Research Report

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Central Interior Ecoregional Assessment: Terrestrial ecological system representation in regional conservation planning

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Abstract

This article describes the approach used to incorporate terrestrial ecological systems into regional conservation planning as part of the ecoregional assessment completed by the Nature Conservancy of Canada for the Central Interior of British Columbia, a vast area of 25.7 million ha. The goal of our assessment was to develop a suite of conservation areas that, once protected or managed for conservation, would represent all of the biodiversity and ecosystem functions of the Central Interior. The process involved several teams focussed on different areas (aquatic and terrestrial ecosystems; plant, and animal species). This article describes the efforts of the terrestrial coarse-scale ecological systems team. We developed an ecological systems classification to be used as coarse-filter targets, created an ecoregion-wide map of distribution, and modelled distributions of riparian ecosystems and fine-scale ecological land units to capture elevation and micro-topographic slope and aspect diversity. We also developed minimum dynamic area criteria for large-scale forest ecosystems. The final set of prioritized potential conservation areas covers 7.7 million ha (30%) of the Central Interior. We also integrated climate adaptive strategies into a plan that included large, enduring landscapes with topographic diversity, which allows for species movement or migration and populations of species at the northern limit of their range within the Central Interior.

KEYWORDS: *biodiversity; British Columbia; Central Interior Ecoregional Assessment; climate change; conservation planning; Marxan analysis; Nature Conservancy of Canada; terrestrial ecological systems.*

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Introduction

Ecoregional assessments provide a regional-scale, biodiversity-based context for implementing conservation efforts. The intent of the assessments is to create a shared vision for agencies and other organizations at the international, national, provincial, and local levels to form partnerships and ensure efficient allocation of conservation resources. The Nature Conservancy of Canada conducted an ecoregional plan to develop a selection of prioritized conservation areas that, if protected or managed for conservation, could represent all of the biodiversity in the Central Interior Ecoregion (Iachetti and Howard 2011). This assessment seamlessly incorporated all lands, with the resulting suite of areas covering both private and Crown-owned lands. We leave the specific type of conservation implementation to the Nature Conservancy of Canada, its partners, and all who care about protecting biodiversity in British Columbia.

Several teams conducted the assessment including

- an aquatic team responsible for including coarse-scale aquatic systems and fine-scale aquatic species;
- a terrestrial team responsible for including coarse-scale and fine-scale ecological systems (vegetation mapping of uplands, wetlands, and riparian areas);
- a terrestrial team responsible for including plant species;
- a terrestrial team that focussed on animal species, from large-scale, wide-roaming carnivores to fine-scale small creatures (vertebrates and invertebrates);
- a team to incorporate climate change considerations;
- a team to include ecosystem services and carbon sequestration; and
- a technical team to conduct the geographic information systems (GIS) processing.

Many of these teams also have articles in this issue. The assessment used Marxan, a computerized decision support tool for reserve system design. This tool is helpful when the primary goal is to achieve a representation of biodiversity (species and ecosystems) using the most efficient amount of land (or with the least cost) (Ball and Possingham 2000; Game and Grantham 2008). The Marxan process involves selecting conservation targets (representative ecosystems and species) and identifying threats to those targets (included in the suitability index). Each assessment unit contains values for targets and threats and Marxan tries to select a group of assessment units that meet the target goals while minimizing threats. It is a powerful tool that computes all possible combinations of assessment units through millions of iterations until a "best solution" is achieved. The "best solution" is a suite of single and aggregated assessment units that meets as many goals as possible for all targets with the lowest possible amount of threat. Inputs from all teams were included in the Marxan analysis. For more details on the Marxan methods used in this analysis, see Loos (2011).

> *The Nature Conservancy of Canada conducted an ecoregional plan to develop a selection of prioritized conservation areas that, if protected or managed for conservation, could represent all of the biodiversity in the Central Interior Ecoregion.*

This article describes the approach used by the terrestrial team to incorporate coarse-scale and fine-scale terrestrial ecological systems into the conservation assessment. The Central Interior ecoregion encompasses the Sub-Boreal Interior and Central Interior ecoprovinces (Demarchi 1996), which are contained entirely within British Columbia. This ecoregion covers 25.7 million ha and includes vast areas of spruce, subalpine fir, Douglas-fir, and lodgepole pine forests from foothill to subalpine elevations. It also contains alpine areas, many streams and lakes, wetlands and riparian areas, high flat plateaus, several mountain ranges, and deep river valleys (see Map 1 from Nature Conservancy of Canada, 2010).[1] The vegetation of the ecoregion is primarily forested but contains a wide diversity of ecosystems as it spans several gradients of environmental transitions—from coastal maritime influence in the west to sub-boreal climate in the interior, becoming true boreal in the north, gradually changing to the warmer lowland interior climate toward the Okanagan plateau in the south, and transitioning again as it rises to meet the Rocky Mountains in the east.

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[1] Throughout this article, we refer to maps that available online at *http://science.natureconservancy.ca/resources/docs/CI_ERA_Maps_sm.pdf*.

Our Terrestrial Ecosystems team consists of ecologists with expertise on plant community classification and vegetation mapping. We developed:

- an ecological system classification to be used as targets;
- a seamless ecoregion-wide distribution map of ecological systems for the entire study area;
- modelled distributions of wetland and riparian ecosystems; and
- fine-scale ecological land units to capture unique combinations of elevation, micro-topographic slope and aspect.

We also developed minimum dynamic area criteria for large-scale forest ecosystems and incorporated additional targets to account for climate change, as well as assigned goals for the terrestrial targets to be used in the multi-component site-selection process.

Terrestrial targets

In this assessment, a "target" is an ecosystem or species we wish to conserve; the term "goal" refers to the number of populations or total area we hope to obtain. To design a suite of conservation areas, we wanted to represent all of the biodiversity in the region such that what is protected will capture known and unknown species, plant communities, and the ecological processes on which they depend. Our design encompassed the fine-filter/coarse-filter approach (Groves 2003). Fine-filter conservation targets are those small-scale plant communities (e.g., at-risk communities) for which we have specific location information. Coarse-filter conservation targets are large-scale ecosystems that capture forested landscapes, local patchy shrublands, large and small grasslands, and riparian areas that can be mapped or modelled. The word "filter" means that although we want to represent and capture all terrestrial species and ecosystems within the conservation design, we acknowledge we do not have the data to do so; by including large ecosystems, we can incorporate species into the assessment that we cannot account for individually. To accomplish this goal, the Terrestrial Ecosystems team developed a set of targets for the ecoregion that included fine-filter (plant communities) and coarse-filter (ecological systems) spatial representations of these targets (models and maps), uncertainties in the representation of coarse- and fine-filter targets, and documentation of how conservation goals are defined within this context.

NatureServe ecological systems concept

NatureServe is a non-profit organization that standardizes biodiversity information for conservation purposes (*http://www.natureserve.org*). It is the umbrella organization for natural heritage programs and conservation data centres throughout the western hemisphere. The British Columbia Conservation Data Centre is one of NatureServe's member programs. NatureServe has developed and maintains the International Vegetation Classification, a hierarchical classification of vegetation types from broad formations (Forests, Shrublands, Herbaceous, Barrens) to fine-scale plant associations. In addition, NatureServe has developed a classification of "ecological systems" as a mid-scale unit that is practical for mapping land areas (Comer et al. 2003). An ecological system is a dynamic assemblage of plant communities that occur together on the landscape and are tied together by similar ecological processes such as underlying abiotic environmental factors or gradients. Ecological systems form a readily identifiable unit on the ground at intermediate geographic scales of 10s–1000s of hectares, and generally persist for 50 or more years (and thus include seral stages) (Comer et al. 2003). These systems have been mapped for the entire contiguous United States (NatureServe 2009). In British Columbia, ecological systems have been developed, mapped, and used for conservation planning by the Nature Conservancy of Canada in ecoregions surrounding the Central Interior except to the north. These ecoregions are the Canadian Rocky Mountains (to the east), the Okanagan (to the south), the Northern Cascade and Pacific Ranges (to the Southwest), and the Coastal Forest and Mountains Ecoregions (to the west) (see *http://science.natureconservancy.ca/initiatives/ecoregmap_w.php*).

To represent the terrestrial coarse filter, the Terrestrial Ecosystems team developed a set of ecological systems for the Central Interior through an iterative process of review and modification.

Interior British Columbia

British Columbia has developed a provincial biogeoclimatic ecosystem classification (Meidinger and Pojar [editors] 1991). The terrestrial, wetland, and riparian ecological systems proposed here for the Central Interior were developed from the field data collected to support the biogeoclimatic vegetation, zonal, and site classification, and other provincial sources. Published tables of plant species abundance by biogeoclimatic unit (e.g., zone/subzone/variant/phase) and by site series (e.g., DeLong et al. 1993), along with environmental setting information and inventory data (Vegetation Resource Inventory 2005), was used to describe each ecological system. Areas with similar species composition in overstorey and understorey layers and similar environmental habitats form the basis for each ecological system. For example, the site series "SBS mc 2/01," which occurs on mesic well-drained slopes where hybrid spruce (*Picea glauca* × *engelmannii*) is the dominant tree often co-dominated with lodgepole pine or subalpine fir (*Abies lasiocarpa*), was included in the "North Pacific Sub-Boreal Mesic Hybrid Spruce Forest Ecological System." In another example, the site series "BWBSdk 1/03" is called "White Spruce–wildrye–toadflax," which occurs on dry rocky ridges where fires are frequent; however, the stand data show that lodgepole pine (*Pinus contorta*) is the dominant tree with few other tree species present. This site series was therefore included in the "North Pacific Sub-Boreal Dry Lodgepole Pine Forest Ecological System." In this later example, fire is the driving environmental factor, and thus such a site series will be included in a lodgepole pine system and not a hybrid spruce system (see Table 1 for more examples of biogeoclimatic units used to develop ecological systems).

Seral stages that tend to last less than 50–70 years after disturbance are included in the concept of most forested systems, such that mapped areas of biogeoclimatic units may include seral stands of aspen or lodgepole pine, and will be called by the expected forest type that the stand succeeds to within 50–70 years. Therefore, stands of lodgepole pine that are co-dominant with hybrid spruce on moist sites will be included in a hybrid spruce ecological system because fire occurs infrequently and lodgepole pine will become sub-dominant to hybrid spruce within 50–70 years. Some lodgepole pine forests, which burn more frequently and are classified through biogeoclimatic ecosystem classification as a spruce type because of the presence of spruce in the understorey, were classified as a lodgepole pine ecological system because fire maintains the dominance of lodgepole pine. Therefore, the ecological system classification is based on existing vegetation and the ecological processes that maintain the system and not on potential vegetation (Comer et al. 2003).

The main source of information for ecological systems within the Central Interior region was found in the B.C. Ministry of Forests, Lands and Natural Resource Operations' field guide series to site identification and interpretation. In all, twenty-three references were used to develop and map ecological systems (Douglas 1980; Mitchell and Green 1981a and 1981b; Pojar et al. 1984; Roberts 1984; Pojar 1986; DeLong 1988, 2003, 2004; Meidinger et al. 1988; Steen and Roberts 1988; Burns and Honkala [technical co-ordinators] 1990; DeLong et al. 1990, 1993, 1994; Lloyd et al. 1990; MacKinnon et al. 1990; Meidinger and Pojar [editors] 1991; Banner et al. 1993; MacKenzie and Moran 2004; MacKenzie and Meidinger 2006; B.C. Ministry of Sustainable Resource Management 2005; Vegetation Resource Inventory 2005; ***http://www.for.gov.bc.ca/hre/becweb***).

Mapping of ecological systems

Although site series information was used to develop each ecological system and its description, only biogeoclimatic units have been mapped province-wide (see ***http://www.for.gov.bc.ca/hre/becweb***).[2] In crosswalking biogeoclimatic unit information to ecological systems, we used the existing map of biogeoclimatic units to represent ecological system distribution for the Central Interior. Only ecological systems that included zonal site series were mapped (see Tables 1 and 2); however, non-zonal wetland and riparian ecological system distributions were modelled (see "Wetland and Riparian Ecological Systems" below). Finer-scale mapping is preferable, especially to represent the drier non-zonal systems within variants (e.g., rocky ridges), but this was simply not possible for the entire 27 million ha Central Interior Ecoregion. In addition, Vegetation Resources Inventory forest data and leading species polygons (B.C. Ministry of Sustainable Resource Management 2005; Vegetation Resource Inventory 2005) were overlain on biogeoclimatic units as another source of existing vegetation, as the biogeoclimatic maps show potential vegetation and we wanted to represent existing vegetation as much as possible. Based on this additional information and local expert knowledge, these polygons were incorporated into the ecological systems map.

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[2] All data layers used for mapping were acquired by the Nature Conservancy of Canada in 2006 through the Integrated Land Management Bureau's Land and Resources Data Warehouse (***http://www.lrdw.ca***). Terrestrial Ecosystem Mapping (Resources Inventory Committee 2000) data was not used, as it was not available across the entire area.

TABLE 1. Example of how the zonal site series of each biogeoclimatic unit were combined into ecological systems (see *http://www.natureserve.org/explorer*). Drier and wetter site series within each biogeoclimatic unit (e.g., 02 or 09 may be placed into separate ecological systems). For zone/subzone/variant definitions, see *http://www.for.gov.bc.ca/hre/becweb*.

Ecological system	Biogeoclimatic unit	Hectares
North Pacific Sub-Boreal Dry Lodgepole Pine Forest	MSdv	36 443
	MSxk	14 613
	MSxv	880 121
	SBPSdc	399 817
	SBPSmc	324 794
	SBPSmk	493 235
	SBPSxc	1 118 963
North Pacific Sub-Boreal Mesic Hybrid Spruce Forest	SBSdk	1 061 247
	SBSmc1	33 647
	SBSmc2	2 210 775
	SBSmc3	265 558
	SBSmk1	1 397 577
	SBSmk2	388 639
	SBSwk1	550 212
	SBSwk2	507 762
	SBSwk3	444 755
North Pacific Sub-Boreal Mesic Hybrid Spruce–Douglas-fir Forest	SBSdw1	412 805
	SBSdw2	471 900
	SBSdw3	971 743
	SBSmh	108 179
	SBSmw	218 402

TABLE 2. Mapped ecological systems and modeled riparian ecosystems used in Marxan runs for the two ecoregions included in the study area: Central Interior and Sub-Boreal Interior. Descriptions of ecological systems are available at *http://www.natureserve.org/explorer*.

Mapped ecological systems	Total area (ha)
CENTRAL INTERIOR ECOREGION TERRESTRIAL ECOSYSTEMS	
Boreal Alpine Fescue Dwarf Shrubland and Grassland	461 913
North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow	330 623
North Pacific Interior Dry Douglas-fir Forest	226 495
North Pacific Interior Dry–Mesic Conifer Forest (Pl, Fd, Sxw, Cw, Bl)	12 399
North Pacific Interior Lodgepole Pine–Douglas-fir Woodland and Forest	1 186 582
North Pacific Interior Wet Toeslope/Riparian Hybrid Spruce–Western Redcedar Forest	262 199
North Pacific Interior Wet Toeslope/Riparian Mixed Conifer Forest	53 010
North Pacific Interior Wetland (Swamp, Bog, Fen and Marsh) Composite	410 492
North Pacific Maritime Mesic–Wet Douglas-fir–Western Hemlock Forest	27 440
North Pacific Mesic Western Hemlock–Silver Fir Forest	14 731
North Pacific Montane Riparian Woodland and Shrubland	71 601
North Pacific Mountain Hemlock Forest	83 679
North Pacific Mountain Hemlock Parkland	22 423
North Pacific Sub-Boreal Dry Lodgepole Pine Forest	2 810 561
North Pacific Sub-Boreal Mesic Hybrid Spruce Forest	2 054 670

TABLE 2. (Continued)

Mapped ecological systems	**Total area (ha)**
North Pacific Sub-Boreal Mesic Hybrid Spruce–Douglas-fir Forest	1 194 382
North Pacific Sub-Boreal Mesic Subalpine Fir–Hybrid Spruce Forest	1 184 622
North Pacific Sub-Boreal Mesic Subalpine Fir–Hybrid Spruce Parkland	90 399
North Pacific Sub-Boreal Riparian Woodland and Shrubland	39 377
North Pacific Sub-Boreal Wet Toeslope/Riparian Hybrid Spruce Forest	44 545
Northern Rocky Mountain Dry–Mesic Montane Mixed Conifer Forest (Fd and Py)	29 257
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	102 123
Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	77 280
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	946
Rocky Mountain Subalpine Mesic–Wet Spruce–Fir Forest and Woodland	40 528
Rocky Mountain Subalpine–Montane Riparian Shrubland	758
No data	111 794
Total Central Interior Ecoregion terrestrial systems	***10 944 829***
Total Central Interior Ecoregion subunit area	***11 399 139***
Sub-Boreal Interior Ecoregion terrestrial ecosystems	
Boreal Alpine Fescue Dwarf Shrubland and Grassland	1 312 918
Boreal Open Scrub/Willow Peatland	79 516
Boreal White Spruce Forest and Woodland	623 091
North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow	29 800
North Pacific Hypermaritime Sitka Spruce Forest	2105
North Pacific Interior Dry–Mesic Mixed Conifer Forest (Pl, Fd, Sxw, Cw, Bl)	123 912
North Pacific Interior Wet Toeslope/Riparian Hybrid Spruce–Western Redcedar Forest	226 354
North Pacific Interior Wet Toeslope/Riparian Mixed Conifer Forest	346 671
North Pacific Interior Wetland (Swamp, Bog, Fen, and Marsh) Composite	345 338
North Pacific Montane Riparian Woodland and Shrubland	57 836
North Pacific Mountain Hemlock Forest	2501
North Pacific Sub-Boreal Mesic Hybrid Spruce Forest	3 661 880
North Pacific Sub-Boreal Mesic Hybrid Spruce–Douglas-fir Forest	690 032
North Pacific Sub-Boreal Mesic Subalpine Fir–Hybrid Spruce Forest	3 583 405
North Pacific Sub-Boreal Mesic Subalpine Fir–Hybrid Spruce Parkland	835 468
North Pacific Sub-Boreal Riparian Woodland and Shrubland	13 716
North Pacific Sub-Boreal Wet Toeslope/Riparian Hybrid Spruce Forest	334 934
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	141 204
Rocky Mountain Subalpine Mesic–Wet Spruce–Fir Forest and Woodland	1 291 794
Rocky Mountain Subalpine-Montane Riparian Shrubland	6634
No data	36 421
Total Sub-Boreal Ecoregion terrestrial systems	***13 745 528***
Total Sub-Boreal Ecoregion subunit area	***14 286 349***
Total mapped and modelled ecological systems	**24 690 357**
Total Project Area	***25 685 488***

Table 2 lists all mapped ecological systems and their respective hectare areas. As mentioned above, not all ecological systems could be represented on the map either because of the very small scale of the occurrences, a lack of data, or because they occur only in the narrow outer fringes of the ecoregion (Table 3). We assumed that many of these unmapped systems were captured within the scale of the surrounding ecological systems or were represented by modelled riparian areas or ecological land unit topography (see "Ecological Land Units" below). Because these systems could not be individually represented on the map, they were not included as targets in the ecoregional plan. To view the final ecological systems map, see Nature Conservancy of Canada (2010).

Wetland and riparian ecological systems

Wetland and riparian ecosystems were compiled and described from published site series (e.g., Sub-Boreal Spruce wetlands and Interior Douglas-fir wetlands; DeLong et al. 2003; Mackenzie and Moran 2004). To map these ecosystems, we modelled their locations by buffering lakes and streams represented by mapped hydrology data from the Corporate Watershed Base.[3] The following three separate components were generated and merged together to create the riparian systems layer.

1. Riparian systems were modelled for the study area using a 25 × 25 m Digital Elevation Model (DEM), and specifying a 20 km^2 catchment area, a method developed by Mike Heiner for the Okanagan Ecoregional Plan (see Pryce et al. 2006, Appendix 9, Section 2.2).
2. River polygons (double linework) in the Corporate Watershed Base 1:20 000 data[4] were buffered using criteria based on provincial guidelines[5] as follows: (a) river segments over 100 m wide and at least 1 km long = 100 m buffer, (b) river segments 20–100 m wide = 70 m buffer, (c) river segments 5–20m wide = 50 m buffer, (d) river segments 1.5–5 m wide = 40 m buffer, (e) river segments < 1.5 m = 30 m buffer.
3. Lake features in the Corporate Watershed Base were buffered out to 50 m based on core team and expert discussions.

Before combining the above three riparian layer components, the riparian layer inputs were processed using the following method.

- Corporate Watershed Base lake and river polygon features were overlaid with, and used to override, DEM-modelled riparian data.
- Wetland polygons (developed from TRIM 1:20 000 data) were overlaid with, and used to override, DEM-modelled riparian data and Corporate Watershed Base river and lake polygon buffer data.
- Baseline Thematic Mapping (1:250 000)[6] polygon data representing urban, agricultural, and mixed agricultural areas were overlaid with, and used to override, DEM-modelled riparian data and Corporate Watershed Base river and lake polygon buffer data.
- Slivers created during the overlay/override processes were removed; slivers were defined as any riparian polygon features with an area less than 25 m^2.
- Any polygons originating from the DEM with an area less than 625 m^2 were removed. The rationale employed was that the DEM-modelled riparian data were generated from a 25 × 25 m grid, where each grid cell has an area of 625 m^2 and therefore riparian polygons smaller than this were likely the result of an overlay/override process.

Depending on the local hydrology layer, elevation, and geography, riparian and wetland systems were classified to an ecological system in the following manner.

- Wetlands not associated with streams were identified as North Pacific Interior Wetland (Swamp, Bog, Fen, and Marsh Composite).
- Foothill and lower montane elevations stream segments east of the Fraser River in the Central Rocky Mountains section were modelled as Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland.
- Higher montane and subalpine elevations stream segments were modelled as Rocky Mountain Subalpine–Montane Riparian Shrubland.

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[3] Data acquired March 31, 2006 from the Corporate Watershed Base, a watershed atlas and associated stream and lake networks. Based on TRIM 1:20 000 digital topographic base map (*http://archive.ilmb.gov.bc.ca/crgb/products/mapdata/corporate_watershed_base_products.htm*).

[4] *Ibid.*

[5] See *Forest and Range Practices Act*, Forest Planning and Practices Regulation, Part 4, Division 3 – Riparian Areas: *http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/12_14_2004#part4_division3*.

[6] GeoBC. 2007. Baseline Thematic Mapping Present Land Use Mapping at 1:250 000 (Theme). *https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=37011&recordSet=ISO19115*.

- Stream segments in the Omineca Mountains sections were modelled as North Pacific Sub-Boreal Riparian Woodland and Shrubland.
- Stream segments outside of the above regions were modelled as the North Pacific Montane Riparian Woodland and Shrubland (see Nature Conservancy of Canada, 2010).

TABLE 3. Ecological systems that occur within the planning area but that could not be mapped because of a lack of data, extremely small scale, and (or) occurrence in tiny amounts on the fringes of the study area. These systems were not included as targets in the ecoregional plan. Many of these ecological systems are based on non-zonal (e.g., drier and wetter) site series within each biogeoclimatic unit (e.g., 02 or 09). Descriptions of ecological systems are available at ***http://www.natureserve.org/explorer***.

Unmapped ecological systems
Boreal Black Spruce Swamp or Bog
Boreal Depressional Bog
Boreal Dry Scrub Birch Shrubland
Boreal Dry Shrub Steppe
Boreal Wet Scrub Birch Shrubland
Boreal White Spruce Swamp or Bog
Boreal Willow Shrubland
North Pacific Alpine and Subalpine Bedrock and Scree
North Pacific Alpine and Subalpine Dry Grassland
North Pacific Avalanche Chute and Talus Shrubland
North Pacific Hypermaritime Western Redcedar–Western Hemlock Forest
North Pacific Interior Aspen Forest
North Pacific Interior Dry Grassland
North Pacific Interior Lodgepole Pine–Whitebark Pine Forest
North Pacific Interior Lodgepole Pine Bog
North Pacific Interior Mesic Western Hemlock–Western Redcedar Forest
North Pacific Interior Mesic–Wet Roche Spruce–Mixed Conifer Forest
North Pacific Interior Subalpine Fen
North Pacific Mesic Western Hemlock–Yellow-cedar Forest
North Pacific Sub-Boreal Low–Montane Fen
Rocky Mountain Alpine Dwarf-Shrubland
Rocky Mountain Alpine–Montane Wet Meadow
Rocky Mountain Lodgepole Pine Forest
Rocky Mountain Subalpine–Montane Fen
Rocky Mountain Subalpine–Montane Mesic Meadow
Temperate Pacific Subalpine–Montane Wet Meadow

Modelled wetlands were also included in the freshwater coarse-filter targets (Howard and Carver 2011). The rationale for including wetlands in both the terrestrial and aquatic analyses was that species dependent on wetlands often require both the aquatic and upland areas and therefore it did not make ecological sense to leave wetlands out of either assessment. This may result in "overrepresentation" of wetlands in the final solution; however, wetlands are important ecosystems facing many threats and this overrepresentation is preferred to "underrepresentation."

Ecological land units

In addition to spatial representation of the vegetation of the ecoregion, we also wanted to capture the diversity of topographic surfaces to include the variety of elevation, micro-drainage patterns and solar aspect within each mapped system. In setting the goals for how much of any ecological system target to capture in the final selection of conservation areas, we wanted to also represent the diversity of topographic settings on which this system occurred. We developed a classification of discrete land units based on slope, aspect, and elevation criteria using 30 × 30 m DEM. Ecological land units were developed for each sub-region of the ecoregion by running cluster analyses to determine the most common and repeatable "units" of slope, elevation, and aspect (Figure 1). The final terrestrial targets for the ecoregion were ecological systems overlain onto ecological land units, such that this combination was the final "Target." For each ecological system, the final conservation areas must meet target goals and spatially represent the full array of component ecological land units. Table 4 shows ecological land units developed for each subsection. Predictive Ecosystem Mapping (***http://www.env.gov.bc.ca/fia/pem.htm***) was used to verify land units in locations where this mapping coverage was available.

Mountain pine beetle

Much of the forested area in the Central Interior Ecoregion was infested during the recent mountain pine beetle outbreak. The B.C. Ministry of Forests, Lands and Natural Resource Operations has designated affected stands with a "percent dead" statistic, which represents the percentage of pine within the stand that is visibly killed (as determined from aerial photography); however, even a "90% dead" designation does not indicate that a stand is "dead" (J. Burleigh, Provincial Forest Entomologist, B.C. Ministry of Forests, Lands and Natural Resources Operations, pers. comm., 2007).

TABLE 4. Ecological land units developed from cluster analysis of 30 m DEM

Ecoregional subsection	Ecological land unit	
Skeena Mountains	1	North-facing toeslope
	2	Mid-slopes, south-facing
	3	Gentle slopes and bottomlands
	4	Flat, glacial till river bottom
	5	Gentle ridge tops, rounded tops, flat plateau areas
	6	Steep mid-slopes, from less steep areas
	7	North-facing upper slopes
	8	North-acing ridge tops
	9	Upper steep slopes south-facing
	10	High points, ridge tops
Omineca Mountains Subunit	1	Steep valley bottoms
	2	Steep upper slopes, north-facing slopes
	3	Gentle slopes and bottomlands
	4	Lower elevation, flat topography
	5	Flat upper plateau topography
	6	Lower slopes, north-facing
	7	Lower gentle slopes
	8	Steep upper south-facing slopes
	9	Ridge tops, south-facing
	10	Ridge tops, north-facing
Central Canadian Rocky Mountains	1	Concave, trough bottom, semi-gentle slopes, both aspects
	2	North-facing low to toeslope
	3	Valley bottom, lower elevation
	4	Gentle slopes, higher in elevations
	5	Gentle mid-slopes, NW–NE aspects
	6	Gentle rounded ridge tops
	7	Ridge top, north-facing
	8	South-facing, steepish mid- to toeslopes
	9	South-facing, steepish mid- to upper slopes
	10	South ridge tops
Fraser Basin	1	North-facing slopes
	2	Flat, bottom land
	3	South-facing slopes
Fraser Plateau South	1	North-facing slopes
	2	Flat, bottom land
	3	South-facing slopes
Fraser Plateau North	1	North-facing slopes
	2	Flat, bottom land
	3	South-facing slopes

TABLE 4. (Continued)

Ecoregional subsection	Ecological land unit	
Eastern Hazelton Mountains	1	High valley bottoms with steep sides, north toeslopes
	2	South-facing toeslopes
	3	Flat to gentle toeslopes
	4	Flat valley bottom
	5	High flat plateaus
	6	South-facing upper gentle slopes
	7	South gentle lower slopes
	8	South-facing upper steep slopes
	9	Ridge top north-facing
	10	Ridge top south-facing
Chilcotin	1	Lower and toeslopes in higher valleys
	2	North-facing steep mid- to low slopes
	3	Toeslopes and V-shaped bottoms
	4	Gentle nearly flat areas
	5	North-facing less-steep mid- to low slopes
	6	Gentle sloping upper slopes
	7	Steep upper slopes
	8	Steep mid-slopes south-facing slopes
	9	Ridge tops, north-facing
	10	Ridge tops, south-facing

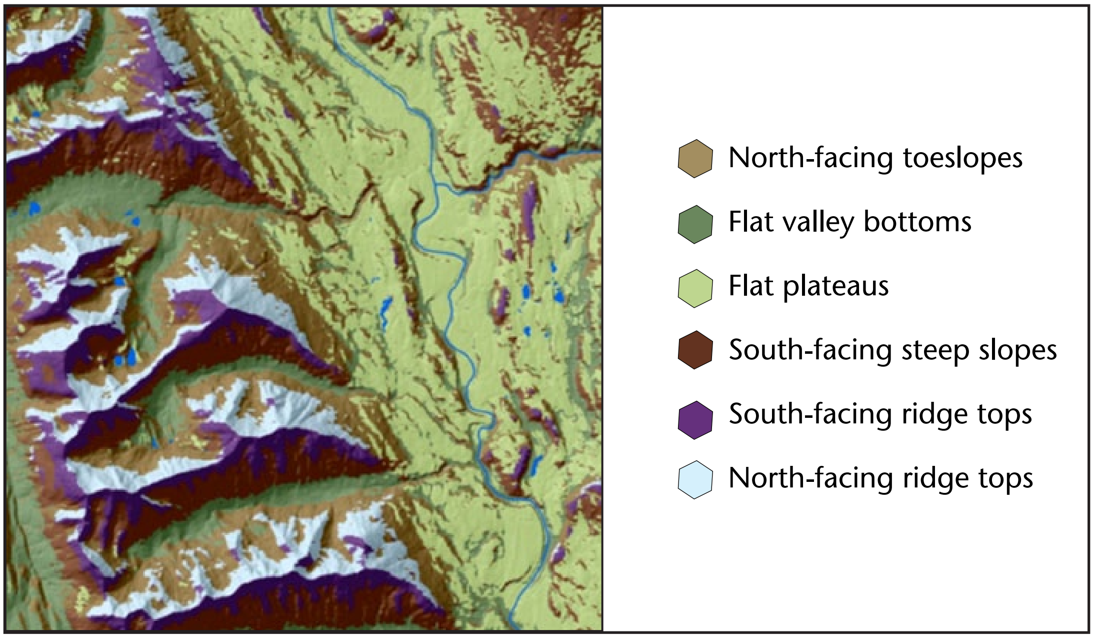

FIGURE 1. Example of ecological land units developed for the Omineca Mountains subregion.

In fact, most wet and moist sites have considerable understorey of either young pine or spruce (Griesbauer and Green 2006), although dry stands may have little understorey. Our Terrestrial Ecosystems team considered these forests as ecosystems that are still alive and viable, and with values such as structure, cover, and food intact and usable for many species dependent of forest habitat. To assess the current status of the forest, we decided to use the beetle impact map, but not in a way that would direct conservation away from or toward these areas. We did recognize, however, that large beetle-killed areas might be slated for salvage logging (Winkler et al. 2008; J. Burleigh Provincial Forest Entomologist, B.C. Ministry of Forests, Lands and Natural Resources Operations, pers. comm., 2007). Such actions would stress an already stressed ecosystem and would not be consistent with the long-term sustainability and conservation of the forest ecosystem. Beetle-kill areas that overlapped identified areas of important biodiversity value in the final portfolio were given high priority for conservation action, which would protect them from logging and associated road building.

Minimum dynamic area

When designing individual conservation sites, we addressed the question of the most appropriate size for ecosystems to sustainably persist in perpetuity. The continuous tracts of forest in the Central Interior represent the predominant vegetative cover for much of the ecoregion. A good preserve design considers ecosystem dynamics and processes to ensure that the forest will be healthy and persist with normal re-growth patterns. To plan for this, we looked at the size and dynamics of the common driving forces such as natural wildfire disturbances. The minimum dynamic area is the smallest area needed to maintain a natural habitat, community, or population based on natural disturbance regimes and the ability of the biota to recolonize or restabilize component species. In this context, identification of a minimum dynamic area for a particular conservation target is based on the size of patches created by various disturbances, the frequency of those disturbances, the longevity of the resulting patches, and the ability of the component species to disperse through the greater mosaic. More recent work in landscape ecology has expanded this definition to include not only issues related to species viability but also the maintenance of the disturbance regime itself (Shugart and West 1981; Anderson 1999).

Mark Anderson's (1999) dissertation, "Viability and Spatial Assessment of Ecological Communities in the Northern Appalachian Ecoregion," provides an excellent literature review on preserve design and the incorporation of disturbance dynamics to preserve viable examples of large matrix forest ecosystems in the northeastern United States. The essence of "how much is enough" is defined by Anderson as the critical area needed to ensure that a system can absorb, buffer, and recover from disturbance. For forested landscapes in New England, 15–25% of an area may be expected to be in a severely disturbed state at any given time under natural conditions. Anderson's general guideline is that a preserve needs to be about four times the size of the largest, most severely disturbed patch (total canopy removal). This is about three times larger than the size Shugart and West (1981) suggested, which is 50 times the mean disturbance patch size. In addition, we also know that naturally occurring wildfires can leave 3–15% of mature forest unburned within the burn boundary (DeLong and Tanner 1996), which increases the resiliency and reduces the recovery time of an area after a burn. In applying this theory, if a natural area is large enough, then at any given moment no more than 25% of the area will have experienced severe disturbance.

In the boreal forests of Alberta, Weir et al. (2000) found that more than 25% of the 3461 km^2 Prince Albert National Park was burned at any given time over the past 235 years. This offers one confirmation that Anderson's theory can be applied to western North America's fire-prone forests.

A literature review revealed several studies directly related to the forested landscapes of western Canada and their natural fire regimes, two of which applied to the Central Interior of British Columbia, where the largest fires ranged from 1219 ha to 13 549 ha and mean fire sizes ranged from 18 ha to 500 ha (Hawkes et al. 1997; DeLong and Tanner 1996); one 200 000 ha fire was also reported in the boreal mixed forests of Alberta (Weir et al. 2000). Applying Anderson's (1999) minimum dynamic area theory (i.e., 25% of a forest will be disturbed at any given point in time), we can reason that preserve size needs to be at least four times the size of the largest known fires, which gives a range of approximately 5000–55 000 ha (the boreal forest example was considered an outlier to our study and thrown out). To compare, we applied Shugart and West's (1981) theory that a sustainable preserve size should be fifty times the mean fire size, which gives us a range from 900 ha to 25 000 ha. Thus, we could set the minimum dynamic area for matrix forested ecosystems in the Central Interior at an average of 40 000 ha. The team, however, chose a more conservative estimate, by simply using the largest estimate (55 000 ha) as the minimum dynamic area (i.e., 550 km^2 or 23.5 km × 23.5 km), which would require 110 continuous 500-ha hexagons in Marxan. Mountain pine beetle kill areas are also large, but we discount them as a current measure of natural disturbance and believe the best patch sizes to emulate will be from the fire regime. Other studies from Coastal British Columbia have addressed "how much is enough" and suggest a percentage of existing forested area to remain (e.g., 38–68%, see Price et al. 2007) but do not present actual sizes or disturbance scales.

Climate change

In considering the magnitude of climate change expected for British Columbia, including the Central Interior Ecoregion (e.g., Spittlehouse 2008; Rodenhuis et al. 2009), the Terrestrial Ecosystems team decided to focus conservation on large, enduring landscapes. By "enduring landscapes," we mean large areas with great variety of physical site conditions (soils, geology, aspects, slope) that can support a variety of ecosystems. Within the Central Interior Ecoregion, we propose to include areas of high physical habitat heterogeneity as well as areas with low heterogeneity. For example, flat plateaus may be prime areas for native grassland invasion from the south, and highly heterogeneous sites may have more options for local species movement from nearby areas. By including the ecological land units modelled from DEM, which represent a diversity of elevation, micro-drainage patterns, topography, and solar aspect, physical landscape variation is already part of our target selections. When considering how ecosystems may respond to climate change, the physical landscape becomes our focus for conservation. We want to include large viable areas of forest but expect the composition of the forest will change. The goal of preserving the enduring landscape is to provide the physical habitat on which species may move and respond to changing climate. For example, mesic forest ecosystems may become drier with greater fire frequency but with large, protected areas, these forests may be able to survive as they shift and respond. The absence of roads and logging activity within the area keeps the threat of erosion and arrival and spread of invasive species after fires to a minimum.

As well as enduring landscapes, the team decided to target populations of species that do not have additional populations further north (e.g., Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and ponderosa pine (*Pinus ponderosa* var. *ponderosa*). These species may increase their range significantly northward with future climate change scenarios (Hamann and Wang 2006). In contrast to the range expansion indicated in these models, subsequent re-analysis showed a much more limited expansion, but still northward (T. Wang, Centre for Forest Gene Conservation, University of British Columbia, pers. comm., 2009). Recognizing the uncertainties associated with modelled scenarios, it seemed prudent to target species that are at their northern limits in North America. The paleolimnological record shows that the range of Douglas-fir has increased in British Columbia with warmer climates and higher fire frequency (Hallett and Hills 2006). More recently, Douglas-fir has been shown as sensitive to increases in moisture if not temperature changes (Griesbauer and Green 2010). Ponderosa pine seedlings can be killed when night-time temperatures fall below –5°C when very young (36 days old) and are susceptible to death by frost without snow cover (Burns and Honkala 1990). Spring-time minimum temperatures also limit the survival of seedlings of Douglas-fir (Burns and Honkala 1990). Both species do well after fire if adequate moisture is available, and with a warmer and drier climate, increased fire frequency may be an outcome; however, both species are not prolific seed producers throughout their range and many seed predators deter natural regeneration of both species. Although climate change scenarios are only projections, our selection of conservation areas may be sufficiently robust to provide protection to these northern populations and the land needed for expansion to the north or to adjacent suitable areas, regardless of direction.

Goals

Conservation goals are the ecological criteria established for measuring the persistence and variability of conservation targets across an ecoregion. Although it is impossible to say with certainty the exact amount to ensure persistence in the face of climatic or other environmental changes, conservation goals provide guidance as to "how much is enough?" (Noss 1996; Soulé and Sanjayan 1998; Price et al. 2007). Conservation of multiple, viable examples of each target, located across its geographic and ecological range, addresses the ecological and genetic variability of the target, and provides sufficient redundancy and representation for persistence in the face of environmental stochasticity and human perturbations (Comer 2005).

Goals for ecological systems are based on species diversity/area curves. These curves are conceptual models that provide an approximation of the proportion of species that might be lost given the reduction in habitat areas (Price et al. 2007). These relationships grew from empirical observations of island biogeography (MacArthur and Wilson 1967) and have been shown to exist for mainland habitat "islands" in terrestrial and aquatic landscapes. Estimations of terrestrial species loss associated with the percent habitat remaining suggest that 30–40% of the historic area of a given community or ecological system would likely contain 80–90% of the species that occur in them (Groves 2003).

For the Central Interior Ecoregion, ecological systems are represented across major biophysical gradients to capture environmental gradients, ecological variability, and potential genetic variability of targets. This gradient representation also helps to ensure that each regional scenario encompasses native ecological system diversity while providing a hedge against a changing climate. Targets were represented by their natural distribution within each of the ecoregional subsections and in combination with ecological/biophysical land units to represent the full range of variability of the ecosystem and ecological gradients on which it occurs.

Terrestrial system targets were assigned area-based goals within each stratification unit. Goals were set equal to 30% of the estimated historical (i.e., circa 1860) extent (in hectares) of the system in the ecoregion. We developed our estimate of the historical extent by examining the relevant literature and current land-cover data, combined with expert opinion. In the Central Interior, the overall condition of many forests has changed with fire suppression and recent mountain pine beetle outbreaks and various areas have been impacted by logging and development; however, we concluded that for the vast majority of the landscape, current vegetation is essentially equal to its historic extent. Therefore, we set the goal of 30% of current mapped distribution for each subsection across all ecological land units for each ecological system in the Marxan runs.

Suitability index

The suitability index is based on a spatially explicit layer of known human impacts. The index is used in Marxan as a cost measure to represent the degree of threat influencing the suitability of an assessment unit for conservation (see Map 13 [Terrestrial Suitability Index] from Nature Conservancy of Canada, 2010). Main threats to terrestrial biodiversity are the location and density of roads (including logging roads), transportation and energy transmission corridors, ski area developments, and urban areas. Loos (2011) explains in more depth the methods used to develop and implement the suitability index to characterize these threats. The ecoregion-wide map of ecological systems created by the Terrestrial team (described above) is a continuous seamless surface, occurring in every planning unit. As a target for conservation, this is unusual, as most targets are extremely limited in their distribution. There are an infinite number of ways to fulfill the 30% goal. By including the suitability layer, Marxan will choose assessment units with the lowest amount of threat or human impact to meet the area (hectares) goal for each ecological system, thus driving the solution to the most viable areas.

Assessment units

Marxan can accept any size and shape of assessment unit. For the terrestrial analyses, we chose to use 500-ha hexagons as the assessment unit. The Central Interior assessment area contains a total of 51 561 hexagons (see Map 4 [Terrestrial Assessment Units] from Nature Conservancy of Canada, 2010). Using consistently sized assessment units makes it more transparent why one unit is chosen over another in Marxan (i.e., what is in each unit). The hexagon shape also neatly aggregates up into larger conglomerates. The rational for the 500 ha (5 km^2) size unit is that it is sufficient for representing small-scale targets in localized areas and also allows for aggregation of units into extensive landscape-scale sites (Neely et al. 2001). Ecological systems are a unique set of coarse-filter targets because every single assessment unit contains hectares of at least one ecological system. No other set of targets in Marxan form a continuous, wall-to-wall seamless ecoregion-wide layer. This means that Marxan can generate many options to efficiently meet the goals of other targets and still meet the goals of terrestrial ecological systems.

Marxan results

The purpose of our analysis was not to determine the amount of biodiversity that current protected areas contain but to independently select areas of high biodiversity, regardless of protected status. We ran several Marxan runs, with and without current protected areas included, to establish the influence of these areas on the final selection of sites. (For a further discussion of Marxan scenarios, see Loos [2011]). All course-filter terrestrial mapped ecological systems goals of 30% within each subsection of the Central Interior Ecoregion were met (see Map 17 [Terrestrial "Best" Marxan Output] from Nature Conservancy of Canada, 2010). Because the mapped ecological systems occur in every planning unit, the Marxan solutions show a high degree of variation of location to meet these spatially explicit goals (see Map 18 [Terrestrial Summed Solution Marxan Output] from Nature Conservancy of Canada, 2010). Assessment units chosen greater than 60% in all Marxan runs have targets whose goals can only be met by including those units. Assessment units that are chosen less often represent areas where target's goals can be met in a variety of ways. The "summed solution" depicted in Map 18 (Nature Conservancy of Canada 2010) shows the areas that are chosen greater than 60% of the time and that are critical to meeting goals as well as those areas that are needed to meet goals but which have no fixed physical location. This type of prioritization will be very helpful during the site-level planning stage when additional local factors come into play.

Unfortunately, funding constraints prevented the inclusion of the additional targets for the northern-most populations of Douglas-fir and ponderosa pine in the Marxan runs and therefore these areas are not included in the final "climate change portfolio" (see Map 27 [Terrestrial Climate Changed Summed Solution] from Nature Conservancy of Canada, 2010). Funding constraints also prevented the inclusion of the minimum dynamic area of 55 000 ha in the Marxan runs. Many of the areas chosen within the "best terrestrial portfolio" are larger than the 110 continuous planning units required to meet the 55 000 ha criterion for the minimum dynamic area; however, these results are coincidental and not consistent across all systems in all subsections of the ecoregion.

The Terrestrial Ecosystems team felt that the "enduring landscapes" represented by the ecological land units at 30% within each subsection, captured a large and diverse landscape that could allow for species movement and ecosystem change. Thus, the team decided there was no need to increase the goals for terrestrial ecosystems when considering various climate change scenarios.

Summary and additional work

Slightly greater than 30% for all terrestrial ecological systems were included in the final suite of prioritized conservation areas to be protected or managed for biodiversity conservation. Enduring landscapes with a wide range in variation of elevation, local drainage, topography, and solar aspects are also included, ensuring a diversity of habitats for all terrestrial ecosystems. We hope these heterogeneous areas will allow for species dispersal and colonization of healthy populations with changing climates. Many of the portfolio areas are greater than 55 000 ha (550 km^2), the minimum dynamic area we suggest is required for a sustainable forest preserve with a natural fire regime; however, not all subsections have selected areas this large, most notably the Fraser Basin subsection. Wildfires are expected to occur more frequently if the climate becomes warmer and drier (Johnson and Larsen 1991; DeLong 2000; Leroux et al. 2007; Spittlehouse 2008; Rodenhuis et al. 2009). Therefore, it is imperative that local conservation managers incorporate the concept of a minimum dynamic area into the boundary configuration for each area considered for biodiversity preservation or management.

> *If all areas identified in this ecoregional assessment are successfully and completely protected from further threats and ecosystem processes such as fire are allowed to occur, we believe these ecosystems have a chance for long-term survival in the face of changing climates.*

If all areas identified in this ecoregional assessment (see Map 22 [Prioritized Terrestrial Portfolio] from Nature Conservancy of Canada, 2010) are successfully and completely protected from further threats (e.g., road building, development, fire suppression, and salvage logging) and ecosystem processes such as fire are allowed to occur, we believe these ecosystems have a chance for long-term survival in the face of changing climates.

With climate change targets and goals brought in by other ecoregional planning teams (terrestrial fine-filter species and aquatic teams), the "climate change" portfolio has a larger footprint (Kittel et al. 2011). With additional time and resources, the Terrestrial Ecosystems team would like to re-run the climate change Marxan run to include minimum dynamic area criteria, target the northern-most populations of Douglas-fir and ponderosa pine, and increase the total percent area goal. The impacts of climate warming on the ecosystems of North America are already being observed (Kittel et al. 2010). Depending solely on "enduring landscapes" may not be enough to counter large changes including increased fire frequency. Ecosystems will need more area and more buffering to adapt to these changes. Increasing the conservation goal to greater than 30% may capture additional species that depend on these ecosystems for survival (Groves 2003; Price et al. 2007).

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Test Your Knowledge . . .

Central Interior Ecoregional Assessment: Terrestrial ecological system representation in regional conservation planning

How well can you recall some of the main messages in the preceding Research Report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Biogeoclimatic ecosystem classification units were used to:
    A) Develop an ecological systems classification
    B) Develop a map of ecological systems
    C) Develop an ecological systems classification and a map

2. By "ecological land units" we mean:
    A) Units of land with the same elevation, aspect and slope
    B) Landscapes with topographic heterogeneity
    C) Units of land with many different vegetation types

3. Goals set for terrestrial ecological systems in this ecoregional plan were:
    A) 30%
    B) 10%
    C) 70%

ANSWERS

1. C 2. A 3. A