes, SI30 has limited overlap with riparian and wetlands, salmon habitat, and 7 of the 12 fish ranges. However, while SI30 overlaps with many of the fish ranges, most of the intersection areas are of low habitat value, leading to a low freshwater Zonation score.

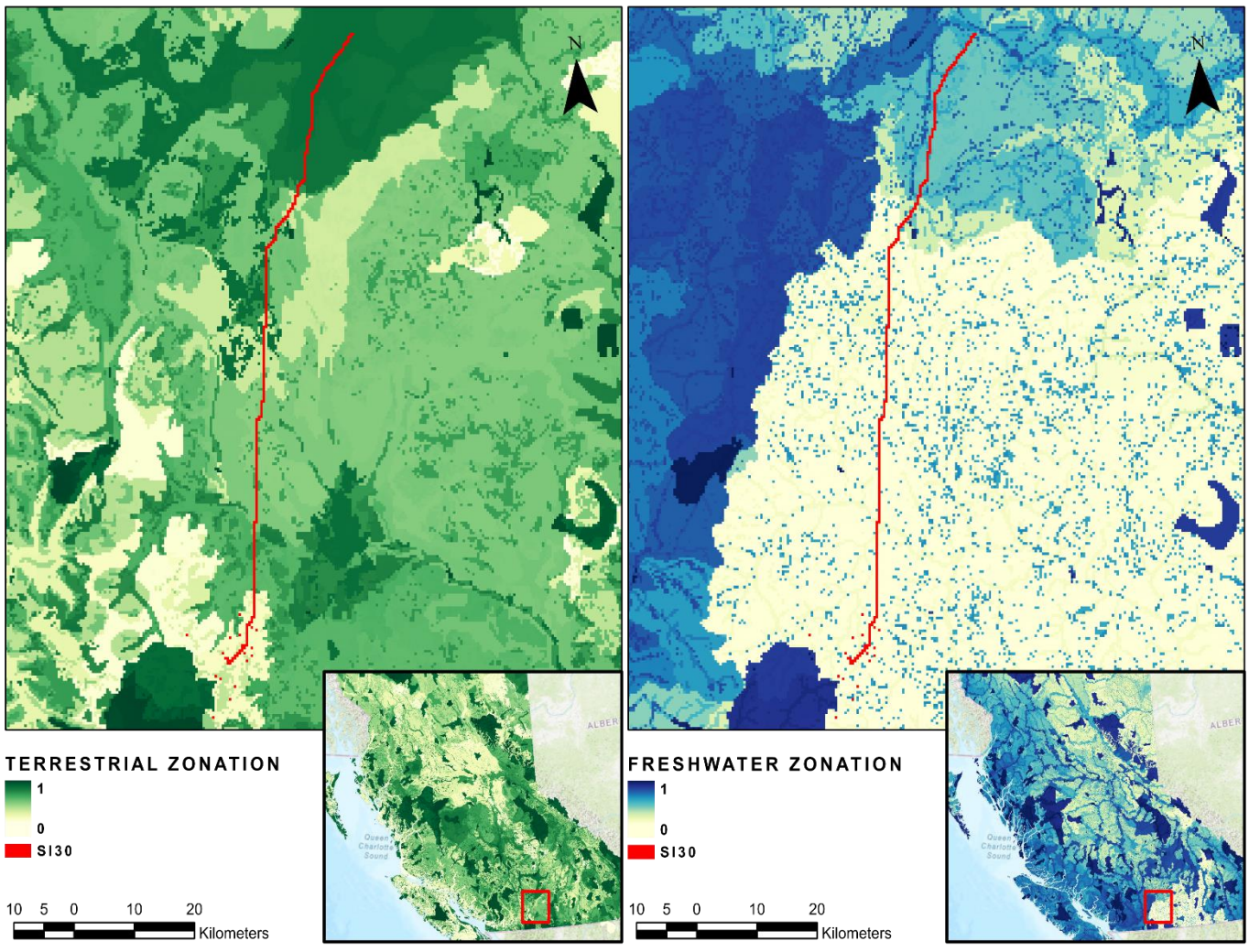

Figure 10: Project footprint of SI30, including ATG and linear infrastructure, overlaid on raw Zonation raster map.

Example 4: Low Terrestrial and Low Freshwater Score - Kinskuch (Figure 11) is a small storage hydro project with an ATG footprint of 989 ha, linear footprint of 49 km, and installed capacity of 175 MW. Despite having the largest ATG footprint of any project, the linear infrastructure of the project still covers nearly two times the area of the ATG footprint. Kinskuch has a scaled Zonation score of 0.26 and 0.19 for terrestrial and freshwater respectively. In terms of terrestrial attributes, Kinskuch overlaps very few layers, including the large extent layers such as large mammal, grizzly bear conservation, and undisturbed, and also some smaller extent layers such as marbled murrelet critical habitat, old growth extent, and old growth management areas. In terms of freshwater layers, Kinskuch overlaps with riparian and wetlands, salmon habitat, and 9 of the 12 fish ranges, with most of the overlap being high habitat value areas. High freshwater Zonation scores for Kinskuch therefore mostly stem from high overlap with fish ranges.

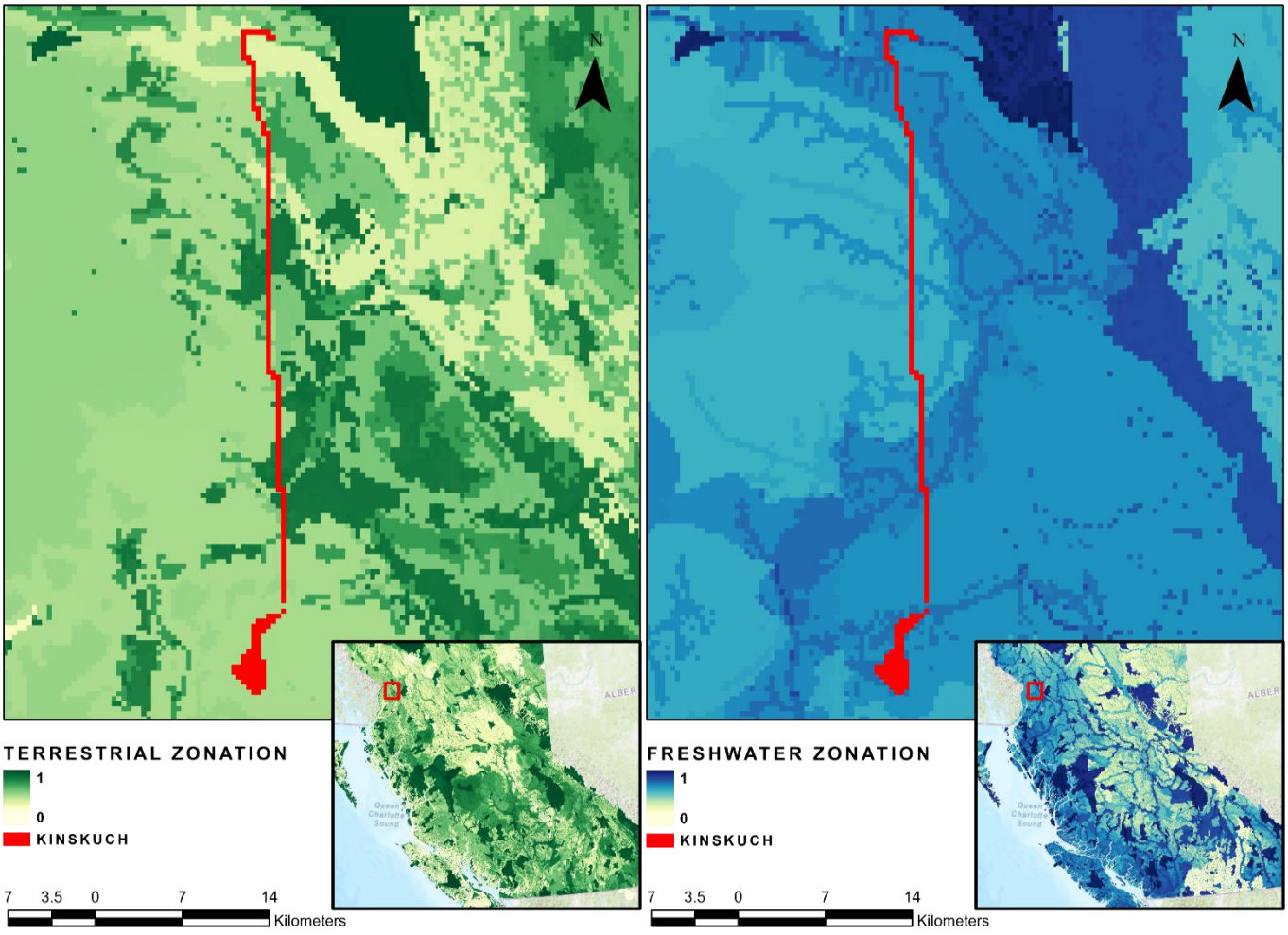

Figure 11: Project footprint of Kinskuch, including ATG and linear infrastructure, overlaid on raw Zonation raster map.

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5 DISCUSSION

5.1 INTERPRETATION OF KEY RESULTS

We took a systematic conservation planning approach to identify high conservation value areas for terrestrial, freshwater, and marine biodiversity in British Columbia and evaluate the potential overlap of new energy development (project and associated linear infrastructure) with conservation priorities. Using this framework, we developed project and portfolio-based metrics that (1) rank energy projects based on their potential environmental footprint, and (2) allow for a comparison of environmental footprints among portfolios. The terrestrial, freshwater, and marine environmental attributes include species, habitats, protected areas, and other biodiversity data types, which cumulatively provide an ensemble view of species, habitat, and ecosystem diversity in British Columbia. The Zonation-based scores were scaled between 0 and 1 for each ecosystem-type (i.e., terrestrial, freshwater, marine). High Zonation-based scores denote high potential environmental footprints due to overlap with high value conservation areas and hence can be interpreted as approximations of potential environmental impact.

The Zonation prioritization outputs (Figures 1, 2, 3) showcase patterns that were expected based on the known distribution of sensitive species and critical habitat: South-Central BC and Rockies for terrestrial prioritization, Coastal BC (and to a lesser extent the Rockies) for freshwater prioritization, and shallow coastal margins for marine prioritization. Given the number and varying spatial extent of input data layers, the spatial distribution of priorities is heterogeneous. Protected areas (~16% of the province) were considered to have the highest conservation value regardless of the underlying biodiversity. This ensured that projects whose infrastructure crossed protected areas were penalized.

The prioritization framework and project- and portfolio-based metrics described here highlighted several important key conclusions.

1) Linear infrastructure of potential energy projects had the greatest impact on the Zonation-based scores. The footprint of linear infrastructure was often much higher (sometimes by orders of magnitude) than the At-The-Gate footprint (ATG). Thus, projects associated with long new powerlines and roads emerged as those with the highest environmental footprint.
2) In most cases, the terrestrial footprint of potential development projects contributed more than the freshwater footprint to combined Zonation-based scores. This pattern is due to the high number of projects that overlap with high value conservation areas in the Peace, Nicola Kelly, and Vancouver Island regions (mostly onshore wind). Freshwater areas of high conservation priority were concentrated in coastal BC, which overlap with a relatively small number of potential development projects.
3) Resource types varied in their Zonation-based scores. Battery storage and biomass projects had the lowest potential environmental footprint due to their occurrence in areas of existing disturbance, and close to existing transmission infrastructure. Geothermal, onshore wind, and solar projects had the largest potential environmental footprint, but also highly variable Zonation-based scores. This suggests that there are potential 'winners' among these energy types, and that some projects or their linear infrastructure are sited in locations that could have high impact on species and habitats (e.g., in caribou and other sensitive species habitat, protected areas, salmon conservation areas, old-growth forest management areas, and undisturbed habitat). Thus,

portfolios including multiple energy types could be further optimized to reduce the potential aggregate environmental footprint.

4) Major transmission lines had high Zonation scores. Transmission lines not associated with individual projects had very high Zonation-based scores due to their long, continuous, and linear nature, which often intersected high conservation value areas for terrestrial and freshwater prioritizations. While some of these transmission lines were part of the portfolios analyzed here, we did not include them for portfolio comparison purposes due to their disproportionate contribution to aggregate portfolio scores. However, the Zonation scores of transmission lines can easily be incorporated into portfolio-based aggregate scores for future applications.
5) As expected, the comparison between Portfolio R (n = 12 energy projects) and Portfolio X (n = 66 energy projects) revealed much higher aggregate environmental footprint for Portfolio X (Aggregated Zonation-based scores: X = 20.8, R = 3.8), but in addition, the relative environmental footprint (per project) was also higher for Portfolio X, where the average contribution of each energy project was ~19% higher (X = 0.32/project, R = 0.27/project) for Portfolio X compared to R. Such comparisons are powerful, especially when many alternative Portfolios of similar capacity are included.

These results must be interpreted within the assumptions of the Zonation prioritization algorithm, which does not exclude projects from portfolios if their infrastructure overlaps with "no-go" areas such as protected areas, critical caribou and threatened and endangered species habitat, or areas with special regulatory or cultural status. While these areas are given a high conservation value score in the prioritization, and the weighting scheme emphasizes their importance in the calculation of the Zonation-based scores for each project, they may not be the main features that determine high Zonation scores. If a project's infrastructure and footprint overlap such areas, the projects must be removed from the prioritization *a priori*. Therefore, the portfolio-based results may differ from the ones calculated here, if such projects are removed from the dataset by BCH based purely on their overlap with 'no-go' areas. Such projects should be identified *a priori* through a consultation process and removed from the dataset, as most of the comparisons we make here are relative and therefore fundamentally dependent on the projects included.

5.2 METHODOLOGICAL CONSIDERATIONS

Project Uncertainty - One of the main assumptions of this work is that the location of the potential development projects and infrastructure considered here is known without error. This analysis assumes that the spatial footprint of the projects is known with certainty and that the development will match the exact At-The-Gate footprint and transmission line and road locations from GIS[6]. This assumption has important implications. First, it is possible that infrastructure overlapping highly sensitive areas or 'no-go' could be rerouted to low conservation value areas if the energy project remains cost-effective. As such, projects that are predicted to have high potential footprint could be redesigned to avoid high conservation value areas and have overall lower environmental impact.

Second, there were varying levels of spatial uncertainty associated with the location of all energy types. The siting of individual turbines for onshore wind farms is unknown. This was especially true for plateau wind projects. To mitigate this, we simulated turbine site locations within the boundaries proposed by BCH, but the uncertainty remains high in terms of the range of potential impacts that could

[6] Similarly, during the competitive procurement process, which projects get built, as well as their associated spatial details, may deviate substantially from portfolios identified by BCH in the IRP.

be created by infrastructure within those boundaries. Small storage hydropower and pumped storage projects were also subject to high uncertainty, particularly when determining the footprint of the potential reservoirs. Reservoir basins derived from 15 m DEMs (higher spatial resolution and more detailed than what was used to originally calculate the reservoir locations in the resource options report) often did not exactly match the reported small storage hydro reservoir sizes. Pump storage infrastructure that connects the upper and lower reservoirs, as well as the reservoirs themselves, were also estimated to have high spatial uncertainty. Other energy types such as solar, geothermal, biomass, and battery storage all contained spatial uncertainty since their ATG locations were estimated using a simple circular buffer around the project location point. Some of these energy types, such as battery storage as well as some biomass and geothermal projects, often have lower uncertainty because of the small footprint of such projects and the fact that they are proposed to be built in already developed areas.

Environmental layers - A total of seventy-one terrestrial, twenty-four freshwater, and eight marine input layers were included in the final Zonation runs. While selected input layers had to fulfill certain criteria (Section 33.1) such as sufficient scale and range, quantitative benchmarks, and relevance to conservation goals, inconsistent technical features were still identified within some input layers. For example, input layers ranged in size from a few pixels (e.g., bat critical habitat) to the entire provincial extent (e.g. continuous undisturbed layer). Other technical inconsistencies included limitations due to the resolution of the data sources from which the input layers were derived and a lack of contemporary data (see Appendix 7.1 for a full list of input layers and their assumptions and limitations).

While many layers had inconsistent spatial extents, this is not an important limitation for this conservation prioritization study. Zonation can accommodate data layers with different extents and tends to prioritize environmental features that are poorly represented (the smaller the distribution or spatial extent, the higher the priority and conservation value). Also, Zonation can include layers with different ranges of values, as the first step of the algorithm scales each layer to span values between 0 and 1, as well as presence-only layers (value of 1 where a specific habitat or species is present). The latter was common in our data, and it represented features such as caribou habitat, critical habitat, West Moberly, etc. (Appendix

Table 5).

Zonation-based scores - the weighted scaled Zonation scores for terrestrial, freshwater, and marine prioritizations were identified as the most relevant metrics through an iterative process in consultation with BCH. While the extraction of Zonation scores based on overlap with infrastructure followed existing literature (see Popescu et al. 2020 for aggregate scores across energy development types), identifying an optimal metric at a project level that both represents the potential footprint and has the ability to discriminate between projects is more difficult. After several iterations that included simple metrics such as the mean or median Zonation scores across all grid cells overlapped by a project and its infrastructure, a weighted scheme performed best at discriminating between projects with potentially high and low environmental footprint.

Using Zonation scores as a proxy for environmental footprint and impact - The project-based scores estimated in this study can provide insight into the magnitude of physical footprint (At-The-Gate, linear infrastructure) while accounting for the conservation value of the areas of overlap. However, these scores should not be equated with direct environmental impact on species and habitats. While there is often knowledge of specific effects of stressors on species and habitats, such as forest disturbance

affecting the behaviour and distribution of sensitive taxa, stream flow alteration exceeding thresholds of habitat quality for salmonid fishes, or wind turbines leading to mortality in birds and bats, Zonation scores cannot capture such fine-scale details. The Zonation scores we present here can provide a useful relative comparison between projects in terms of their overall overlap with high conservation value areas, which can be used in a "precautionary principle" approach to prioritize those projects with the lowest potential footprint. However, impacts on sensitive species from high and low-score projects could be similar when assessed in the field. For example, an array of twenty wind turbines constructed in both low and high-Zonation score locations in the same general region could still induce similar mortality levels in birds and bats. Zonation scores are reasonable general proxies of the potential for environmental impact, but given the coarse nature of Provincial-scale data and the inability of map-based approaches to capture dynamic interactions, should be interpreted with caution and validated with field-based assessments.

In addition, the conservation prioritization implemented here does not represent the entire biodiversity of BC due to limitations of the available biodiversity data: either completely missing species and habitats, or incomplete knowledge of the occurrence of sensitive species and their habitats. These prioritization algorithms are also not designed to deal with complex interactions that are common in ecological systems; if some species or habitat is affected or altered, this can have cascading effects on other components of biodiversity, leading to environmental impacts that are larger than the sum of individual impacts (termed synergistic effects) and are often difficult to predict from coarse-scale information such as what we are able to provide here. These types of interactions, and specific impacts on sensitive species and habitats can only be determined through field-based assessments and monitoring pre-and post-project construction. In conclusion, Zonation scores can provide a broad perspective and meaningful comparison of overall environmental footprint while accounting for environmental attributes considered here, but it cannot be used as direct measures of environmental impact or as a substitute for site-specific environmental evaluation.

5.3 AGGREGATE ZONATION SCORES AND OPTIMIZATION

The value of this work is greatest when used at a higher level, where results are integrated into a portfolio-based decision process. While we provide detailed information on individual projects, ranging from relative terrestrial and freshwater footprints based on Zonation scores, to absolute values of overlap between infrastructure and key environmental layers, we strongly recommend comparing aggregate project scores among portfolios. This approach facilitates the integration of the environmental footprint proxies calculated here with other factors such as cost, demand, geography, seasonality, and lifecycle climate considerations (GHG emissions). For example, our analysis of the two hypothetical portfolios provided by BCH found that the potential environmental footprint was greater for Portfolio X, cumulatively (overall aggregate score) and per project (score/project) compared to Portfolio R.

When considering the types of energy projects selected for inclusion in a given portfolio, this work provides a pathway for the hierarchical optimization of portfolios for the lowest environmental footprint by:

1) Excluding projects that overlap with sensitive (or "no-go") areas from the calculation of Zonation scores
2) Prioritizing projects with low Zonation scores (in our case <0.5) and determining which combination of projects meet other goals such as demand, cost, geography, and GHG emissions. Portfolios can further be selected to minimize per project Zonation scores, as well as minimizing the cumulative environmental footprint of the portfolio.

Relying on simple metrics, such as scaled Zonation scores or combined terrestrial and freshwater scores, is appealing for decision-making. Our work provides complementary information that can further inform the discussion around projects that are subject to debate, or when deciding among competing portfolios. The diversity of energy options, along with the large number of projects with combined terrestrial and freshwater score <0.5 suggests that low environmental footprint portfolios can be selected while meeting other optimization goals, and potential projects subject to debate can be removed in favour of other low footprint projects with less conflict.

5.4 COMPARISON BETWEEN EXAMPLE ZONATION SCORES AND ENVIRONMENTAL ATTRIBUTES

We illustrated the relationships between scaled Zonation scores and a subset of key environmental attributes for four example projects (Section 4.5) to highlight the utility of the Zonation algorithm. The visualization of how these four projects overlap with the maps of terrestrial and freshwater zonation scores illustrates the inadequacy of using single layers to explain the overall scaled Zonation scores we calculate for each potential development project. The Zonation algorithm solves a high-order optimization problem (including dozens of environmental layers interacting in ways that are difficult to predict *a priori*) based on ecological principles of reserve design (using richness and complementarity), in which each individual layer plays a role based on its spatial extent and range of values. Therefore, by design, any single layer is unlikely to have a major influence on the prioritization outcome, and relationships between potential development projects and specific environmental attributes should be interpreted with caution.

5.5 ENVIRONMENTAL CHALLENGES OF RENEWABLE ENERGY RESOURCES

Globally, oil, coal, and natural gas generate the vast majority (67%) of current electricity (IEA 2014), and electricity demand is predicted to increase by 40% in the next two decades (WEC 2012). The widespread adoption of renewable energy technologies (wind, solar, hydropower, geothermal) is often motivated by reducing reliance on fossil fuels as well as curbing greenhouse gas emissions. Yet, renewable energy projects act as additional stressors on terrestrial and aquatic ecosystems, and the rapid pace at which these energy resources have been developed has often outpaced our understanding of their unintended and aggregate impacts, leading to emerging conflicts with biodiversity conservation (Northrup and Wittemyer 2012). Individual renewable energies have unique local biodiversity impacts (e.g., bird and bat mortality at wind turbines (Barrios and Rodriguez 2004, Kunz et al. 2007, Cryan and Barclay 2009, Pearce-Higgins et al. 2012), habitat loss and fragmentation and light pollution at solar facilities (Lovich and Ennen 2011), small and large dams as barriers to the movement of sediment and fishes (Kubecka et al. 1997, Lucas et al. 2009, Fuller et al. 2016). However, the distributed character of renewable energies for solving grid-based electricity problems also creates biotic impacts from access roads and powerline infrastructure, which need to be evaluated in aggregate rather than individually. The evaluation of aggregate (or cumulative) effects on biodiversity within the renewable energy sector and the synergies with co-occurring human activities has generally been difficult to address in the environmental assessment process, fueled by the lack of methodologies and a poor mechanistic understanding of interactions between stressors (Therivel and Ross 2007, Harriman and Noble 2008). This uncertainty has fueled social conflict around energy development generally and utility-scale renewable technologies in particular, and we hope that the methodology we developed here will aid in more effective and inclusive decision making with regard to potential cumulative environmental effects.

5.6 SUMMARY

Our approach to evaluating the potential environmental footprint of proposed energy projects yielded simple project-based and portfolio-based metrics that can be integrated with other optimization goals to map the energy future of British Columbia. We developed a framework and process of integrating information on terrestrial, freshwater, and marine biodiversity and sensitive habitat that is intended to help identify development scenarios (projects and portfolios) that minimize the cumulative environmental footprint of future energy infrastructure. The approach we developed is flexible in that it can accommodate additional data in the future, including new projects and portfolios, social and cultural information generated through public and industry consultation processes, and improvements in predictions of environmental impacts in advance of development decisions. The two-tiered results we provide in this report (project- and portfolio-based) are complementary, where portfolio-based aggregate metrics allow for direct comparison of proposals that reflect alternative futures, and project-level scores can be used to support decisions on optimal portfolios. Given large uncertainties associated with project siting, the trade-offs between energy and environmental goals are most visible at the portfolio-level, as the environmental footprint scores of individual projects may shift if there are changes in the location of proposed infrastructure. The diversity of energy options considered here, along with the comparison of two hypothetical portfolios, suggest that many avenues to selecting low environmental footprint projects and portfolios exist. As such, these results can support the work of BCH to integrate environmental considerations into decision-making and optimize energy portfolios that meet multiple goals (e.g., economic, environmental, social).

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7 APPENDIX

7.1 LIST OF ENVIRONMENTAL ATTRIBUTES WITH ASSUMPTIONS/LIMITATIONS

7.1.1 TERRESTRIAL ATTRIBUTES (N = 71)

- **Agricultural Land Reserve (ALR)** – The ALR is a provincially designated area in which agricultural land use is prioritized. ALR polygons were selected from the Canada Land Inventory (CLI) and BC Land Inventory (BCLI) based on biophysical information related to the land and climate. This layer came from the Provincial Agricultural Land Commission as a polygon shapefile.

    - Assumptions: The CLI and BCLI map datasets used to delineate ALRs were created at a 1:50,000 and 1:20,000 scale respectively, resulting in features that are more detailed than the MMU of this project. The CLI and BCLI were created between 1960-1995.

- **Conservation Lands** – Conservation Lands include administered and non-administered lands acquired through purchase, land exchange, donation, lease, or obtained through Land Act mechanisms; Wildlife Management Areas (WMAs), which are designated under Section 4(2) of the BC Wildlife Act, are included as part of this dataset.

- **Critical Habitat - terrestrial (split into n = 43 individual species layers)** – This dataset includes all designated critical habitat (final and proposed) for nonaquatic species at risk listed on the Schedule 1 of the federal Species at Risk Act in BC. Critical habitat (CH) is defined in the federal Species at Risk Act as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or action plan for the species" (Species at Risk Act, 2002). Biological complexities such as mobility, life history characteristics, changing landscapes, as well as other biophysical attributes are taken into consideration when delineating critical habitat polygons and vary by species. This layer came from the BC Data Catalogue as a polygon shapefile and was split into separate layers by species (36 terrestrial species). Critical habitat for bats (Little Brown Myotis and Northern Myotis) and snakes (Great Basin Gophersnake, Western Rattlesnake, and Desert Nightsnake) were originally represented as UTM grid squares due to data sensitivity reasons. UTM squares were replaced by actual extent of the critical habitat for these species received from the Canadian Wildlife Service when available. The critical habitat (terrestrial) dataset was split into 43 different layers and each inputted separately into Zonation.

    - Assumptions: Most of the critical habitat within this layer represents the exact extent of the critical area, however, in cases where data sensitivity is an issue, the critical habitat might be represented as 'grid squares' (1, 10, 50, or 100 km2 squares based on UTM grids) (Species at Risk Act Implementation Guidance for Recovery Practitioners, 2016). This was the case for snakes (including Desert Nightsnake, Western Rattlesnake, and Great Basin Gophersnake) and bats (Little Brown Myotis and Northern Myotis). However, more spatially specific data was obtained from federal and provincial scientists.

- Methods for establishing CH are variable and dependent on species characteristics. For many species (e.g. Pacific water-shrew, marbled murrelets), particularly more cryptic ones, CH may have been inferred from historic records and/or assumed habitat types with minimal ground-truthing (Environment Canada, 2014a; Environment Canada, 2014b), which could result in either over- or under-estimation of CH. Specific information regarding the spatial extent can be found in individual species' recovery documents.

- **Important Bird Area Terrestrial (IBA)** – IBAs are distinct areas that are deemed significant for the conservation of birds and biodiversity based on certain internationally agreed upon criteria, including the application of quantitative ornithological criteria and expert opinion. A polygon shapefile layer of all IBAs in BC was provided by IBA Canada. Terrestrial IBAs were selected for this input layer.

  - Assumptions: The spatial layer was created by combining selected protected areas with products of manual digitization. Digitization was completed using 1:50 000 or 1:250 000 National Topographic Database layers (1944-2005), and later available Google Earth air and satellite imagery, as reference. IBAs are not legally recognized entities and do not have any regulatory status.

- **Old Growth Management Areas (OGMA)** – OGMAs are legal areas of old growth forest where forestry development is prevented or constrained. The spatial extent is identified during landscape unit planning or operational planning. This layer came from the BC Data Catalogue as a polygon shapefile.

  - Assumptions: OGMA's are limited in representing remaining old growth forest in BC and include approximately 1/3 (4.4 out of 13.2 million hectares) of total old growth forest extent in BC.

- **Old Growth Extent** – The old growth extent layer is a product provided by the BC forest inventory team that indicates the extent of old growth forests as defined by the BC Biodiversity Guidebook – published as required in the Forest Practices Code of British Columbia Act and Regulations (Parminter, 1995).

  - Assumptions: The extent of old growth depends on the definition of old growth applied. For this layer the definition of old growth incorporates tree age, biogeoclimatic zones, and frequency of natural disturbances. More detail can be found in the Biodiversity Guidebook (Parminter, 1995).

- **Species and Ecosystems at Risk** – This layer includes polygon shapefiles of all mapped locations of species or ecosystems at risk in BC recognized by federal, provincial, and local governments. All species and ecosystems within this layer are assigned to the red, blue, or yellow conservation priority list, as well as

ranked on the provincial conservation status list. Data for this layer are sourced from various repositories (reports, inventories, citizen science resources, etc.) (Conservation Data Centre, 2020). Two layers of this dataset (one publicly available and one secured) were acquired from the BC Data Catalogue and merged.

  - Assumptions: The size of polygons in this dataset may reflect the locational uncertainty of the source data, this uncertainty is recorded in the 'representational accuracy' field of the attributes.

- **Ungulate Winter Range (UWR)** – UWR are provincially designated areas under the Forest Range Practices Act (FRPA) that contain habitat necessary to meet the winter habitat requirements of ungulate species. Habitats are delineated by analyzing topographic and vegetative features. This layer came from the BC Data Catalogue as a polygon shapefile.

- **Wildlife Habitat Area (WHA)** – WHAs are provincially designated areas under the FRPA that contain critical habitats where activities are managed to limit impacts on species categorized as Species at Risk or Regionally Important Wildlife within BC. Two layers of this dataset (one publicly available and one secured) were acquired from the BC Data Catalogue and merged.

- **Biogeoclimatic Ecosystem Classification - BEC (split into n = 16 individual ecosystem layers)** – The BEC classification system has been used by provincial managers for forest, range, and wildlife management since the 1970s. The system uses vegetation, soils, and topography to infer regional ecological effects (Biogeoclimatic Ecosystem Classification Program, N.D.). At the regional level the province is divided into 16 biogeoclimatic zones. These 14 zones were selected and split into 16 separate layers for input.

  - Assumptions: In addition to the 14 regional zones, the BEC classification splits up ecosystems into more specific subzones, variants, and phases, which are based on climate and precipitation differences. These more detailed classifications are not captured in the 14 regional BEC layers.

- **Undisturbed Layer** – This layer (300m x 300m) was created based on the Canada Human Footprint (HFP) layer (Hirsh-Pearson, 2020). The original layer included: (1) the extent of built environments; (2) crop land; (3) pasture land; (4) human population density; (5) nighttime lights; (6) railways; (7) roads; (8) navigable waterways; (9) dams and associated reservoirs; (10) mining activity; (11) oil and gas; and (12) anthropogenic forest disturbances. Additional disturbance information that is missing from the above list such as a more comprehensive road layer (Digital Road Atlas, forest tenure roads), other forest disturbances (fire, insect), geophysical oil and gas infrastructure (including seismic lines), and transmission and distribution lines were added to this dataset. The undisturbed layer is calculated by rescaling the HFP to 0-1 and summing the four additional layers. The layer was then resampled to 400m x 400m, and an "undisturbed" layer was extracted from the results.

- Assumptions: For a comprehensive review of the assumptions and limitations of the HFP dataset please refer to (Hirsh-Pearson, 2020). This layer uses best available data to map different forms of anthropogenic disturbance, and by inference, identify the most undisturbed areas in the province. Incomplete, inaccurate, or outdated data layers represent the most important limitations to the undisturbed layer, as many forms of disturbance are missed by the individual data sources (e.g. some small forestry roads, skid trails, seismic lines). These errors of omission mean that this layer is precautionary in that some areas we identify as undisturbed may in fact be disturbed.

- **Grizzly Bear Conservation Status** – This layer derived from the Grizzly Bear Population Units dataset from BC Data Catalogue describes the conservation status (M5 very low, M4 low, M3 moderate, M2 high, M1 extreme) of Grizzly Bears in BC. Conservation status is used and is provided by provincial biologists but is calculated by NatureServe and reflects the population size and trend, genetic and demographic isolation, as well as threats to bears and their habitats per Grizzly Bear Population Unit.

- **Terrestrial Priority Species Range** –Priority terrestrial species ranges come from continental range estimates from previous work, expert consultations with relevant government research bodies, and recent provincial status reports (Laliberte and Ripple, 2004; Popescu et al., 2020). The species were selected based on the sensitivity to habitat fragmentation, conservation status in British Columbia and cultural value, particularly to First Nations: Bighorn Sheep (Blood 2000, Allen et al. 2016), Grizzly Bear (Morgan et al. 2019), Fisher (Weir 2003, Weir et al. 2012, Sweitzer et al. 2016), and Mountain Goat (Parks et al. 2015). All terrestrial animal ranges (occurrence =1 / non-occurrence = 0) have been summed to form a single Terrestrial Priority Species Range layer.

- **Caribou range** - Caribou (Seip 1992, Polfus et al. 2011, Moreau et al. 2012) species range was selected as an individual layer because of BCH's focus on Caribou as an important terrestrial species and as a keystone species.

7.1.2 FRESHWATER ATTRIBUTES (N = 24)

- **Fisheries Sensitive Watersheds (FSW)** – FSWs are provincially designated areas selected based on criteria set out in the Forest Practices and Range Act. Management within FSWs aim to conserve important watershed level attributes such as stream bed dynamics, channel integrity, water flow, and hydrological conditions. This layer came from the BC Data Catalogue as a polygon shapefile.

  - Assumptions: Watershed boundaries are derived from the Freshwater Atlas, which itself is based on 1:20,000 scale TRIM base maps (Geographic Data BC, 1997). Boundaries were edited based on additional air/satellite imagery and topographical data interpolation in order to fully represent each watershed's alluvial fan.

- **Critical Habitat (freshwater)** - This dataset includes all designated critical habitat (final and proposed) for aquatic species at risk listed on the Schedule 1 of the federal Species at Risk Act in BC, including species that are extirpated, endangered, or threatened. This dataset originally included both marine and freshwater critical habitats, and only freshwater habitats were selected to create this layer. This dataset is managed by DFO and comes from the Open Government Portal. The dataset was split into separate layers by species (n=8). The critical habitat (freshwater) dataset was split into 8 different layers and each inputted separately into Zonation.

    - Assumptions: As with terrestrial critical habitat most of the critical habitat represents the exact extent of the critical area, however, in cases where data sensitivity is an issue the critical habitats might be represented as 'grid squares' (1, 10, 50, or 100 km2 squares based on UTM grids) (Species at Risk Act Implementation Guidance for Recovery Practitioners, 2016). Additionally, methods for establishing CH are variable and dependent on species (see Critical Habitat (terrestrial) above for additional detail).

- **Riparian Zones** – Riparian Zones were derived from the provincial Freshwater Atlas (FWA) datasets. The FWA was derived from the provincial TRIM dataset (1:20,000 scale topographic base maps) (Geographic Data BC, 1997). Riparian habitat and riparian related disturbances are defined provincially as those occurring within 30m of a stream (Interim Assessment Protocol for Aquatic Ecosystems in British Columbia, 2019), however, due to raster scale constraints a buffer of 200m was applied to all rivers, lakes, and streams to create the riparian layer. Another component of the Riparian zone layer are wetlands, which are also derived from the FWA dataset.

    - Assumptions: Key limitations for this layer arise from the data quality of the TRIM dataset. TRIM data misses many sub-hectare sized wetlands otherwise identifiable via air photos or satellite imagery, which may be the majority (numerically) of wetlands in the Province. Predictive mapping of wetlands based on airphotos, Landsat-8, and Sentinel-2 imagery has been shown to yield better results, however these more accurate datasets are not yet available province-wide (Dilatow, Carswell, and Cameron, 2018). A 30m buffer would not yield results on a raster with an MMU of 160,000 m2 (or 400m*400m cell size). Therefore, we created a riparian layer by applying a 200 m radius buffer to all streams, rivers, and lakes from the FWA, which represents a precautionary measure of riparian characteristics

- **Stream Crossings** – The stream crossings layer is a modelled product resulting from the provincial fish passage program (Mount et al. 2011). This layer was created by overlaying and finding the intersections between the FWA and road layers (Digital Road Atlas (DRA) and forest tenure roads). These intersections represent any kind of stream crossing such as bridges, culverts, and fords and are proxy for anthropogenic fragmentation of river networks. This layer was provided by provincial scientists working within the fish passage program.

- Assumptions: The main limitation for this layer is the lack of a complete road layer for the province. The BCDRA and forest tenure roads do not include a large number of deactivated forestry roads and roads constructed on cutblocks (Forest Practices Board, 2015).

- **Freshwater Priority Species Range** – Priority freshwater species were determined by BCH, with input from the research team, and include Arctic grayling, Bull trout, Coastal cutthroat trout, Chinook salmon, Pink salmon, Chum salmon, Coho salmon, Sockeye/Kokanee salmon, Steelhead/Rainbow trout, Westslope Cutthroat trout, Dolly Varden trout and White sturgeon (n=11). Individual species ranges are derived from a 2008 provincial report that estimated the distribution of fish species based on occurrence/abundance datasets, habitat characteristics, and barrier passage information. Spatial extent is based on previously available province wide 1:50,000 scale spatial layers (Porter et al, 2008). All freshwater ranges have been merged to form a single freshwater Priority Species Range layer.

- **Anadromous Salmon Conservation Unit Biological Status** – This layer provides a biological status (for Sockeye, Coho, Chum, Pink, and Chinook Salmon within conservation unit boundaries. Conservation units and biological status assessments are part of DFO's Wild Salmon Policy's (WSP) strategy for implementation. Rather than presence absence, this layer is represented as fair (1), and poor (2), and no data or absence (0). Data for this layer was compiled from the Pacific Salmon Foundation's spatial and tabular databases.

- **Undisturbed Layer** - Please see information for Undisturbed Layer under 'Terrestrial Attributes'.

7.1.3 MARINE ATTRIBUTES (N = 8)

- **Critical Habitat (marine)** - This dataset includes all designated critical habitat (final and proposed) for aquatic species at risk listed on the Schedule 1 of the federal Species at Risk Act in BC, including species that are extirpated, endangered or threatened. This dataset originally included both marine and freshwater critical habitats, and for this layer, only marine habitats were included. This dataset is managed by DFO and comes from the Open Government Portal. The dataset was split into separate layers by species, however, only one marine species (Orcinus orca) overlapped with the study extent.

  - Assumptions: As with terrestrial and freshwater critical habitat most of the critical habitat represents the exact extent of the critical area, however, in cases where data sensitivity is an issue the critical habitats might be represented as 'grid squares' (1, 10, 50, or 100 km2 squares based on UTM grids) (Species at Risk Act Implementation Guidance for Recovery Practitioners, 2016). Additionally, methods for establishing CH are variable and dependent on species (see Critical Habitat (terrestrial) above for additional detail).

- **Rockfish Conservation Areas (RCA)** – RCAs are federally designated areas under the Fisheries Act, where inshore rockfish are protected from all recreational and commercial fishing activity. The RCA layer is the digitized product of various multi-stakeholder consultations from 2002, and includes verification with fishery catch data, and habitat analyses to determine conservation targets. This layer was provided by DFO scientists as a polygon shapefile.

    - Assumptions: Originally 50% of rockfish habitat was recommended for RCA protection, but ultimately only 20% of habitat was designated. As a result, RCAs represent key areas off limits to commercial and recreational uses but may not be sufficient to protect target rockfish species or reach intended conservation targets.

- **Distribution of Killer Whales** – This polygon shapefile layer came from the BC Data Catalogue. The data was derived from fisheries officer interviews, species models, sightings, as well as historical records. This dataset includes the distribution of northern and southern resident killer whales.

    - Assumptions: The accuracy of this layer is dependent on the quality of the data source, some of which may be dated historical records (Baird and Guenther, 1991).

- **Intertidal Zones** – Intertidal zones were selected from the Shore Unit Classification layer acquired from the BC Data Catalogue. The shore unit classification dataset determines habitat attributes like tidal zones through aerial imagery photography. This line shapefile layer was then buffered with a 200m radius to meet the MMU of the input datasets.

    - Assumptions: This layer only includes the intertidal zone and excludes supratidal and subtidal zones.

- **Important Bird Area Marine (IBA)** – IBAs are distinct areas that are deemed significant for the conservation of birds and biodiversity based on internationally agreed upon criteria including the application of quantitative ornithological measures and expert opinion. A polygon shapefile of all IBAs in BC was provided by IBA Canada. Marine IBAs were selected for this layer.

    - Assumptions: The spatial layer was created by combining selected protected areas with products of manual digitization. Digitization was completed using 1:50 000 or 1:250 000 National Topographic Database layers (1944-2005), and later available Google Earth air and satellite imagery, as reference. IBAs are not legally recognized entities and do not have any regulatory status.

- **Estuaries** – Estuary spatial extent was mapped as part of the work published in the technical report Ryder et al, 2007. Estuary boundaries were defined to include the intertidal zones, supratidal zones, and physiological habitat features up to 500m upstream. This layer came from the Canadian Wildlife Service as a polygon shapefile.

    - Assumptions: Physiological features and tidal zones were identified using a combination of data from TRIM (1:20,000), digital orthophotos (1:20,000), airphotos (1:15,00 - 1:40,000), and various digital marine charts. Habitat features that are not identifiable on maps using the above scale will not be included within the estuary boundary.

- **Ecologically and Biologically Significant Areas (EBSAs)** – EBSAs are areas designated by DFO and used for marine planning (e.g. environmental assessments). EBSAs are identified by compiling scientific based species and ecosystem related data and traditional ecological knowledge. This layer came from the BC Marine Conservation Analysis (BCMCA) as a shapefile.

    - Assumptions: EBSA boundaries may change and additional areas may be identified in response to new knowledge and environmental changes.

- **Ecological Feature Counts** – This layer created by the BC Marine Conservation Analysis (BCMCA) identifies areas of high conservation value by measuring the count of 172 different ecological features. Ecological features include fish and invertebrate, marine bird, marine mammal, marine plant, and physical features. A list of all ecological features can be found in the metadata associated with this layer. This layer came from the BC Marine Conservation Analysis (BCMCA) as a shapefile.

    - Assumptions: Certain relevant ecological features are not represented in this layer due to a lack of available spatial data.

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7.2 LIST OF POTENTIAL DEVELOPMENT PROJECTS

Table 4: Reference list of projects with energy type and usage in hypothetical portfolios (n = 137).

Project Name	Energy Type	Portfolio
Batt_VI	Battery storage	X, R
WBBio_CB_RR	Biomass	-
WBBio_LM_RR	Biomass	-
WBBio_LM_ST_1	Biomass	-
WBBio_LM_ST_2	Biomass	-
WBBio_NE_ST_1	Biomass	-
WBBio_NE_ST_2	Biomass	-
WBBio_NE_ST_3	Biomass	-
WBBio_NW_ST	Biomass	-
WBBio_SP_RR	Biomass	-
WBBio_SP_ST	Biomass	-
WBBio_WPR_PL	Biomass	-
Geo_Canoe Creek_Valemount	Geothermal	X
Geo_Clarke Lake	Geothermal	-
Geo_Jedney Area	Geothermal	-
Geo_Lakelse Lake	Geothermal	-
Geo_Meager_Creek	Geothermal	X
Geo_Mt. Cayley	Geothermal	-
Geo_Pebble_Creek	Geothermal	X
Geo_Sloquet Creek	Geothermal	-
MSW 1	MSW	-
MSW 2	MSW	-
MSW 3	MSW	-
OW_BC18	Onshore Wind	X
OW_BC19	Onshore Wind	X
OW_BC20	Onshore Wind	X
OW_BC21	Onshore Wind	-
OW_BC22	Onshore Wind	-
OW_BC23	Onshore Wind	X
OW_NC01	Onshore Wind	X
OW_NC02	Onshore Wind	-
OW_NC07	Onshore Wind	X

OW_NC08	Onshore Wind	X
OW_NC09	Onshore Wind	X, R
OW_NC10	Onshore Wind	X
OW_NC12	Onshore Wind	X
OW_PC06	Onshore Wind	X
OW_PC09	Onshore Wind	X
OW_PC10	Onshore Wind	X, R
OW_PC11	Onshore Wind	X
OW_PC12	Onshore Wind	-
OW_PC13	Onshore Wind	X
OW_PC14	Onshore Wind	X, R
OW_PC15	Onshore Wind	X
OW_PC16	Onshore Wind	X
OW_PC17	Onshore Wind	X
OW_PC18	Onshore Wind	X, R
OW_PC19	Onshore Wind	X, R
OW_PC20	Onshore Wind	X, R
OW_PC21	Onshore Wind	X
OW_PC25	Onshore Wind	X
OW_PC26	Onshore Wind	X
OW_PC27	Onshore Wind	X
OW_PC28	Onshore Wind	X, R
OW_PC32	Onshore Wind	-
OW_PC34	Onshore Wind	X
OW_PC36	Onshore Wind	-
OW_PC37	Onshore Wind	-
OW_PC38	Onshore Wind	-
OW_PC39	Onshore Wind	X
OW_PC40	Onshore Wind	X
OW_PC41	Onshore Wind	X
OW_PC42	Onshore Wind	X
OW_PC46	Onshore Wind	-
OW_PC48	Onshore Wind	X
OW_SI01	Onshore Wind	X
OW_SI03	Onshore Wind	X

OW_SI04	Onshore Wind	X
OW_SI05	Onshore Wind	X
OW_SI06	Onshore Wind	-
OW_SI10	Onshore Wind	-
OW_SI11	Onshore Wind	X
OW_SI12	Onshore Wind	X, R
OW_SI13	Onshore Wind	X
OW_SI14	Onshore Wind	X
OW_SI15	Onshore Wind	X
OW_SI18	Onshore Wind	-
OW_SI19	Onshore Wind	-
OW_SI20	Onshore Wind	-
OW_SI22	Onshore Wind	X
OW_SI23	Onshore Wind	-
OW_SI28	Onshore Wind	X
OW_SI29	Onshore Wind	-
OW_SI30	Onshore Wind	-
OW_SI37	Onshore Wind	X
OW_VI02	Onshore Wind	-
OW_VI04	Onshore Wind	X
OW_VI05	Onshore Wind	-
OW_VI06	Onshore Wind	-
OW_VI07	Onshore Wind	-
OW_VI09	Onshore Wind	-
OW_VI11	Onshore Wind	X
OW_VI12	Onshore Wind	X
OW_VI13	Onshore Wind	-
OW_VI14	Onshore Wind	-
OW_VI15	Onshore Wind	-
Bookhout 2	Pumped Storage	-
Kenyon - Stave	Pumped Storage	-
Knight - Fourth	Pumped Storage	-
Quimper - Bulson	Pumped Storage	X
Upper Clore	Pumped Storage	-
Upper Deserted - Un-named	Pumped Storage	-

Upper Misery - Lower Misery	Pumped Storage	-
Upper Vancouver - Lower Vancouver	Pumped Storage	-
ROR_5018	Run of River Hydro	-
ROR_5101	Run of River Hydro	-
ROR_5332	Run of River Hydro	-
Chemainus_River-8hr	Small Storage Hydro	X, R
Elaho_River-8hr	Small Storage Hydro	X
Freda_Creek-8hr	Small Storage Hydro	X
Kinskuch_River_8h	Small Storage Hydro	X
Nahatlatch_River-8hr	Small Storage Hydro	X
Nimpkish_River_B-8hr	Small Storage Hydro	X, R
Silverhope_Creek-8hr	Small Storage Hydro	X
Siwash_Creek_8h	Small Storage Hydro	X
SSH_South_Creek	Small Storage Hydro	-
SSH_Spuzzum_Creek	Small Storage Hydro	-
SSH_Anudol_Creek	Small Storage Hydro	-
SSH_Ball_Creek	Small Storage Hydro	-
SSH_More_Creek	Small Storage Hydro	-
SSH_Nass_River-8hr	Small Storage Hydro	-
SSH_Squamish_River	Small Storage Hydro	-
Zymoetz_River-8hr	Small Storage Hydro	X
Solar69283	Solar	-
Solar69284	Solar	-
Solar70163	Solar	-
Solar70993	Solar	-
Solar78421	Solar	-
T_2L129	Transmission	-
T_5L003	Transmission	-
T_5L007	Transmission	-
T_5L013	Transmission	-
T_5L042	Transmission	-
T_5L061	Transmission	-
T_5L062	Transmission	-
T_5L063	Transmission	-
T_5L042	Transmission	-

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7.3 FINAL LIST OF ENVIRONMENTAL ATTRIBUTES

Table 5: List of environmental attributes included in the Zonation prioritization. Note that the environmental attributes corresponding to Critical Habitat Terrestrial and Biogeoclimatic Ecosystem Classification in section 7.1 were split into 43 and 16 separate attribute layers, respectively, before being considered in the Zonation prioritization. This led to a total of 71 separate layers (or environmental attributes) contributing to terrestrial environmental attribute prioritization.

Category	Attribute	Number of Layers	Source	Year	Initial Format
Terrestrial	Agricultural Land Reserve (ALR)	1	www.ALR.gov.bc.ca	2020	Polygon
	BC Land Act Conservation Lands	1	DataBC	2020	Polygon
	Critical Habitat Terrestrial (split per species)	43	DataBC	2020	Polygon
	Important Bird Area (IBA)	1	Requested from IBA Canada	2020	Polygon
	Old Growth Management Areas (OGMA)	1	DataBC	2020	Polygon
	Old Growth Extent	1	Derived from Vegetation Resources Inventories (VRI) – Province of BC	2020	Polygon
	Species and Ecosystems at Risk (CDC red, blue, and yellow list)	1	DataBC – Conservation Data Centre (CDC)	2020	Polygon
	Ungulate Winter Range (UWR)	1	DataBC	2020	Polygon
	Wildlife Habitat Area (WHA)	1	DataBC	2020	Polygon
	Undisturbed Areas	1	Hirsh-Pearson, 2020	2020	Raster
	Grizzly Bear Conservation Status	1	DataBC	2020	Polygon
	Biogeoclimatic Ecosystem Classification (BEC) Zones	16	DataBC	2020	Polygon
	Large mammal layer - Bighorn Sheep	1	Blood 2000, Allen et al. 2016	2000-2016	Polygon
	Large mammal layer - Grizzly Bear		Morgan et al. 2019	2019	Polygon
	Large mammal layer - Fisher		Weir 2003, Weir et al. 2012, Sweitzer et al. 2016	2003-2016	Polygon
	Large mammal layer - Mountain Goat		Parks et al. 2015	2015	Polygon
	Caribou range	1	Seip 1992, Polfus et al. 2011, Moreau et al. 2012	1992-2012	Polygon
Freshwater	Fisheries Sensitive Watersheds	1	DataBC	2020	Polygon
	Critical Habitat Freshwater (split per species)	1	Fisheries and Oceans Canada (DFO)	2020	Polygon
	Riparian Zones and Wetlands	1	DataBC	2020	Polygon
	Stream Crossings	1	BC Fish Program	2020	Polygon
	Arctic Grayling	1	Porter et al, 2008	2008	Raster

	Bull Trout	1	Porter et al, 2008	2008	Raster
	Pink Salmon	1	Porter et al, 2008	2008	Raster
	Chum Salmon	1	Porter et al, 2008	2008	Raster
	Coho Salmon	1	Porter et al, 2008	2008	Raster
	Chinook Salmon	1	Porter et al, 2008	2008	Raster
	Sockeye Salmon	1	Porter et al, 2008	2008	Raster
	Steelhead / Rainbow Trout	1	Porter et al, 2008	2008	Raster
	Westslope Cutthroat	1	Porter et al, 2008	2008	Raster
	White Sturgeon	1	Porter et al, 2008	2008	Raster
	Dolly Varden trout	1	Porter et al, 2008	2008	Raster
	Westslope Cutthroat trout	1	Porter et al, 2008	2008	Raster
	Anadromous Salmon Conservation Unit Biological Status	1	Pacific Salmon Foundation	2020	Polygon
Marine	Critical Habitat	1	Fisheries and Oceans Canada (DFO)	2020	Polygon
	Rockfish Conservation Areas	1	Fisheries and Oceans Canada (DFO)	2020	Polygon
	Killer Whale Distribution	1	DataBC	2020	Polygon
	Intertidal Zones	1	DataBC	2020	Polygon
	Important Bird Area (IBA)	1	Requested from IBA Canada	2020	Polygon
	Estuaries	1	Canadian Wildlife Service (CWS)	2020	Polygon
	Ecologically and Biologically Significant Areas (ESBA)	1	BC Marine Conservation Analysts	2020	Polygon
	Ecological Feature Count	1	BC Marine Conservation Analysts	2020	Polygon

7.4 RELATIONSHIP BETWEEN PROJECT ZONATION SCORES AND OVERLAP WITH KEY ENVIRONMENTAL ATTRIBUTES

7.4.1 QUANTIFYING THE OVERLAP BETWEEN PROJECT INFRASTRUCTURE AND KEY ENVIRONMENTAL ATTRIBUTES

To better understand the Zonation-based terrestrial and freshwater scores for each individual project (Section 3.3), we explored the relationship between the scaled weighted terrestrial scores and the approximate overlap of energy projects with a subset of key environmental attributes (Table 6). We provide these proxies (herein called *absolute values*), in simplified units (e.g., km of linear infrastructure in caribou or grizzly habitat), to allow for a more intuitive overview of how individual layers contribute to environmental footprints. However, these *absolute values* only include the linear features (e.g., roads, powerlines) estimated beyond the ATG footprint, as these are subject to less uncertainty compared to the actual siting location of the project (see section 5.2). Exploring these relationships must be considered with caution, as disaggregating and interpreting partial project overlap with a subset of individual environmental layers is not consistent with the intention or scope of the Zonation methodology described above. The Zonation methodology and prioritization algorithm we developed includes all environmental layers deemed to be important for the IRP, as well as their complex interactions in space (e.g.,

complementarity, differences in spatial extent). In contrast, for the calculation of these *absolute values*, we selected a small subset of environmental attributes in each habitat-type based on feedback from BCH (Table 6), and calculated the absolute value of overlap, in familiar units (such as km of new linear features), between projects and individual environmental layers. Importantly, the exploration of the *absolute values* must be regarded as ancillary information to help interpret the Zonation-based scores, not used to explain the Zonation-based scores due to the complexity of Zonation algorithm.

Table 6: List of environmental attributes selected for linear project infrastructure overlap analysis

Caribou Habitat
Conservation Lands
Species and Ecosystem at Risk (red and blue list)
Undisturbed Areas
Old Growth (including old growth management area + old growth extent)
Terrestrial Critical habitat for species at risk
Ungulate Winter Range
Large Mammal Layer (including Bighorn sheep, Grizzly bear, Fisher, and Mountain goat ranges)
Agricultural Land Reserve
Protected Areas
West Moberly Partnership Agreement Conservation areas

7.4.2 EVALUATING RELATIONSHIPS BETWEEN ZONATION SCORES AND PROJECT OVERLAP WITH ENVIRONMENTAL ATTRIBUTES

We assessed the correlation between Zonation-based scores and the overlap of proposed infrastructure with a subset of key environmental attributes in terrestrial (caribou habitat, undisturbed) and freshwater (salmon habitat) habitats agreed upon in consultation with BCH. The goal here was to explore the relationships between Zonation-based scores produced from solving a complex higher-order problem (e.g., terrestrial prioritization included 71 layers and freshwater prioritization included 24 layers) and individual environmental attributes of interest. Importantly, this effort was not intended to provide a validation of the Zonation-based scores for each project, as true validation of the potential environmental impact of projects can only be performed via field-based surveys and assessments. Hence, the *post hoc* analysis described below serves only as a check on whether project infrastructure overlaps with sensitive areas and whether Zonation-based scores reflect such situations.

In addition, it is important to note that the Zonation algorithm and the scaled weighted scores do not prevent the ranking of projects that occur in or cross 'no-go' areas. While overlap with high conservation value areas is penalized by applying the weighting system, it may not result in a high overall Zonation score for a given project. If a project's infrastructure or its ATG footprint occurs in an area that is deemed unsuitable for regulatory, cultural, or other reasons, the projects must be removed from the prioritization in advance.

Using the overlap of linear infrastructure outside of the ATG (Section 37.4.1) we explored the relationship with Zonation scores using a Random Forest algorithm to evaluate the contribution of several environmental layers selected in consultation with BCH (Table 6) to the scaled weighted terrestrial Zonation scores. This classification and prediction algorithm produces a regression tree that uses thresholds in the predictor data (i.e., the absolute values for environmental attribute layers in Table 6; see section 3.4.1) to classify the observations (i.e., summed weighted terrestrial Zonation scores), and yields information on the contribution of each individual environmental layer to the observed patterns of summed weighted Zonation score. Because we applied a weighting scheme to calculate the summed weighted Zonation scores, we took a similar approach and weighted the linear distances for project infrastructure by the same weighting scheme (Table 1). For example, if 1000 m of infrastructure overlaps Zonation scores between 0.5 and 0.6, the length is multiplied by six, and the resulting value used in this analysis is 6000. Thus, while we present absolute values of overlap in Appendix 7.2, the Random Forest algorithm uses weighted distances to evaluate the relative contribution of each environmental layer to the summed weighted Zonation score of each project. We ran the Random Forest algorithm for all one hundred twenty-eight energy projects.

7.4.3 RANDOM FOREST RESULTS

We used Random Forest models to examine the contribution of a subset of key environmental attributes in terrestrial (caribou habitat, undisturbed) and freshwater (salmon habitat) habitats agreed upon in consultation with BCH. Using the summed weighted terrestrial Zonation score as the predicted values, and the weighted absolute values of overlap of linear infrastructure with key environmental attributes (Table 6), we found that the layer with the highest importance in determining a high Zonation score (i.e., for projects with highest potential environmental footprint) was the disturbance layer (i.e., undisturbed areas of the province), followed by grizzly conservation units, old growth forests, ungulate winter ranges, and caribou and large mammals habitat (Figure 12). All of these layers have both large extents (thus high potential for overlapping with project infrastructure) and tend to co-occur in some regions of the province (Rockies, Peace River region). Layers with restricted spatial extents (agricultural land reserves, important bird areas, West Moberly Conservation Agreement) are estimated to make only small contributions to the scaled weighted Zonation scores.

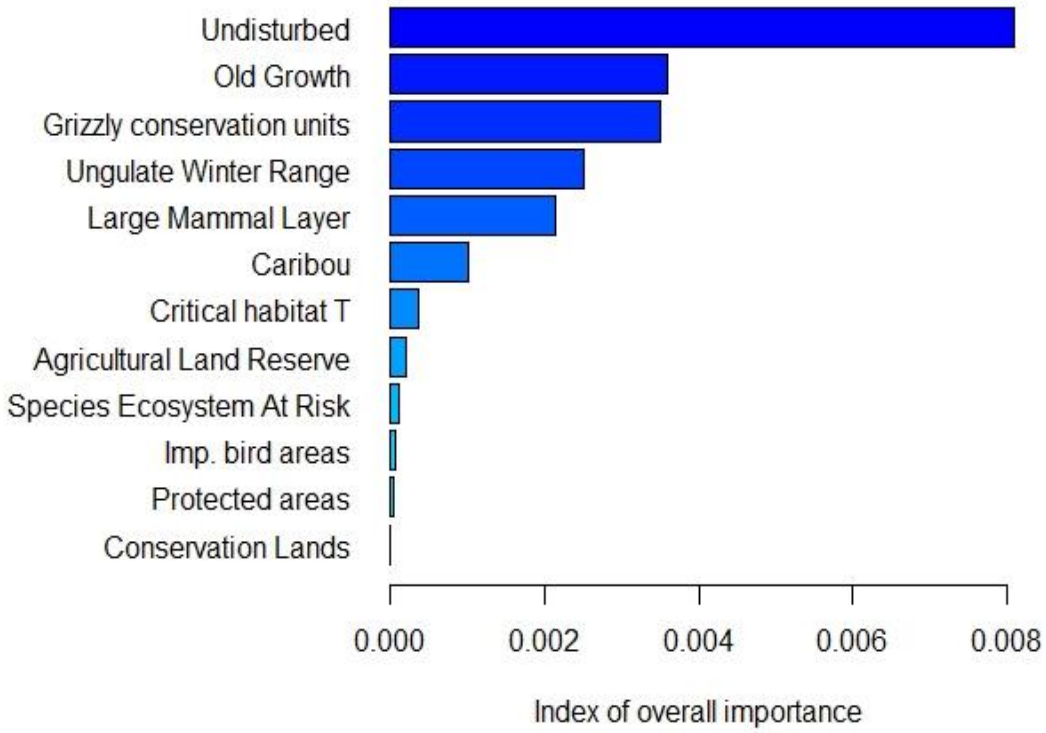

Figure 12: Importance values for selected terrestrial environmental attributes derived from the Random Forest approach.

7.4.4 RANDOM FOREST INTERPRETATION

We explored the relationships between scaled Zonation scores and a subset of key environmental attributes to assess the performance of the Zonation algorithm. The Random Forest approach provides some independent inference regarding the relative importance of key environmental layers in explaining scaled Zonation scores. Within the constraints of this analysis, the Random Forest results indicated that layers with a broad geographic extent that also vary greatly in their values (disturbance, large mammals, grizzly management units) contribute most to the scaled Zonation scores. This was expected because each project we considered had non-zero values for these layers due to their large spatial extent (e.g., Province-wide coverage). In contrast, only a few projects overlapped with caribou habitat or critical habitat for BC listed species, meaning that these single variables have lower overall influence on the scaled Zonation scores when considering all projects.

A key limitation to the approach described here (Random Forest models) is that layers not included in the list of "key environmental layers" are ignored, yet they contribute to the calculation of the Zonation-based values. There are many environmental layers that we did not select for investigating in this *post-hoc* analysis (see Table 6) that contribute to the overall Zonation score (n = 71 for terrestrial, n = 24 for freshwater). In addition, many layers do not intersect with project footprints and will yield an absolute value of 0. For example, no project infrastructure intersects with bat critical habitat, but bat habitat will strongly affect overall Zonation values calculated for all cells because of its small spatial extent and high degree of fragmentation.

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8 GLOSSARY

Absolute values – Proxies created based on a subset of environmental attributes used to explore the relationship between scaled terrestrial Zonation scores and overlap of energy projects (e.g., km in undisturbed).

Aggregate Environmental Footprint – Total environmental footprint, including ATG and linear infrastructure footprints.

Aggregate Scaled Zonation Score - The sum of all scaled Zonation scores (T+FW combined) for a particular set of projects (i.e., Portfolio X, R, no portfolio, and all projects).

ATG – The At the Gate footprint of an energy project includes the spatial footprint of all project infrastructure but excluding linear infrastructure (i.e.; connecting roads and powerlines). Examples of project spatial footprints include reservoirs, turbines, PV infrastructure, powerhouses, etc. Please see section 2.1 for more details on how ATG footprints are calculated for each energy type.

Combined Zonation Score - Combined terrestrial and freshwater summed weighted Zonation score. A single metric that showcases the hierarchy of environmental footprint of the projects. Calculated by summing scaled Zonation score for terrestrial and freshwater. Maximum value of this combined Zonation score is 2. The lower the value, the lower the environmental impact.

Condition layer – An optional input layer that is usually an indicator of landscape condition (characteristics of natural ecosystems and their processes), with values ranging from 0-1, with 1 being areas of highest conservation and ecological value. The condition layer will affect how other input layers affect the Zonation algorithm and outputs by empathising areas of layer overlap with areas of lower landscape condition. The undisturbed layer was previously used as a condition layer in past iterations, but the most recent version of Zonation output does not include a condition layer.

Environmental Attribute - Environmental, biodiversity, or conservation related attributes used as input layers for terrestrial, freshwater, and marine Zonation (please see section 3.1 for more information).

Hierarchical removal mask – An optional input layer that prioritizes the Zonation algorithm to remove the cells overlapped by the layer first so that values within this layer have the highest raw Zonation scores.

Linear infrastructure – The spatial footprint of a project, including all roads and transmission lines and excluding all project spatial footprints.

Scaled Zonation Score – Scaled Zonation score for terrestrial, freshwater, or combined. A product of scaling the weighted sum of Zonation scores for all projects so that each project is ranked from 0-1, with 1 being the project with the highest weighted sum of Zonation score.

Raw Zonation score – The raw value outputted by the Zonation algorithm. Ranges from 0-1, with a uniform distribution of values across all grid cells, with no cells having identical values.

Weighted sum of Zonation score – The sum of the raw zonation scores of all cells that overlap a project multiplied by a weighting scheme. This metric further emphasises the environmental value in the score and accounts for the magnitude/size of the project.