# BEYOND TARGETS:

A PATHWAY FOR PROTECTED AREAS TO HELP MEET BIODIVERSITY AND CLIMATE GOALS IN AN ETHICAL AND RIGHTS-DRIVEN WAY

*Technical Supplement*

*2022*

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## Overview

This analysis identifies ecological representation gaps in Canada's terrestrial protected area network and where they coincide with areas of high importance for biodiversity and climate change to assess areas of conservation priority for the establishment of new protected areas in Canada. The methodology of this analysis builds on the original Assessment of Ecological Representation tool developed by Iacobelli *et al.* (2006), which was used as a decision-support tool for conservation planning. This technical brief will describe the datasets and methodology used for this two-part analysis, including 1) the evaluation of ecological representation of Canada's current protected areas network, and 2) the integration of key conservation values to assess priorities for protected area establishment.

### *What is an Assessment of Ecological Representation?*

Our Assessment of Ecological Representation is a gap analysis that evaluates the ecological representation of Canada's terrestrial protected areas network. Ecological representation encompasses the notion that a protected area network should "represent" all ecosystem types, maintain all populations of native species, ecological and evolutionary processes, and allow for natural environmental change. The Assessment of Ecological Representation provides a measure of how effective an existing protected areas network is by evaluating the network against a set of developed criteria that incorporates considerations of size, connectivity and quality. As a secondary component, the identification of gaps in ecological representation permits subsequent spatial prioritization for the establishment of new protected and conserved areas in the future.

Ecological representation is assessed using several criteria which capture important aspects of a protected area network, such as size, connectivity and quality. Size and connectivity criteria evaluate the degree to which protected areas are adequately large, have sufficient coverage, and are contiguous—elements that are important to maintain viable populations of native species and sustain ecological processes for climate resilience (Martin & Watson, 2016; Schmitz *et al.,* 2015). Alternatively, quality criteria capture the diversity of environmental gradients, shoreline and intactness (i.e., containing minimal roads and development) within protected areas. The following datasets in Table 1 were used in this analysis.

Table 1. Input datasets contributing to the assessment of ecological representation of Canada's protected areas network.

| Dataset | Source | Specifications |
|---|---|---|
| Enduring Features | WWF-Canada<br>Publication date: 2005 | Vector, polygon |
| Natural Disturbance Zones | Olson *et al*., 2001<br>Publication date: 2001<br>Updated: 2004 | Vector, polygon |
| Protected Areas | Canadian Protected and Conserved Areas Database (CPCAD)<br>Environment and Climate Change Canada (ECCC)<br>Publication date: 2022<br>Updated: December 2021 | Vector, polygon |

| | | |
|---|---|---|
| Elevation | Earth Resources Observation and Science Center (EROS)<br>Publication date: November 2010<br>Updated: August 2014 | Raster, DEM<br>30 arc-second resolution |
| Shorelines | Atlas of Canada National Frameworks – Rivers and Lakes<br>Natural Resources Canada<br>Publication date: 2014 | Vector, line<br>1:1 000 000 scale |
| Roads and Seismic Lines | Poley *et al*., 2022 | Vector, line |
| Climate Refugia | Retrieved from AdaptWest<br>Michalak *et al.,* 2018 | Raster<br>1-km resolution |
| Species At Risk | Environment and Climate Change Canada (ECCC)<br>Publication date: 2016 | Vector, polygon |
| Land Cover | North American Land Change Monitoring System (NALCMS)<br>Commission for Environmental Cooperation (CEC)<br>Publication date: 2015 | Raster<br>30-m resolution |
| Carbon Density | Sothe *et al.,* 2022 | Raster<br>250-m resolution |
| Climate Connectivity | Retrieved from AdaptWest<br>Carroll *et al.,* 2018 | Raster<br>300-m resolution |
| Ecological Connectivity | Pither *et al.,* 2021 (preprint) | Raster<br>5-km resolution |

### *Enduring features*

Enduring features are defined as physical habitat components that are anticipated to persist through time. These features account for the regional geology, terrain and topography of a region – essentially the abiotic (or non-living features) that make up a habitat. Enduring features are the unit of analysis used in our Assessment of Ecological Representation for Canada's protected areas network.

Beginning in 1992, WWF-Canada along with the Canadian Council on Ecological Areas (CCEA) coordinated pilot studies to delineate enduring features. Working with academic partners as well as Geomatics International Inc., these studies helped develop a framework for a nation-wide delineation. Based on results of these pilot studies, WWF-Canada developed a method to identify enduring features using the Soil Landscapes of Canada. Each soil landscape was differentiated by its landform, using a combination of topography, texture, and surficial deposits. With this database and using the framework by Geomatics International Inc. (1994), an enduring feature map was created for all of Canada (Figure 1).

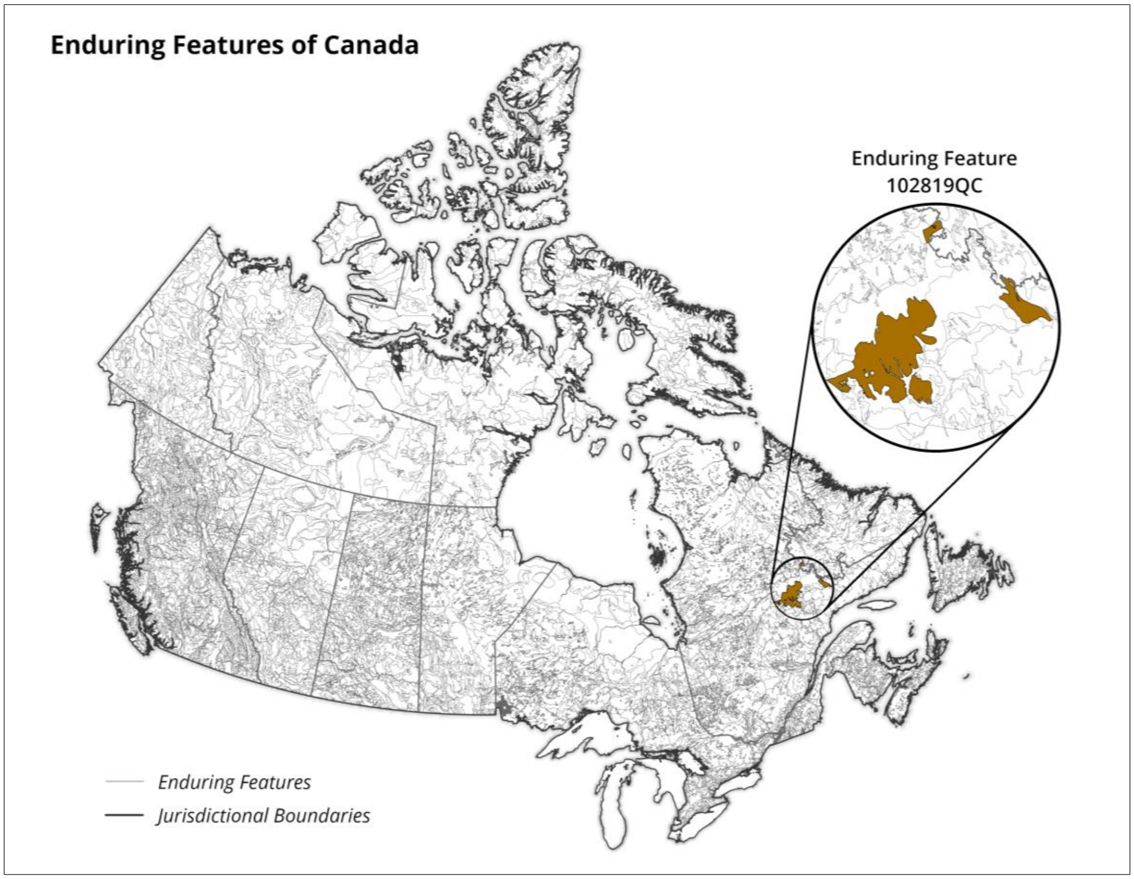


Figure 1. Enduring features of Canada with jurisdictional boundaries.

Enduring features are part of the natural region framework as they are embedded within provincial ecodistricts, which are nested within natural regions (Figure 2). Characterized by similar climate and landscape, natural regions can be grouped together into larger disturbance zones based on similar disturbance regimes, which also provide the basis for size guidelines of protected areas (Figure 3).

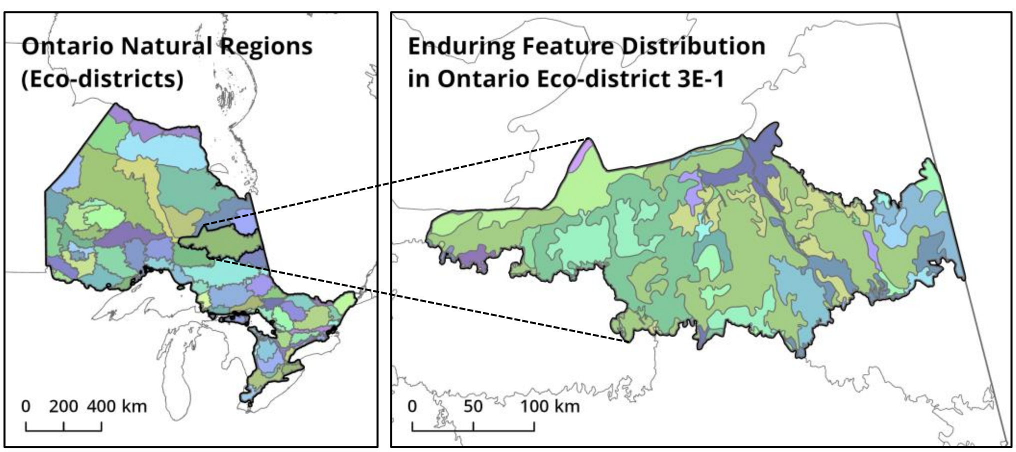


Figure 2. Distribution of enduring features in Ontario, nested within ecodistricts. Data from the Ontario Ministry of Natural Resources (2002).

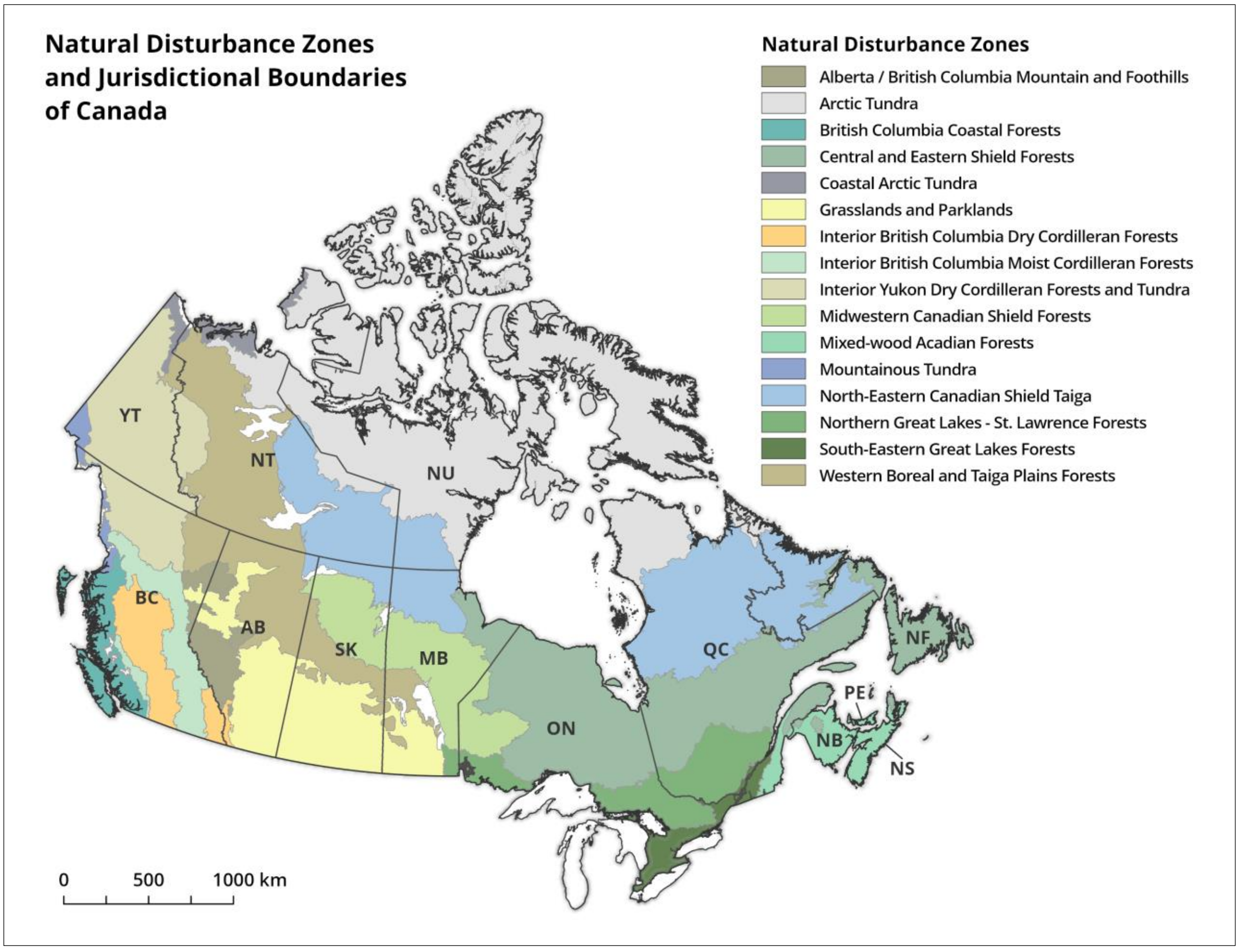


Figure 3. Natural disturbance zones used to define size requirements for protected areas, and jurisdictional boundaries in Canada. Data from Olson *et al.* (2001).

Since the enduring feature dataset was generated by integrating several biophysical regionalization schemes, there are instances of provincial boundary misalignment. Consequently, for this analysis enduring features were re-aligned to current jurisdictional boundaries to improve the spatial accuracy of the analysis and overcome issues associated with misalignment.

*Protected and conserved areas*

An effective, climate-smart protected areas network is necessary for mitigating and adapting to the dual crisis of biodiversity loss and climate change. Protected and conserved areas were obtained from the Canadian Protected and Conserved Areas Database (CPCAD) with data availability to December 2021 (ECCC, 2022). Protected areas were filtered by biome (i.e., selecting for terrestrial protected and conserved areas) as well as their contribution to Aichi Target 11. Interim sites were also included, recognizing their value in contributing to an ecologically representative protected areas network. The filtered dataset resulted in 9,953 protected and conserved areas (Figure 4).

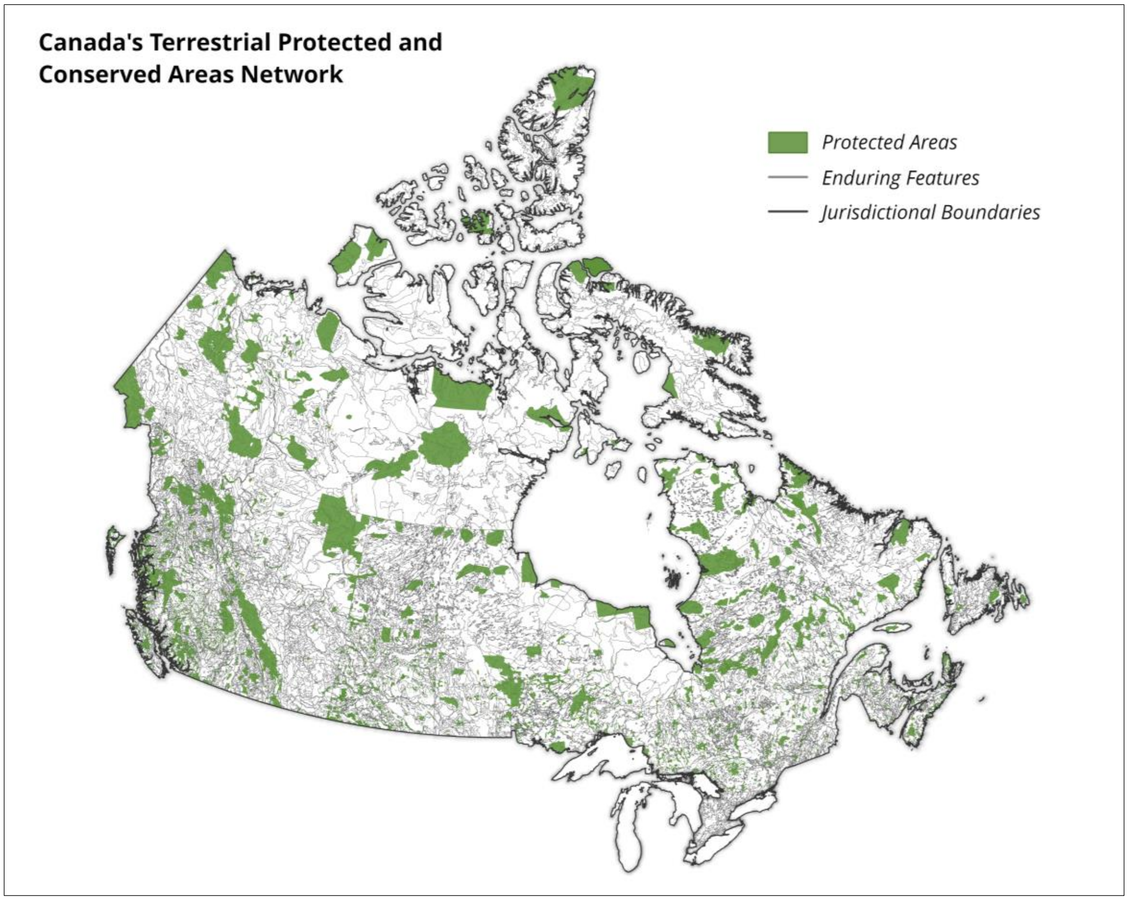


Figure 4. Terrestrial protected areas that contribute to Aichi Target 11 in Canada as of December 2021. Data from Environment and Climate Change Canada (2022).

Prior to the assessment of ecological representation, the protected area dataset was dissolved to remove management-defined boundaries between adjacent sites, and then split into single-part features. This approach permitted the treatment of protected areas as distinct based on their spatial contiguity rather than administrative boundaries.

*Criteria for assessing ecological representation*

To assess ecological representation of the national protected area network, each enduring feature was evaluated using six criteria that included elements of size, connectivity and quality of its protected areas (Figure 5). The calculations and scoring for each metric are explained below.


Figure 5. Criteria used for the calculation of ecological representation.

*Size A: Protected area size*

Protected area size guidelines developed by Iacobelli *et al.* (2006) were used to assess adequate protection for enduring features. These size guidelines were derived to satisfy two guiding principles in the design of effective protected area networks: 1) to account for differing spatial scales of key ecological processes, and 2) to be able to maintain viable populations of native species. Larger protected areas, or greater coverage across several protected areas can capture a range of physical habitats. This provides support for a greater diversity of wildlife, strengthening their resilience to natural disturbances (Cumming *et al.,* 2015). For each natural disturbance zone, a unique log-log equation based on disturbance event patterns (i.e., forest fire size) and the areal requirements of focal species is used to find the minimum protected area size that can sustain ecological function, given the size of an enduring feature. Further detail on the derivation of these equations can be found in the Appendix of Iacobelli *et al.* (2006).

Based on the natural disturbance zone of each enduring feature, the appropriate size threshold equation was chosen and used to find its recommended minimum protected area size. The protected area network was clipped to the enduring feature boundary to identify the largest contiguous protected area mass (Figure 6b), and its size was compared to the recommended size by calculating a percentage between 0 and 100%. This percentage was reclassified into a score between 0 and 5 for largest protected area size, based on the scoring rubric in Table 3.

Table 3. Scoring rubric for ecological representation criteria.

| Representation Criteria | | Scoring Guidelines for Representation Criteria (scores are indicated in brackets) | | | | | |
|---|---|---|---|---|---|---|---|
| **Size:** Protected Area Size | a) Largest single protected area mass in enduring feature | Meets size guideline (≥ 95% of the recommended size is protected) **(5)** | Is ≥ 75% of the recommended size **(4)** | Is ≥ 50% of the recommended size **(3)** | Is ≥ 25% of the recommended size **(2)** | Is < 25% of the recommended size **(1)** | If no protected area exists **(0)** |
| **Size:** Protected Area Coverage | b) Total area protected in enduring feature | Meets size guideline (≥ 95% of the recommended size is protected) and size score A is met **(5)** | Is ≥ 75% of the recommended size **(4)** | Is ≥ 50% of the recommended size **(3)** | Is ≥ 25% of the recommended size **(2)** | Is < 25% of the recommended size **(1)** | If no protected area exists **(0)** |
| **Connectivity:** Adjacent Protected Areas | c) Size of largest contiguous protected area network intersecting the enduring feature | Meets ≥ 95% of recommended connectivity value and size score A is met **(5)** | Is ≥ 75% of the recommended connectivity value **(4)** | Is ≥ 50% of the recommended connectivity value **(3)** | Is ≥ 25% of the recommended connectivity value **(2)** | Is < 25% of the recommended connectivity value **(1)** | If no protected area exists **(0)** |
| **Quality:** Environmental Gradients | Protected areas capture elevational variation within the enduring feature | The modified variance test statistic (ModVar) < 0.05 and size score A is met **(5)** | ModVar < 0.25 **(4)** | ModVar ≥ 0.25 **(3)** | ModVar ≥ 0.50 **(2)** | ModVar ≥ 0.75 **(1)** | If no protected area exists **(0)** |
| **Quality:** Shoreline | Protected areas capture shoreline and stream habitat density of the enduring feature | Protected shoreline density is ≥ 95% of the shoreline density in the enduring feature and size score A is met **(5)** | Protected shoreline density is ≥ 75% of the shoreline density in the enduring feature **(4)** | Protected shoreline density is ≥ 50% of the shoreline density in the enduring feature **(3)** | Protected shoreline density is ≥ 25% of the shoreline density in the enduring feature **(2)** | Protected shoreline density is < 25% of the shoreline density in the enduring feature **(1)** | If no protected area exists **(0)** |
| **Quality:** Intactness | Proportion of unfragmented protected area in an enduring feature | Intact protected area is ≥ 95% of the protected area size and size score A is met **(5)** | Intact protected area is ≥ 75% of the protected area size **(4)** | Intact protected area is ≥ 50% of the protected area size **(3)** | Intact protected area is ≥ 25% of the protected area size **(2)** | Intact protected area is < 25% of the protected area size **(1)** | If no protected area exists **(0)** |

*Size B: Protected area coverage*

Using the same recommended protected area size target as described above, the protected area coverage scores were evaluated. For this criterion, the total sum of protected areas within each enduring feature (Figure 6c) was calculated and compared to the recommended area by calculating a percentage between 0 and 100%. This percentage was reclassified into a score between 0 and 5 for total protected area coverage, based on the scoring rubric in Table 3.

*Connectivity: Adjacent protected areas*

Connectivity is an important component of a well-designed protected areas network. Specifically, we assessed the contiguous extent of protected area coverage beyond the boundaries of the enduring feature. Larger protected area networks tend to capture a greater variety of physical habitats, and the connection between multiple landscapes allow wildlife to migrate for mating and resources. To evaluate this criterion, the largest contiguous protected area that intersects each enduring feature was identified (Figure 6d), and its size was compared to a connectivity value for each enduring feature that differs based on natural disturbance zone. A percentage between 0 and 100% was computed and reclassified into a score between 0 and 5 based on the scoring rubric in Table 3. The ecological rationale for connectivity values can be found in Appendix 7 of Iacobelli *et al.* (2006).

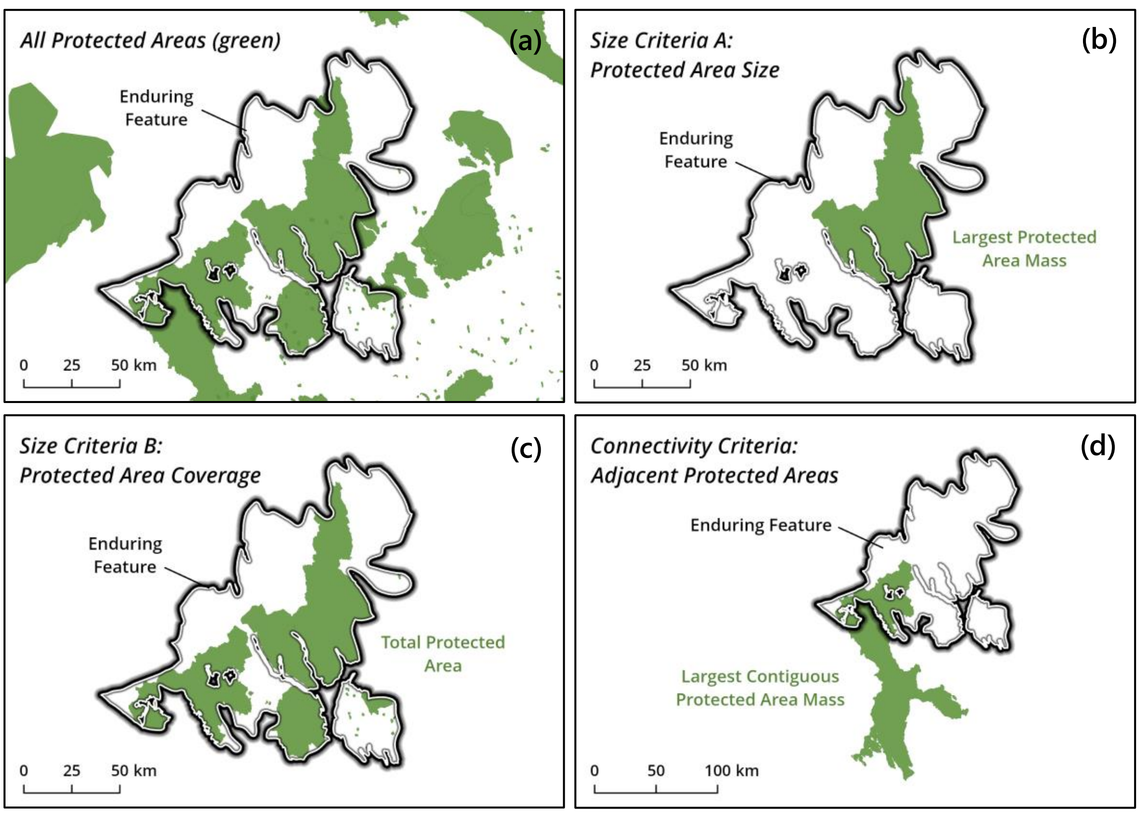


Figure 6. Example of enduring feature with (a) all surrounding protected areas, (b) its largest protected area mass for size criteria A, (c) its total protected area coverage for size criteria B, and (d) its largest intersecting contiguous protected area mass for the connectivity criteria.

*Quality: Environmental gradients*

The environmental gradients criterion assesses how well protected areas capture the range of elevations available in an enduring feature. Topographic variation allows for a greater diversity of soil and climate conditions to support species diversity within different ecological communities (Stein e*t al.,* 2014). To measure how representative protected areas are of the surrounding elevational gradient, a digital elevation model (EROS, 2010) was used to calculate both the mean and standard deviation of elevation for the entire enduring feature, and for all its protected areas. These values were used to calculate the modified variance test statistic as the following equation describes:

$$ModVar_{EF} = \frac{|\mu_{EF} - \mu_{PA}|}{(\sigma_{EF} + \sigma_{PA})/2}$$

where:

| | |
|---|---|
| $ModVar_{EF}$ | is the modified variance test statistic for an enduring feature, |
| $\mu_{EF}$ | is the mean elevation in the enduring feature, |
| $\mu_{PA}$ | is the mean elevation in the protected areas, |
| $\sigma_{EF}$ | is the standard deviation of elevation in the enduring feature, and |
| $\sigma_{PA}$ | is the standard deviation of elevation in the protected areas. |

A larger modified variance test statistic value indicates that the elevation ranges for the enduring feature and its protected portions are more dissimilar; therefore, a smaller value implies that the protected areas can better represent the elevational gradient within the enduring feature. The scores were rescaled between 0 and 1 and reclassified based on the scoring rubric in Table 3.

*Quality: Shoreline*

This criterion assesses the shoreline density of protected areas within each enduring feature. Shorelines, including lake and riparian zone habitats, support a multitude of aquatic and terrestrial species. Furthermore, they also perform important ecological functions such as maintaining water quality and preventing erosion (Postel & Carpenter, 1997). To calculate shoreline density for protected areas in the enduring feature as well as for the entire enduring feature, the total length of shoreline in each area was divided by the area covered. The shoreline density of protected areas was compared to the shoreline density of the enduring feature by calculating a percentage between 0 and 100%. The percentages were reclassified into a score between 0 and 5 based on the scoring rubric in Table 3.

$$P_{SD} = \left(\frac{SL_{PA}/A_{PA}}{SL_{EF}/A_{EF}}\right) * 100$$

where:

| | |
|---|---|
| $P_{SD}$ | is the percentage of protected shoreline density in an enduring feature, |
| $SL_{PA}$ | is the length of shoreline habitat in protected areas, |
| $A_{PA}$ | is the total protected area, |
| $SL_{EF}$ | is the length of shoreline habitat in the enduring feature, and |
| $A_{EF}$ | is the total area of the enduring feature. |

*Quality: Intactness*

The intactness of protected areas within an enduring feature was calculated as the amount of land that remains undisturbed by human activity. Development such as road and seismic lines fragment protected areas, restricting the movement of wildlife and reducing the amount of natural habitat available for species. To measure intactness, road and seismic data were buffered using standard widths of the features (Table 4) and clipped to protected areas within each enduring feature. The area of roads and seismic lines was summed and divided by the total protected area in the enduring feature to produce a footprint of linear disturbance. The percentage was subtracted from 100% to assess the percentage of unfragmented area, and was reclassified into a score between 0 and 5 based on the scoring rubric in Table 3.

$$Unfrag_{PA} = 100 - \left(\frac{A_{frag}}{A_{PA}} * 100\right)$$

where:

$Unfrag_{PA}$ is the percentage of unfragmented area in protected areas,
$A_{frag}$ is the total fragmented area, and
$A_{PA}$ is the total protected area.

Table 4. Road and seismic line width standards as described in Kennedy *et al.* (2019).

| Class | Width (m) | Buffer distance (m) |
|---|---|---|
| Motorway | 30 | 15 |
| Trunk | 30 | 15 |
| Primary road | 30 | 15 |
| Secondary road | 30 | 15 |
| Tertiary road | 15 | 7.5 |
| Residential road | 15 | 7.5 |
| Unclassified road | 15 | 7.5 |
| Track | 3 | 1.5 |
| Seismic line | 3 | 1.5 |

*Calculating the ecological representation of Canada's current protected areas network*

After calculating all scores for the six representation criteria, a total representation score was calculated to identify gaps in ecological representation across the national protected areas network. First, three subscores ranging between 0 to 5 were determined to assess the size, connectivity and quality of protected areas within each enduring feature (Figure 7). The size subscore takes the largest score between criteria for protected area size and protected area coverage; the connectivity subscore is specific to the score for adjacent protected areas; and the quality subscore takes the median score of environmental gradients, shoreline and intactness criteria. Finally, the overall ecological representation score was determined by taking the median of the size, connectivity and quality subscores.


Figure 7. Decision tree for deriving an overall score for ecological representation.

Total ecological representation scores for each enduring feature range from 0 to 5. Areas of no protection (0), very poor (1), poor (2), and fair (3) ecological representation are catagorized as inadequate. Areas of good (4) and very good (5) ecological representation are categorized as adequate. For the second component of our two-part protected areas analysis, only areas with very poor ecological representation or no protection were considered gaps and were therefore considered priorities for protected area establishment (Figure 8).

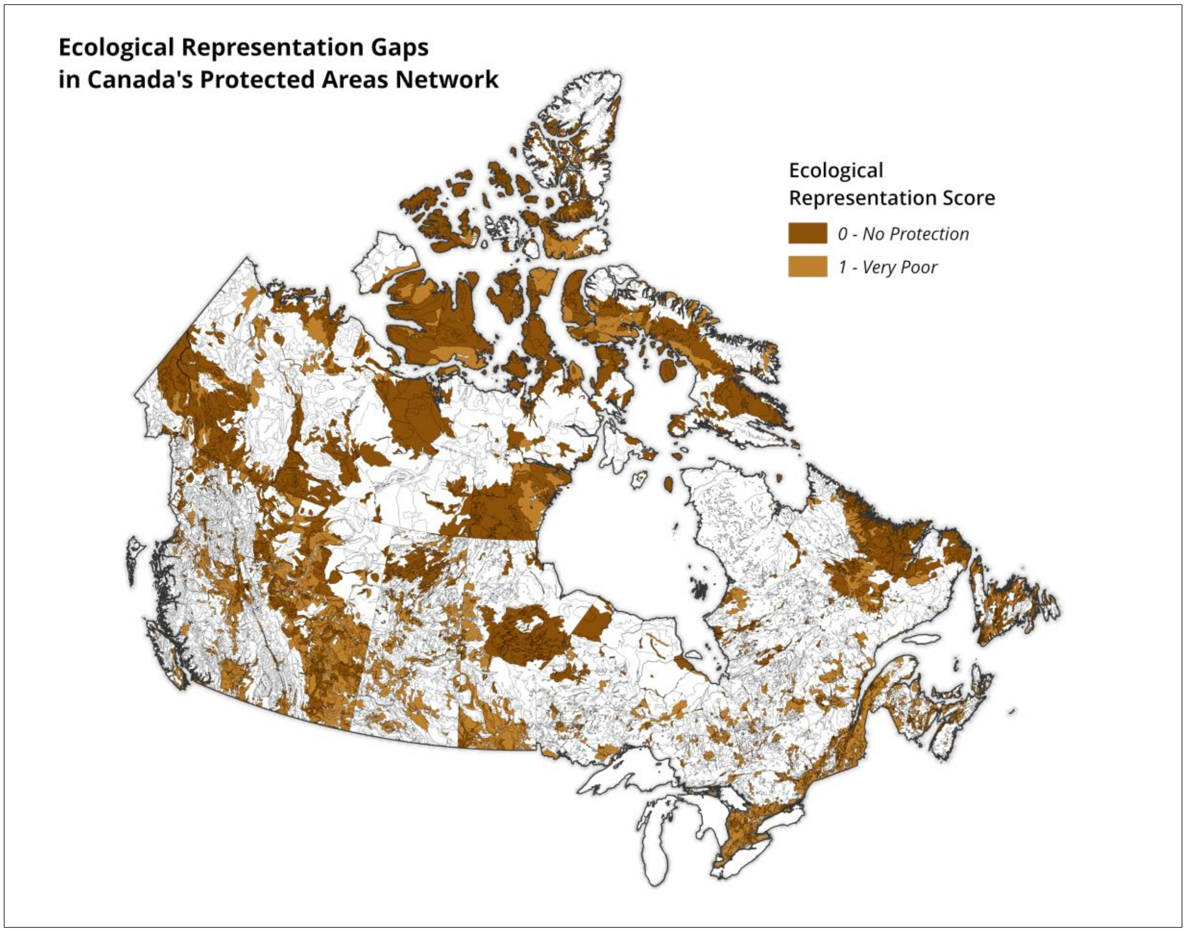


Figure 8. Gaps in ecological representation with a score of 0 or 1 for ecological representation.

***Key considerations for a protected areas network that benefits biodiversity and climate***

Areas that maximize climate and biodiversity benefits act as climate-smart protected areas networks. They enhance ecological representation to deliver upon environmental targets and should be prioritized for protection. Priorities for protected area establishment through the lens of NbCS were identified by selecting for gaps in ecological representation (i.e., scores of no protection or very poor protection) and incorporating key conservation values (i.e., species at risk, carbon, ecological connectivity and climate resiliency).

*Key conservation values*

To identify areas of high conservation value, gaps in the national protected area network were further assessed for their potential value in safeguarding biodiversity and mitigating/adapting to climate change. The four key conservation values assessed in this analysis include species at risk, total carbon density, climate resiliency and ecological connectivity. The methodology and scoring for each are described below.

*Species at Risk*

Areas that support a greater number of vulnerable species should be prioritized to maximize the benefits of protection. Spatial ranges of 458 COSEWIC-assessed species at risk were retrieved from Environment and Climate Change Canada (2016), including those with a status of 'special concern', 'threatened', and 'endangered'. Historical records were removed where new records existed, and the ranges were dissolved by species (COSEWIC ID). In additional to ranges, habitat preferences for each species were assigned using information from COSEWIC assessment reports. Using 30 m-resolution land cover data from the North American Land Change Monitoring System (CEC, 2015) resampled to 250 m, the species ranges were refined to include only land cover types that matched with its individual habitat preferences, including agriculture, forest, grassland, wetlands, settlement, shrubland, sparse vegetation, bare areas, and water. The refined species ranges were overlayed to obtain a raster of species at risk richness across Canada.

For each enduring feature, the maximum number of species at risk was computed and reclassified into five quantiles, each corresponding to a score from 1 to 5. For example, enduring features with the maximum number of species at risk in the lowest quantile (0-20$^{th}$ percentile) receive a score of 1, and those in the highest quantile (80-100$^{th}$ percentile) receive a score of 5. Enduring features for which there were insufficient data or too small of an area to capture meaningful values received a score of 0. Figure 9 shows the maximum number of species at risk by enduring feature, and the resulting scores after distribution of values to each quantile range.

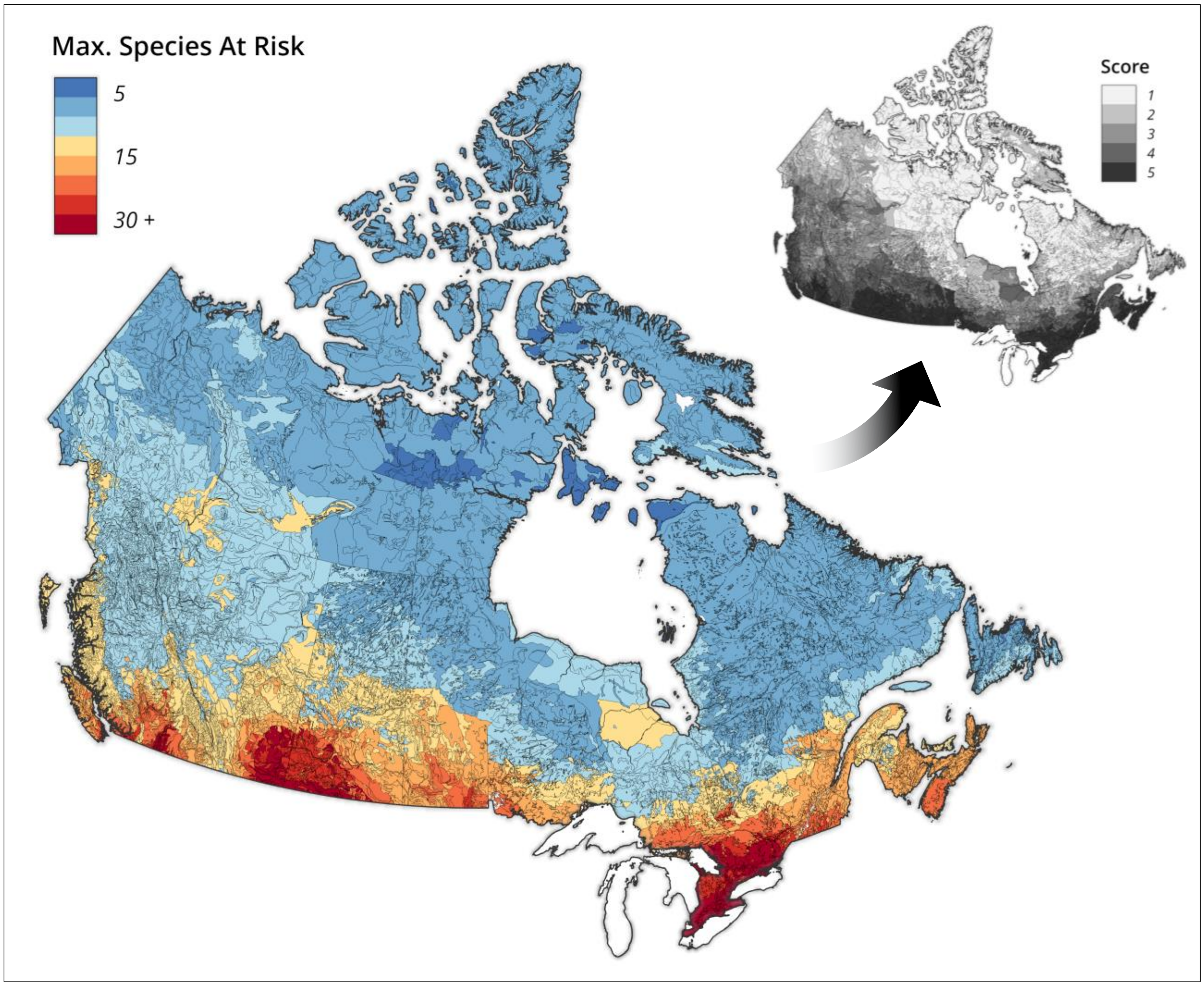


Figure 9. The maximum number of species at risk per enduring feature were binned into five quantiles to obtain a score for this key conservation value from 1-5.

*Carbon density*

Protecting large carbon stocks is imperative for preventing the release of ecosystem carbon to the atmosphere. The average density of ecosystem carbon (aboveground carbon and soil carbon to a depth of 1m) was extracted from Sothe *et al.* (2022). For each enduring feature, the average total carbon density (kg/m$^2$) was computed and reclassified into five quantiles, each corresponding to a score from 1 to 5. Enduring features for which there was insufficient data or too small of an area to capture meaningful values received a score of 0. Figure 10 shows the average carbon density by enduring feature, and the resulting scores after the distribution of values to each quantile range.

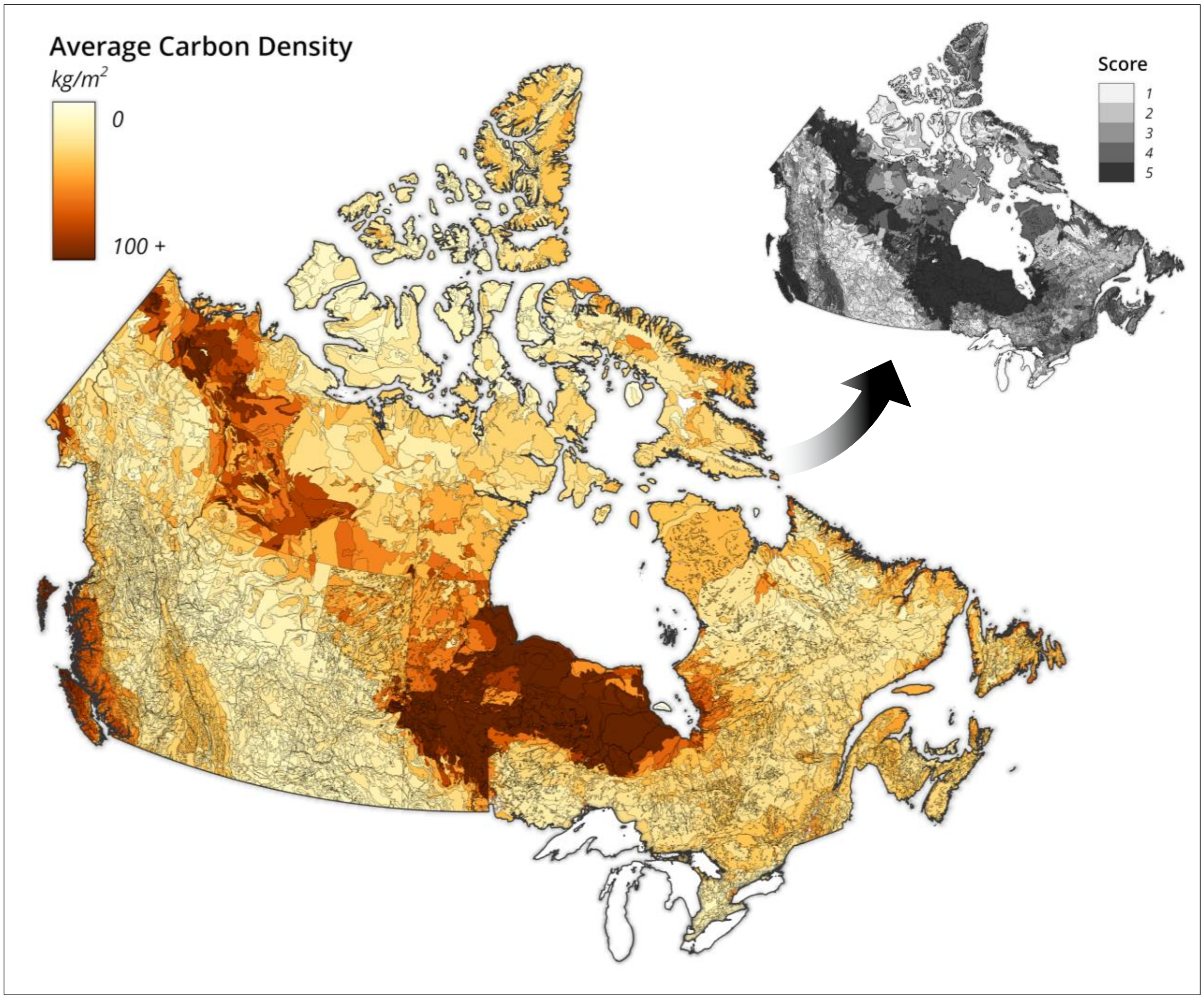


Figure 10. The average total carbon density per enduring feature were binned into five quantiles to obtain a score for this key conservation value from 1-5.

<u>*Climate resiliency*</u>

It is important to protect areas with high climate resiliency, as they provide stable habitats for species in the future despite climate-induced disturbances. Climate resiliency is assessed based on 1) climate refugia, which are areas with unique climate conditions anticipated to remain stable under future climate change, and 2) climate connectivity which represents the presence of corridors between current climates and their future locations for wildlife migration. Potential climate refugia were identified by Michalak *et al.* (2018) using range boundaries for 1000 North American mammal, bird, amphibian and tree species, including areas with less climate sensitivity under different climate change models for 2050. Climate connectivity values were determined by Carroll *et al.* (2018), by modelling the net dispersal flow between current (1981-2010) and projected future (2071-2100) climate types.

The average net dispersal values were found per enduring feature and reclassified into five quantiles, each corresponding to a score from 1 to 5. Enduring features for which there were insufficient data or too small of an area to capture meaningful values received a score of 0. Additionally, enduring features with more than 5% area of potential climate refugia defaulted to a score of 5 for climate resiliency. Figure 11 shows the average net dispersal flow values, location of climate refugia, and resulting climate resiliency scores by enduring feature.

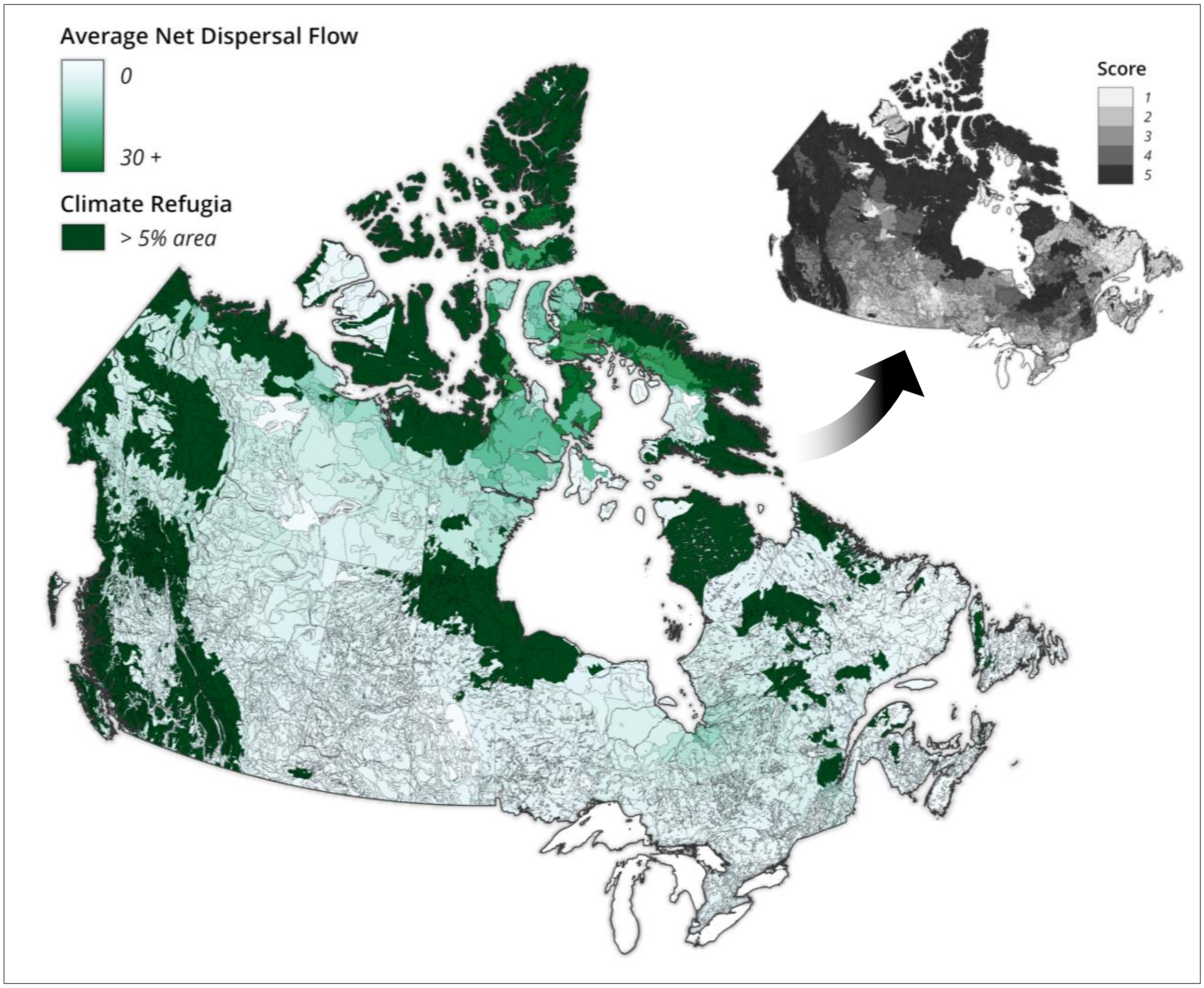


Figure 11. The average net dispersal flow values per enduring feature were binned into five quantiles and combined with the location of climate refugia to obtain a score for this key conservation value from 1-5.

## _Ecological connectivity_

Ecological connectivity, specifically functional connectivity, captures the actual ability of species to move across connected habitats. Aside from the continuity of available habitat and ecological processes, functional connectivity is essential for conserving biodiversity at several scales—through the successful dispersal of species, individuals and genes. Pither *et al.* (2021) developed a multi-species movement cost surface for Canada based on human land cover and land use data, which was analyzed using circuit theory to assess omni-directional connectivity. This resulted in a 300 m-resolution current density raster representing ecological connectivity.

Using the data from Pither *et al.* (2021), the average ecological connectivity value was found for each enduring feature and reclassified into five quantiles, each corresponding to a score from 1 to 5. Enduring features for which there were insufficient data or too small of an area to capture meaningful values received a score of 0. Finally, a simple correlation analysis demonstrated that ecological connectivity and climate connectivity (mentioned previously), were sufficiently uncorrelated to include as distinct key conservation values for our prioritization exercise (Pearson's r = 0.1). Figure 12 shows the average connectivity value by enduring feature and resulting scores after distribution of values to each quantile range.

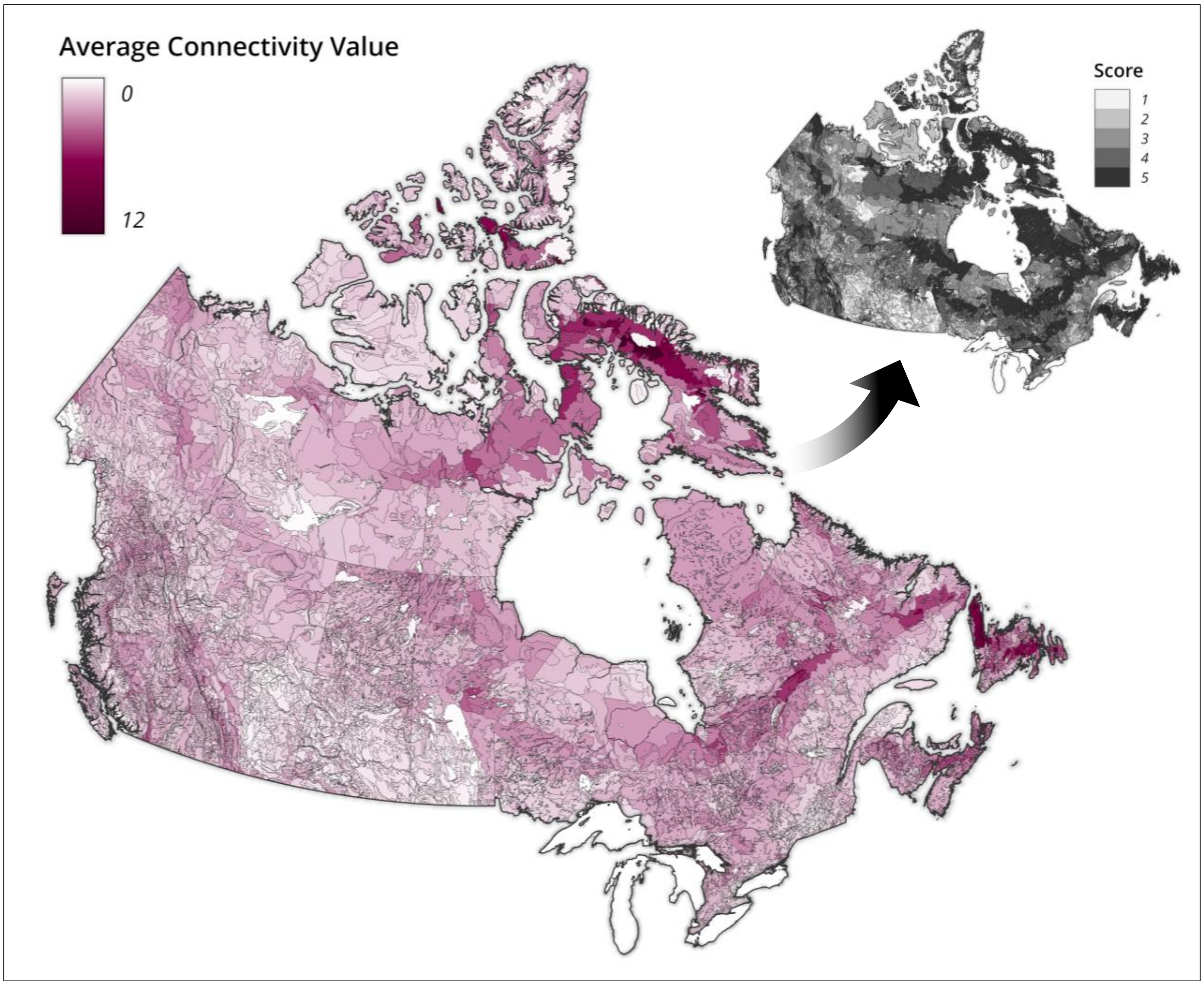


Figure 12. The average ecological connectivity values per enduring feature were binned into five quantiles to obtain a score for this key conservation value from 1-5.

*Identifying priority areas for the establishment of new protected and conserved areas*

To identify and rank areas of priority for the establishment of new protected and conserved areas, ecological representation gaps (i.e., scores of very poor or no protection) (Figure 7) were overlayed with the four key conservation values described above. Ecological representation gaps were given a starting priority score of 1. Within each ecological representation gap, the number of overlapping key conservation values (e.g., species at risk, carbon density, climate resiliency and ecological connectivity) that were classified as high or very high were summed to give a total priority score ranging from 1 (simply an ecological representation gap) to 5 (an ecological representation gap with high values for all four key conservation values). Figure 13 depicts the priority scoring scheme.

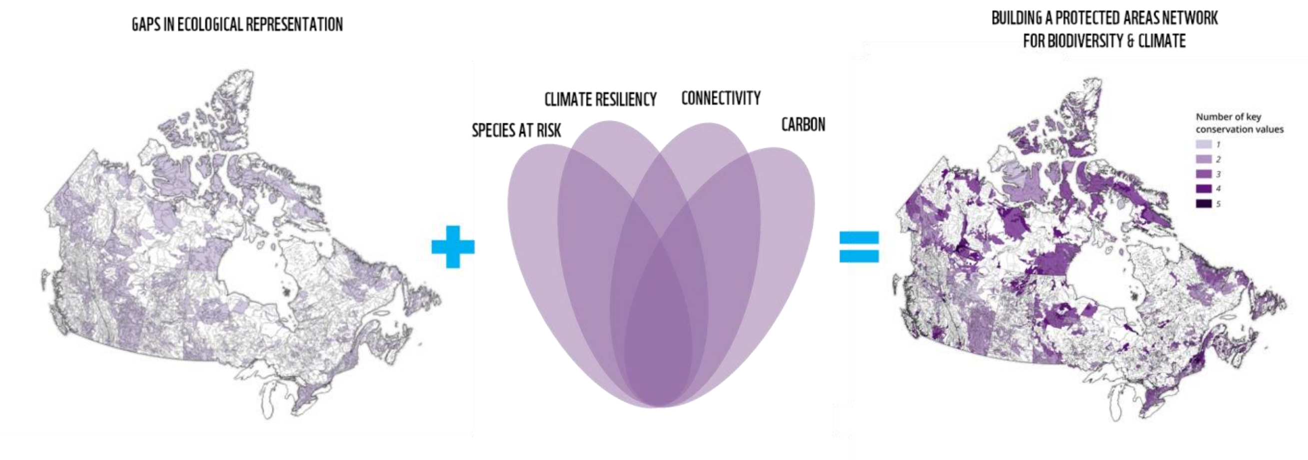


Figure 13. Calculation of the final priority score as the sum of scores for gaps in total representation and four other key considerations.

If you would like to explore areas of priority for protected and conserved area establishment, please visit our [interactive map on Tableau](). Importantly, the final data output for our analysis can be found on [FigShare](). Table 5 describes each attribute in the final data output.

Table 5. Output shapefile attribute summary.

| Column name | Attribute | Type | Unit | Value Limit |
|---|---|---|---|---|
| **FID** | ArcGIS unique identifier | Object ID | | |
| **Shape** | Feature geometry type | Geometry | | |
| **EFCODE** | Enduring feature code | String | | |
| **DIST_ZONE** | Disturbance zone of enduring feature | Double | | |
| **EFZONE_DZ** | Unique identifier for enduring feature code and disturbance zone | String | | |
| **COUNT** | Count of features | Double | | |

| | | | | |
|---|---|---|---|---|
| **LARGESTPA** | Size score A for size of largest protected area (PA) mass within enduring feature | Double | | 0-5 |
| **TOTALPA** | Size score B for size of total PA within enduring feature | Double | | 0-5 |
| **CONNPA** | Connectivity score for size of largest connected PA network intersecting the enduring feature | Double | | 0-5 |
| **ELEV** | Quality score for environmental gradients | Double | | 0-5 |
| **SHORE** | Quality score for shoreline habitats | Double | | 0-5 |
| **INTACT** | Quality score for intactness | Double | | 0-5 |
| **INTACT_PER** | Percentage of unfragmented area in PAs of enduring feature | Double | % | 0-100, No data= -9999 |
| **REFUGIA** | Climate refugia score | Double | | 0 or 1 |
| **MAXPA_AREA** | Area of largest PA mass within enduring feature | Double | Ha | |
| **MAXPA_PER** | Percentage of largest PA mass area to recommended PA size | Double | % | 0-100 |
| **TOTPA_AREA** | Total protected area within enduring feature | Double | Ha | |
| **TOTPA_PER** | Percentage of total PA to recommended PA size | Double | % | 0-100 |
| **CONN_AREA** | Area of largest connected PA network intersecting enduring feature | Double | Ha | |
| **CONN_PER** | Percentage of largest connected PA to connectivity value | Double | % | 0-100 |
| **EMEAN_ELEV** | Mean elevation of enduring feature | Double | | |
| **ESTD_ELEV** | Standard deviation of elevation of enduring feature | Double | | |
| **PMEAN_ELEV** | Mean elevation of PAs in enduring feature | Double | | |
| **PSTD_ELEV** | Standard elevation of PAs in enduring feature | Double | | |
| **MODVARS** | Modified variance test statistic | Double | | No data= -9999 |
| **ELEV_PER** | Modified variance test statistic capped to 0-1 range | Double | | 0-1 |
| **P_RIVERDEN** | River density of PAs in enduring feature | Double | | |
| **E_RIVERDEN** | River density of enduring feature | Double | | |
| **SHORE_PER** | Percentage of PA river density to enduring feature river density | Double | % | 0-100 |
| **PROAD_AREA** | Buffered road and seismic line area within PAs in enduring feature | Double | Ha | |
| **REFUG_AREA** | Area of climate refugia in enduring feature | Double | Ha | |
| **REFUG_PER** | Percentage of climate refugia in enduring feature | Double | % | 0-100 |
| **AOR_SCORE** | Total ecological representation score | Double | | 0-5 |
| **SPECIES** | Maximum number of coinciding species at risk in enduring feature | Double | | 1-42 |
| **SPECIES_5** | Species at risk score | Double | | 0-5 |
| **CARBON** | Average total carbon density in enduring feature | Double | $kg/m^2$ | |
| **CARBON_5** | Total carbon density score | Double | | 0-5 |
| **CLIMCONN** | Average climate connectivity value in enduring feature | Double | | |
| **CLIMCONN_5** | Climate connectivity score | Double | | 0-5 |

| | | | | |
|---|---|---|---|---|
| **CLIMRES_5** | Climate resiliency score combining climate refugia and connectivity scores | Double | | 0-5 |
| **CANCONN** | Average ecological connectivity value in enduring feature | Double | | |
| **CANCONN_5** | Ecological connectivity score | Double | | 0-5 |
| **PRIORITY** | Final priority score with AOR score and 4 key conservation values: species at risk, carbon, climate resiliency and ecological connectivity | Double | | 1-5, 0=not a priority |
| **PROV** | Province of enduring feature | String | | |
| **EF_AREA_HA** | Area of enduring feature | Double | Ha | |

Green: Major criteria and final scores

***Secondary Analyses***

*Lands available for conservation*

To examine the extent to which adequate representation of physical habitats may not be possible in regions with extensive human modification, we undertook an analysis to quantify the amount of remaining natural or near-natural landcover nationally. This was accomplished by integrating a number of existing datasets which describe the extent of human land use, land cover, and human footprint in Canada (Table 6).

Table 6. Categorization of landcover types based on criteria for human-dominated and near-natural landscapes.

| Landcover | Human-Dominated Criteria | Near-Natural Criteria | Source |
|---|---|---|---|
| Urban | Always considered of human origin | Never considered of natural origin | AAFC 2019; CEC 2015 |
| Linear Disturbance | Always considered human-induced | Never considered of natural origin | Poley *et al.,* 2022 |
| Cropland | Always considered human-induced | Never considered of natural origin | AAFC 2019 |
| Barren | HF mining score ≥ 2 (and/ or) HF nighttime lights score ≥ 1 (and/or) HF oil & gas score ≥ 6<br><br>No natural disturbance | HF mining score < 2 (and/ or) HF nighttime lights score < 1 (and/or) HF oil & gas score < 6 | AAFC 2019; CEC 2015; Hirsh-Pearson *et al.,* 2022 |
| Shrubland | HF mining score ≥ 2 (and/ or) HF nighttime lights score ≥ 1 (and/or) HF oil & gas score ≥ 6<br><br>No natural disturbance<br><br>In a forested ecozone | HF mining score < 2 (and/ or) HF nighttime lights score < 1 (and/or) HF oil & gas score < 6 | AAFC 2019; CEC 2015; Hirsh-Pearson *et al*., 2021; Guindon *et al*., 2017 |
| Grassland | HF mining score ≥ 2 (and/ or) HF nighttime lights score ≥ 1 (and/or) HF oil & gas score ≥ 6 | HF mining score < 2 (and/ or) HF nighttime lights score < 1 (and/or) HF oil & gas score < 6 | AAFC 2019; CEC 2015; Hirsh-Pearson *et al.,* 2021; Guindon *et al*., 2017 |

| | | | |
|---|---|---|---|
| | No natural disturbance<br>In a forested ecozone | | |
| Forest | Never considered human-induced | Always considered of natural origin | AAFC 2019; CEC 2015 |
| Wetland | Never considered human-induced | Always considered of natural origin | AAFC 2019; CEC 2015 |

Once combined, these datasets cumulatively depict the amount of land in a natural or near-natural state at a resolution of 250m. This layer was subsequently aggregated by each enduring feature and compared to the area targets for the size-based ecological representation sub-criteria (Figure 6). Logically, any enduring feature which currently possesses less near-natural land cover than what is deemed necessary for adequate ecological representation within the protected area network would necessitate a restore-and-protect approach. In practice however, much remaining natural land cover lies on disparate tracts with various land tenures, and so generally adequate protection of near-natural habitat (i.e., ecological representation scores of “good” and “very good” for all enduring features in Canada) is not practical without significant restoration of degraded and converted landscapes in Canada.

*Case studies*

Our analysis also provided the opportunity to assess the impact of proposed protected areas on the ecological representation of Canada’s terrestrial protected and conserved areas network. A number of prospective Indigenous Protected and Conserved Areas (IPCAs) were selected as case studies: Aviqtuuq, Saskatchewan River Delta, and Seal River Watershed. Proposed IPCA boundaries were merged with the protected areas network before dissolving and splitting protected areas into singlepart features. All scores for enduring features which intersect with the new protected area or network of protected areas connected to the new protected area were recalculated to identify changes in ecological representation scores.

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**Contact:**
Chris Liang, Associate Specialist; GIS & Spatial Analysis; cliang@wwfcanada.org
Jessica Currie, Senior Specialist; Nature-based Climate Solutions; jcurrie@wwfcanada.org
Will Merritt, Specialist; GIS & Spatial Analysis; wmerritt@wwfcanada.org