Northern Alberta Conservation Atlas

Nature Conservancy Canada

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Northern Alberta Conservation Atlas

Sandhill Crane. *Janice Melendez*

Nature Conservancy of Canada
and Global Forest Watch Canada

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The maps in this report are for illustrative purposes only. Do not rely on these maps for a precise indication of routes, locations of features, or as a guide to navigation.

Cover photos
Beaver ponds in mixedwood boreal forest southeast of Ft. McMurry. *Global Forest Watch Canada*
Grizzly. *Public domain*
Alberta foothills. *Global Forest Watch Canada*
Great Gray Owl. *Janice Melendez*

Above: Chokecherry. *Jaimee Morozoff*
Title page: Sandhill Crane. *Janice Melendez*

The Nature Conservancy of Canada (NCC) is a non-profit, non-advocacy organization that takes a business-like and supportive approach to land conservation and the preservation of Canada's biological diversity. Its activities involve creative partnerships and solutions with individuals, corporations, community and Aboriginal groups, conservation organizations and government agencies that shares its goals. Since 1962, NCC and its supporters have helped protect 2.6 million acres (1 million hectares) of ecologically significant lands and waters across Canada, and have assisted and advised the owners and managers of many more in their approaches to nature conservation.

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Nature Conservancy of Canada at 1 877 343-3532, or by email at **nature@natureconservancy.ca.**

Data available online
For a link to download the datasets, search for 'Northern Alberta Conservation Atlas' at www.geodiscover.alberta.ca <http://www.geodiscover.alberta.ca> .

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Emergent marsh. Nature Conservancy of Canada

Introduction

NORTHERN ALBERTA'S FORESTS and wetlands, and rivers and lakes, are important both ecologically and economically. Forty-six percent of Alberta's landmass is forest or woodland, most of it in the Alberta ecozones that are the subject of this report: the Boreal Plain, Taiga Plain, Taiga Shield and Boreal Shield. Major decisions will be taken in coming decades regarding the use and stewardship of the public and private lands of northern Alberta. High-quality information is one of the fundamental underpinnings of informed decision-making on the future of these lands and resources, and sharing such information is the primary goal of this *Conservation Atlas*.

In 2010, in collaboration with Global Forest Watch Canada, the Nature Conservancy of Canada (NCC) undertook a project, *Mapping Ecological Values within Alberta's Forest Ecozones*, which used available ecological datasets to map key ecological areas throughout Alberta's north (see Section 3.0 of this report). The project constituted a rapid reconnaissance of ecological values to assist with immediate planning needs, and guide further work. Further data analysis was recommended, which comprises Sections 1.0 and 2.0 of this report (Lee *et al.* 2013), and both projects are shared here in the form of a *Conservation Atlas*.

The Nature Conservancy of Canada has conducted conservation assessments, or *Conservation Blueprints*, of southern Canada's ecoregions from coast to coast, employing computer-based GIS analysis (Geographic Information


Lake basin and conifer swamp peatland. Global Forest Watch Canada

An atlas of various data relating to the biological diversity of a region has many uses, including among others the assessment of the natural areas which, if appropriately conserved, could sustain the biodiversity of a region.

Boreal Chickadee. Merv Cormier

Systems). Their goal was to assemble, classify, map and analyze the available information on the biological diversity of natural geographic regions. Among others, the published blueprints dealt with southern and western Alberta ecozones, the Prairies and Parklands, and Rocky Mountains of Alberta (Riley *et al*. 2007).

NCC continued these landscape analyses northward, learning from its southern experience. Its 2009-2013 Labrador Nature Atlas focused more effort on the assembly and sharing of map-based conservation data, in support of the land-use and resource decisions that are the responsibility of public agencies, Aboriginal governments and organizations, and others on private and public lands. This information was released in 2014 in hardcopy atlases and as an interactive, on-line web portal (www.nlnatureatlas.ca).

The approach adopted by this study represents a made-in-Alberta approach, one that may be, in part, applicable to the broader northern ecozones extending beyond the Alberta study area.

Table 1. Ecozones of northern Alberta

ECOZONE	CANADA		NORTHERN ALBERTA		
	square kilometres	% of Canada	square kilometres	% of Alberta	% of study area
Boreal Plains	713,787	7.5	381,444	57.6	83.0
Taiga Plains	620,137	6.5	62,377	9.4	13.6
Taiga Shield	1,329,679	13.9	9,282	1.4	2.0
Boreal Shield	1,862,130	19.5	6,429	1.0	1.4
	4,525,733	47.4	459,532	69.3	100

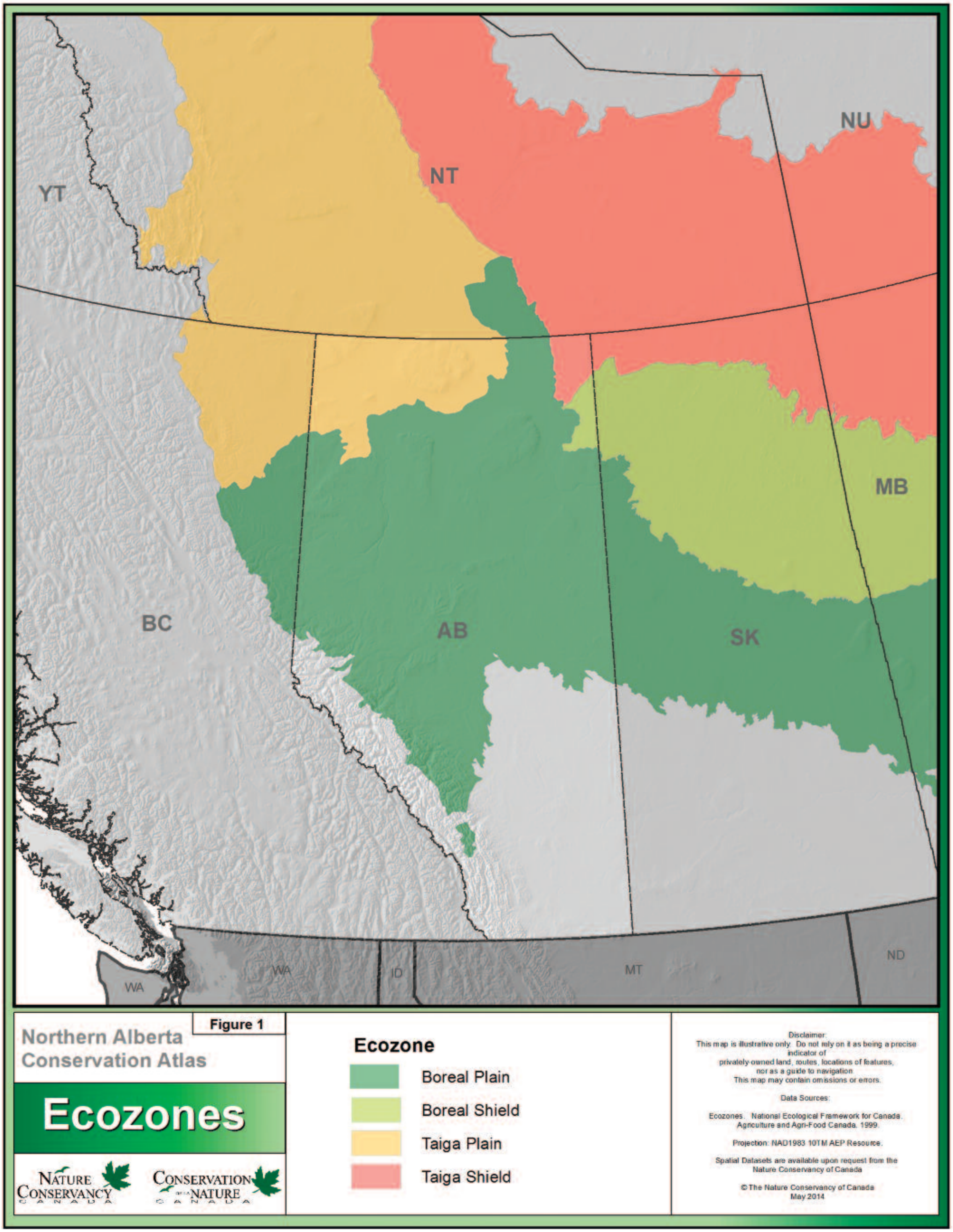


Figure 1. Canadian ecozones in the northern Alberta study area

Alberta foothills. Global Forest Watch Canada

1.0

General Information

Section 1.0 presents and maps some of the important physical and biological characteristics of northern Alberta, as well as its land tenure. The maps presented here are summary maps at coarse scales; full scale data coverages are available at GeoDiscover Alberta. For a link to download the datasets, search for 'Northern Alberta Conservation Atlas' at www.geodiscover.alberta.ca

1.1 Boreal /Taiga Ecozones and Ecodistricts

Ecozones are areas within which there are more or less homogeneous climate, landform and biological diversity (ESWG 1999). Four large ecozones converge in northern Alberta: **Boreal Plain**, **Taiga Plain**, **Taiga Shield** and **Boreal Shield** (Table 1, Figure 1).

The **Boreal Plains** extends across northeast British Columbia, Alberta, Saskatchewan and Manitoba and covers the largest portion of northern Alberta (381,444 km^2, 83% of northern Alberta). Part of the flat interior plains of North America, its subdued relief consists of low-lying valleys and plains. The majority of surface waters are part of the Saskatchewan River, and the Peace, Athabasca and Slave river watersheds. Forests, wetlands and peatlands dominate. Precipitation, surface and groundwater sources are more than enough so support agriculture. A resource frontier, Alberta's Boreal Plains supports major oil and gas development, forestry and mining, as well as road, rail and pipeline networks, and extensive seismic exploration.

The **Taiga Plains** spans northwestern Alberta and the Yukon and Northwest Territories and a small portion of northern Alberta (62,377 km^2, 13.6%). It is a low-lying plain centered on the Mackenzie River and its tributaries. Its southern portion supports the world's largest herd of Wood Bison, the known nesting sites of the Whooping Crane and the wetlands of the Peace-Athabasca Delta.

The **Taiga Shield** of northern Canada extends across the eastern Northwest Territories, northern Saskatchewan and Manitoba and a small portion of northern Alberta (9,282 km^2, 2.0%). Much of it is conifer woodland (*taiga*) on Canadian Shield, where the climate, soils, plants, birds and mammals of the Boreal meet the Arctic.

The **Boreal Shield** is Canada's largest terrestrial ecozone and a very small portion of it lies in northern Alberta (6249 km^2, 1.4%). This is where the Canadian Shield and the boreal forest overlap, extending predominantly as forests, wetlands and peatlands in a continuous belt from the east coast to the Boreal and Taiga Plains.

These ecozones are further described and mapped as *ecodistricts*, areas within which there are similar landforms and physiography in particular, as well as similar soils, vegetation, water bodies and fauna (ESWG 1999; Figure 3). These are the ecological areas (or units) for which the comparative significance of their remaining natural areas were assessed and summarized in this study. From a conservation point of view, the identification of representative natural areas as conservation priorities is often based on this scale of geographic variability.

Alberta agencies employ a parallel system of ecological units termed Natural Regions and Subregions, but this study uses Canada's 1999 *National Ecological Framework* of ecozones, ecoregions and ecodistricts. It does so because this was the framework used by other NCC ecoregional assessments across Canada. The study area conforms to those portions of those ecozones within Alberta not earlier treated in NCC's *Conservation Blueprint for Canada's Prairies and Parklands* or the *Canadian Rocky Mountains Ecoregional Assessment* (Figure 2).

1.2 Land Cover

Land cover, or vegetation, describes the habitats that species select or make use of for particular parts of their life cycles. Legend units correspond generally to broad ecological systems. (See Appendix A.)

Fen peatland, Beaver ponds. Global Forest Watch Canada

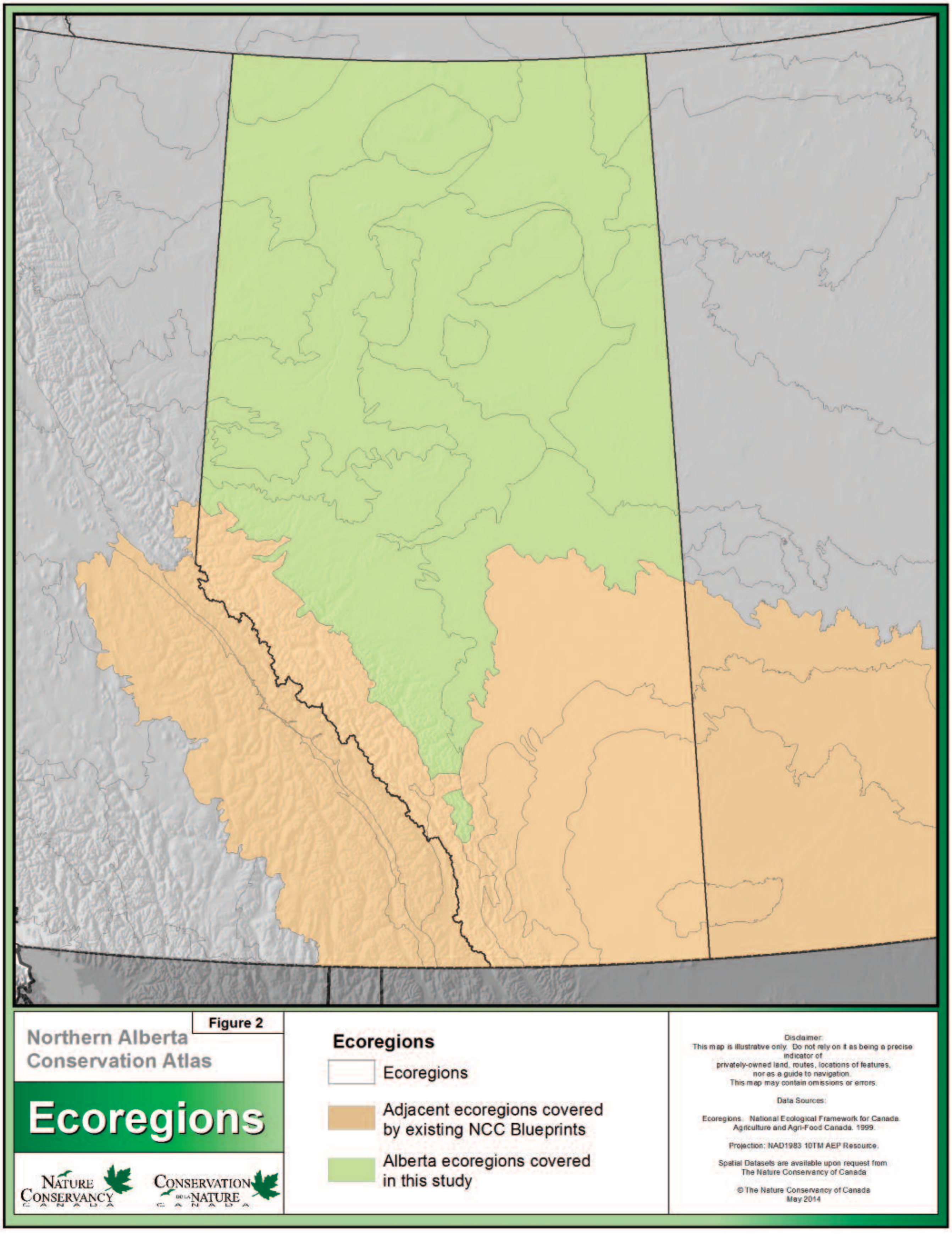


Figure 2. Northern Alberta study area, and areas treated in other NCC Conservation Blueprints

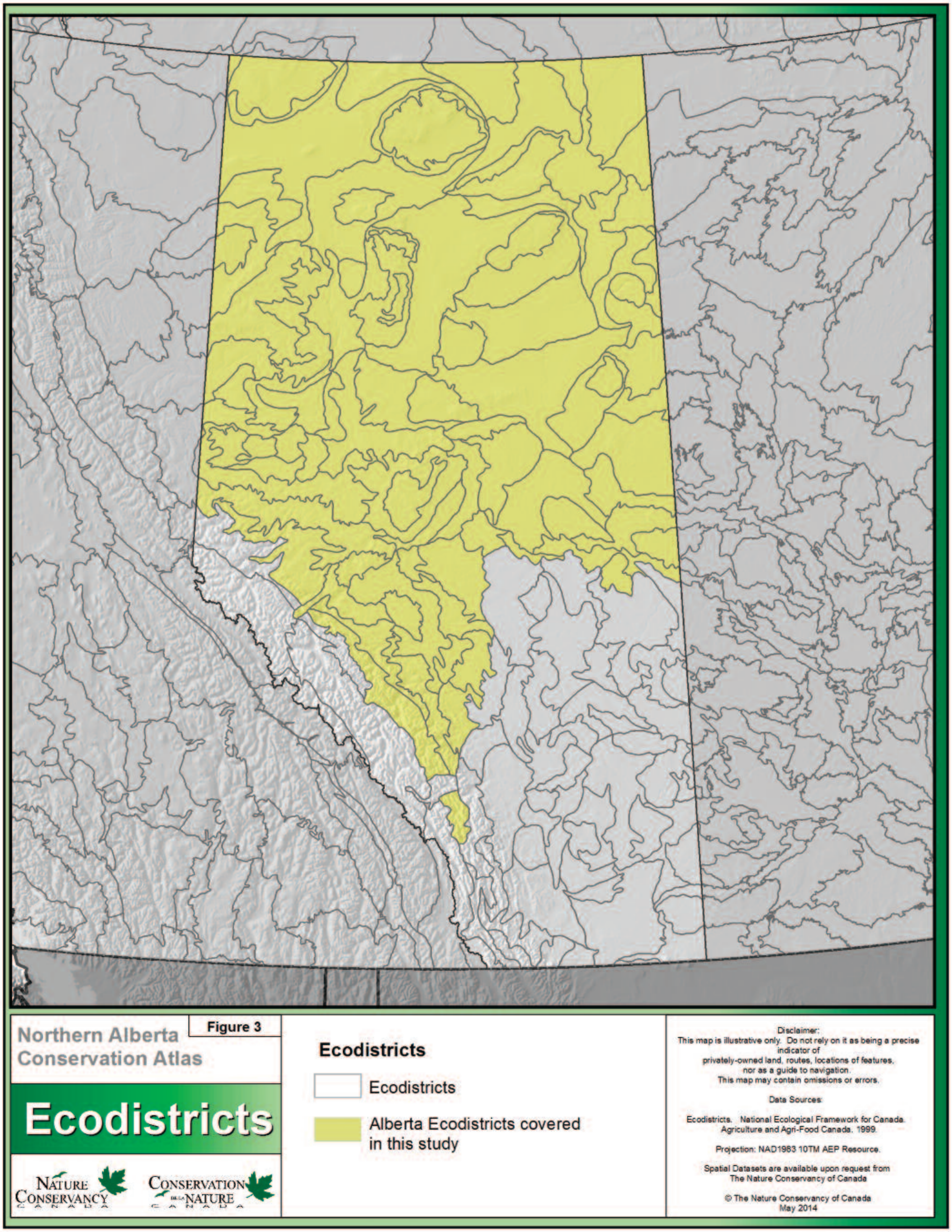


Figure 3. Northern Alberta ecozones, ecoregions and ecodistricts (ESWG 1999)

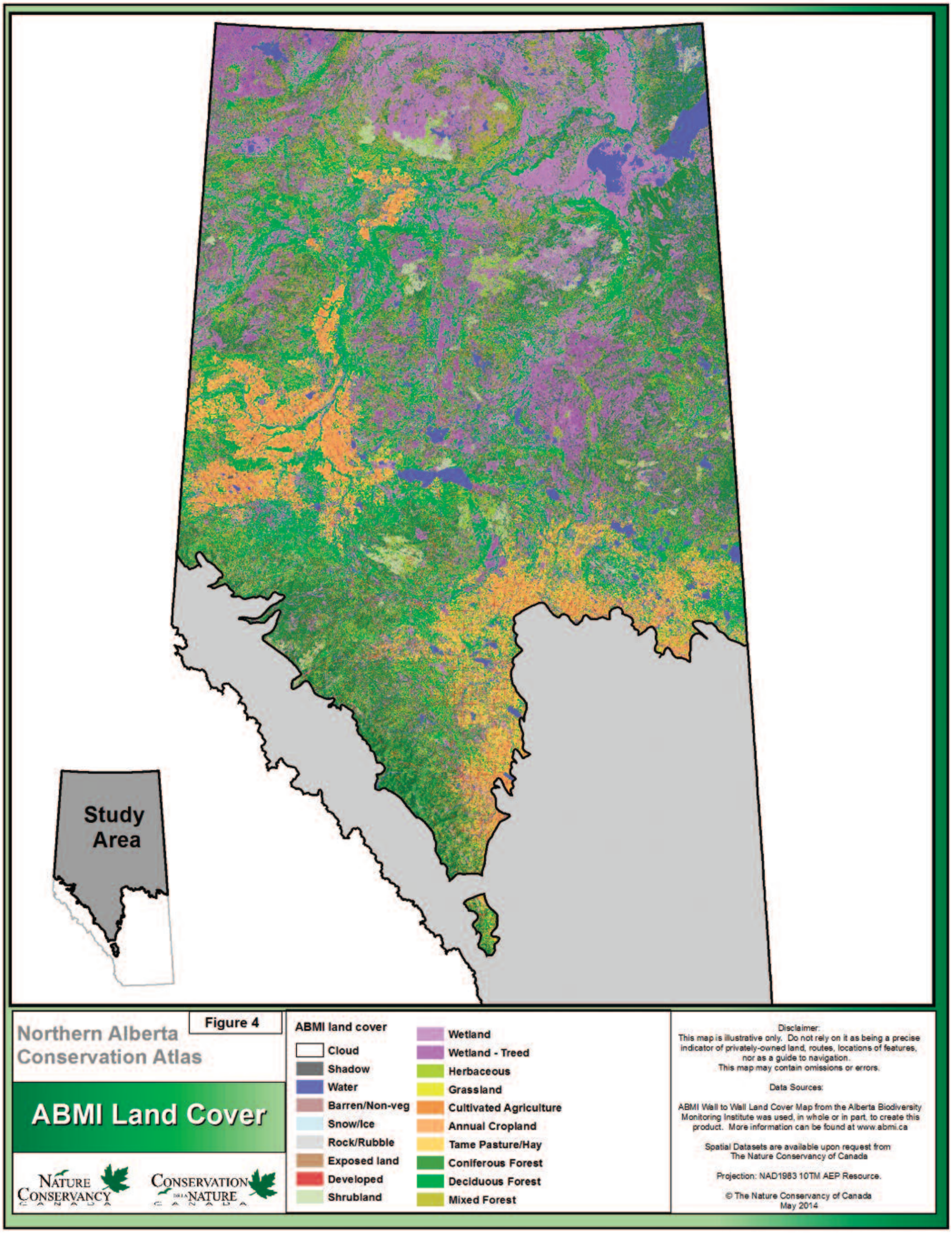


Figure 4. Land cover as mapped by the Alberta Biodiversity Monitoring Institute (ABMI)

1.3 Protected Areas and Other Conservation Lands

Formal protected areas are considered to be basic building blocks in the conservation of biological diversity. Other conservation lands (in addition to formal protected areas) contribute to direct conservation and to limited networks of conserved lands and waters occurring across both working and conserved landscapes (Figure 5 and Tables 2 and 3).

Regulated protected areas have biodiversity conservation as their overt mandate. Other conservation lands have less formal status but also significantly contribute to biodiversity conservation. Digital data and mapping are available for some but not all protected areas and conservation lands in boreal Alberta.

In addition to existing protected areas and otherwise-conserved lands, there are areas recently announced but not yet regulated, for example, in the Lower Athabasca Regional Plan area and adjacent Lower Peace region (1.4, below). The inclusion here of unregulated conservation lands conforms to the inclusive approach adopted by Canada through the international Nagoya-Aichi Target 11, which commits Canada to conserving "*systems of protected areas and other effective area-based conservation measures*."

Table 2. Federal and Provincial Protected Areas (including interim areas) of northern Alberta, by Ecozone

Ecozone	Study area (km²)	Federal protected area (km²)	Federal protected area (% of all permanent and interim protected areas)	Federally protected (% of total federal protected area)	Provincial protected area (km²)	Provincial interim protected area (km²)	Protected area provincially protected (% of study area)	Provincial protected area (% of total provincial protected area)	Private conservation area (km²)	Federal and provincial and private protected area (km²)
Boreal Plain	381,444	26,318	73.87	6.90	8,611	700	26.13	2.26	177	35,106
Boreal Shield	6,429	0	0.00	0.00	157	0	0.00	2.45	0	157
Taiga Plain	62,379	9,752	60.36	15.63	6,395	10	39.64	10.25	0	16,146
Taiga Shield	9,282	161	14.97	1.73	914	0	0.00	9.85	0	1,075
	459,534	**36,231**			**16,077**	**709**			**177**	**52,485**

Table 3. Protected Areas in northern Alberta by Ecozone and IUCN Category

Ecozone	Study area (km²)	IUCN Code								
		IA	IB	II	III	IV	V	VI	NA	not classified
Boreal Plain	381,444	97	6,160	28,496	26	15	4	15	139	654
Boreal Shield	6,429	12	146	0	0	0	0	0	0	0
Taiga Plain	62,379	0	6,395	9,752	0	0	0	0	0	10
Taiga Shield	9,282	0	914	161	0	0	0	0	0	0
	459,534	**108**	**13,614**	**38,409**	**26**	**15**	**4**	**15**	**140**	**664**

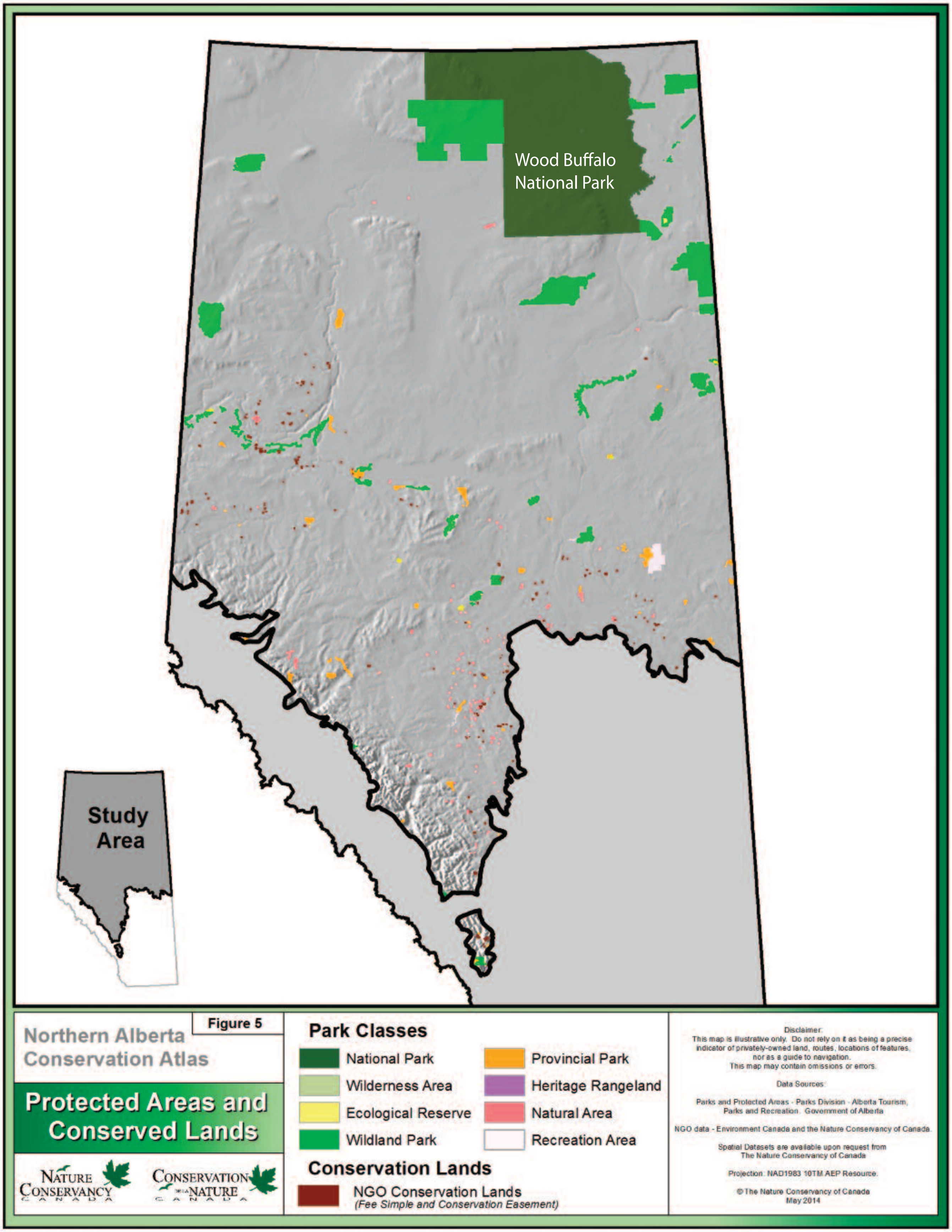
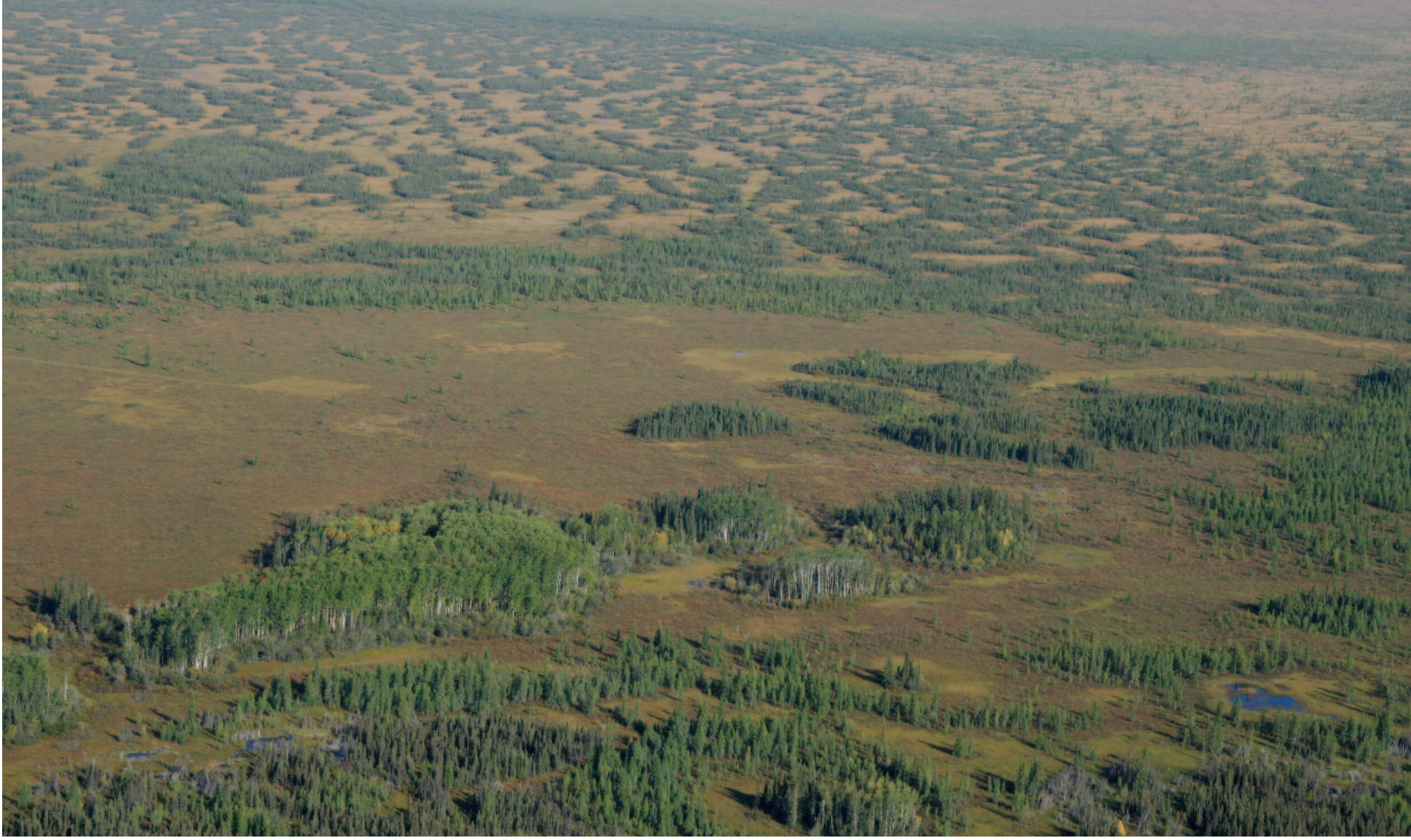


Figure 5. Protected areas and other conservation lands in northern Alberta



Peatland complexes east of Imperial Oil's Kearl Lake oil sands project, 70 km northeast of Ft. McMurray.
Global Forest Watch Canada

1.4 Land Use Plans

Alberta is implementing a land-use planning framework that requires the development of seven regional land-use plans. To date, one plan has been completed in northern Alberta for the Lower Athabasca region (https://www.landuse.alberta.ca/Pages/default.aspx).

The Lower Athabasca Regional Plan was approved by the Alberta Cabinet on 22 August 2012. Although conservation lands were included in the approved plan (Table 4, Figure 6), these areas have yet to be regulated and so are not included among the Protected Areas or Other Conservation Lands as mapped in Section 1.3. In addition to sites approved in the Lower Athabasca Regional Plan, the Alberta Government earlier announced, as part of the Lower Athabasca Regional Plan, candidate areas in the Lower Peace planning area.

Table 4. Lower Athabasca Regional Plan proposed conservation lands, and potential conservation lands in the Lower Peace Regional Plan area.

			Lower Athabasca Regional Plan (LARP)			Lower Peace Areas
Ecozone	Study area (km²)	Federal and provincial and private protected area (km²)	LARP Conservation Areas (km²)	Lower Peace Conservation Areas (km²)	Protected area including LARP and and Lower Peace (km²)	Protected area including LARP and Lower Peace (% of ecozone)
Boreal Plain	381,444	35,106	9,356	6,410	51,572	13.52
Boreal Shield	6,429	157	807	0	964	14.99
Taiga Plain	62,379	16,146	0	13,403	29,559	47.39
Taiga Shield	9,282	1,075	5,562	0	6,637	71.50
	459,534	**52,485**	**15,725**	**19,813**	**88,733**	

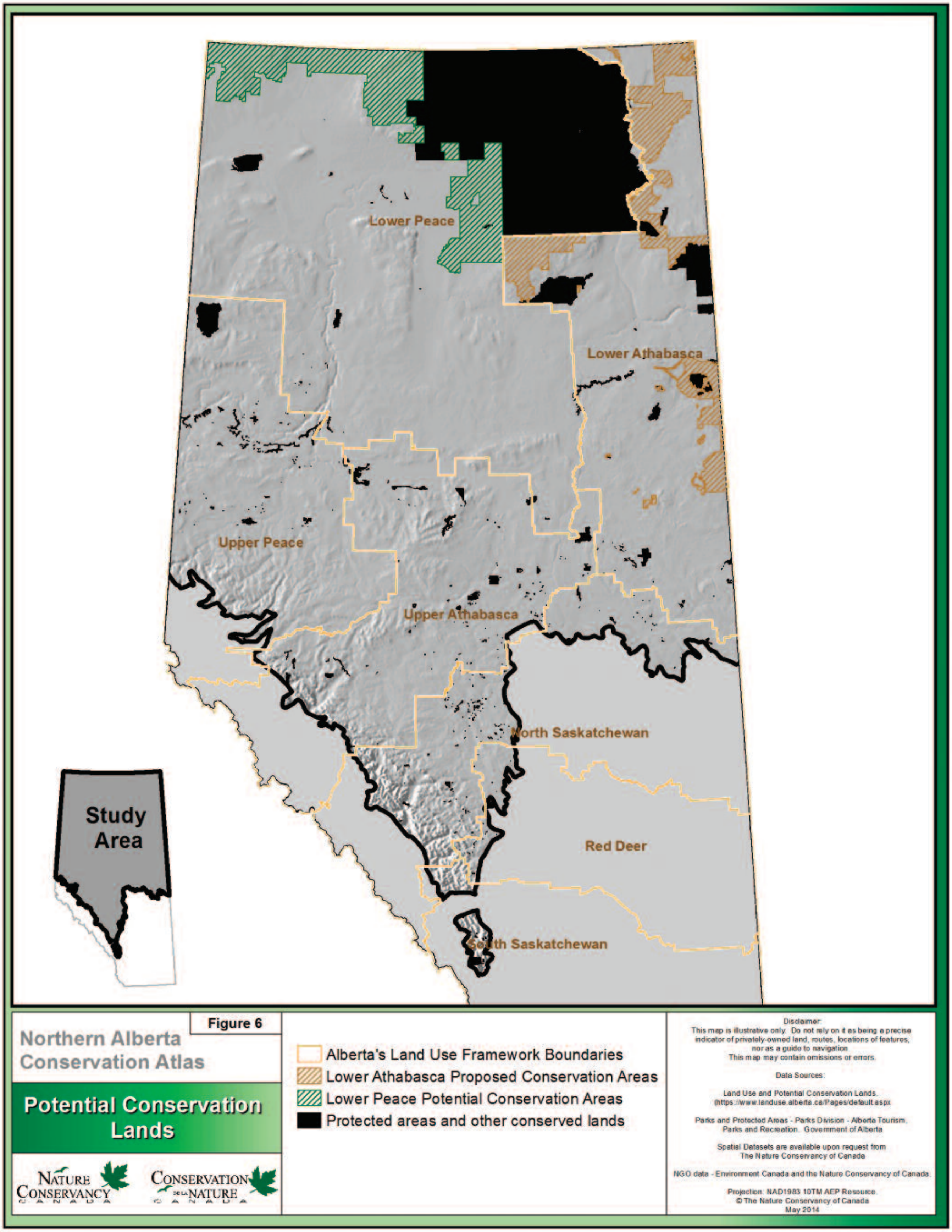


Figure 6. Potential other conservation lands in regional land-use plans.

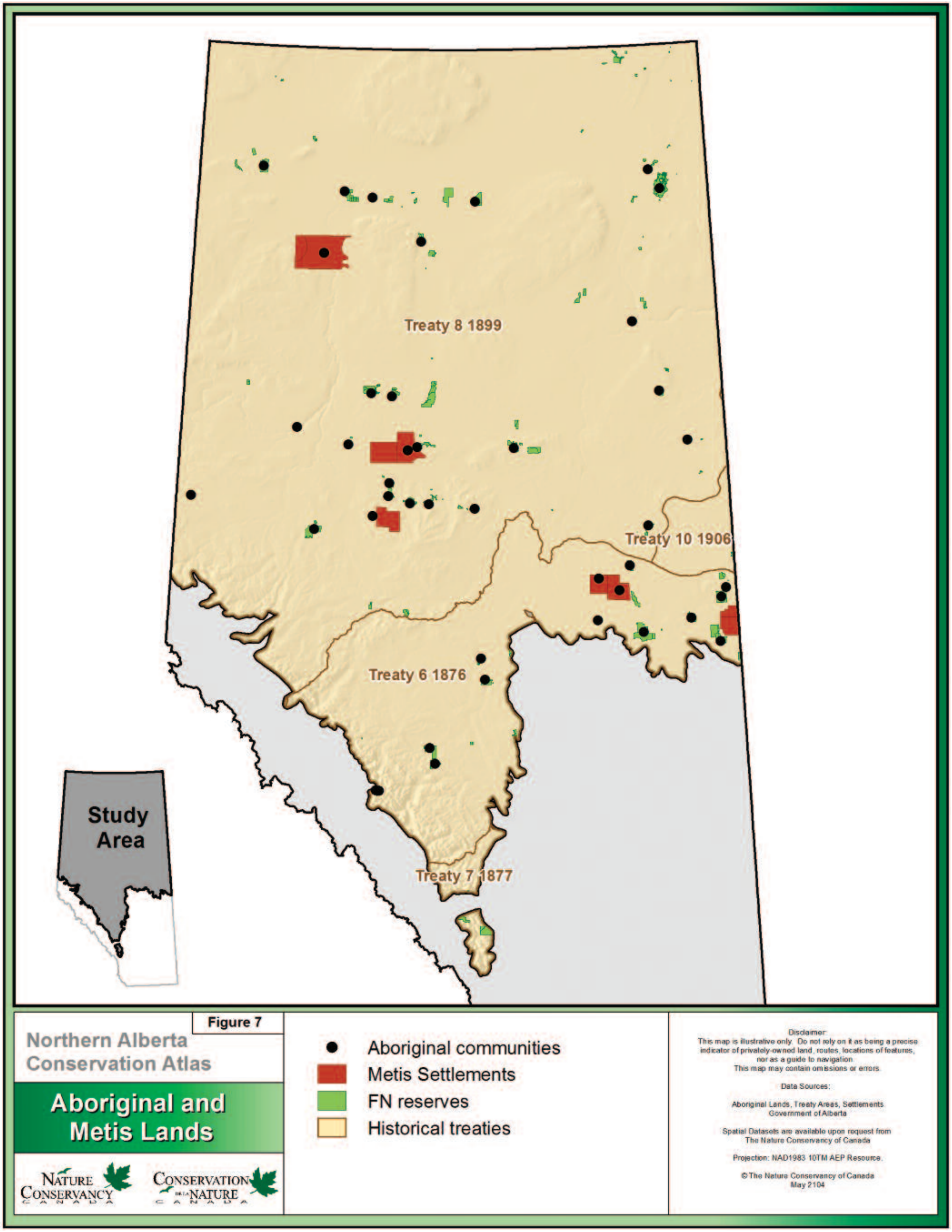


Figure 7. First Nation reserve lands, Aboriginal communities, Métis settlements and historical treaty areas in northern Alberta

1.5 Aboriginal Lands

Northern Alberta has 41 Aboriginal communities, 40 of which are located on the Boreal Plains (Table 5, Figure 7). As well, the 5,776 km^2 of Métis Settlement lands are located almost entirely on the Boreal Plains ecozone. Most of the study area is within the Treaty 8 boundaries and a significant portion is also within the Treaty 6 boundaries. The degree to which such lands may constitute "*other effective area-based conservation measures*" (Nagoya-Aichi Target 11) remains to be assessed in the study area.

Table 5. Aboriginal lands and communities in northern Alberta.

	ECOZONE			
	Boreal Plain	Boreal Shield	Taiga Plain	Taiga Shield
Aboriginal Communities	40	0	1	0
Indian Reserve (km^2)	3,770	8	189	35
Metis Settlements (km^2)	5,458	318	0	0
Treaty 8 (km^2)	291,388	6,429	62,378	9,282
Treaty 6 (km^2)	78,339	0	0	0
Treaty 10 (km^2)	7,453	0	0	0
Treaty 7 (km^2)	4,263	0	0	0

1.6 Public Land, Private Land and Tenure

Approximately 79.9 percent (385,524 km^2) of northern Alberta is public land, and 20.1 percent (74,010 km^2) is private or mixed ownership land (Table 6). The vast majority of privately owned lands occur in the Boreal Plains Ecozone.

Protected areas and conservation lands occur under both types of land ownership: private (freehold, deeded) and public (provincial and federal Crown). Figure 8 shows the distribution of these areas, only a few privately owned conservation lands are presently mapped.

Much of northern Alberta's public lands are subject to multiple industrial tenures (Figure 9).

Table 6. Summary of land ownership in northern Alberta.

Ecozone	Total Area (km^2)	Freehold Area (km^2)	Mixed Ownership (km^2)	Percent Private Ownership (%)	Crown Area (km^2)
Boreal Plain	381,444	69,022	4,531	19.28	307,891
Boreal Shield	6,429	0	0	0.00	6,429
Taiga Plain	62,379	253	198	0.72	61,928
Taiga Shield	9,282	1	5	0.07	9,276
	459,534	**69,276**	**4,734**	**20.07**	**385,524**

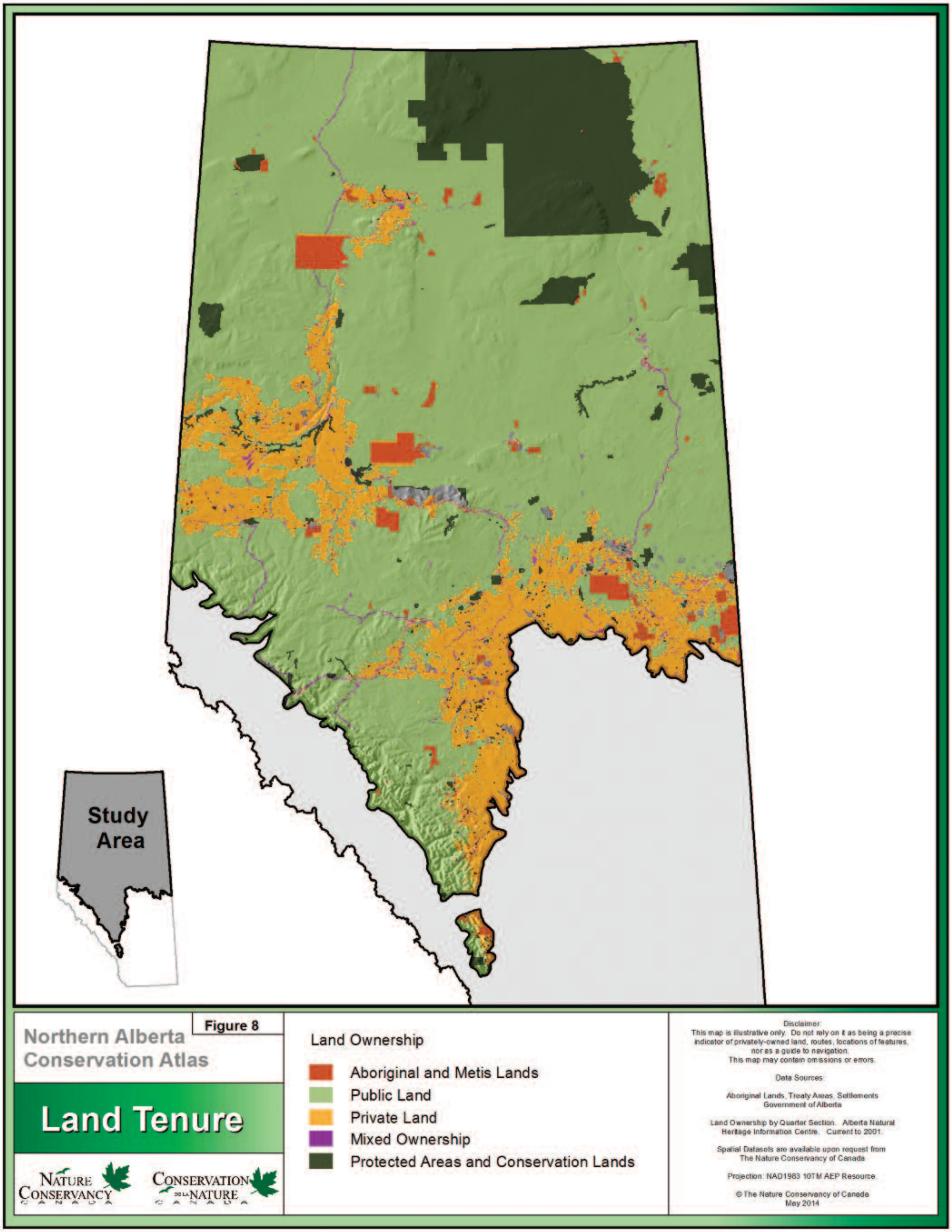


Figure 8. Land tenure in northern Alberta

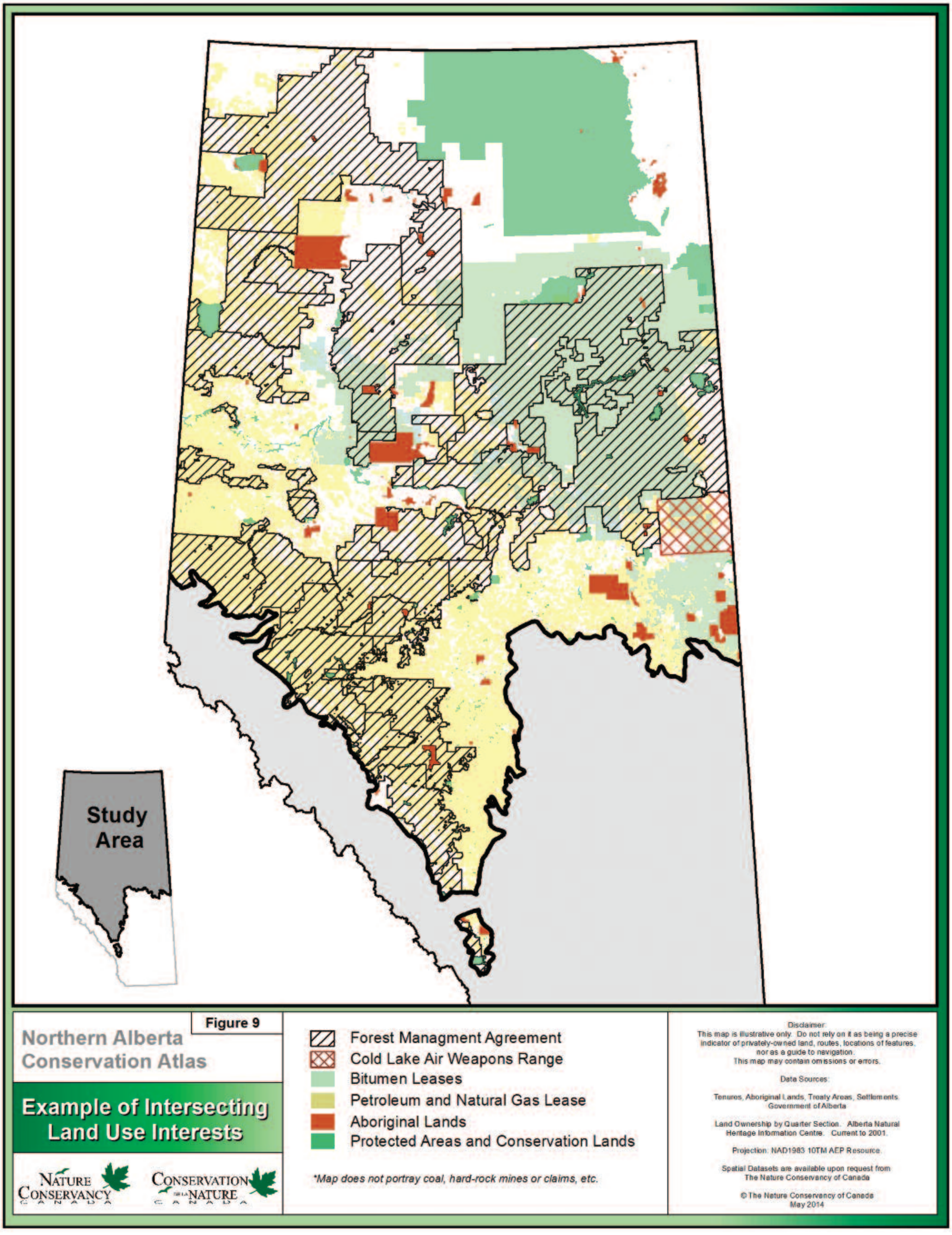


Figure 9. Examples of intersecting land-use interests and tenures in northern Alberta

White Spruce forest. Nature Conservancy of Canada

2.0 Conservation

In addition to general information available for northern Alberta, a series of additional datasets were developed as surrogates for those aspects of Nature's diversity that help inform decisions in support of the conservation of biological diversity. The underlying hypothesis is that *It is possible to identify and assess the lands and waters that, if appropriately conserved, could sustain the essential biological diversity of the region*. A stepping stone towards this goal is useful, shared and credible information and data.

THESE DATASETS, AND THEIR DEVELOPMENT, differ in some respects from those developed in other NCC regional assessments:

- A small group of internal experts developed the project, with the assistance of other individual experts who shared both advice and data (see Acknowledgements, and datasets).
- Most NCC assessments have covered ecoregions rather than jurisdictions, with the exception of the 2009-2013 *Labrador Nature Atlas*.
- Time and resources were limited by comparison.
- As with other NCC assessments, there are made-in-Alberta innovations, such as the use of the software tools *FRAGSTATS* and *LandMapR*.
- Rather than advancing a combined abiotic-biotic 'ecological systems' as the base unit for analysis (see Riley *et al.* 2007), this assessment developed a coverage of abiotic 'ecological land units' (ELUs), emulating the approach developed by the *Labrador Nature Atlas* (Notzl *et al.* 2013).

For northern Alberta, data limitations are significant, particularly in relation to detailed land cover, landform and the identification of the spatial habitat needs of many conservation priorities (or targets). As a result, "surrogate" data layers were developed to address some of these deficiencies. Methods are thus highly perfectible, and this study should be treated as a first-iteration, rapid analysis only.

Based on these direct and surrogate datasets, a coarse-filter/fine-filter approach was adopted:

1. "Ecological land units" (ELUs) were targeted conservation features, as surrogates for the range of habitat types supporting all biota, and each class of ecological land unit was scored for values associated with thirteen variables within four general parameters (Diversity, Condition, Ecological Function, and Special Features). Units (polygons or grids) were assigned relative scores for both the study area and for each ecodistrict in the study area (*coarse-filter analysis*).
2. All ELU polygons in which S1-S3 species occurrences were documented, were added to address conservation goals for priority (or target) rare species or species-at-risk (*fine-filter analysis*).
3. Existing protected areas (PA) and conservation lands (CL) were included in all outputs of analysis.
4. Output maps of conservation values within areas of *remaining semi-natural cover* were scaled relative to ecodistrict. The range of representative ELU values within the ecodistrict were mapped to suggest the various possibilities for conserving networks of functioning conservation lands and waters, acknowledging the role of intervening natural cover in conserving species populations and delivering ecological services.

The resulting maps of areas of relative conservation significance consist of priority conservation sites that critically conserve superior examples of native ecological land units and occurrences of species, nested within networks of sustaining semi-natural cover that secondarily contributes to this goal. The following sections include data sources, assembly procedures, technical methods, and output results, general areas of low-to-high priority to consider in land-use and resource planning.

2.1 Human Development Footprint and Natural Cover

Conservation priorities focus preferentially on lands where human development is least and where "natural cover" is least-disturbed. Natural cover applies here to areas without "permanent" human industrial footprint. For example, areas of timber harvesting and seismic lines are treated as areas of "non-permanent" (temporary) disturbance, while agricultural croplands, roads, pipelines, urban sites and industrial facilities are considered permanent disturbances. As a result, areas of temporary human impact were included in the conservation analysis. Areas subject to previous but temporary industrial activities may be restored to a natural or semi-natural state, and can support important biodiversity values. As such, the area considered for conservation analysis is larger than if all areas affected by both permanent and temporary impacts were included.

Settling ponds north of Ft. McMurray. Global Forest Watch Canada

At the time of analysis, no uniform dataset of permanent development impacts was available. The Alberta Biodiversity Monitoring Institute (ABMI) had developed a dataset illustrating all human impacts, both permanent and non-permanent (Figure 10), except for several gap areas. (Since this analysis, ABMI has published province-wide data on the human footprint *circa* 2010.) ABMI data also permit the discrimination of those elements of the overall footprint that are "soft linear features," such as seismic lines (Figure 11). Figure 12 illustrates a sample area including human footprint categories as mapped by ABMI, but also excluding "soft linear features" such as seismic lines.

In this analysis, ABMI human-footprint categories were extracted and coverage gaps were filled using ancillary datasets. On this basis, and excluding non-permanent impacts such as harvest areas and seismic lines, an overall coverage of "permanent human footprint features" was developed (Figure 13).

The remaining lands, those lands without "permanent human footprint features," is considered to be in a general state of "natural cover" (Figure 14). The Boreal Plains Ecozone contains the highest percent of total land that is permanently disturbed (Table 7). Conversely, it also supports the most land area in natural cover, although the Taiga Shield Ecozone has the highest overall percentage of natural cover (Table 8).

Table 7. Permanent human development in northern Alberta by ecozone.

Ecozone	Ecozone Area (ha)	Human footprint Area (ha)	% HF
Boreal Plains	38,140,724	5,416,565	14.2
Boreal Shield	637,546	569	0.1
Taiga Plains	6,235,484	41,675	0.7
Taiga Shield	924,985	209	0.0
Grand Total	**45,938,740**	**5,459,017**	**11.9**

Table 8. Natural cover in northern Alberta by ecozone.

Ecozone	Ecozone Area (ha)	Natural Area (ha)	% Natural Cover
Boreal Plains	38,140,724	32,086,889	84.1
Boreal Shield	637,546	635,255	99.6
Taiga Plains	6,235,484	6,162,756	98.8
Taiga Shield	924,985	924,434	99.9
Grand Total	**45,938,740**	**39,809,334**	**86.7**

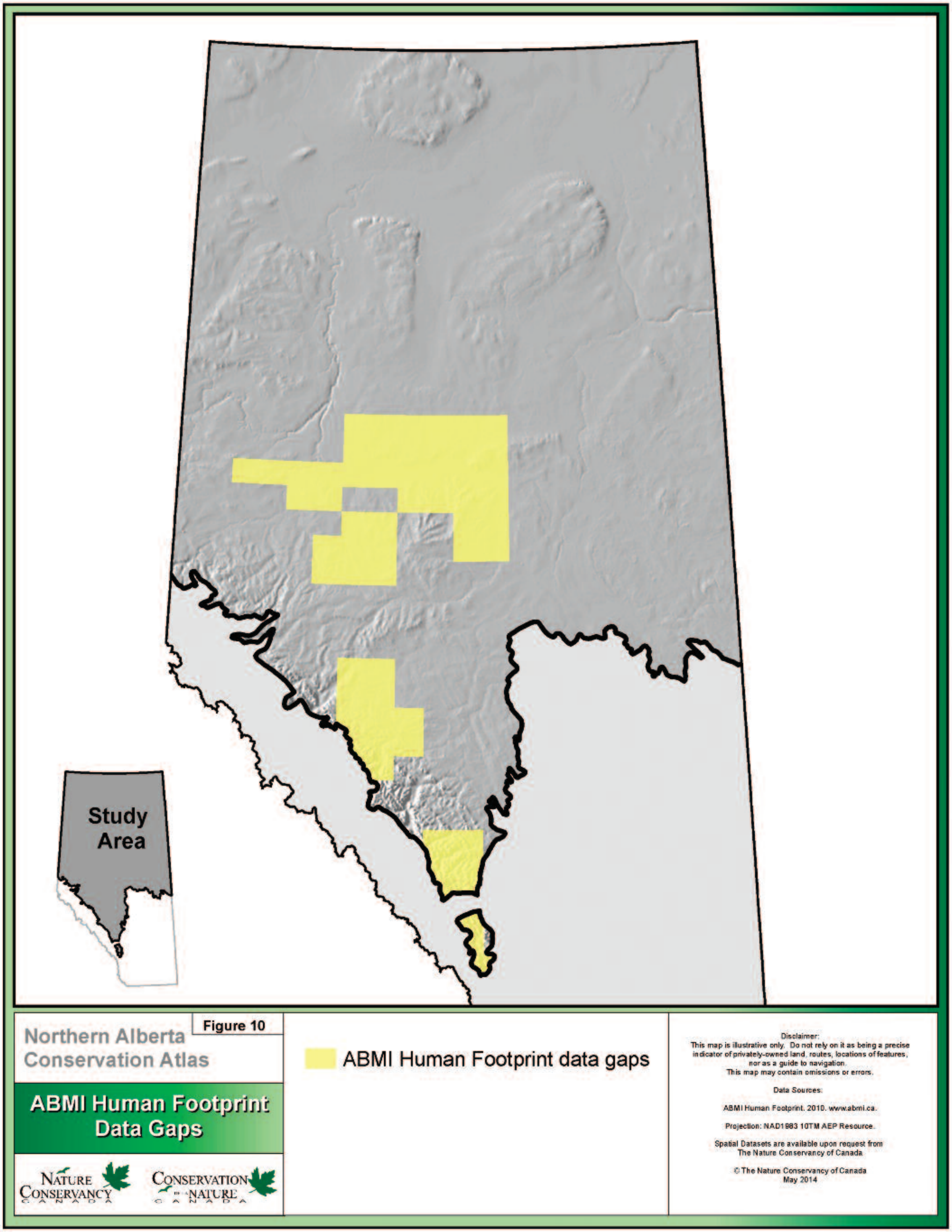


Figure 10. Human disturbance in northern Alberta mapped by ABMI (excluding the gap areas in yellow)

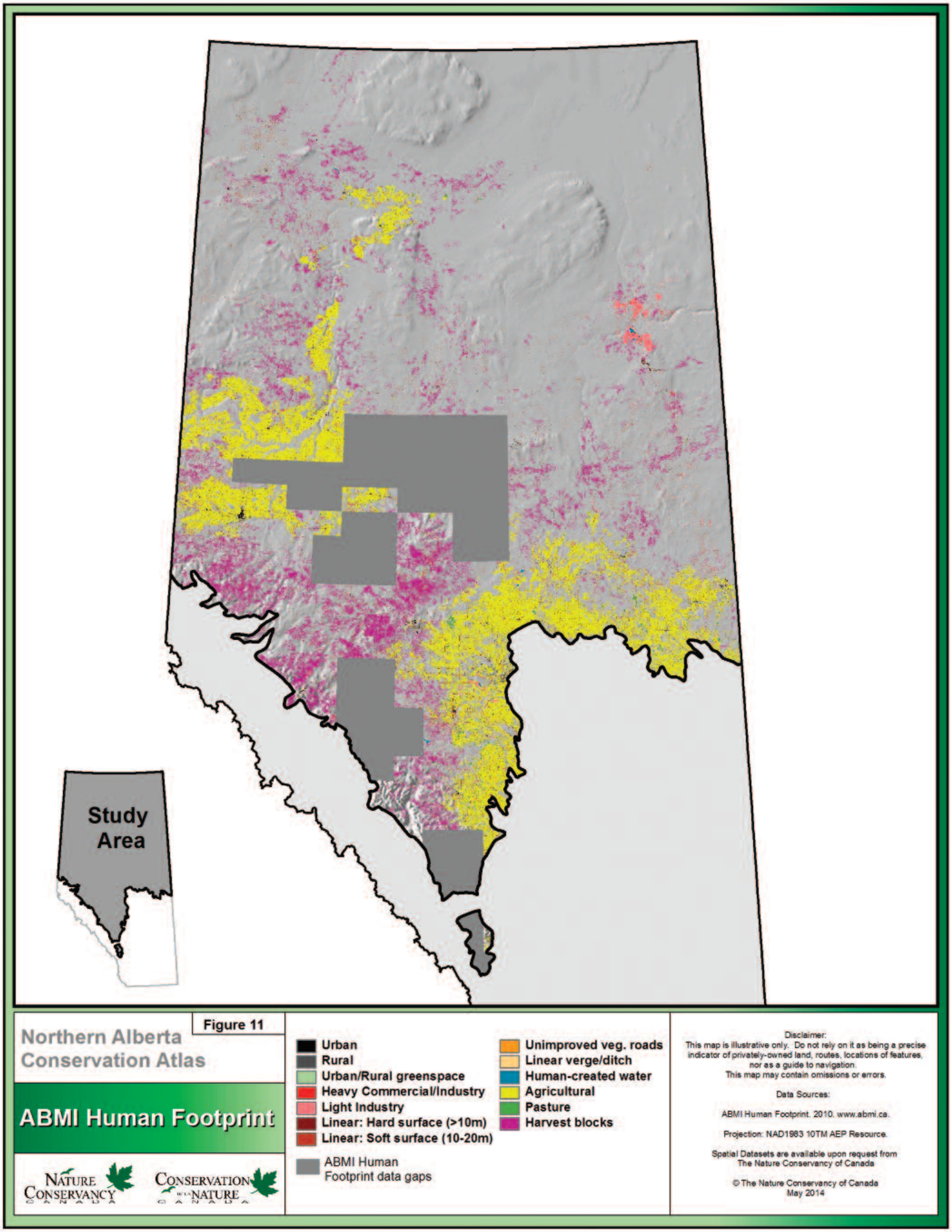


Figure 11. Human footprint as mapped by ABMI, excluding "soft linear features" (e.g., seismic lines)

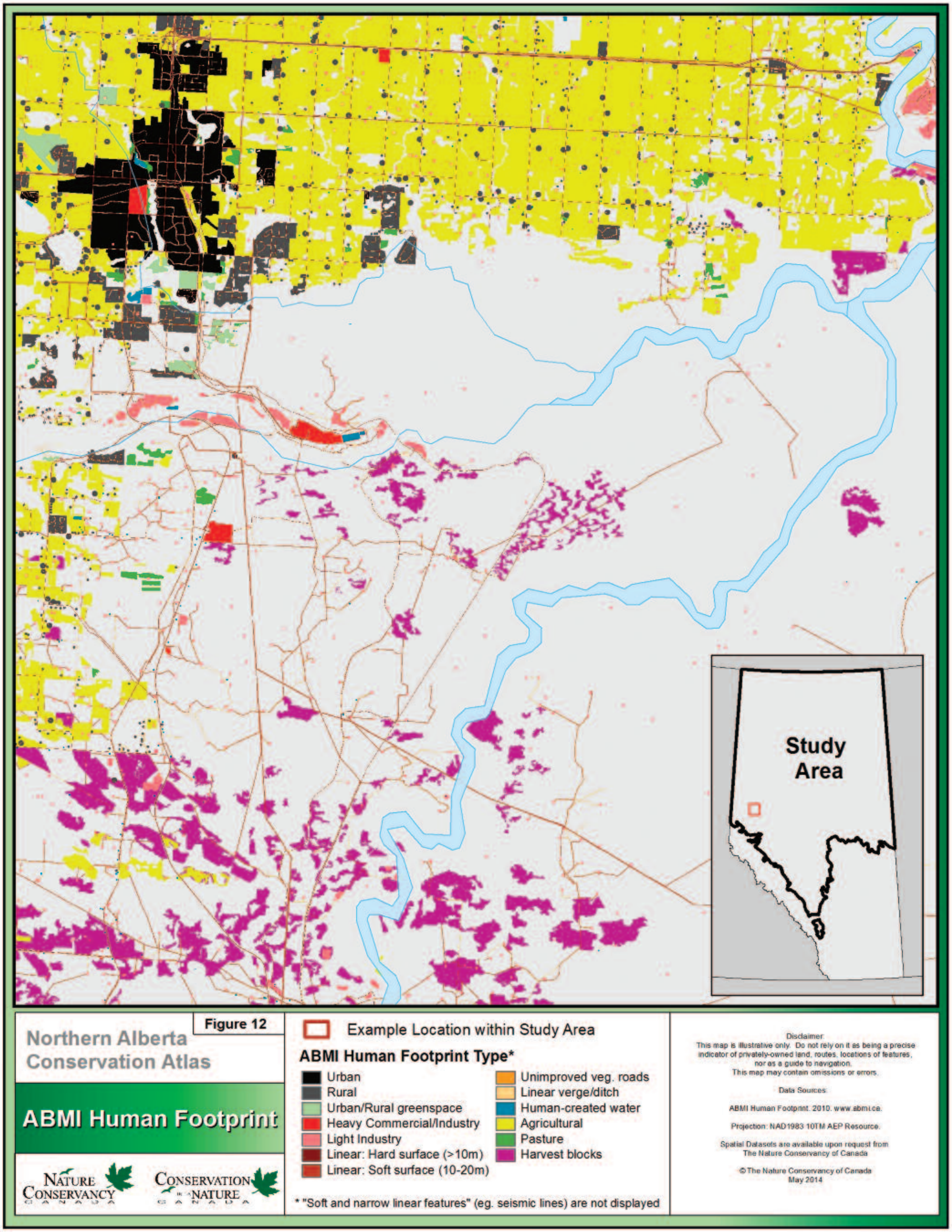


Figure 12. Sample area showing human footprint categories as mapped by ABMI, excluding "soft linear features" such as seismic lines

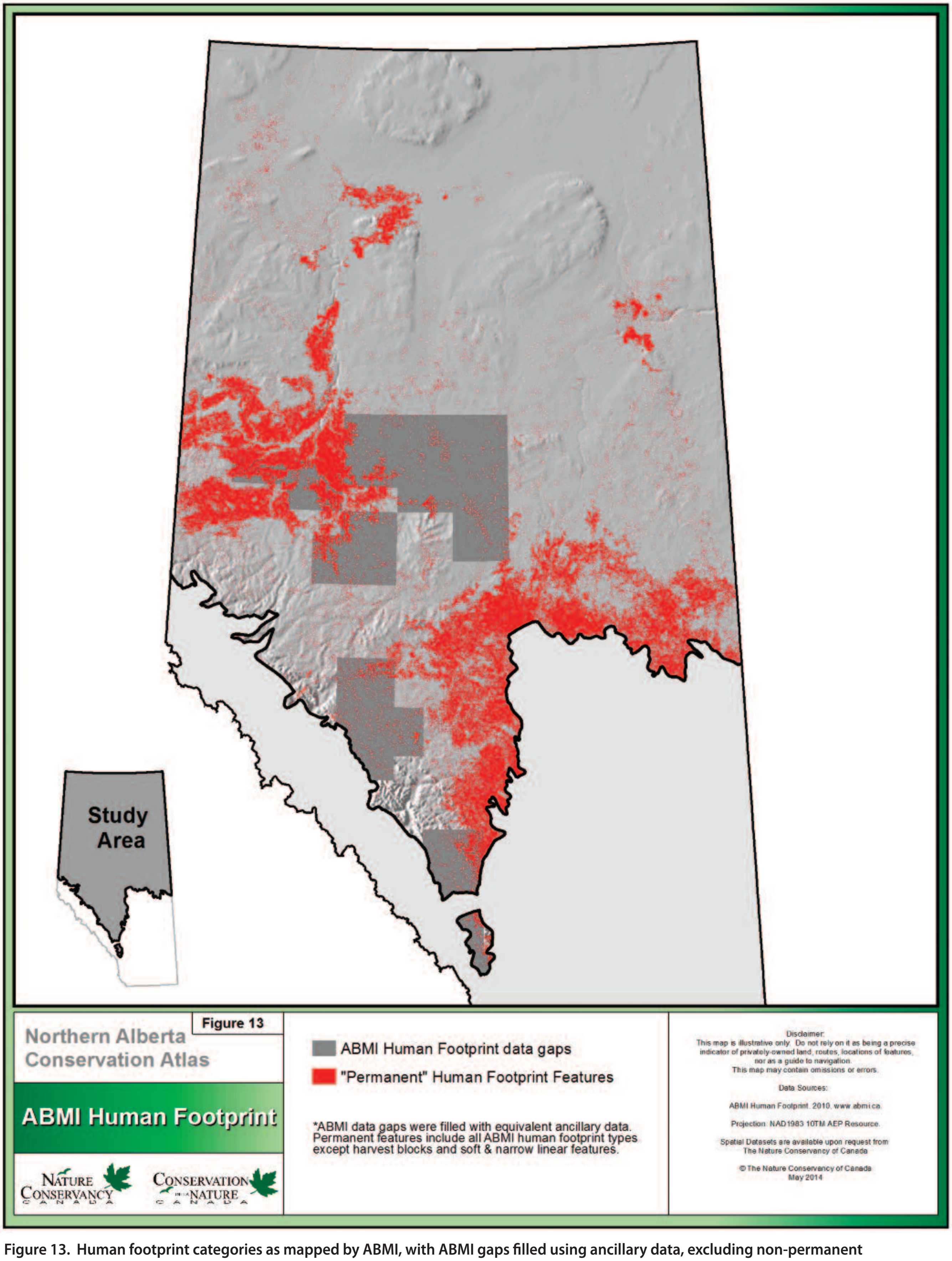


Figure 13. Human footprint categories as mapped by ABMI, with ABMI gaps filled using ancillary data, excluding non-permanent disturbances such as forest harvest areas and seismic lines

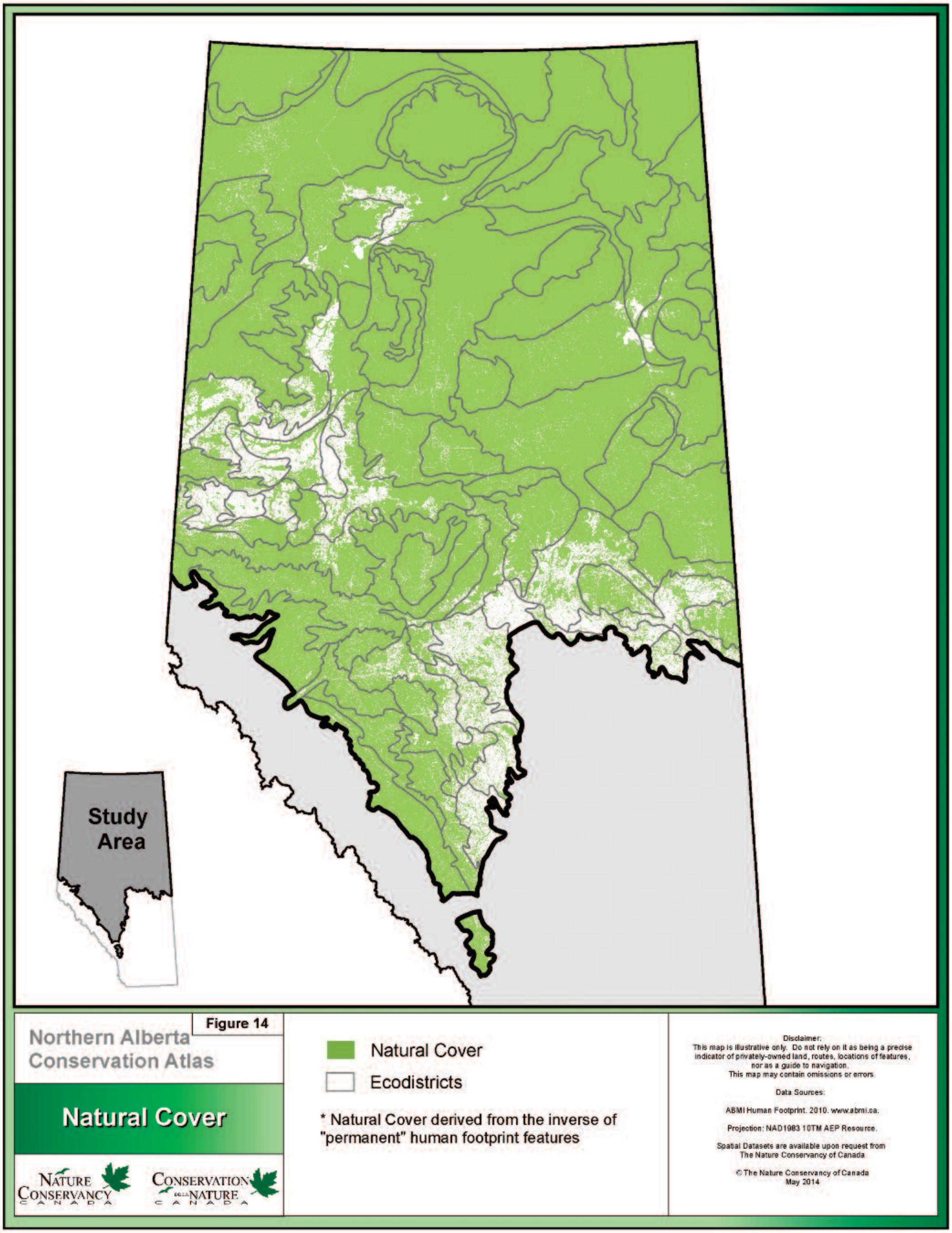


Figure 14. Natural cover of the northern Alberta study area

Emergent lakeshore marsh, Beavertail Creek property, Alberta. Nature Conservancy of Canada

2.2 Ecological Land Units

Conservation planning requires information about 'what' habitats or potential habitats exist on the landscape, and 'where they occur.' In the absence of available and comprehensive land cover, or vegetation mapping, a variety of data were used to develop a digital dataset for this purpose. The resultant 'ecological land units' (ELUs) are discrete abiotic systems (non-biological) that are combinations of substrate and landform. On this basis, ELUs with natural cover can be used as surrogates for the biological diversity and/or habitat potential of the landscape.

Ecological Land Units were developed by intersecting GIS datasets on the basis of landscape characteristics, specifically landform and substrate features at mappable and communicable scales. The resulting units are further identified by ecodistricts. Thus, ELUs are units (polygons or grids) that can be scored individually for their coincidence with other ecological criteria or values, to provide a relative conservation scoring or valuation of the landscape. Further, the ELUs that correspond with areas of "natural cover" (Section 2.1 above) were also identified. Conservation priority is normally extended to those areas most minimally disturbed.

2.2.1 SUBSTRATE

Alberta surficial geology data are available from the Alberta Geological Survey (AGS) on their website at http://www.ags.gov.ab.ca/surficial/index.html. Additional areas of the province mapped by the Geological Survey of Canada (GSC) are available through http://geoscan ess.nrcan.gc.ca/.

The coverage of medium-scale surficial geology mapping by AGS and GSC (1:250,000) is illustrated in Figure 15. The amalgamated classes of surficial geology were simplified in a manner consistent with the classes used in the

Glaciofluvial valley, McKay River. Global Forest Watch Canada

NCC *Conservation Blueprint for Canada's Prairies and Parklands* (Riley *et al*. 2007). More detailed classes were not thought to be reflected in on-the-ground biological differences in vegetation. Cross-walking and re-classification of the original substrate classes is summarized in Appendix B. Where there were multiple categories for particular areas, the class adopted was the overlaying, most surficial class (i.e., the first layer in the label field).

Gaps in AGS and GSC coverages were filled using additional sources:

a. Fulton, R.J. 1995. Surficial Materials of Canada, Geological Survey of Canada, Map 1880A;
b. Fluvial deposits along major rivers based on physiography of Alberta, available from Agriculture and Agri-Food Canada at: http://sis.agr.gc.ca/cansis/publications/surveys/ab/abp/index.html);
c. Organic substrates augmented from mapping of “hybrid wetlands” (Ducks Unlimited Canada).

The surficial geology dataset (a, above) was the primary layer used to fill gaps in coverage. Because its resolution is more coarse than AGS and GSC coverages, surficial materials were updated from other datasets where possible, specifically for 1) glaciofluvial deposits and valley complexes updated using valley mapping (b, above, illustrated in Figure 16), and 2) organic substrates, equivalent in large measure to wetlands (c, above, illustrated in Figure 17).

To ensure consistency and fit with generalized surficial geology classes, additional classes were combined according to the Final Category column in the cross-walk table in Appendix B. Two classes were removed: lakes/glaciers and anthropogenic materials, which were replaced with the substrate classes of surrounding areas. The final surficial geology map is presented in Figure 18, based on the following seven classes of substrate:

1. Bedrock
2. Glaciofluvial Valley
3. Glaciofluvial coarse
4. Glaciofluvial fine
5. Moraine
6. Organic
7. Sand

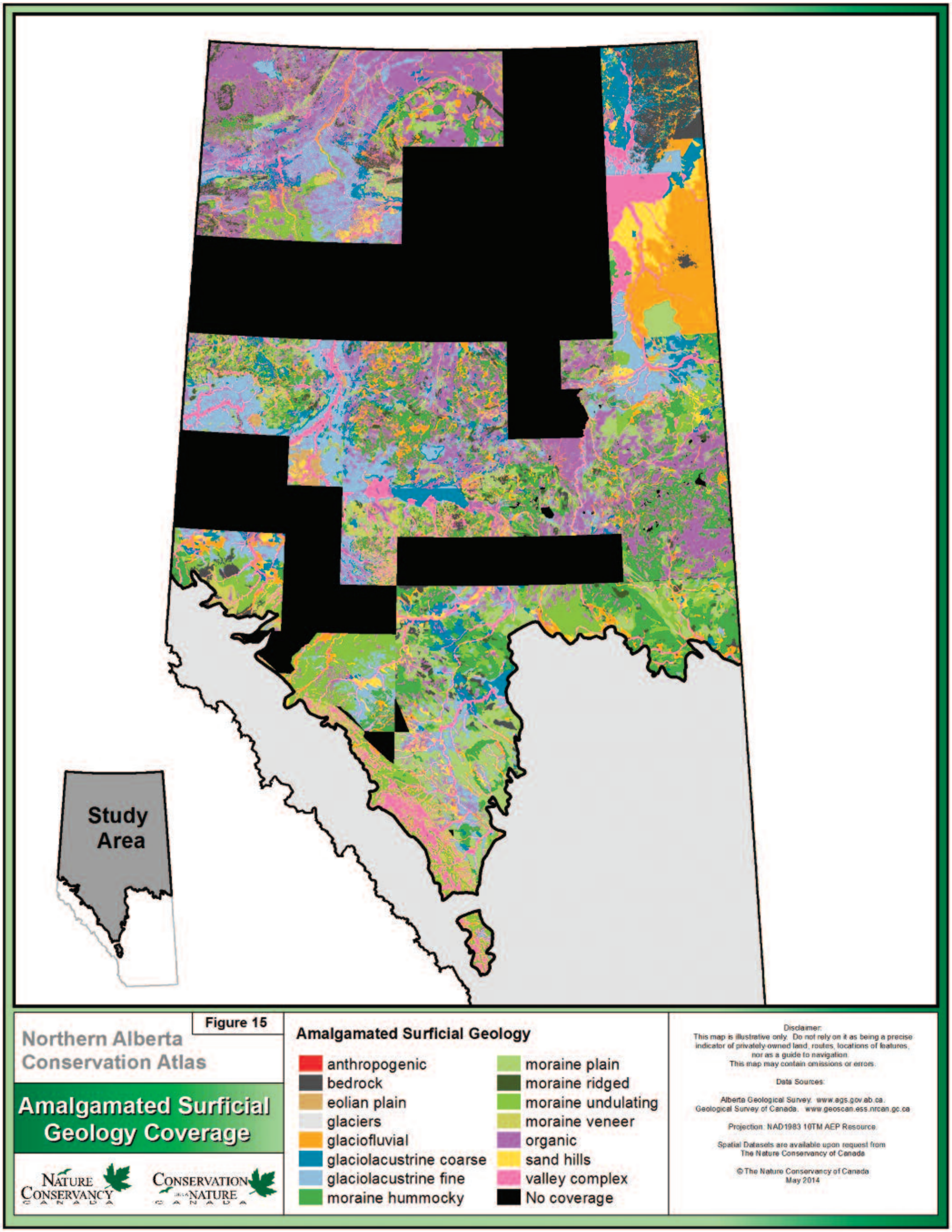


Figure 15. Amalgamated Alberta Geological Survey and Geological Survey of Canada Surficial Geology Mapping showing original classes

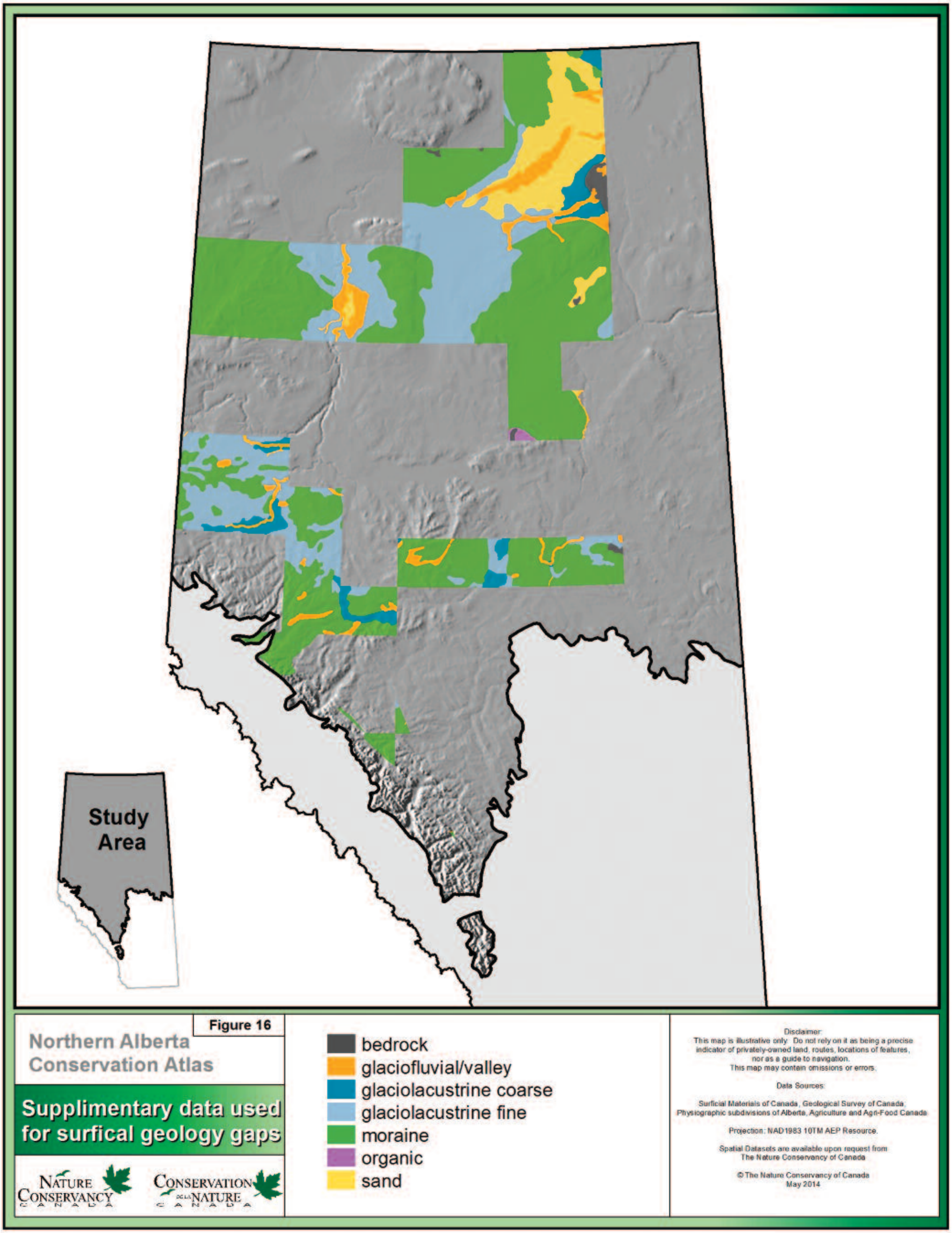


Figure 16. Surficial materials and physiographic subdivisions used to fill the gaps in data coverage

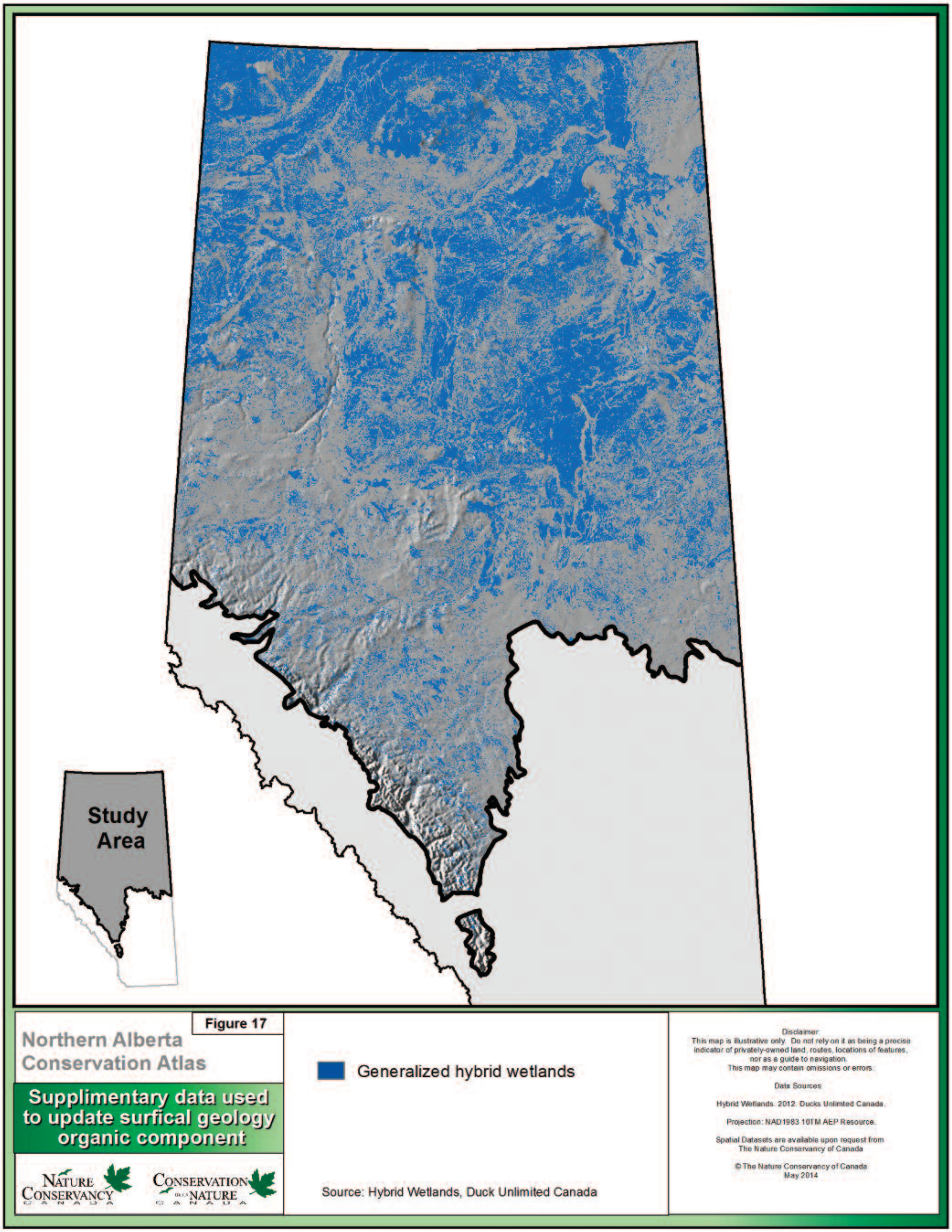


Figure 17. Generalized hybrid wetlands used to update the organic class of surficial geology data

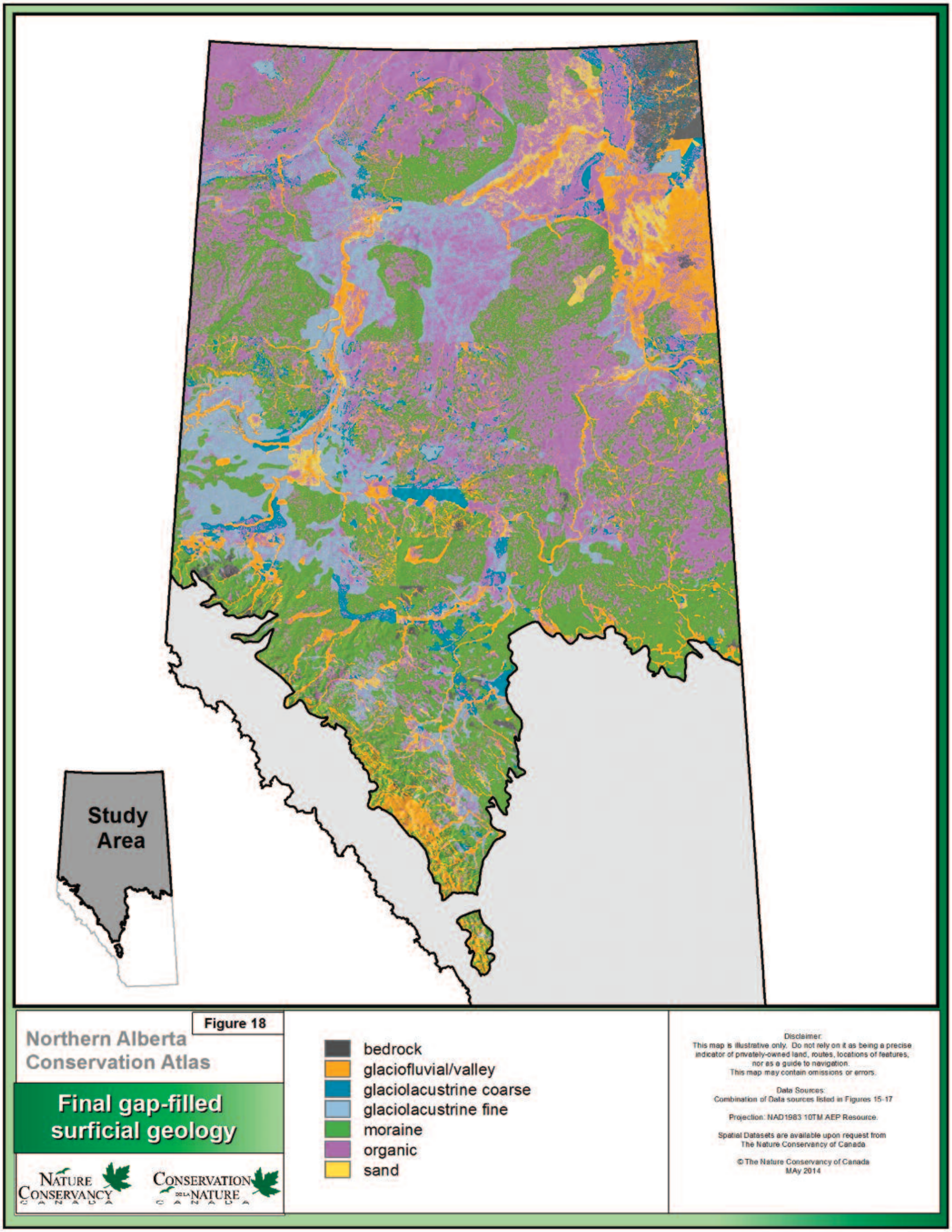


Figure 18. Final Substrate coverage for study area, based on surficial geology

Midslope landscape facet, Harvie property, Athabasca region. Nature Conservancy of Canada

2.2.2 LANDSCAPE FACETS

The other element of the "ecological land unit" (ELU) that complements its substrate material is its landform, or "landscape facet" (Anderson *et al.* 2006):

[The landscape facet is] largely responsible for local variation in solar radiation, soil development, moisture availability, and susceptibility to wind and other disturbances … It is tightly tied to rates of erosion and deposition, and therefore to soil depth, texture, and nutrient availability. These are, with moisture, the primary edaphic controllers of plant productivity and species distributions. If the other … influences on soil formation (climate, time, parent material, and biota) are constant over a given space, it is variation in landform that drives variation in the distribution and composition of natural communities…

Based on the analysis summarized in Appendix C, ten landscape facets were considered to reflect the major variation in ecological processes on northern Alberta landscapes. They combine terrain attributes that include slope, aspect, landscape position, surface curvature, and wetness index (Table 9).

Table 9. Landscape facets used to generate Ecological Land Units

Landscape Facet	Code
Steep slope/cliff (cool)	STC
Steep slope/cliff (warm)	STW
Upper gentle slopes	UGS
Upper depression	UPD
Upper flats	UPF
Mid slope (cool)	SDC
Mid slope (warm)	SDW
Lower gentle slopes	LGS
Lower depressions	LWD
Lower flats	LWF

The analysis of landscape facets is detailed in Appendix C, below, and is presented here in summary form only (Figure 19). A finer-scale portrayal of landscape facets for a particular area, is illustrated in Figure 20.

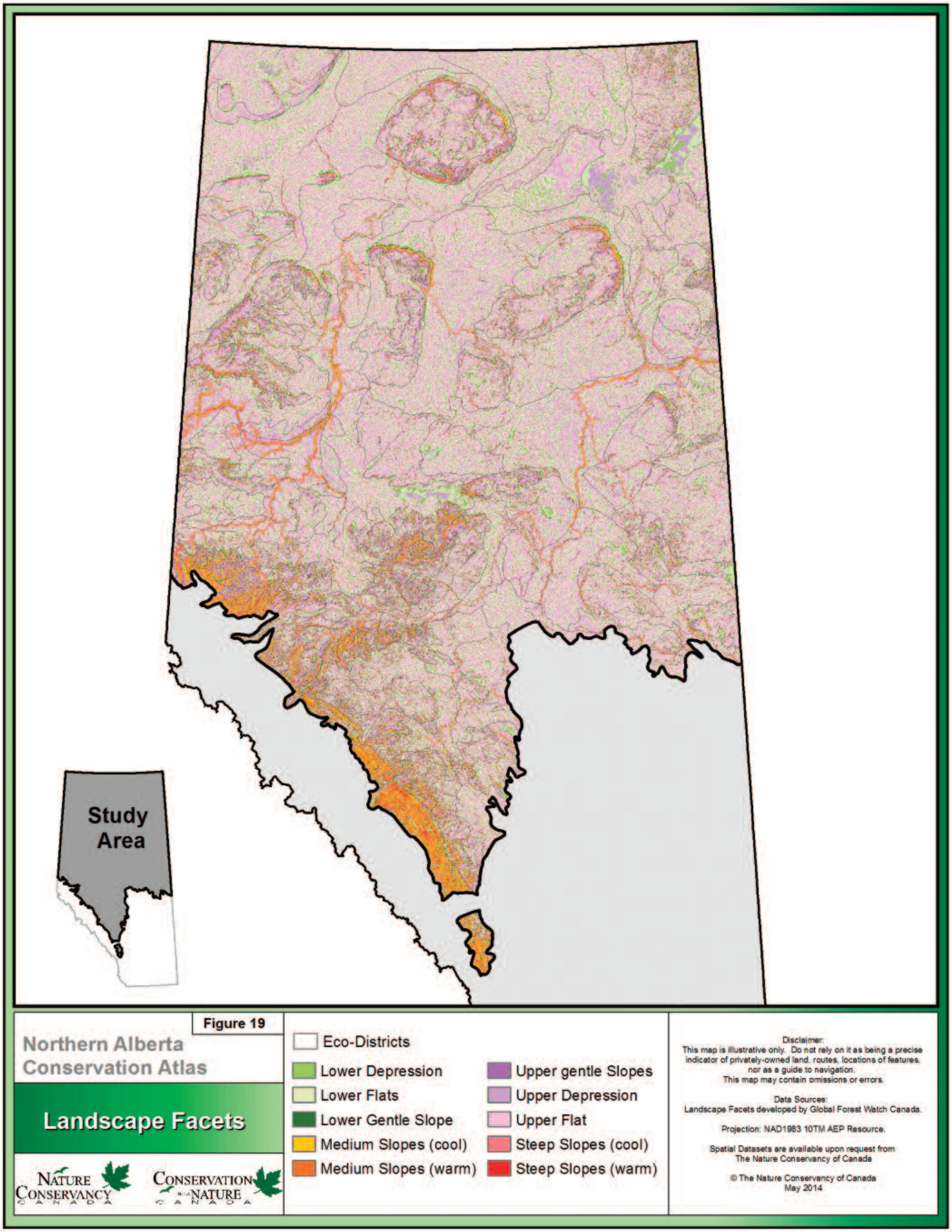


Figure 19. Landscape facets of the northern Alberta study area

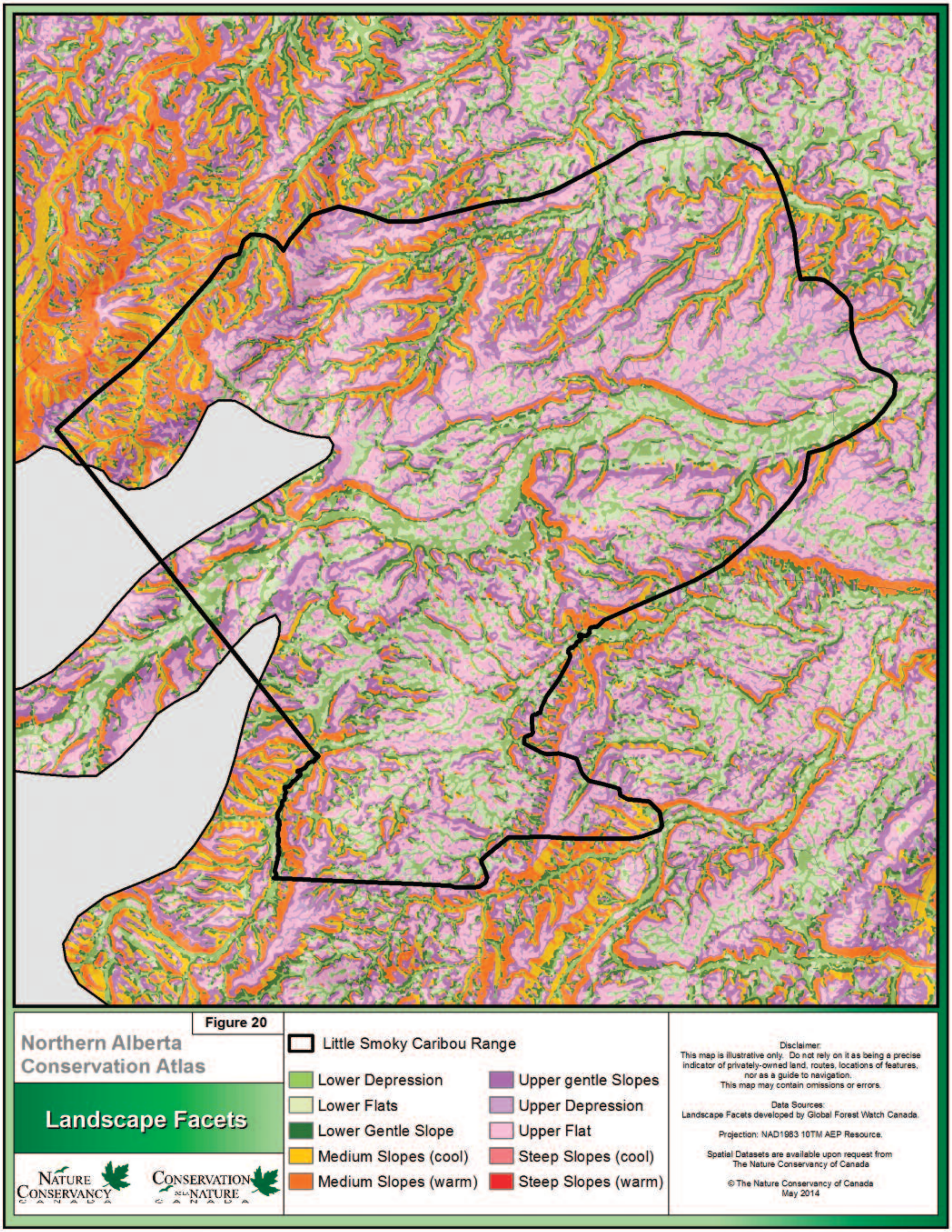


Figure 20. Landscape facets of the Little Smoky caribou herd range, in southwest part of study area

2.2.3 ECOLOGICAL LAND UNITS (ELUS)

The substrate and landscape facet data layers described above contributed two of the three components used to build the Ecological Land Units (ELU) grid. These two layers constitute enduring features of the landscape. The third component is the unique ecodistrict, as mapped by the National Ecological Framework (NEF 1999). According to the NEF, *ecodistricts are a subdivision of an ecoregion characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna and are also the smallest ecological unit within the NEF.* By definition ecodistricts are largely described by similar enduring features to those we chose for ELUs. The mapped ecodistrict framework was used as the initial division of the study area, which was then subdivided by the intersection of substrate and landscape facets to produce the final ELU layer. This method provides a scalable approach.

The three ELU components were converted or resampled to a 25m resolution grid. The class values for each ELU component were converted to coded value and then summed to provide a unique value for each possible class intersection (Table 10). Cell code values are summed using the ArcGIS *Raster Calculator* function. For example, a grid cell in an upper flat (Landscape Facet 34) on moraine substrate (substrate class 200) in the Swan hills ecodistrict (ecodistrict 62000) would be coded 62234. Water features (grid value 9999) were subsequently burned into the ELU dataset using double line water features greater than 0.36 ha from the GeoBase National Hydrography Network.

In total, the ELU grid for the Alberta boreal comprises 4346 unique combinations of ecodistrict, substrate type, and landscape facet.

ELUs with Natural Cover

The comparative scoring of ELUs as described in the following section (2.3) was only performed for ELUs dominated by "natural cover," i.e., those outside of "permanent" human disturbances. In preparing for the comparative ranking of ELUs, the layer was clipped to the Natural Cover dataset created from the human footprint dataset described in section 2.1. ELUs in natural cover are mapped in Figure 21.

Table 10. ELU component input coded values

Ecodistrict	+	Substrate class	+	Landscape Facet
242000 Yates River Plain		100 bedrock		11 lower depression
243000 Buffalo River Plain		200 glaciofluvial/valley		12 lower flats
244000 Hay River Plain		300 glaciolacustrine course		13 lower gentle slope
245000 Rainbow Lake Plain		400 glaciolacustrine fine		21 medium slopes (cool)
249000 Petitot Plain		500 moraine		22 medium slopes (warm)
250000 Cameron Slope		600 sand		31 upper gentle slopes
251000 Cameron Hills Upland		700 organic		33 upper depression
253000 Caribou Slope				34 upper flat
254000 Caribou Upland				41 steep slopes (cool)
263000 Uranium City Upland				42 steep slopes (warm)
… etc (90 ecodistricts total)				9999 water

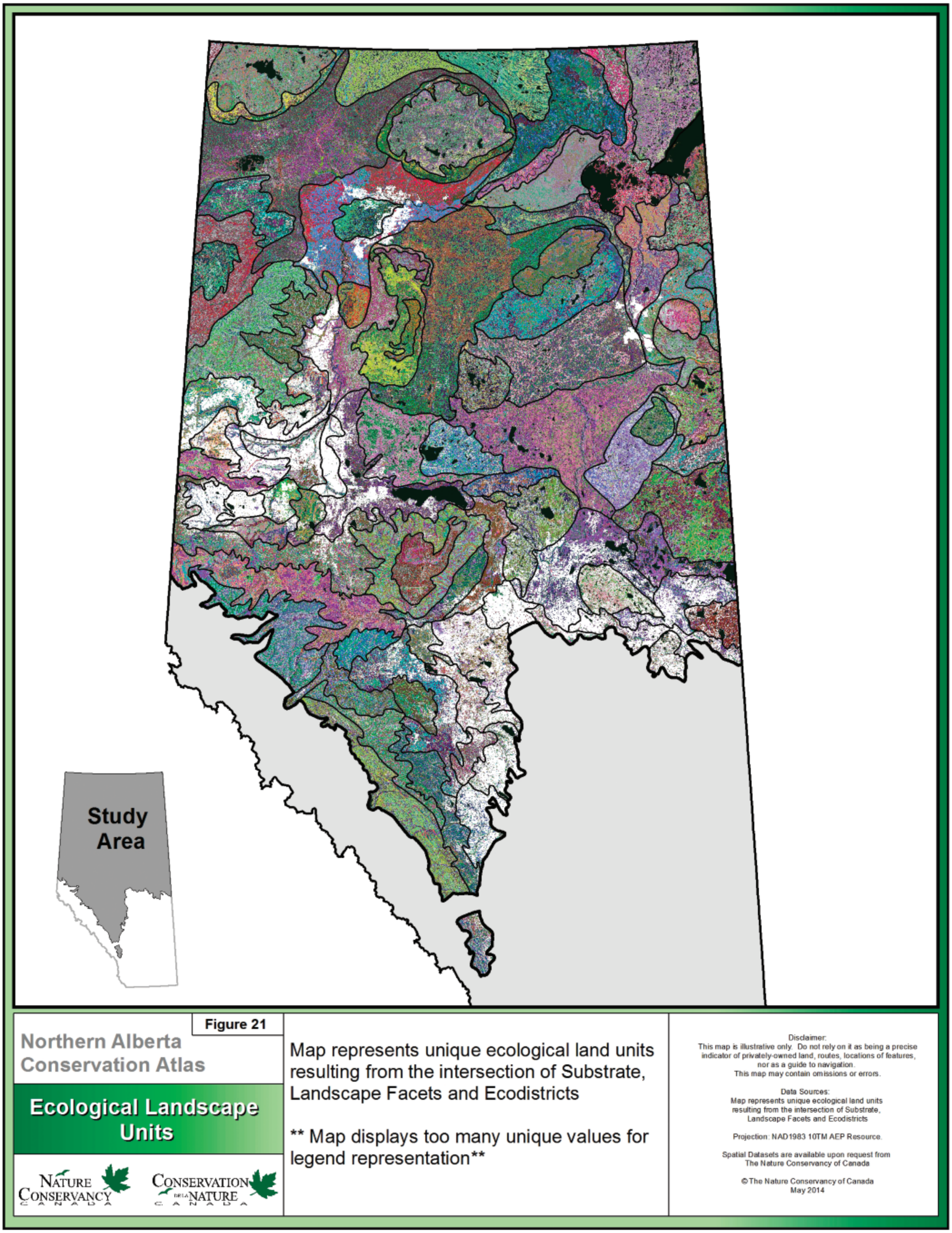


Figure 21. Ecological Land Units in natural cover

Athabasca River valley. Global Forest Watch Canada

2.3 Conservation Ranking of Ecological Land Units

Further analysis and mapping were undertaken to rank each ELU grids (within Natural Cover) in relation to a variety of mapped ecological values.

ELU grids were compared with each other by calculating a specific numeric score for each grid, scaled from 0-100, based on a variety of specific mapped 'values.' The selection of values was driven by four over-arching ecological criteria:

i. *Condition;*

ii. *Diversity;*

iii. *Ecological Function;*

iv. *Special Features.*

The value grids were selected GIS data layers, or map layers, which acted as surrogate values representing each ecological criterion. The value grids were converted or resampled to a 25-metre cell size. These layers either represent continuous information such as percent intact or discrete information such as ecological land unit size. The value grids also represented a variety of coarse-filter (i.e. percent wetland, distance to roads) and fine-filter (i.e. species ranges, element occurrences, etc) data inputs.

Each ecological criterion was given a weighted score out of 100 based on the relative ecological importance within Alberta's northern landscapes, which was determined by expert opinion. In the same way, the weighted score of each criterion was distributed further into its representative value grids based on their relative ecological importance. The score given to each value grid was again distributed into a number of classes based on a histogram classification method or by the discrete zones or feature within the dataset (Table 11).

The scores of each value class were then summed using ArcGIS *Raster Calculator*, so that for any given cell location the final score ranged from 0 to 100 depending on the number of intersecting value grids and their assigned score. The scores of each cell within ELU polygons were averaged to generate a single score for each polygon, or patch. This final total score is termed the polygon's 'conservation value' relative to other ELU patches. The polygons with the highest scores were selected to represent core biodiversity conservation areas among all other polygons of the same ELU type.

The boreal plain with seismic exploration line, Athabasca River north of Ft. McMurray. Global Forest Watch Canada

Table 11. Ranking and scoring Ecological Land Units

Parameter	Variable	Value	Score	Description
CONDITION	Percent Natural cover	0-10	1	Percent of natural cover within 2 km search radius.
15	10	10-20	2	Natural cover derived from "permanent" Human
		20-30	3	Footprint features
		30-40	4	
		40-50	5	
		50-60	6	
		60-70	7	
		70-80	8	
		80-90	9	
		to 90-100	10	
	Distance to road (m)	0-100	1	Distance in meters calculated from National
	5	100-250	2	Road Network
		250-500	3	
		500-1000	4	
		>1000	5	
DIVERSITY	ELU diversity	1-4	1	Number of ELU types within 9x9 cell neighbourhood
5	5	5-6	2	(~200m). The maximum number within each ELU
		7-8	3	was assigned to the ELU polygon
		>8	5	
ECOLOGICAL	Size of patch (ha)	0.81-4	2	Relative measure between ELU polygons
FUNCTION	10	4-16	4	
40		16-64	6	
		64-256	8	
		>256	10	

Parameter	Variable		Value	Score	Description
ECOLOGICAL	Shape index		1.867	5	Calculated from ELU polygons using Fragstats
FUNCTION	5		2.733	4	Relative index measuring a standardized area:
40			3.764	3	edge ratio for each ELU polygon.
			5.099	2	Categories based on natural breaks classification.
			>5.099	1	
	Proximity (Connectivity) index		4.5	1	Calculated from ELU polygons using Fragstats.
	5		27	2	Relative index measuring the number/distance/size
			85.6	3	of similar ELU types for each ELU polygon.
			256.9	4	Categories based on Quantile classification found
			>256.9	5	within 1 standard deviation of the mean.
	Water-edge (lake) density (km/km^2)		0.245	2	Derived from NHN data using a 100 km^2
	10		0.612	4	(5.6km radius) circular search window.
			1.150	6	Categories based on natural breaks classification.
			2.056	8	
			>2.056	10	
	Percent Wetland		25-50	4	Percent wetlands within 1 km search radius
	10		50-75	7	calculated from a modified Ducks Unlimited
			>75	10	Canada Hybrid Wetlands data
SPECIAL	Waterfowl/shorebirds	BPOP	6-11	2	Number of Breeding pairs per sq. mi.
FEATURES	10		>11	5	Dataset derived by Ducks Unlimited Canada
40		IBA	Presence	5	Important bird areas from Bird Studies Canada
					and the Canadian Nature Federation (2004)
	Caribou	Zones	20km Buffer	1	20km buffer representing predator influence zone
	10		Permanent	2	500m buffer around "permanent" Human
			EnvCan		Footprint features
			Intact	4	EnvCan caribou disturbance features areas
				5	outside disturbance
		Status	Increasing	1	Caribou herd status based on the amount of herd
			Stable	3	range disturbance as calculated from Environment
			Threatened	5	Canada caribou disturbance mapping.
	Grizzly	Status	Secondary	5	Relative population status reported by catchment
	10		Core	10	
	Presence of Element		1	1	Number of EOs
	Occurrences		3	2	
	5		5	4	
			>5	5	
	Distance to protected area (km)		1.6	5	Euclidian distance from protected areas and
	5		3.2	3	other conservation lands
			4.8	1	
			>4.8	0	

2.3.1 CONDITION

The relative ecological condition of an area is a challenge to assess on the ground. Any remote assessment of condition is even more difficult. In this project the relative 'intactness' of the natural cover in an area was used as a surrogate value for condition, by measuring the amount of natural cover immediately adjacent to an ecologifcal land unit (ELU) polygon. In addition, the average distance of roads from each ELU polygon was assessed as a measure of disturbance and human accessibility. Thus, ranking of condition was weighted to preferentially select ELUs with a high degree of natural cover and a low average distance to roads. The condition criteria contributed 15 percent of total score. (Table 11).

Percent natural cover in 2km radius

This measure of conservation value related directly to the degree of natural connectivity or isolation that an ELU polygon experiences. The amount of natural cover in an area influences many ecosystem processes, such as dispersal, in that more isolated patches are less likely to be recolonized after an extirpation event.

The percent natural cover was generated from the inverse of the Alberta Biodiversity Monitoring Institute's human footprint ('permanent' disturbances only) converted to grid and resampled to 25m. The amount of natural cover within a 2km radius of each focal pixel was calculated and scored. The scores were divided into 10 equal interval classes representing 10% intervals (Figure 22).

Distance to roads

The distance to roads was calculated as the 'Euclidian Distance' with an output cell size of 25m. The road data were the Natural Resources Canada's National Road Network. The distance to the nearest road from an ELU was then assigned to each ELU by performing a zonal minimum function. For a road passing through an ecological land unit, this distance would be zero. The further the distance an ELU was from its nearest road the higher the score was given to it. The functional distance ranged from 0-1000m with ELUs having a distance greater than this placed in the highest score (Figure 23). The selection of the five categories of distance to roads was somewhat arbitrary (0-100 m; 100-250 m; 250-500 m; 500-1,000; >1,000 m), but also reflected a general view of the authors that the selection likely reflects general avoidances for amphibians (at the lessor distances), forest-dwelling birds (at the medium distances), and woodland caribou and grizzly bear (at the greater distances).

2.3.2 DIVERSITY

Diversity potential was measured as the number of ELUs that neighbour each individual ELU polygon, with diversity greatest where the highest number of unique ELUs are located within the search distance at any given point within the ELU polygon. This was calculated using the neighbourhood statistic focal variety and then the maximum pixel value for each ELU polygon. A 9x9 neighbourhood (ca. 200m search window) was used to count ELUs within the search distance. This calculation assigned higher scores to an ELU where it was near to several different ELUs within the search distance. The polygons that were part of clusters of unique ELUs scored highest (Figure 24).

Mixedwood boreal forest
southeast of Ft. McMurray
Global Forest Watch Canada

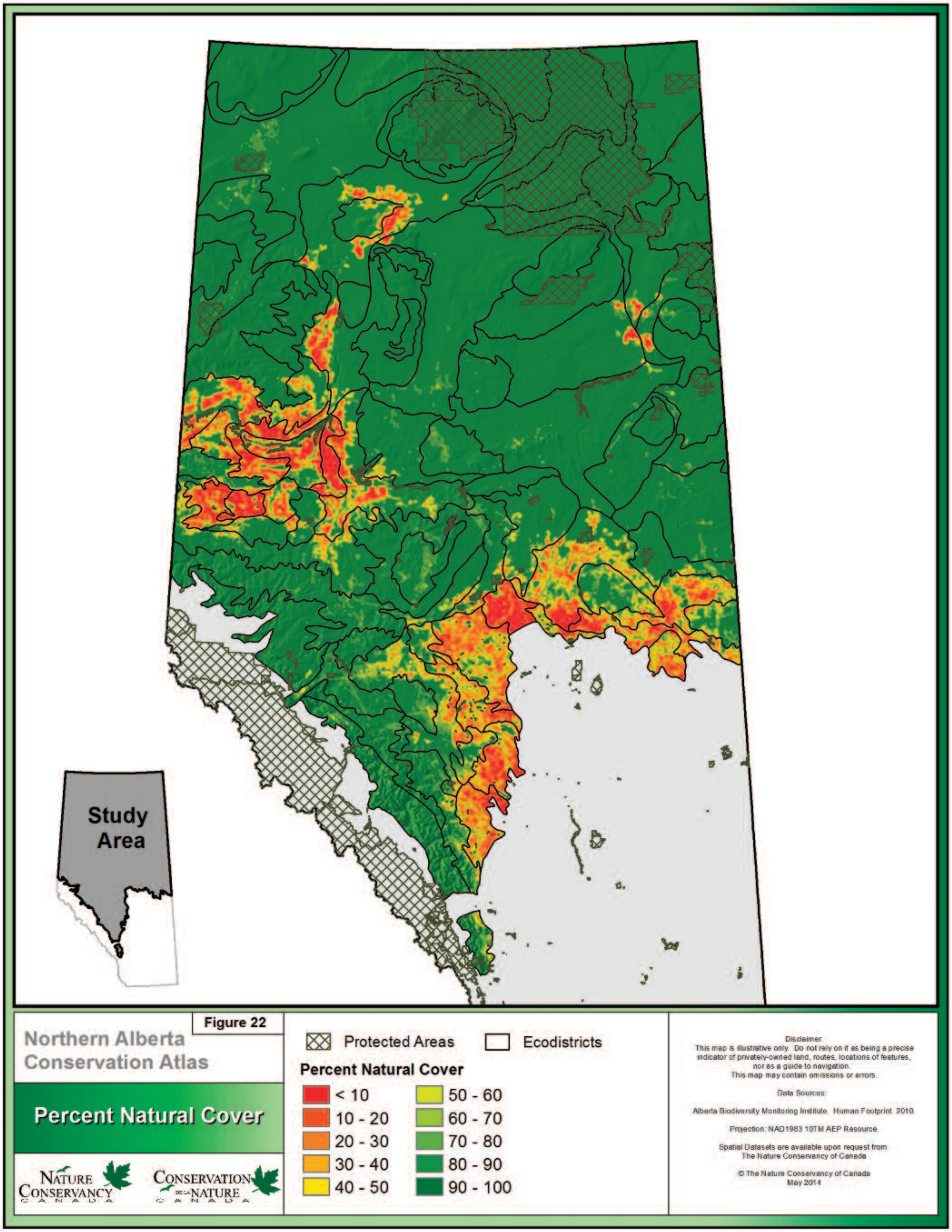


Figure 22. Percent natural cover in northern Alberta

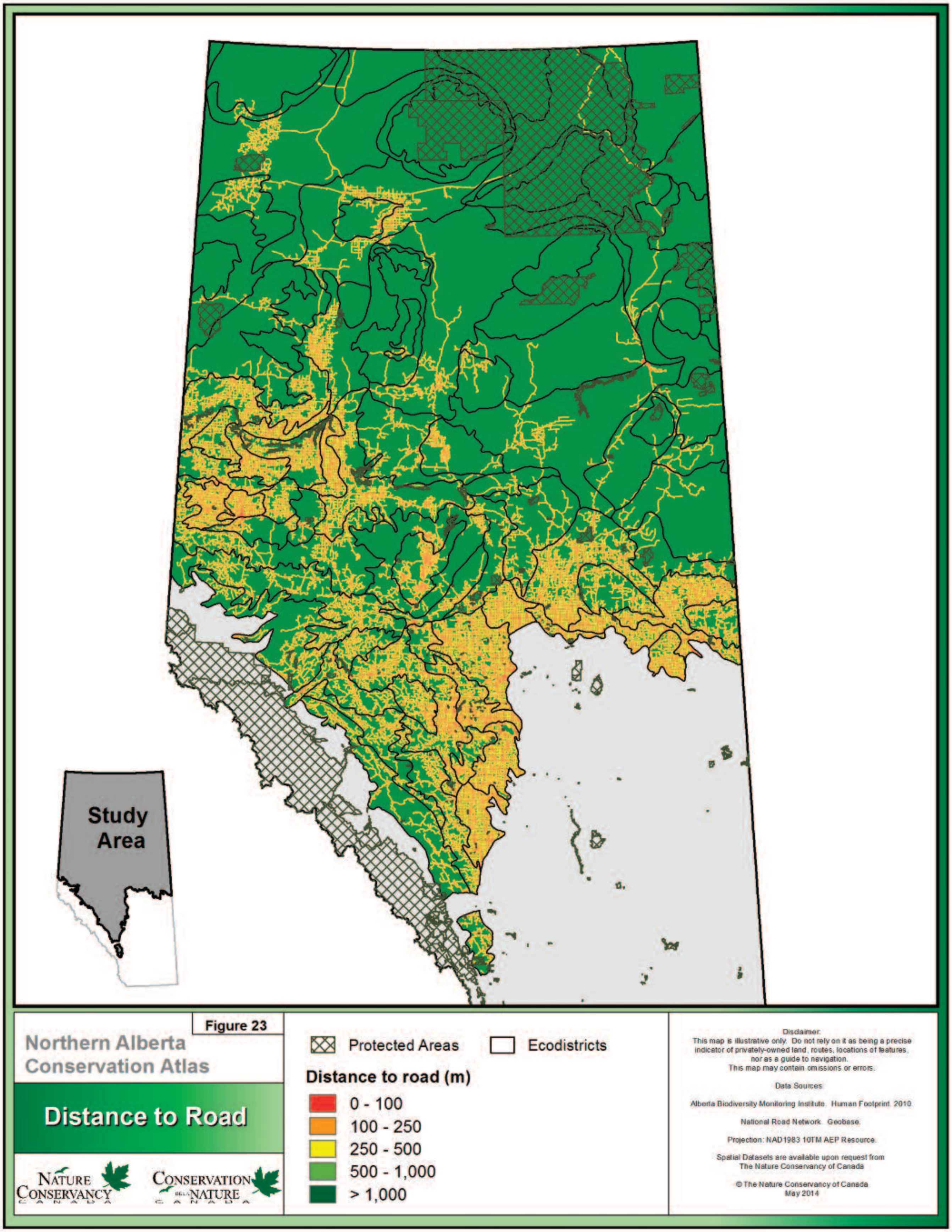


Figure 23. Distance to road in northern Alberta

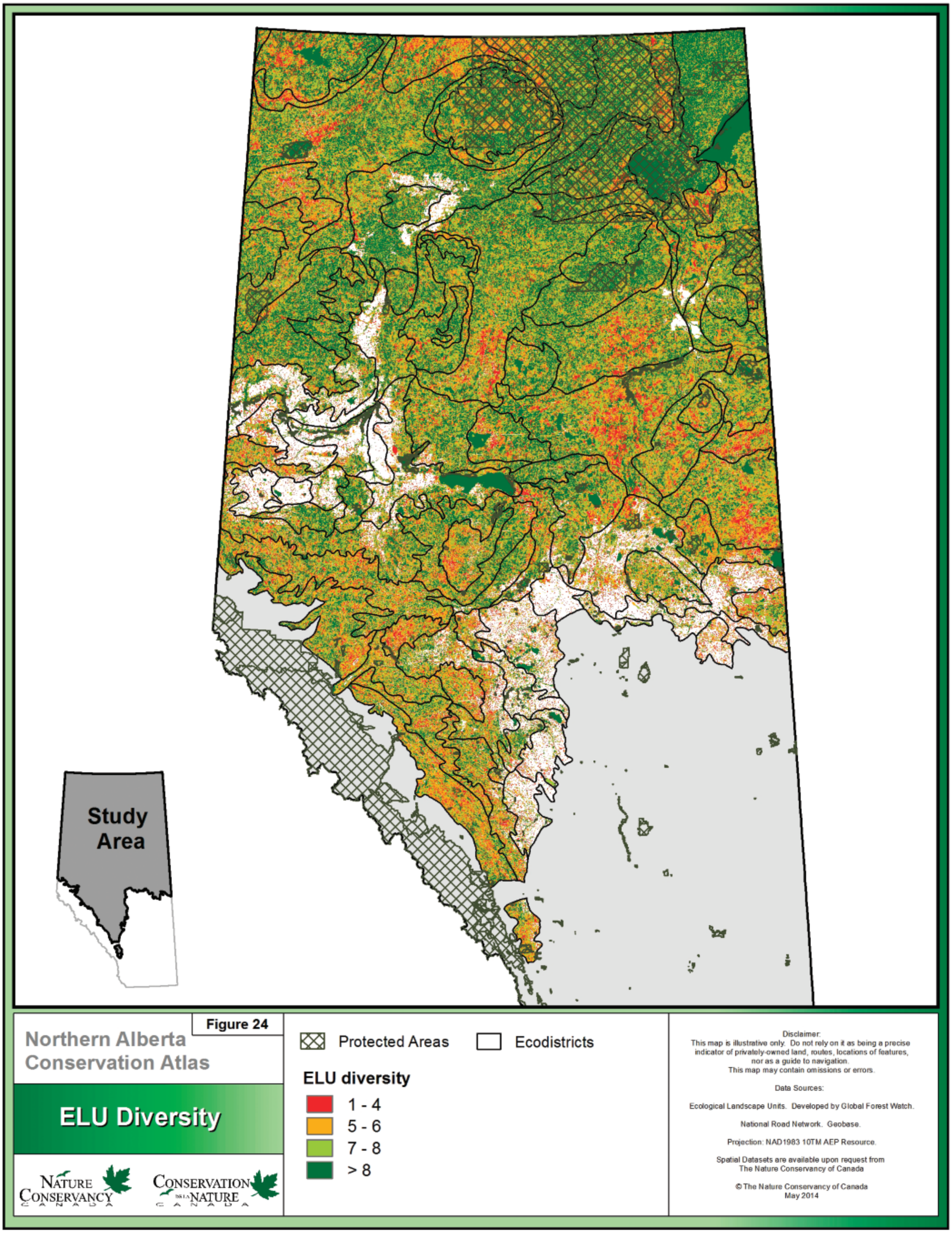


Figure 24. ELU diversity of ELUs in northern Alberta

2.3.3 ECOLOGICAL FUNCTION

The size, shape and connectivity of ELUs as 'patches,' along with their wetland or riparian location, were used to reflect ecological function. Larger patches, of a more compact shape, and with a greater degree of connectivity on the landscape were scored more highly. Areas with a greater amount of wetlands and riparian areas were also scored more highly because of their contribution to local diversity. Ecological function components were assigned a combined weight of 40 percent of the total score.

Patch Size

Scores were assigned to each ecological system polygon based on the total area; with the larger polygons receiving higher scores (Figure 25).

Shape

In assigning conservation value to most terrestrial ecological systems, linear shaped patches are generally considered as less significant for biodiversity than blocky patches of the same size. In this study, shape is considered as the relative complexity of an ELU polygon compared to a standard (square) shape of the same size, which alleviates the size dependency problem found with a simple perimeter-area ratio. Shape of ELU polygons was calculated in Fragstats v4.1 using the patch metric "Shape Index". Fragstats describes the Shape Index as "*patch perimeter divided by the square root of patch area, adjusted by a constant to adjust for a square standard*." See Figure 26.

Shape index is calculated as follows:

$$\text{SHAPE} = \frac{.25\ p_{ij}}{\sqrt{a_{ij}}}$$

p_{ij} = perimeter of patch **ij** in terms of number of cell surfaces.

min p_{ij} = minimum perimeter of patch **ij** in terms of number of cell surfaces

Shape = 1 when the patch is square and increases without limit as patch shape becomes more irregular. A small proportion of ELU polygons were highly complex in shape, which resulted in a highly skewed distribution of the data. Because of this skew, shape was scored based on natural breaks in the data found within 2 standard deviations of the mean, which represented about 90 percent of the data values.

Connectivity

Connectivity is a measure of the potential movement of organisms between habitats of the same type. The size and proximity of ELUs of the same type within a 1km search radius of the focal patch were used to score connectivity. Connectivity of ELU polygons was calculated in Fragstats v4.1 using the patch metric "Proximity Index." Fragstats defines the Proximity Index as "*the sum, over all patches of the corresponding patch type whose edges are within the search radius of the focal patch, of each patch size divided by the square of its distance from the focal patch.*"

Proximity Index is calculated as follows:

$$\text{PROX} = \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^{2}}$$

a_{ijs} = area (m^2) of patch **ijs** within specified neighbourhood (m) of patch **ij**.

h_{ijs} = distance (m) between patch **ijs** and patch **ijs**, based on patch edge-to-edge distance, computed from cell center to cell center.

The Proximity Index is unitless and can only be used as a relative measure (Figure 27). The number and size of the surrounding patches of the same type varied widely between the ELU polygons and the smallest and largest values differed by several orders of magnitude. Similar to the shape index, the resulting values of the Proximity index were highly skewed in distribution. Because of this highly skewed distribution, connectivity was scored based on quantiles found within 1 standard deviation from the mean, which represented approximately 90 percent of the data values. In this case, quantile classification better represented the data distribution than natural breaks due to its highly skewed nature.

Percent Wetland Cover

Percent wetland cover was derived from Ducks Unlimited Canada's Hybrid Wetlands data layer. All wetlands greater than 0.36-ha in size, combined with the organic component from surficial geology data, were considered in the analysis. Percent wetland cover was derived from the total amount of wetland cover calculated within a 1-km search radius (Figure 28).

Lake Edge Density

Lake edge density was calculated from double line water features greater than 0.36-ha from the GeoBase National Hydrography Network. Manmade water features were excluded from the analysis. Density was calculated with in a 100-km^2 circle (5.6-km radius) search window. Each cell location represented the total length (km) of lake edge per square kilometre. See Figure 29.

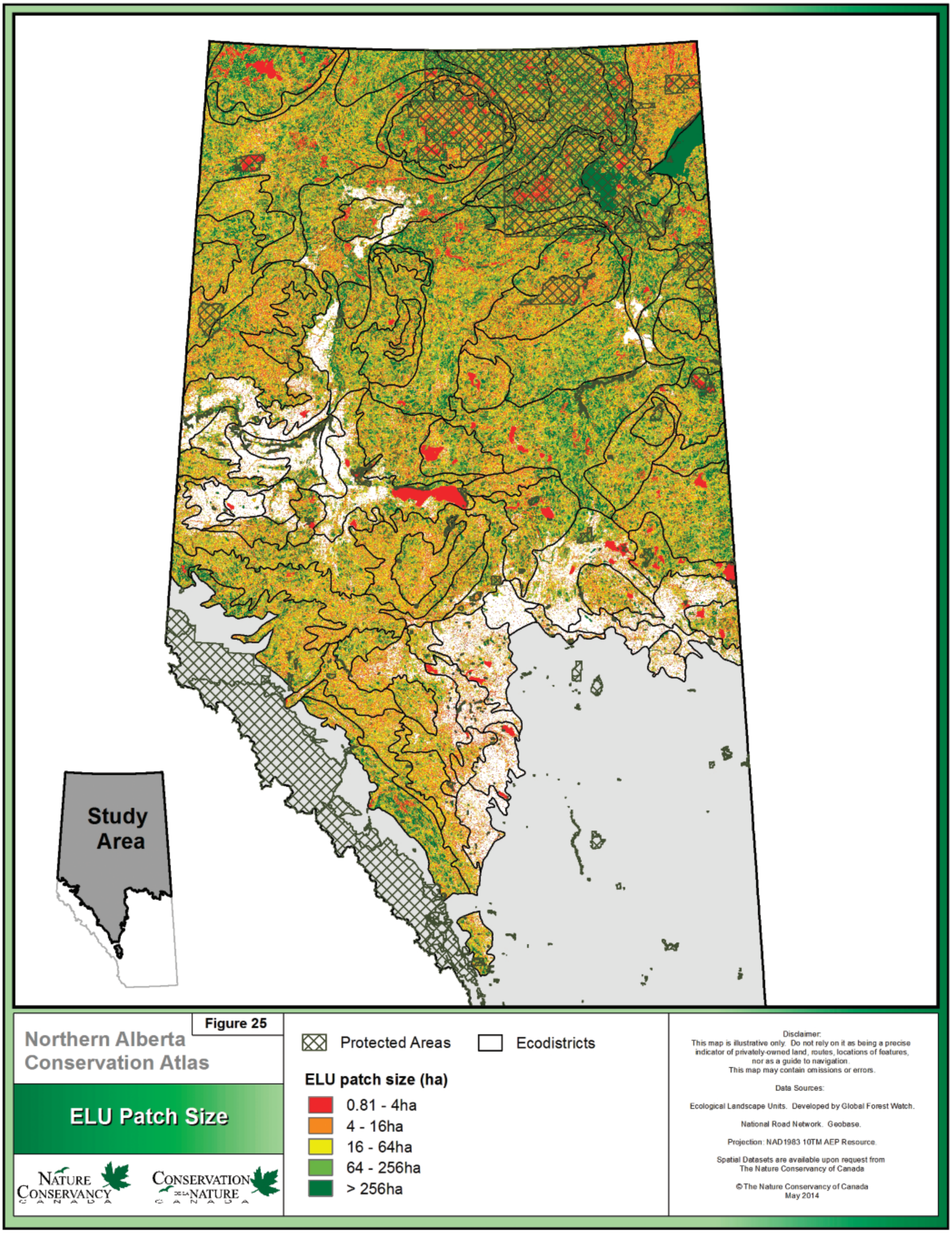


Figure 25. Patch size of ELUs in northern Alberta

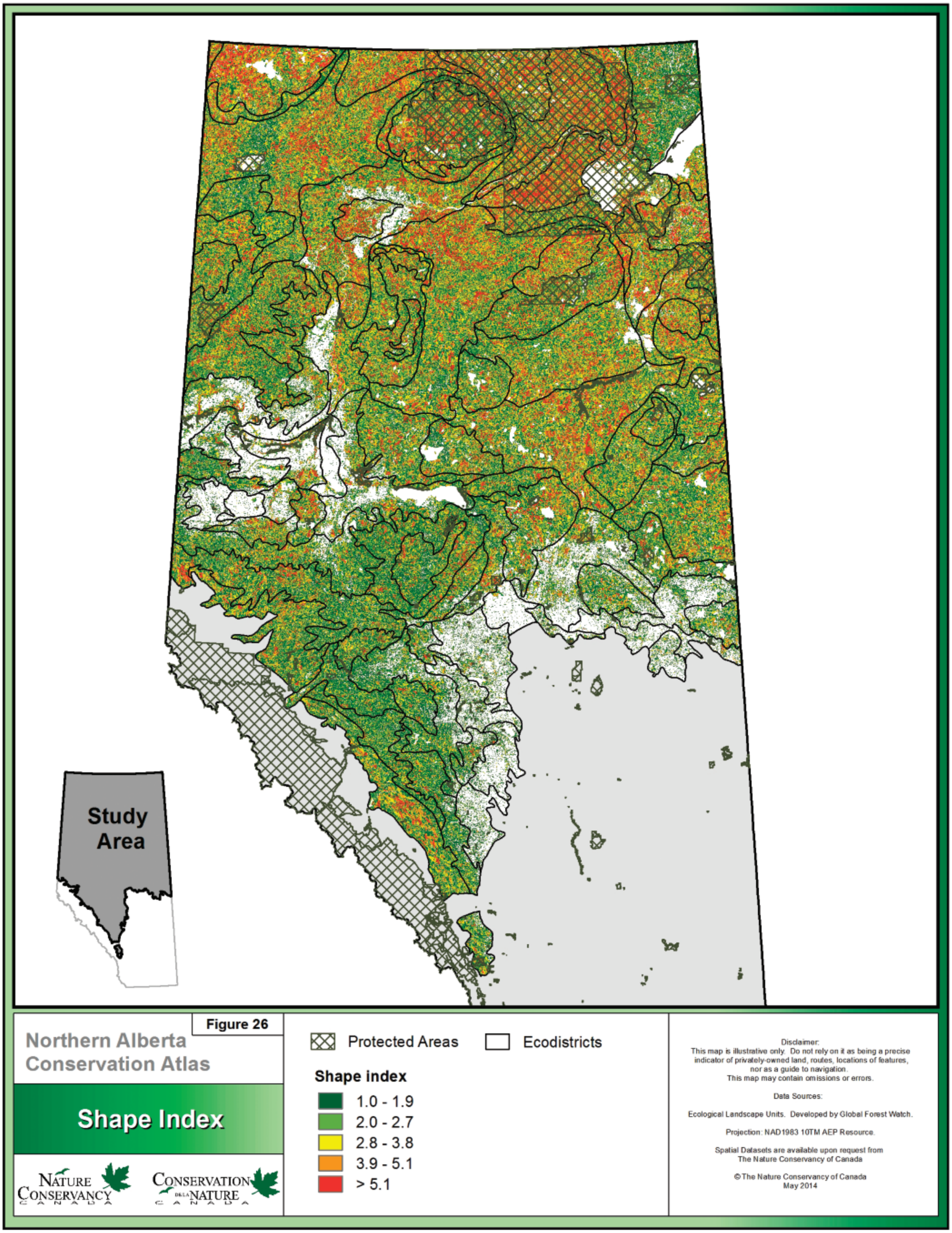


Figure 26. Shape index of ELUs in northern Alberta

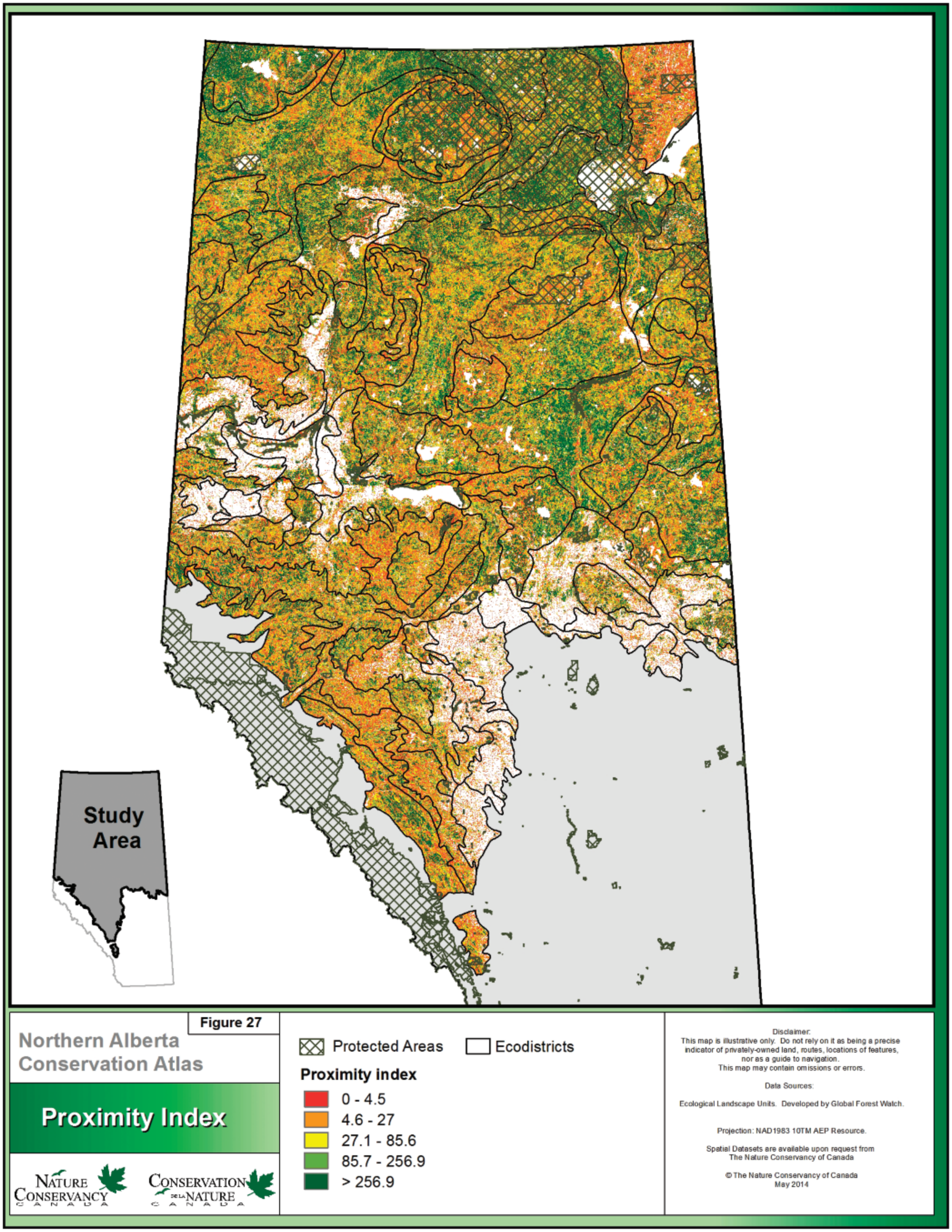


Figure 27. Proximity (connectivity) index of ELUs in northern Alberta

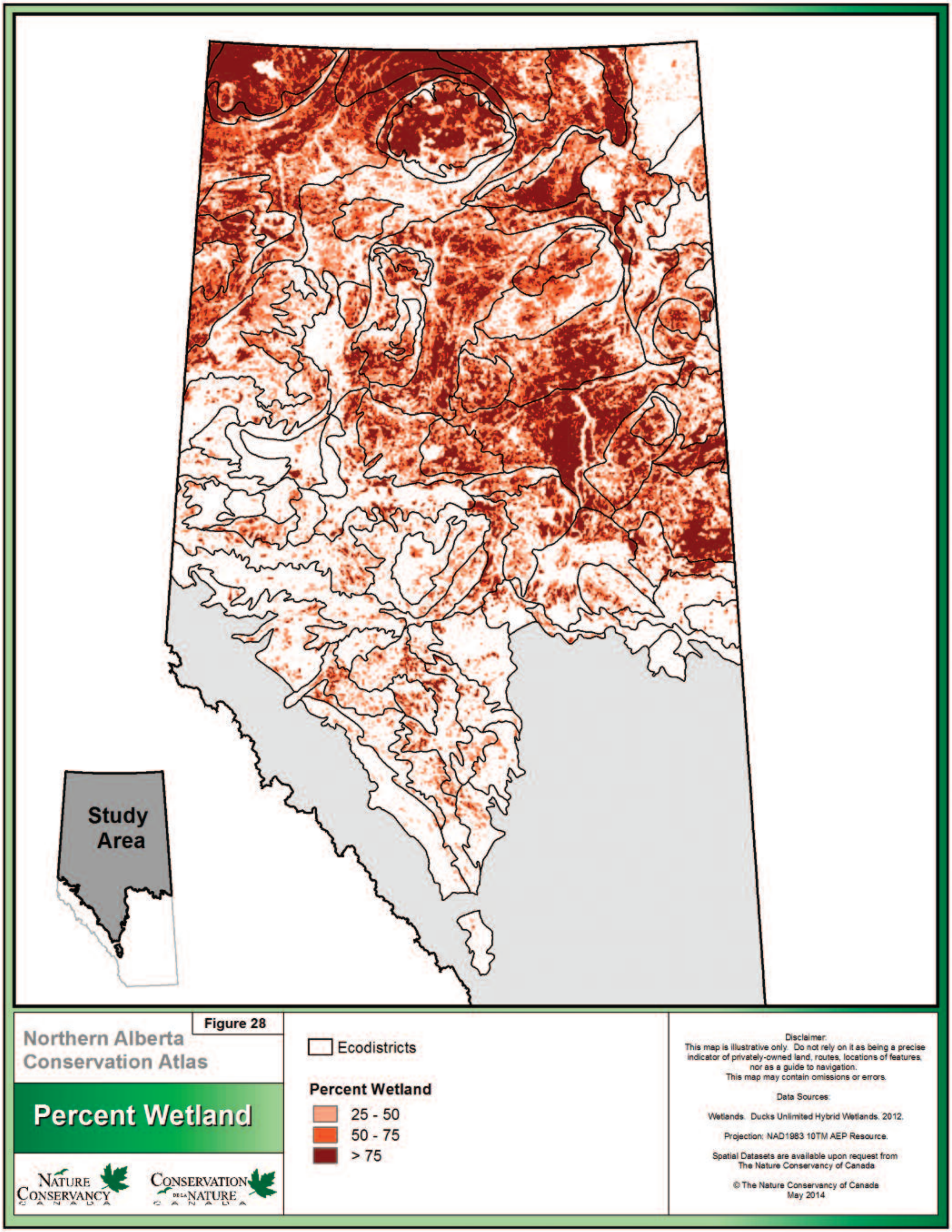


Figure 28. Percent wetland in northern Alberta

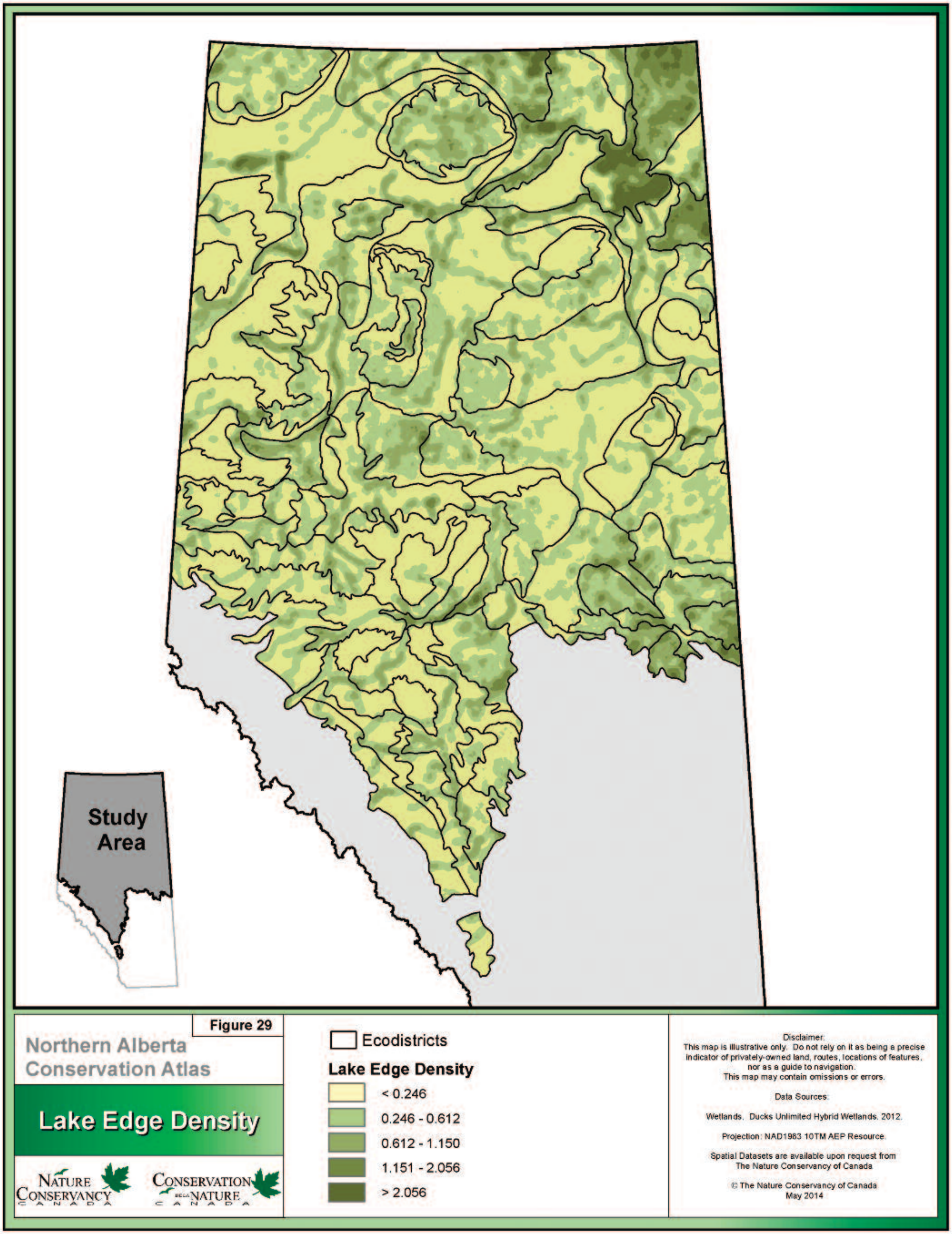


Figure 29. Lake edge density in northern Alberta

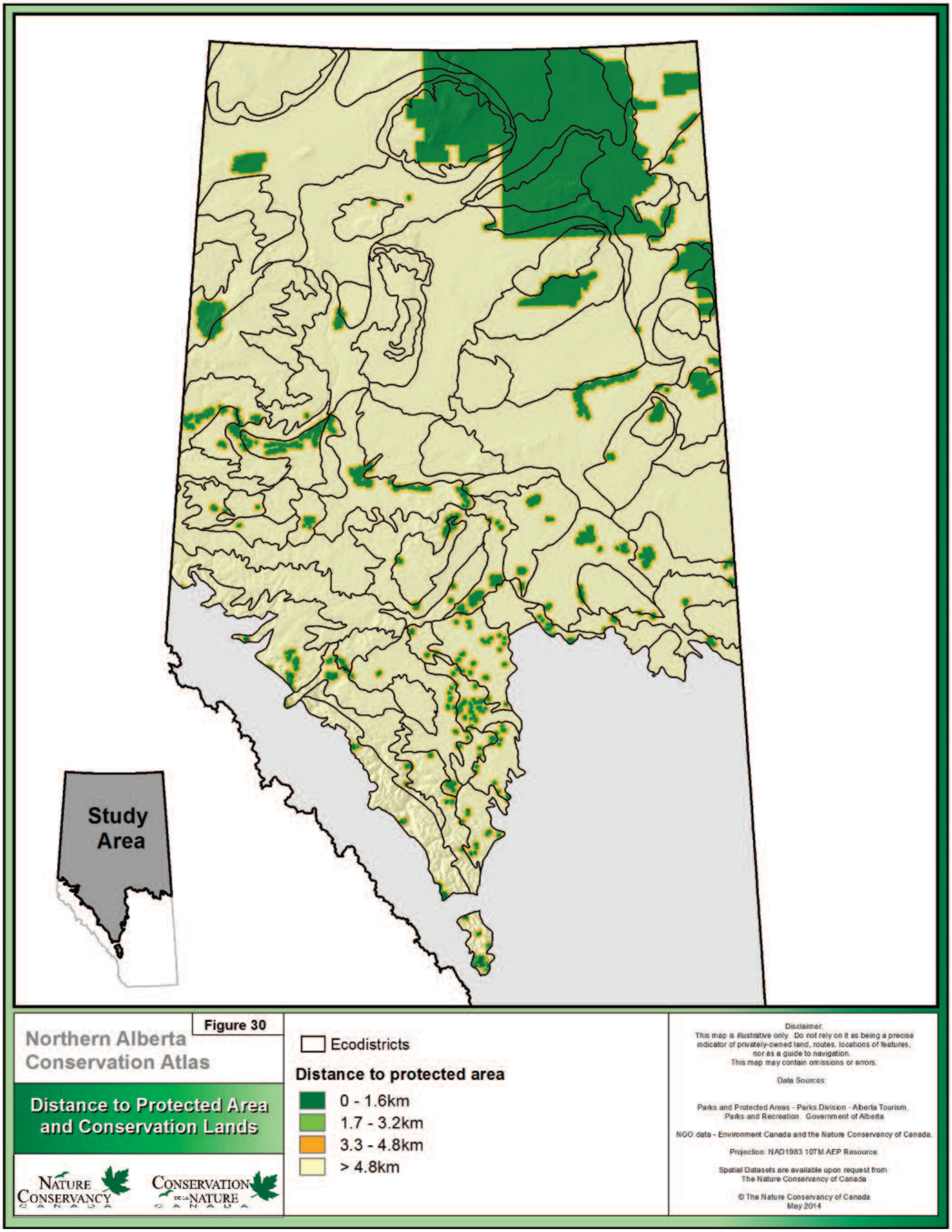


Figure 30. Distance to protected areas and conservation lands in northern Alberta

2.3.4 SPECIAL FEATURES

Special features are those unique features of conservation concern due to their risk or biological importance. These include priority species ranges or occurrences and the proximity to existing conservation areas.

Distance to Protected Areas and Conservation Lands

Formal protected areas and other less formally conserved lands may or may not confer additional natural values on adjacent lands. However, proximity to such sites increases the probability of the presence and movement of wildlife, as well as the influence of propagules dispersed from those areas. On this basis, sites closer to protected areas and conservation lands were scored more highly (Figure 30). All protected areas and conservation lands were given the same weighting and value, regardless of the degree of protection afforded to biodiversity values at the site or the shape or size of the conserved site.

Number of Element Occurrences

Scores were assigned based on the count of the element occurrences (EOs) tracked by Alberta's Conservation Information Management System. EOs are tracked due to their relative conservation concern. Therefore, their presence was included as a fine-scale ecological value with areas having a greater number of overlapping EOs given a higher score. See Figure 36.

Target Species/Species Groups

Grizzly Bear

Alberta represents the contemporary eastern limit of Grizzly Bear range in southern Canada, occupying the western fringe of the province. Grizzly Bears were listed as Threatened under the *Alberta Wildlife Act* in June of 2010 (Alberta Regulation 143/1997: With amendments up to and including Alberta Regulation 185/2012. http://www. qp. alberta.ca/documents/Regs/1997_143.pdf.

Detailed DNA-based studies from 2004 to 2008 estimated a total of 582 Grizzly Bear from south of Grande Prairie to the American border, including parts of Banff and Jasper national parks, and all of Waterton Lakes National Park. Estimates of Grizzly Bear elsewhere in Alberta are much less precise and include 15 immediately to the east of areas where DNA sampling was conducted, 23 in the Swan Hills, and 71 in northwestern Alberta. The status report estimates a total of 691 Grizzly Bear in lands under provincial jurisdiction plus Waterton Lakes National Park and portion of Banff and Jasper national parks. Bear density is much higher in the relatively undisturbed Grande Cache area (18 bears/1,000 km^2) than in areas between Highways 1 (latitude of Calgary) and 16 (latitude of Edmonton) with high levels of industrial activity (5 bears/ 1,000 km^2). South of Highway 1, density increases (12-18 bears/1,000 km^2). Human activities in bear habitat, particularly the expanding network of roads, leads to unsustainable levels of bear mortality. There is not yet reliable population estimates in the Swan Hills and Alberta North areas (ASRD and ACA 2010a).

Most consider the Alberta population to have declined substantially from historic levels with declines likely reflecting recent increases in human access and activity from energy (coal, natural gas, and oil) and forest extraction industries and local human population growth. High rates of human-caused mortality threaten the long-term persistence of Alberta's Grizzly Bear (Nielson *et al.* 2009).

Grizzly were selected as a Special Feature for this analysis as a result of: the continental importance of the species' range in Alberta; its substantial decline in range and population in recent decades; and, the high quality data that was made available by leading Grizzly Bear researcher, Dr. Gordon Stenhouse.

For Grizzly range of southwestern Alberta (including Swan Hills), where population estimates and areas of occupancy are generally more precise than in Alberta North areas, we used the Core and Secondary Conservation Areas as documented in Alberta (ASRD and ACA 2010a; Neilson *et al.* 2009).

For Grizzly Bear range in the Alberta North area, we developed preliminary Core and Secondary Conservation Areas (Figure 31) using a combined index of: 1) average linear access density within catchements (access density of <0.6 km/km^2 for Core Conservation Areas and 0.6 to 1.2 km/ km^2 for Secondary Conservation Areas) and; 2) predicted realized habitat (data supplied by Dr. Gordon Stenhouse of the Alberta Foothills Research Institute, pers. comm.). From the potential realized habitat data, we selected the upper two-thirds range of the data (i.e., >100 was selected from the range of values from 0 to 299) as a requirement for classification as Core Conservation Areas. Core Conservation Areas are scored higher than Secondary Conservation Areas.

Grizzly Bear once roamed from the Pacific Ocean to the Mississippi River, and from Central Mexico to the Arctic. Extensive land clearing for agriculture and high-density human settlement led to the extirpation or substantial reduction of grizzly bear populations over large portions of their range… The southern distribution of Grizzly Bear in North America is now restricted to relatively unsettled areas in the northwestern United States. In the contiguous United States, the Grizzly Bear was eliminated from 98% of its historical range and now remain in five separate populations, four of which are contiguous with populations in Canada. In Canada, the Grizzly is mostly restricted to relatively uninhabited portions of B.C., Alberta and the territories….

(ASRD and ACA 2010a).

Grizzly bear and cub, Grande Cache area.
Dragomir Vujnovic,
Alberta Conservation Management

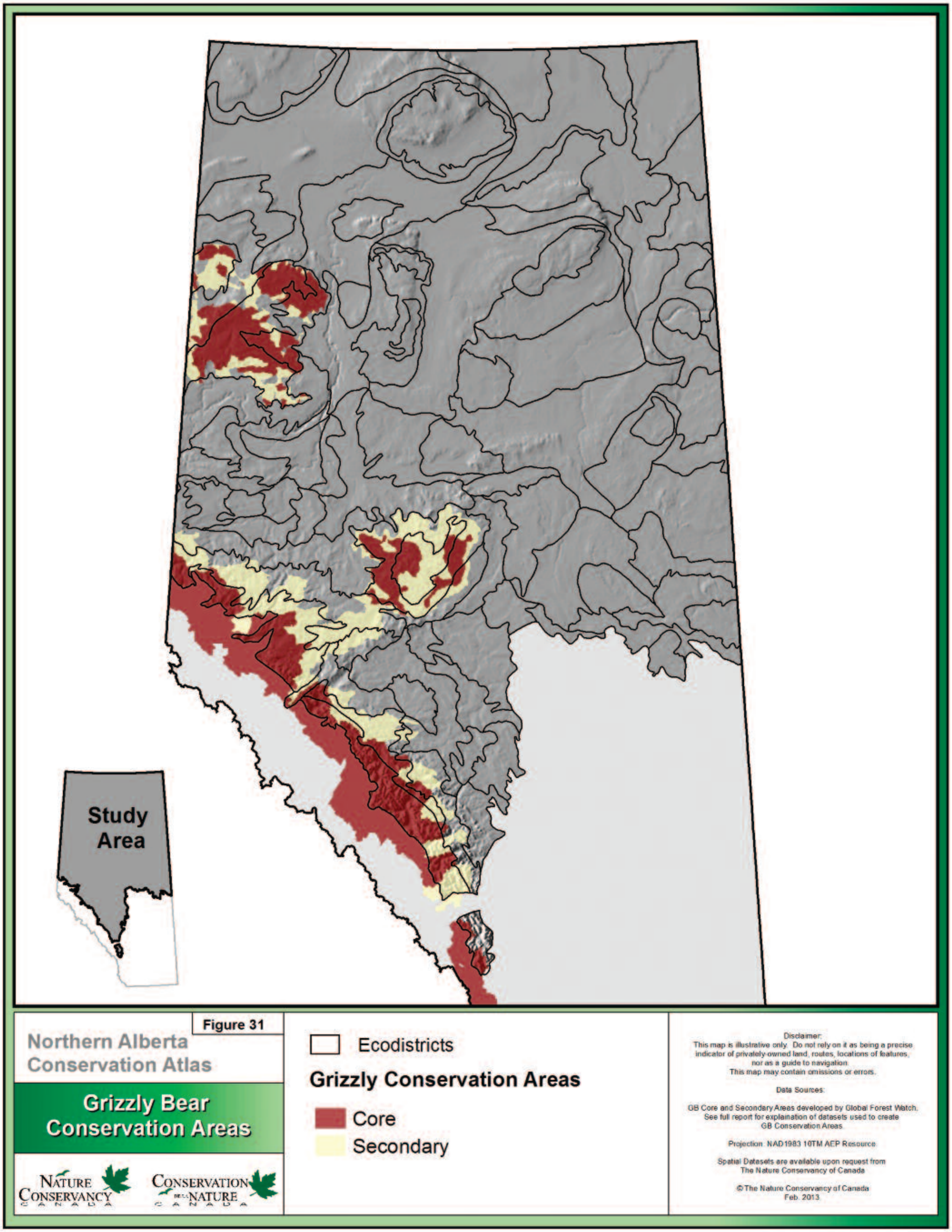


Figure 31. Grizzly Bear conservation priority areas in northern Alberta

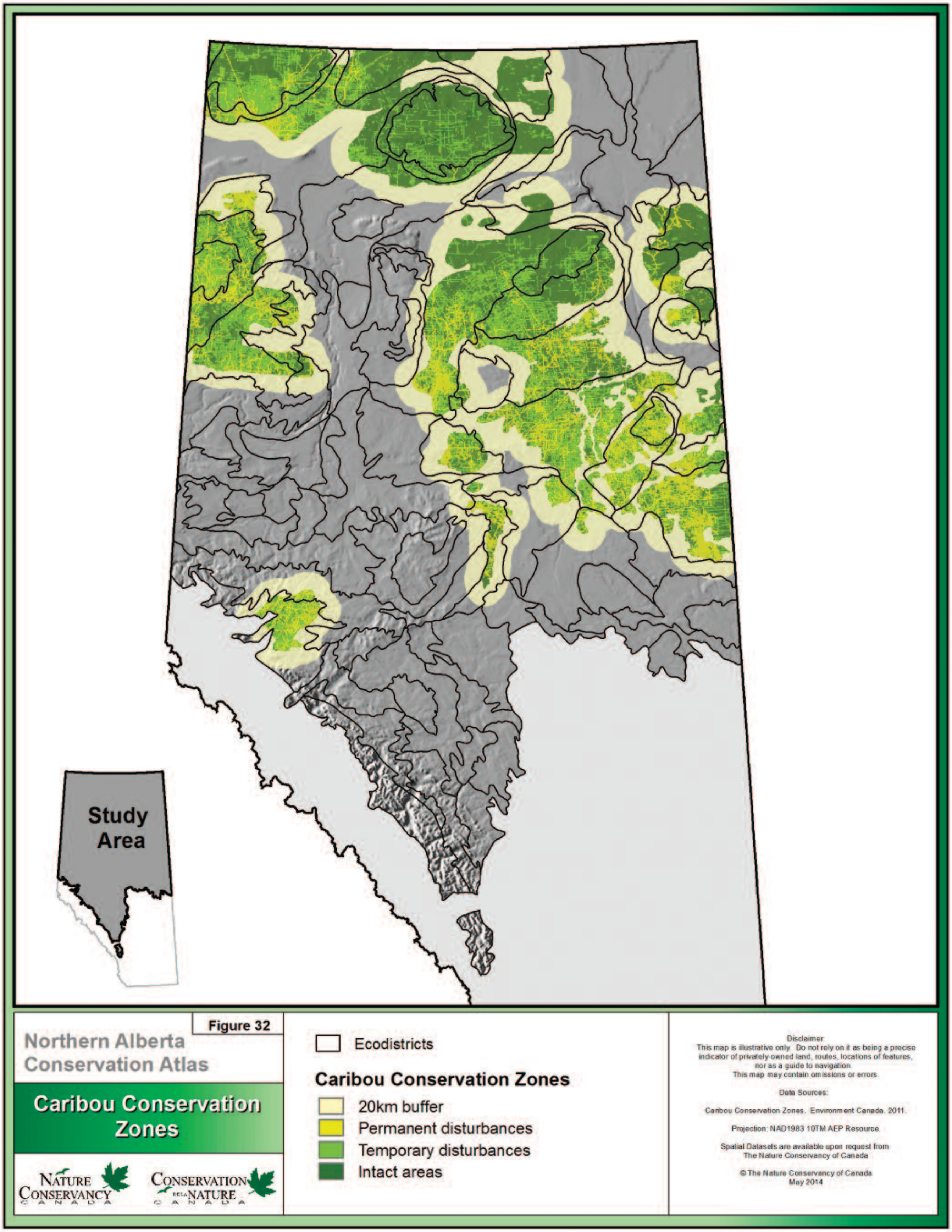


Figure 32. Caribou conservation priority zones in northern Alberta

Woodland Caribou. Dragomir Vujnovic

The distribution of Woodland Caribou in North America has receded northward since the onset of human settlement….. The southern limit of Woodland Caribou distribution east of the Rocky Mountains historically followed the boreal forest, south into the Canadian Maritimes and the northeastern United States. (*ASRD and ACA 2010b*).

Woodland Caribou

In Canada, the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population was listed under the *Species at Risk Act* (SARA) in 2003. The listing decision was made on the basis of an "observed, estimated, inferred or suspected population size reduction of ≥30% over three generations." Evidence of continued declines exists for many regions of Canada and has been well-documented in a number of closely-monitored populations since the 2002 COSEWIC assessment (Environment Canada 2011).

In Alberta, woodland caribou are currently designated as Threatened under *Alberta's Wildlife Act* (Alberta Regulation 143/1997: With amendments up to and including Alberta Regulation 185/2012. http://www.qp alberta ca/ documents/ Regs/1997_143.pdf). The Threatened status was assigned because of reduced distribution, declines in the number and size of provincial caribou populations, and threats of continued declines associated with human activities.

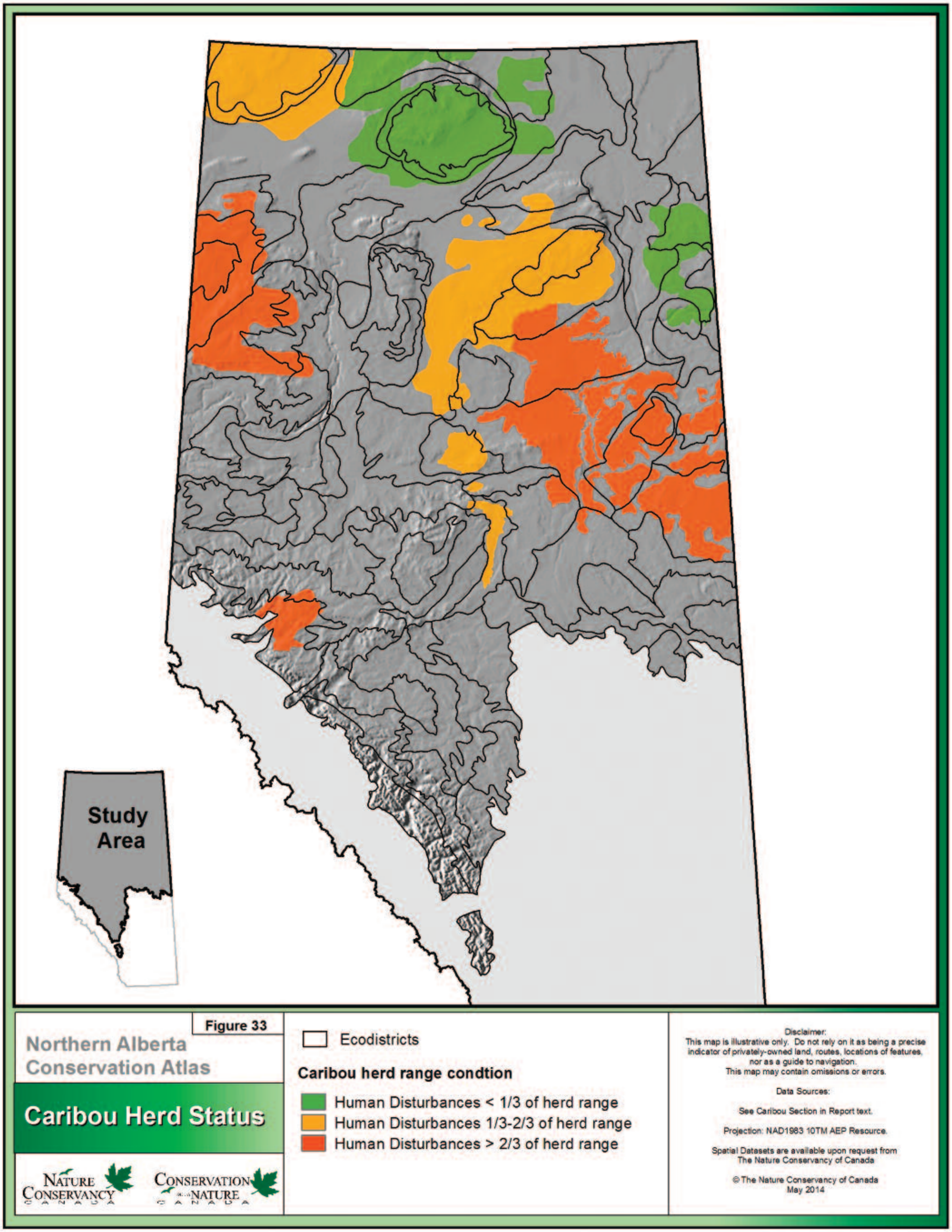


Figure 33. Caribou herd status in northern Alberta

Despite significant declines in the distribution and abundance of Woodland Caribou in Alberta since 1900, they remain in some parts of west-central Alberta along the Rocky Mountain and boreal foothills, and in portions of the boreal forest in northern Alberta. The current extent of occurrence of Woodland Caribou in Alberta is estimated to be approximately 134,833 km^2 (~20% of Alberta), with 118,535 km^2 (~88% of the total extent) in the boreal region and the remainder in the mountain region (ASRD and ACA 2010b). Alberta's populations of Woodland Caribou likely represent approximately 10% of the Canadian population (i.e., inferred from individual herd population by jurisdiction as documented by Environment Canada (2011).

Woodland Caribou were selected as a Special Feature for this assessment as a result of: their declining and threatened status; the high quality data from both Alberta researchers; and Environment Canada's recent analysis.

American Golden Plover. Jean Iron

For Woodland Caribou herd ranges, we developed a combined index of: herd status (Figure 33); and, caribou conservation zones (Figure 32) consisting of herd buffer, intactness and permanent and temporary anthropogenic disturbances. Herd status, as assigned by Environment Canada (Increasing, Stable or Threatened) is scored with the herds assigned as 'Threatened' being scored the highest. The four Caribou Conservation Zones are scored as follows, in order of lowest to highest scores:

- Buffer Zone – 20-km buffer from the edge of the herds range, as consistent with tentative a recommendation by the Regional Working Group of the Canadian Boreal Forest Agreement;
- Permanent Disturbance Zone – Areas mapped as permanently disturbed by anthropogenic activity and buffered by 500 metres;
- Temporary Disturbance Zone – Areas mapped as disturbed by Environment Canada's 2011 scientific assessment;
- Intact Zone – Areas mapped as 'intact' (not disturbed by anthropogenic activity) by Environment Canada assessment (2011).

Waterfowl and Shorebirds

Historic data indicate that since the first settlers arrived in the continental United States, 53 percent of the original 221 million wetland acres (89.4 hectares/894,355 km. sq.) had been destroyed. Wetland losses across settled areas of Canada range from 29 to 71 percent. (North American Waterfowl Management Plan, Value Proposition. http://www.nawmp.ca/pdf/ Value_Prop_March-small.pdf).

Northern Canada and Alaska contain 35 percent of the world's wetlands and are home to 12 to 14 million breeding ducks. In some years, this amounts to 40 percent of the continental breeding duck population. A significant portion of these wetlands are in the Boreal Plains and Taiga Plains Ecozones of Alberta. Alberta hosts eight million waterfowl and 20 million shorebirds that use the province's wetlands and surrounding habitat to mate, nest, hatch and raise their young (Ducks Unlimited Alberta, 2012, http://www.ducks.ca/your-province/alberta/). Alberta is developing quickly, in both residential and commercial growth, and resource extraction, which also impact wetlands and how they function.


Northern Pintail. Janice Melendez


Solitary Sandpiper. Janice Melendez

Marbled Godwit. Ann Brokelman

Waterfowl and shorebirds were selected as Special Features for this analysis as a result of: the continental importance of Alberta's north for breeding waterfowl and shorebirds and for migration and stop-over habitat; the rapid pace and large scale of industrial developments; and, the high quality waterfowl data that was made available by Ducks Unlimited Canada, Western Region (DUC).

For waterfowl, a DUC dataset on distribution of waterfowl breeding pairs was used for this assessment. DUC used data from the US Fish and Wildlife Service's (USFWS) Waterfowl Breeding Population and Habitat Survey (BPOP Survey), Natural Resources Canada's (NRCAN) waterfraction data, and the Land Cover of Canada to produce coarse-scale waterfowl distribution maps in the Canadian Western Boreal Forest. The BPOP surveys have been flown annually in Alberta (and elsewhere) since 1955, and data from 1960 onward were used for the analysis. For an overview of methodology and results, see: Ducks Unlimited Canada 2012. Waterfowl breeding pair densities were scored higher for densities >11 breeding pairs per square mile than for those between 6 and 11 breeding pairs per square mile (within ELUs) (Figure 34). The units are consistent with those from the model developed by Ducks Unlimited Canada.

For shorebirds, the Important Bird Areas dataset was used despite its coarse, generalized nature (Figure 35; see Bird Studies Canada and Canadian Nature Federation 2004-2012; access to the Canadian IBA directory: http:// www.bsc-eoc.org/iba/ibasites.html.) Full metadata for this layer: http://www.bsc-eoc.org/website/metadata/can iba_poly. xml). All shorebird lakes (and other Important Bird Areas) are scored equally and scored within ELUs.

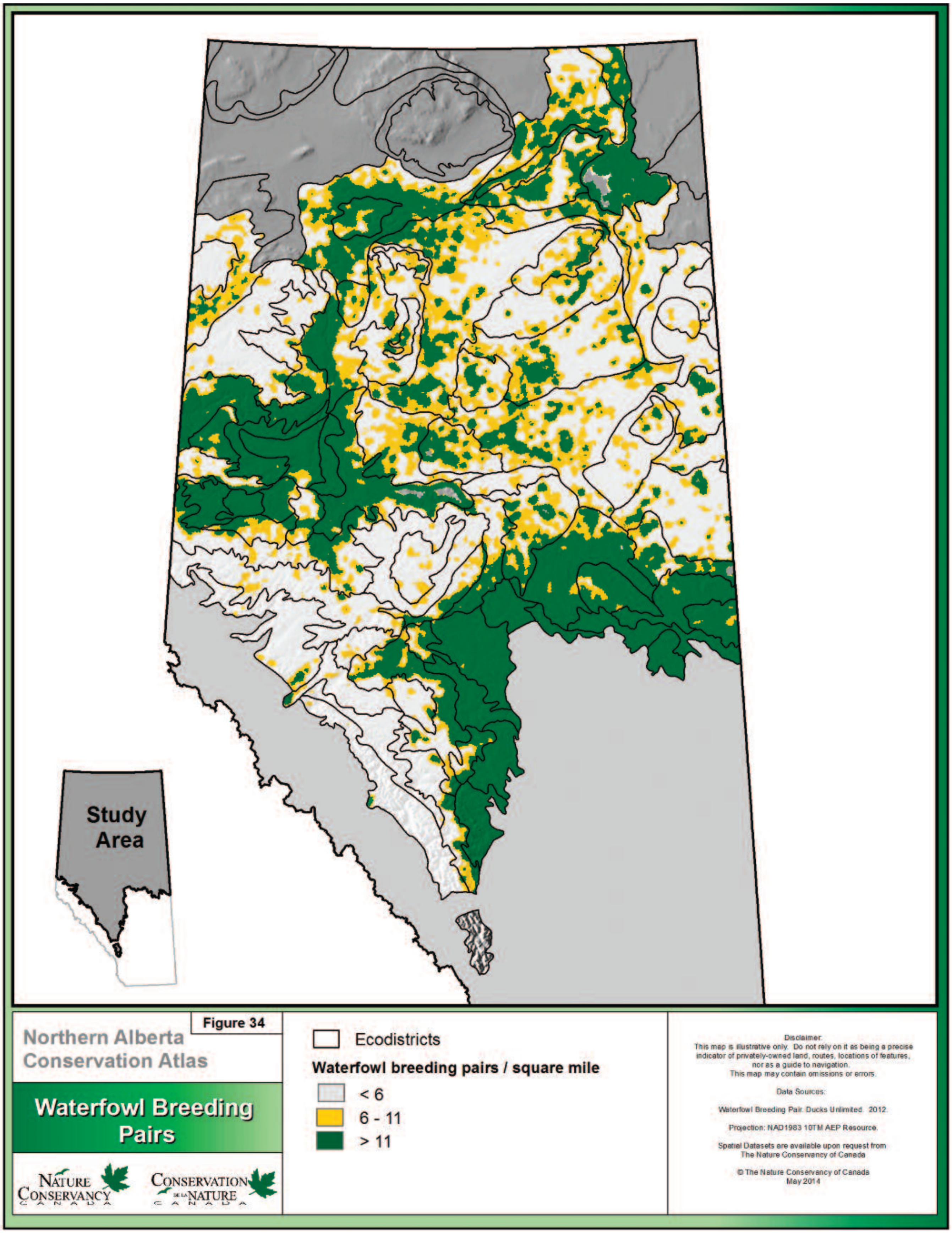


Figure 34. Waterfowl breeding pairs per square mile in northern Alberta (Ducks Unlimited Canada)

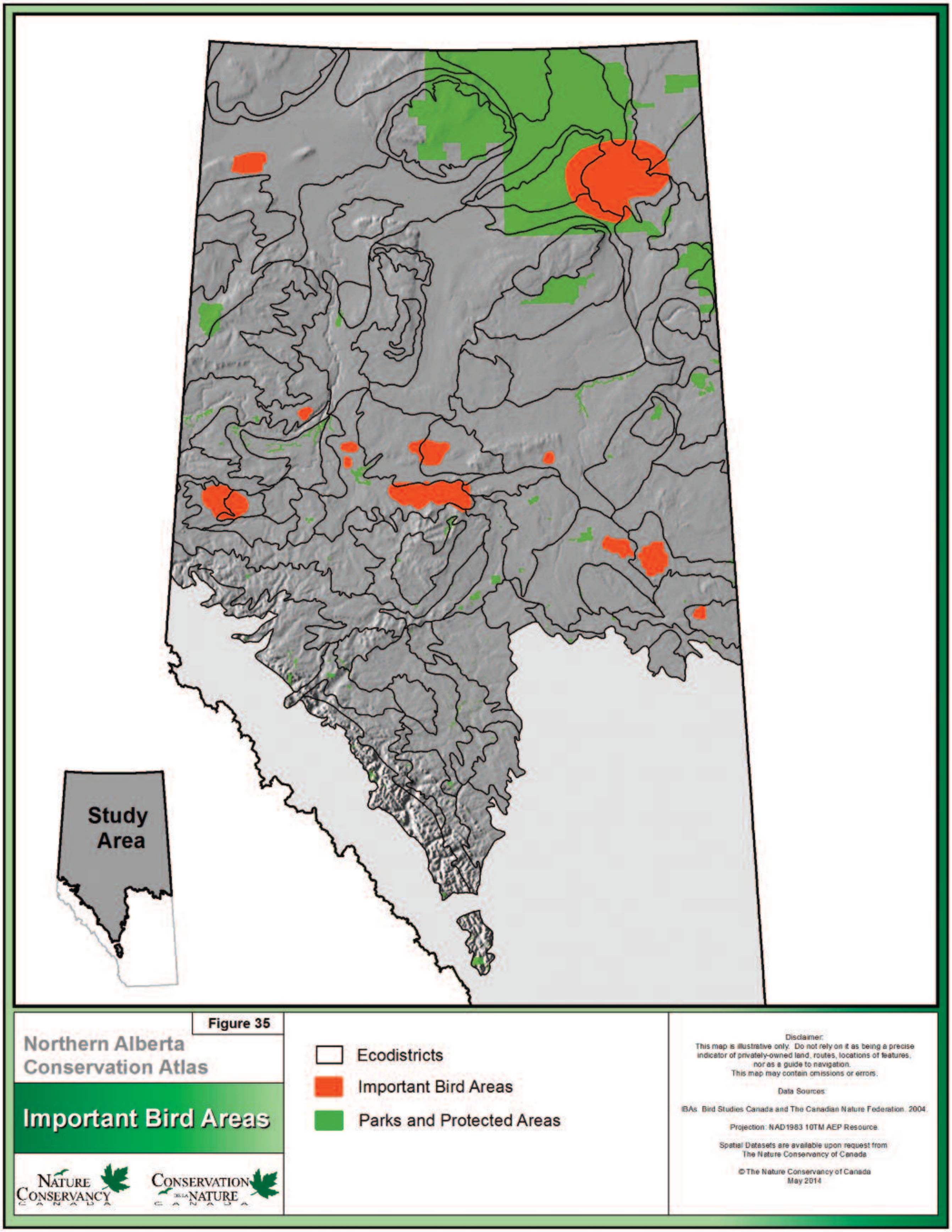


Figure 35. Important Bird Areas (IBAs) in northern Alberta

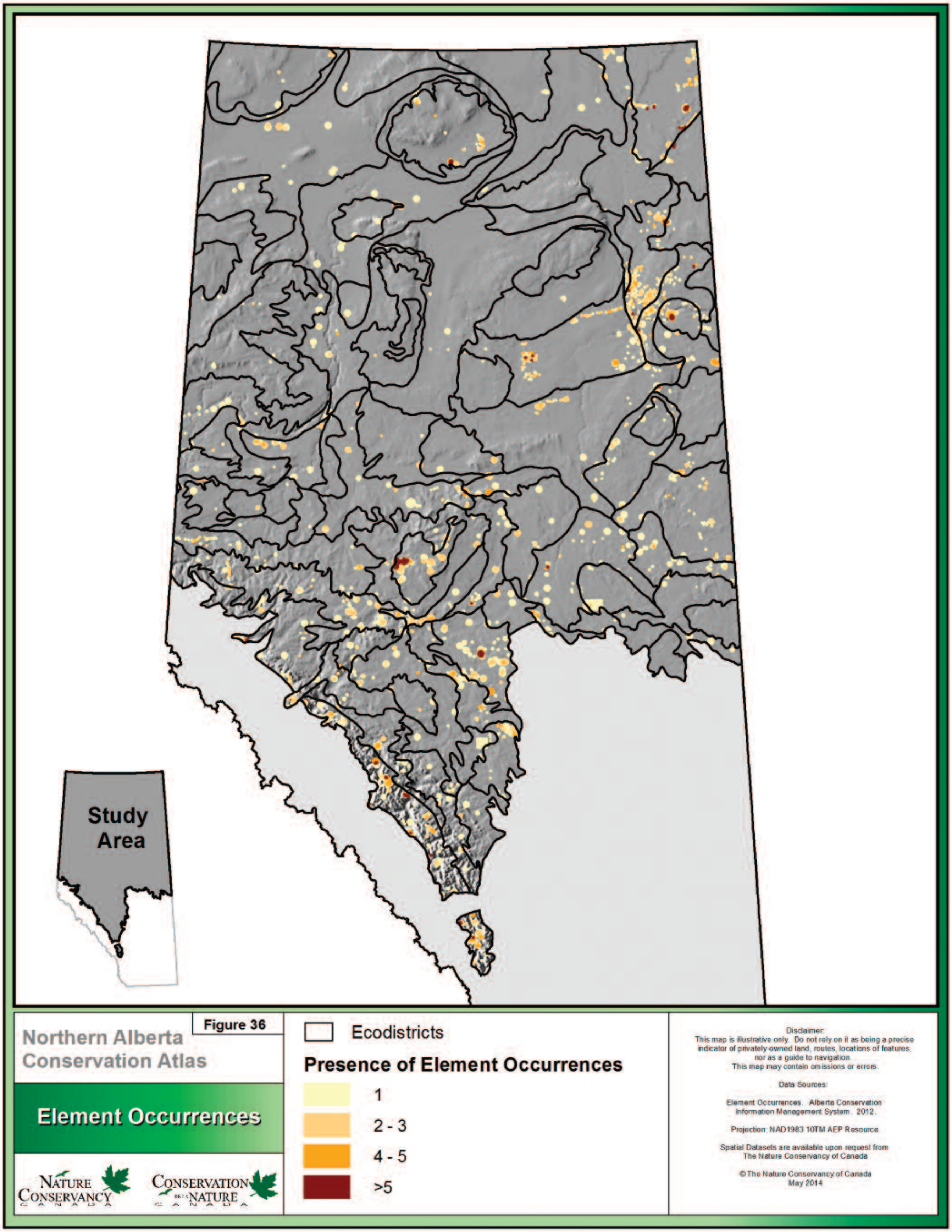


Figure 36. Element occurrences in northern Alberta

Steep incised valley, Athabasca region. Nature Conservancy of Canada

2.4 Conservation Rank Mapping

A goal of this assessment was to identify and compare remaining areas of natural cover, to provide support for decisions about the portfolio of sites that, if properly conserved, could sustain the terrestrial biodiversity of northern Alberta. A series of additional data layers were developed to assist in this regard and, although the new layers, such as for Ecological Land Units, have not yet been fully ground-truthed, they nevertheless provide both classifications and mapping that are useful in describing the natural variability of Alberta's boreal region.

The following series of maps is organized as follows:

Study Area

- Figure 37. Ecological Land Units with assigned conservation values (high to low) and scaled to the entire northern Alberta study area.
- Figure 38. Ecological Land Units with assigned conservation values (high to low) and scaled to individual ecodistricts.

Examples of scaling by study area and by ecodistrict

Ecodistrict 254

- Figure 39. Ecodistrict 254 with assigned conservation values (high to low), scaled to the northern Alberta study area.
- Figure 40. Ecodistrict 254 with assigned conservation values (high to low), scaled to the ecodistrict.

Ecodistrict 605

- Figure 41. Ecodistrict 605 with assigned conservation values (high to low), scaled to the northern Alberta study area.
- Figure 42. Ecodistrict 605 with assigned conservation values (high to low), scaled to the ecodistrict.

Ecodistrict 620

- Figure 43. Ecodistrict 620 with assigned conservation values (high to low), scaled to the northern Alberta study area.
- Figure 44. Ecodistrict 620 with assigned conservation values (high to low), scaled to the ecodistrict.

Tile maps were developed to illustrate the relative conservation ranking of the study area, based on conservation values scaled to the individual ecodistrict:

- Figure 45. Map Tile 1.
- Figure 46. Map Tile 2.
- Figure 47. Map Tile 3.
- Figure 48. Map Tile 4.
- Figure 49. Map Tile 5.
- Figure 50. Map Tile 6.
- Figure 51. Map Tile 7.
- Figure 52. Map Tile 8.
- Figure 53. Map Tile 9.
- Figure 54. Map Tile 10.

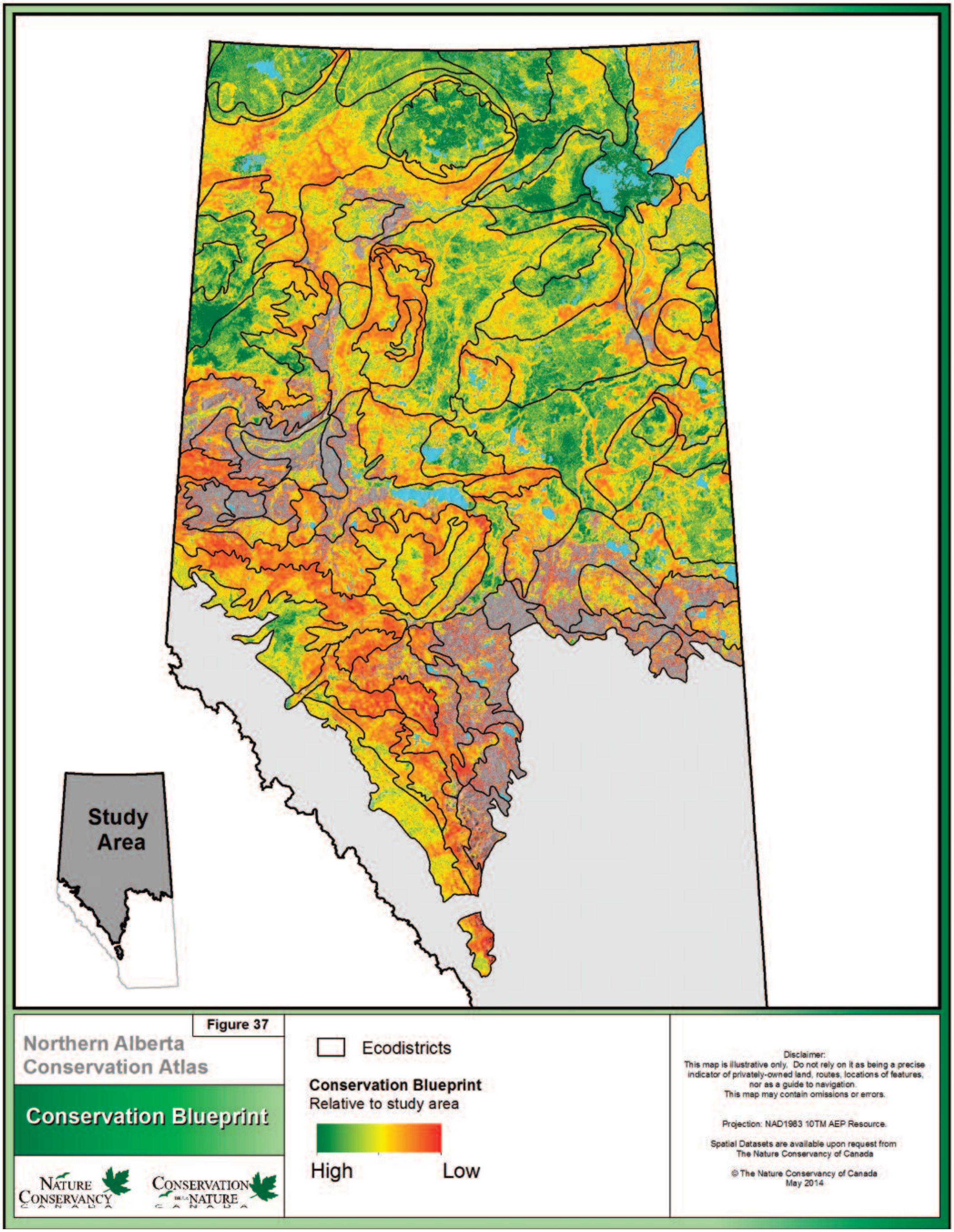


Figure 37. ELUs with assigned conservation values (high to low), scaled to the entire study area

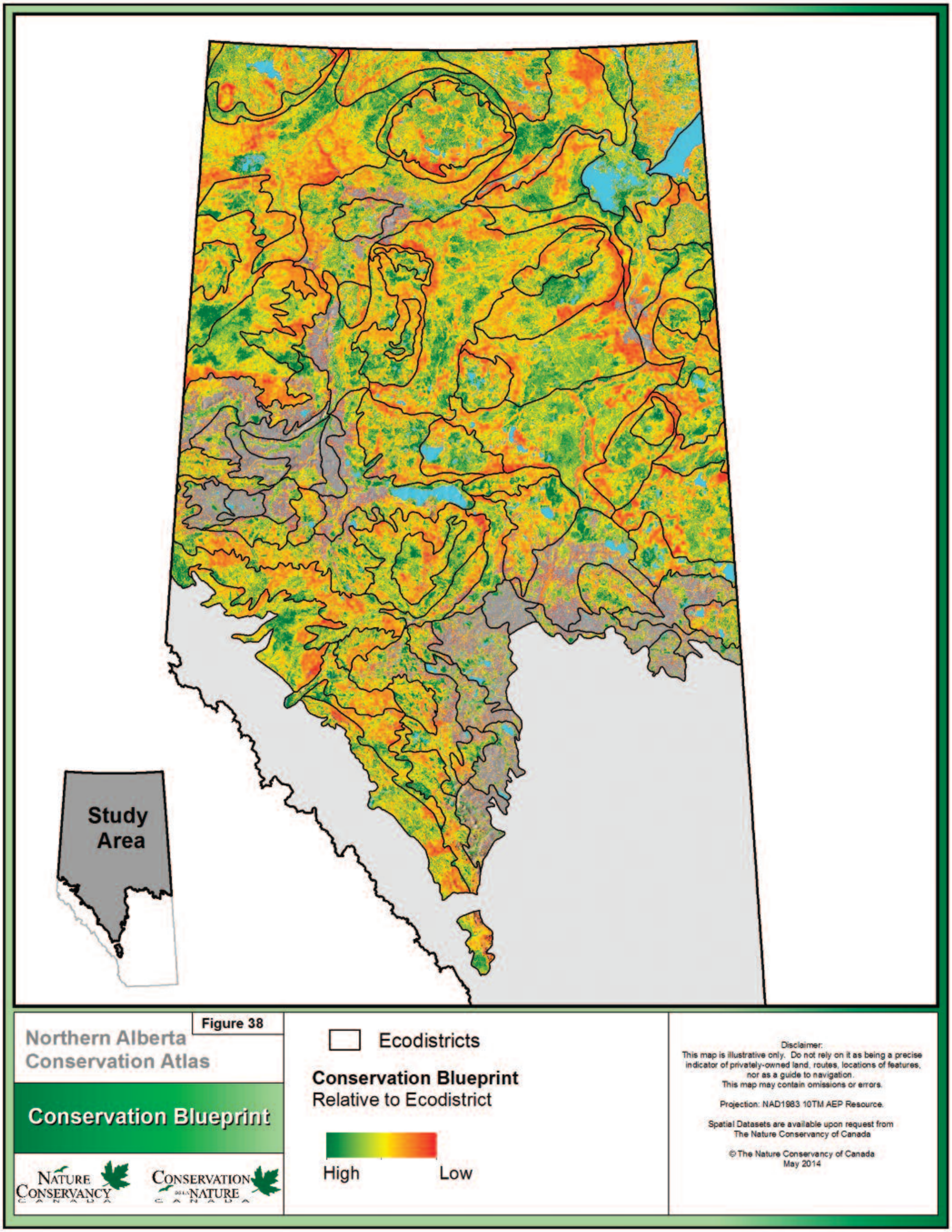


Figure 38. ELUs with assigned conservation values (high to low), scaled to individual ecodistricts

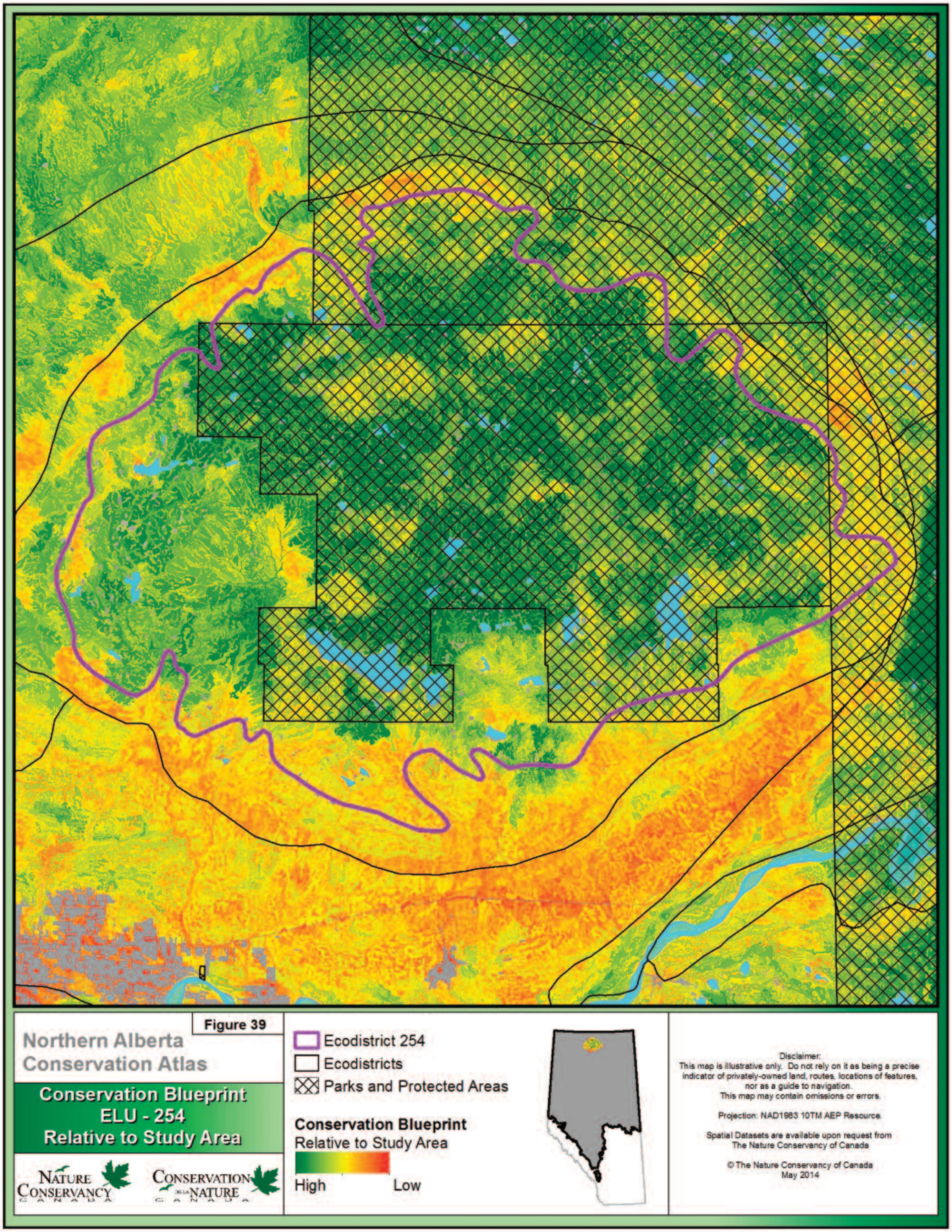


Figure 39. Ecodistrict 254 with assigned conservation values (high to low), scaled to the study area

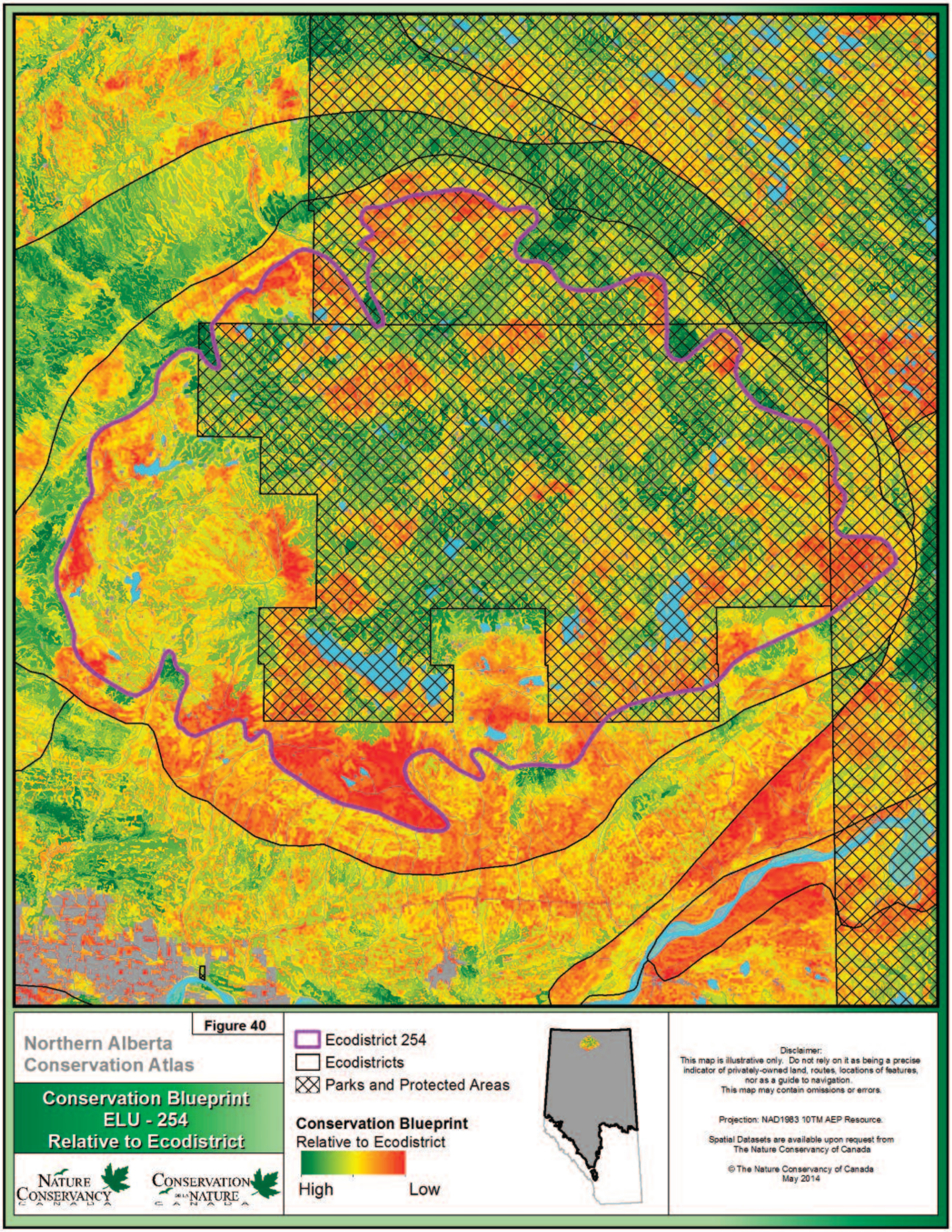


Figure 40. Ecodistrict 254 with assigned conservation values (high to low), scaled to the ecodistrict

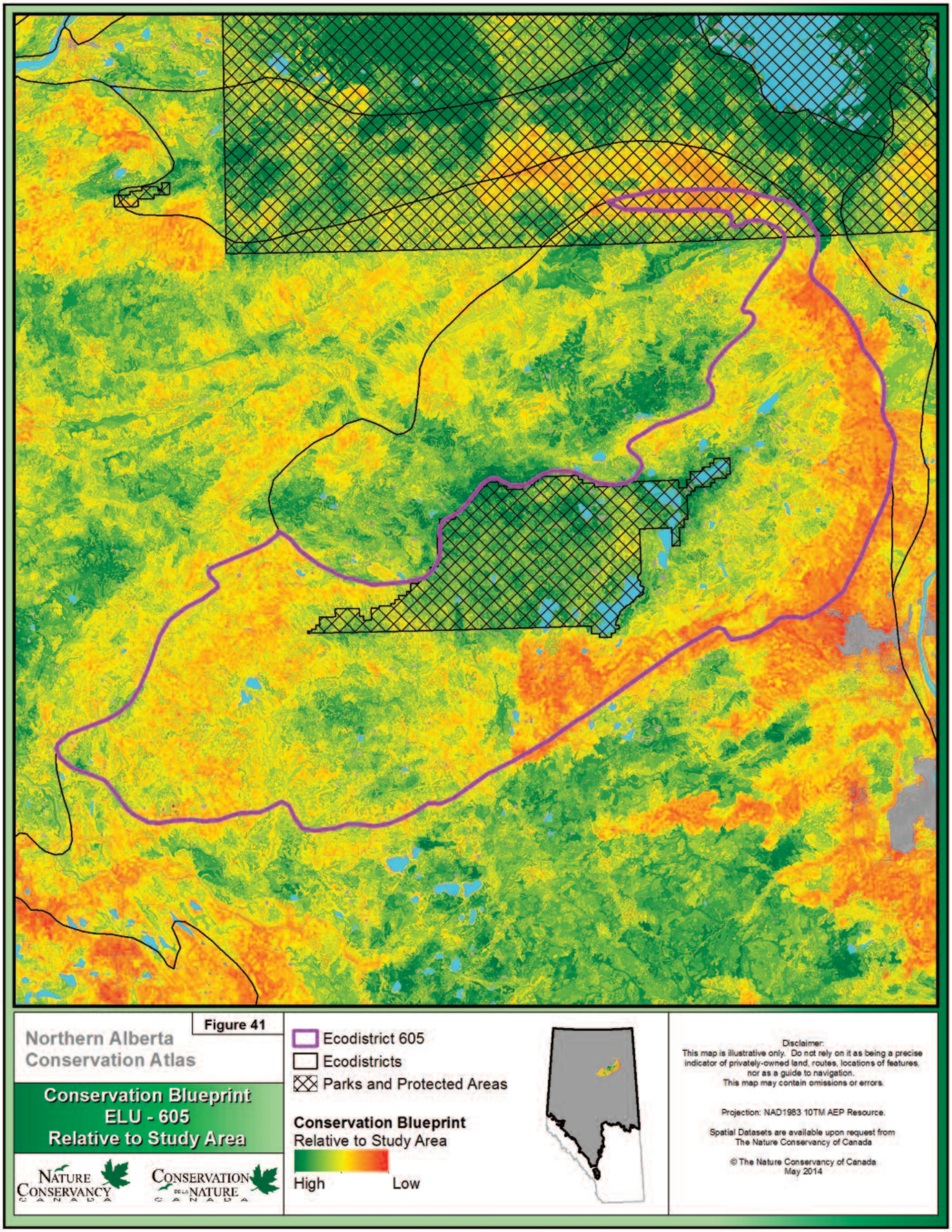


Figure 41. Ecodistrict 605 with assigned conservation values (high to low), scaled to the study area

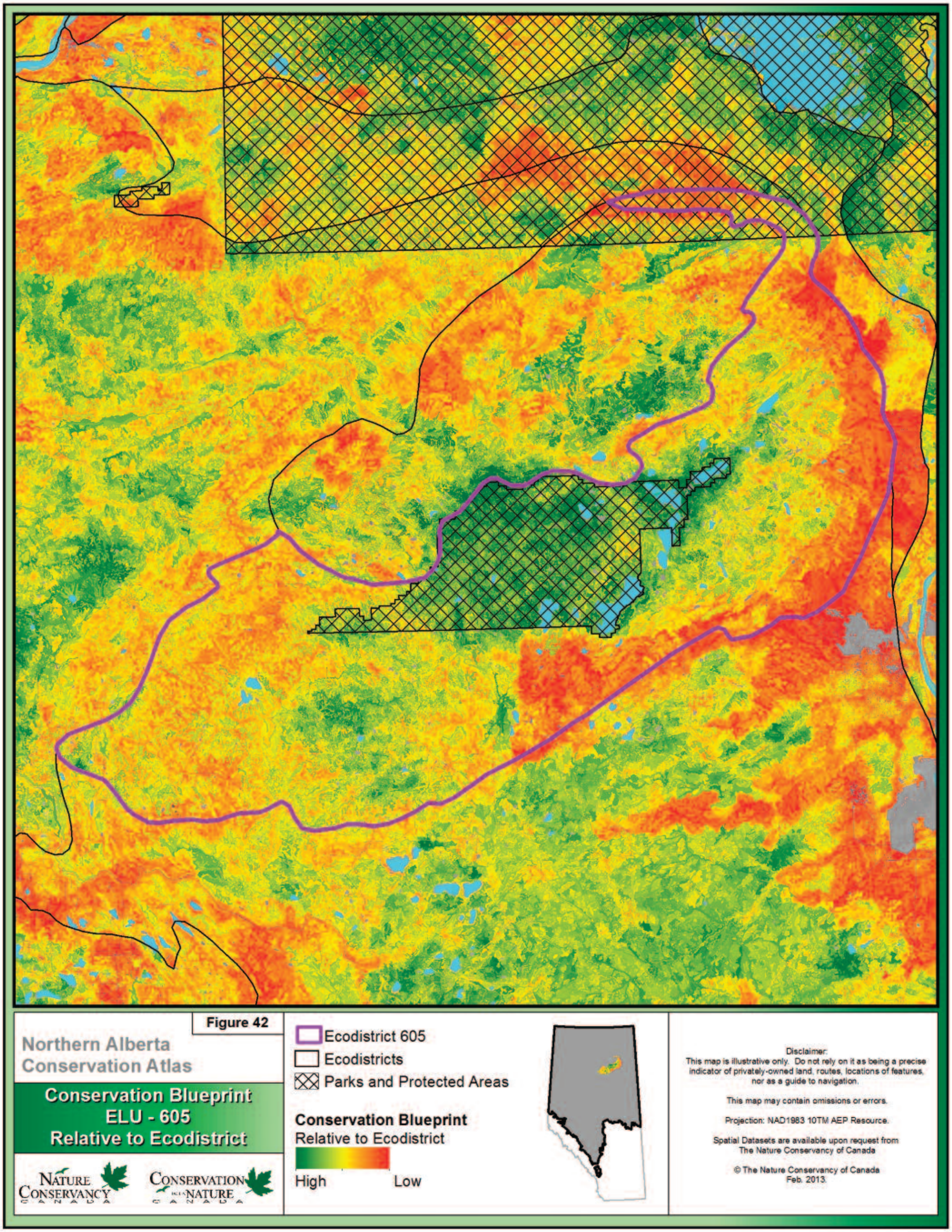


Figure 42. Ecodistrict 605 with assigned conservation values (high to low), scaled to the ecodistrict

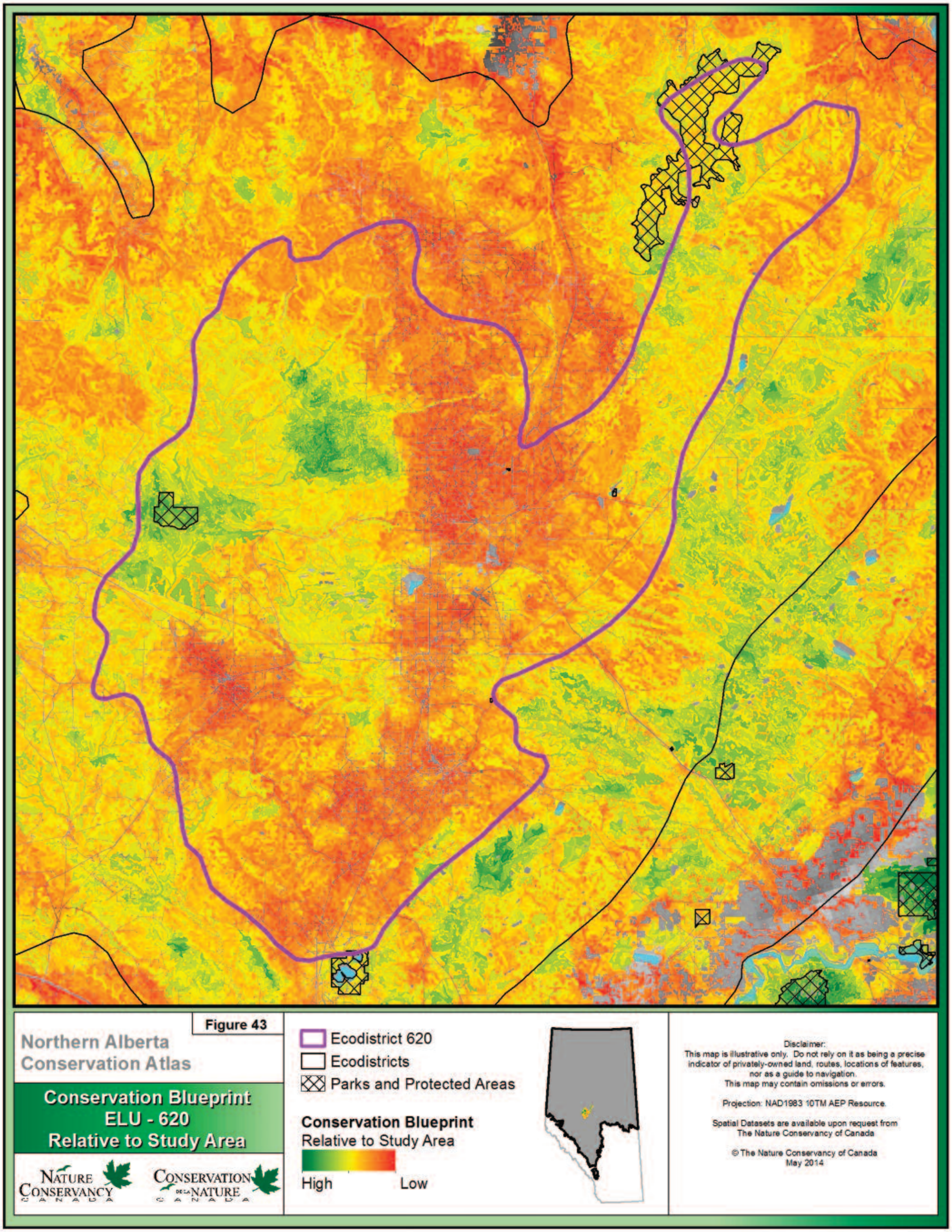


Figure 43. Ecodistrict 620 with assigned conservation values (high to low), scaled to the study area

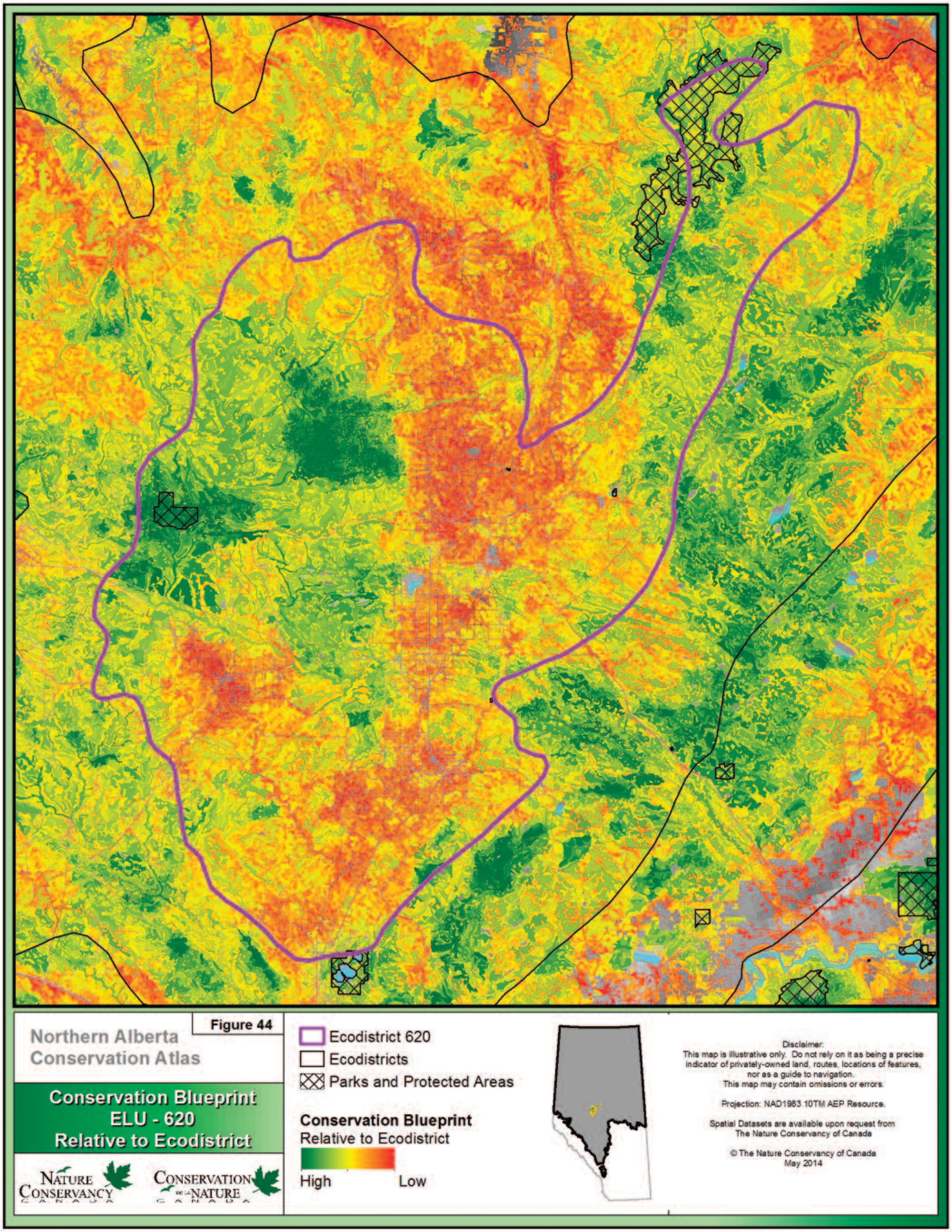


Figure 44. Ecodistrict 620 with assigned conservation values (high to low), scaled to the ecodistrict

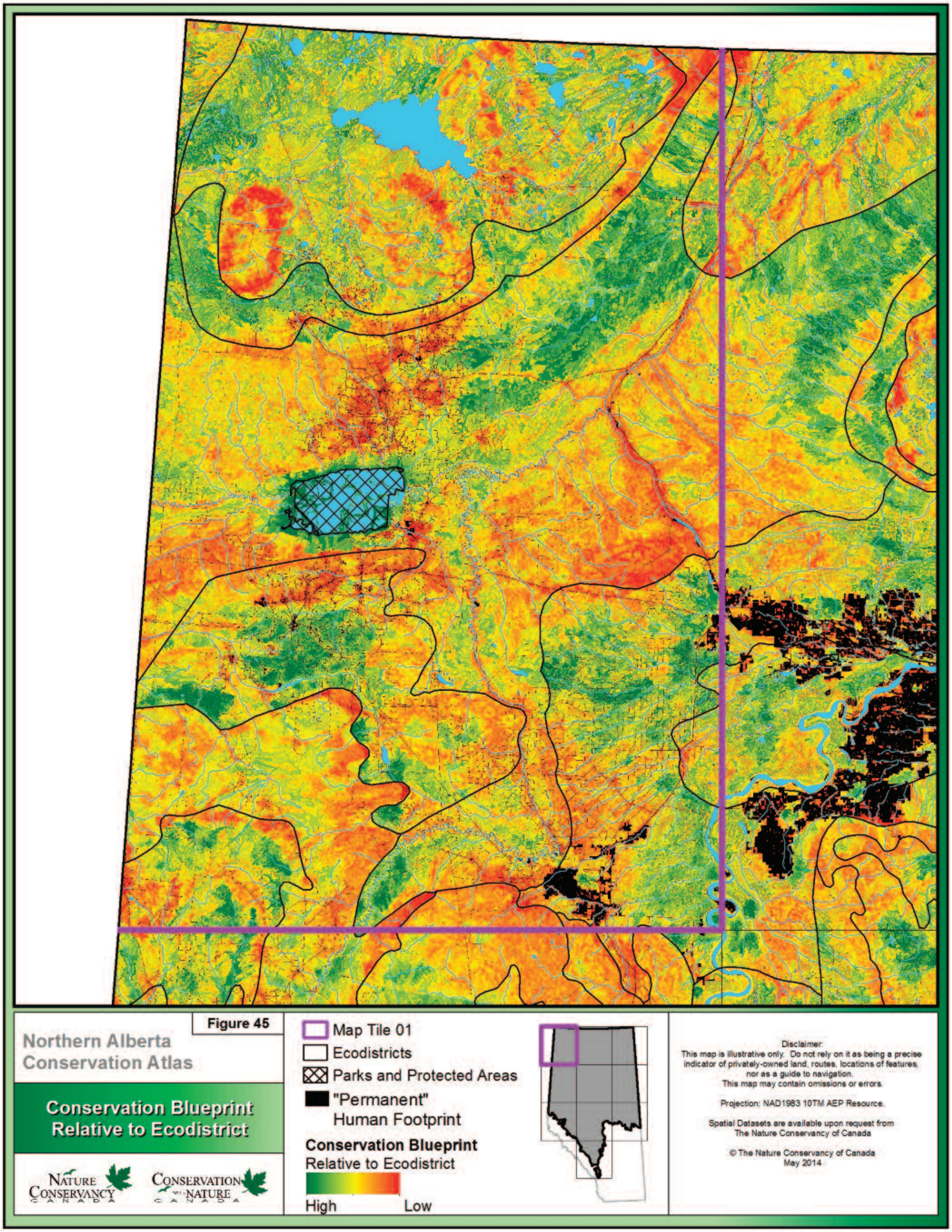


Figure 45. Map Tile 1

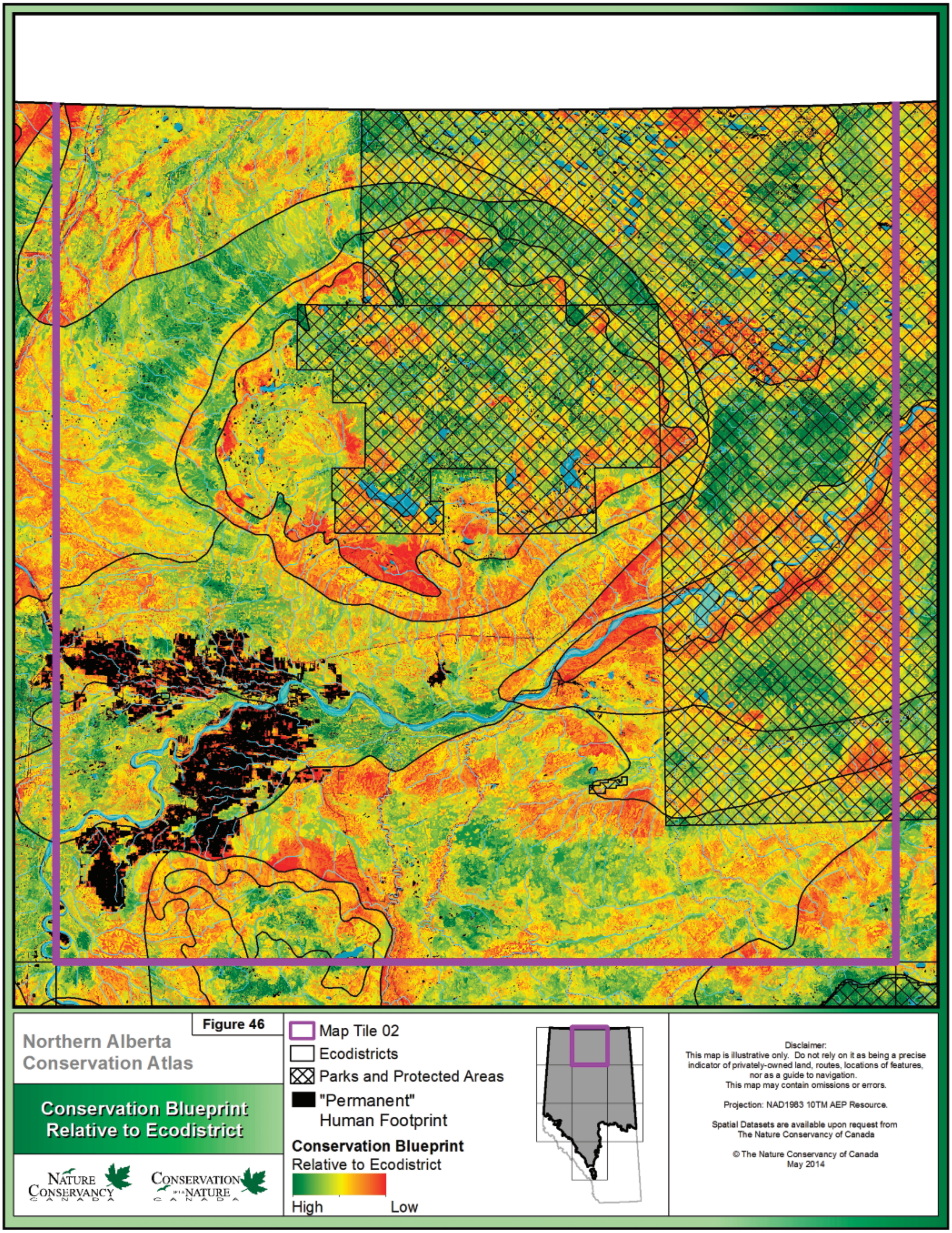


Figure 46. Map Tile 2

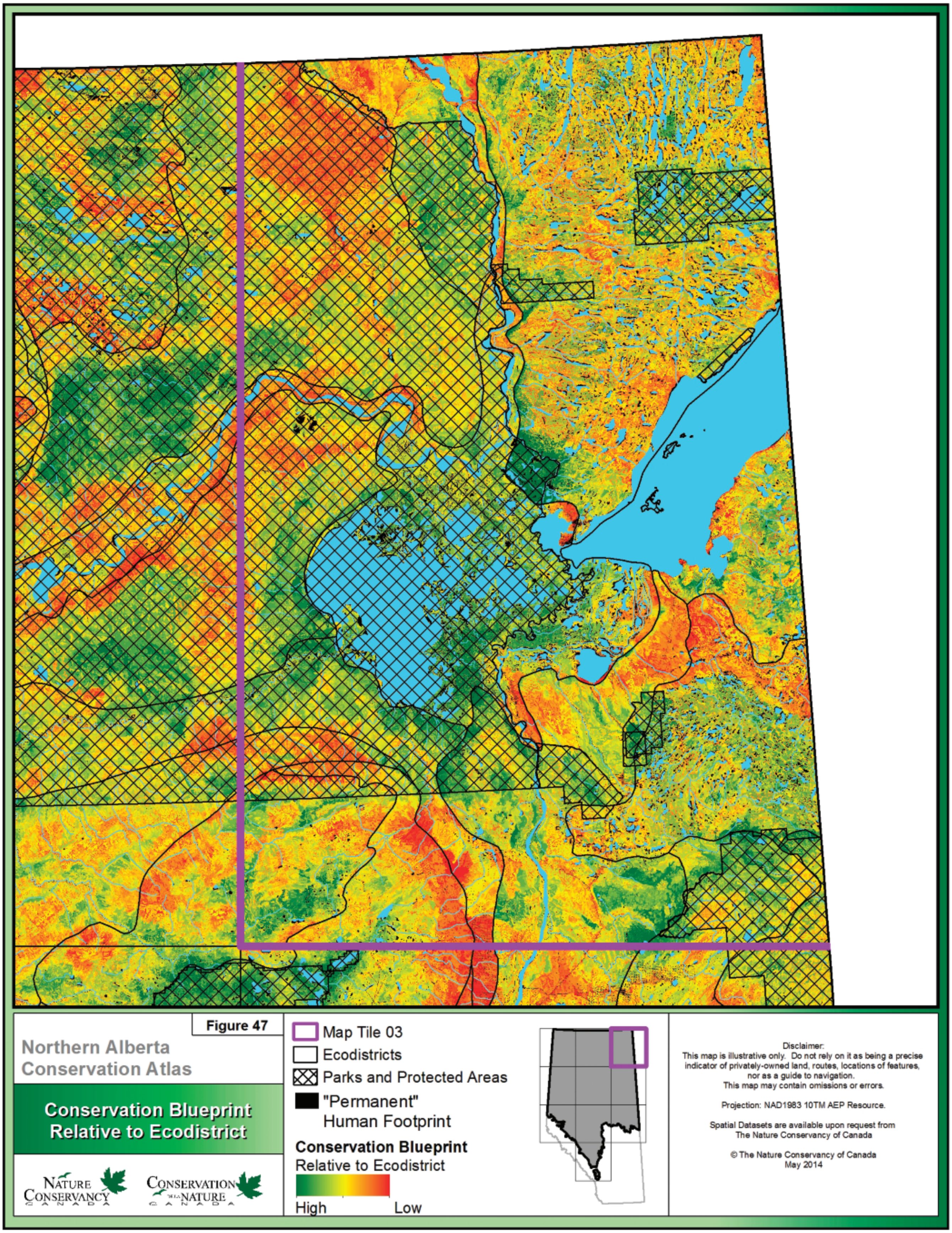


Figure 47. Map Tile 3.

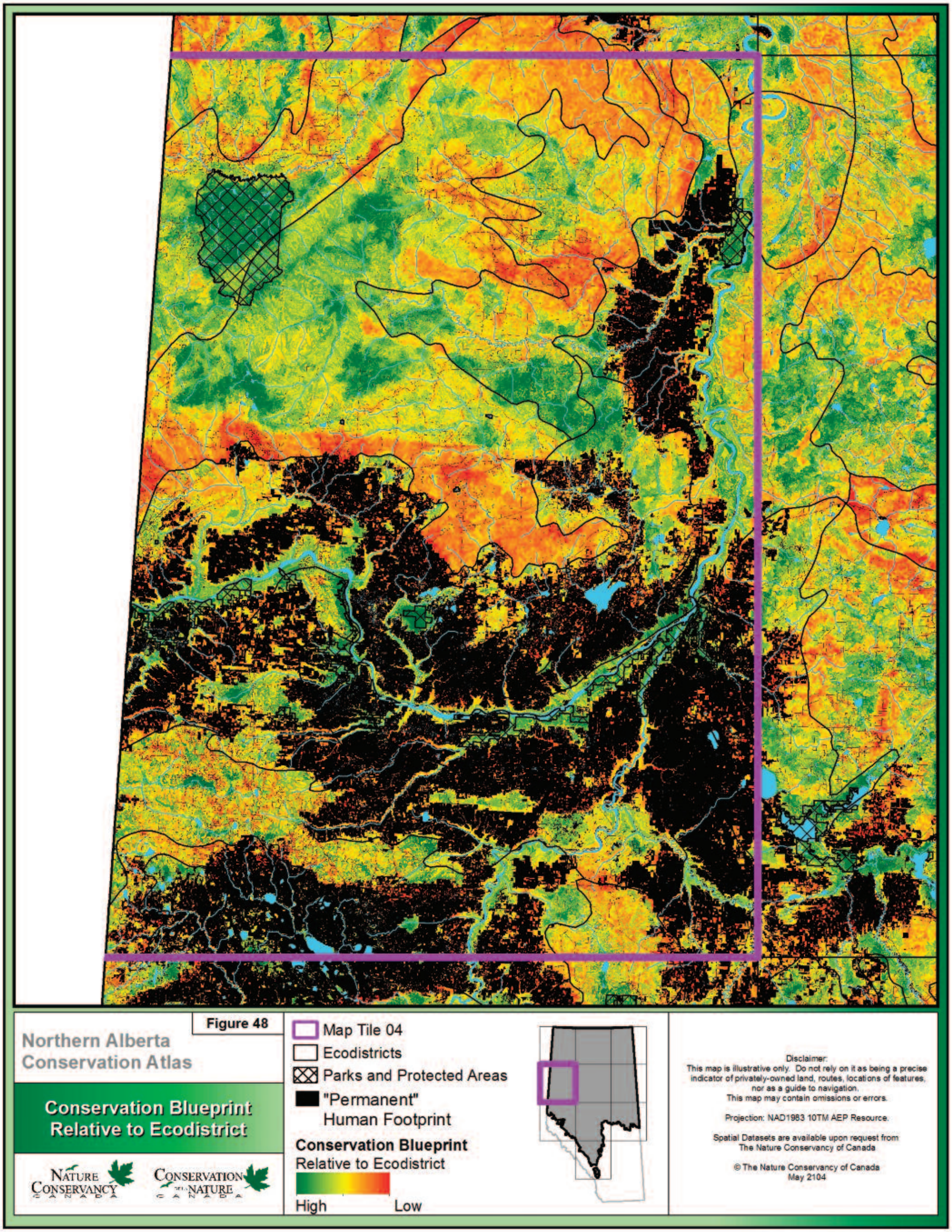


Figure 48. Map Tile 4.

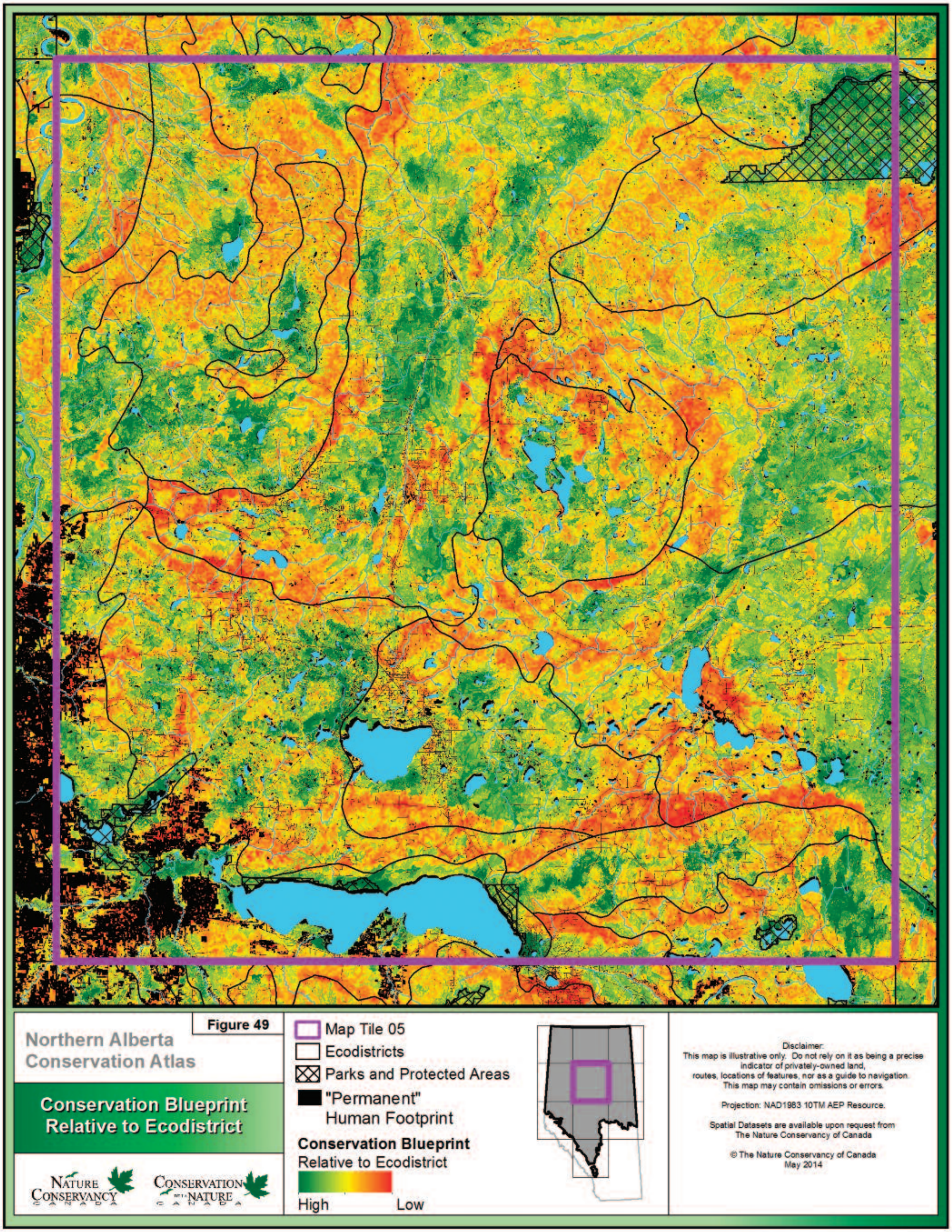


Figure 49. Map Tile 5.

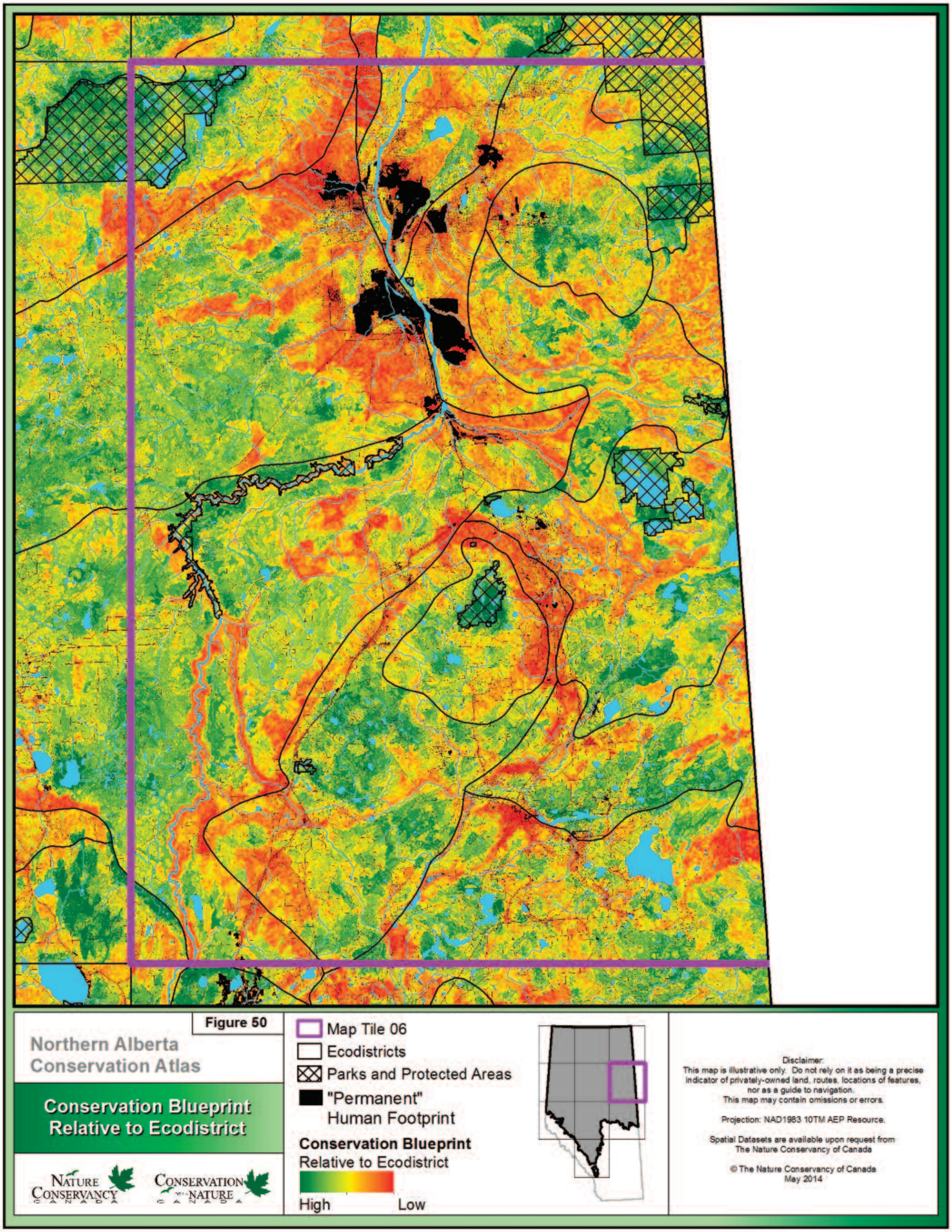


Figure 50. Map Tile 6.

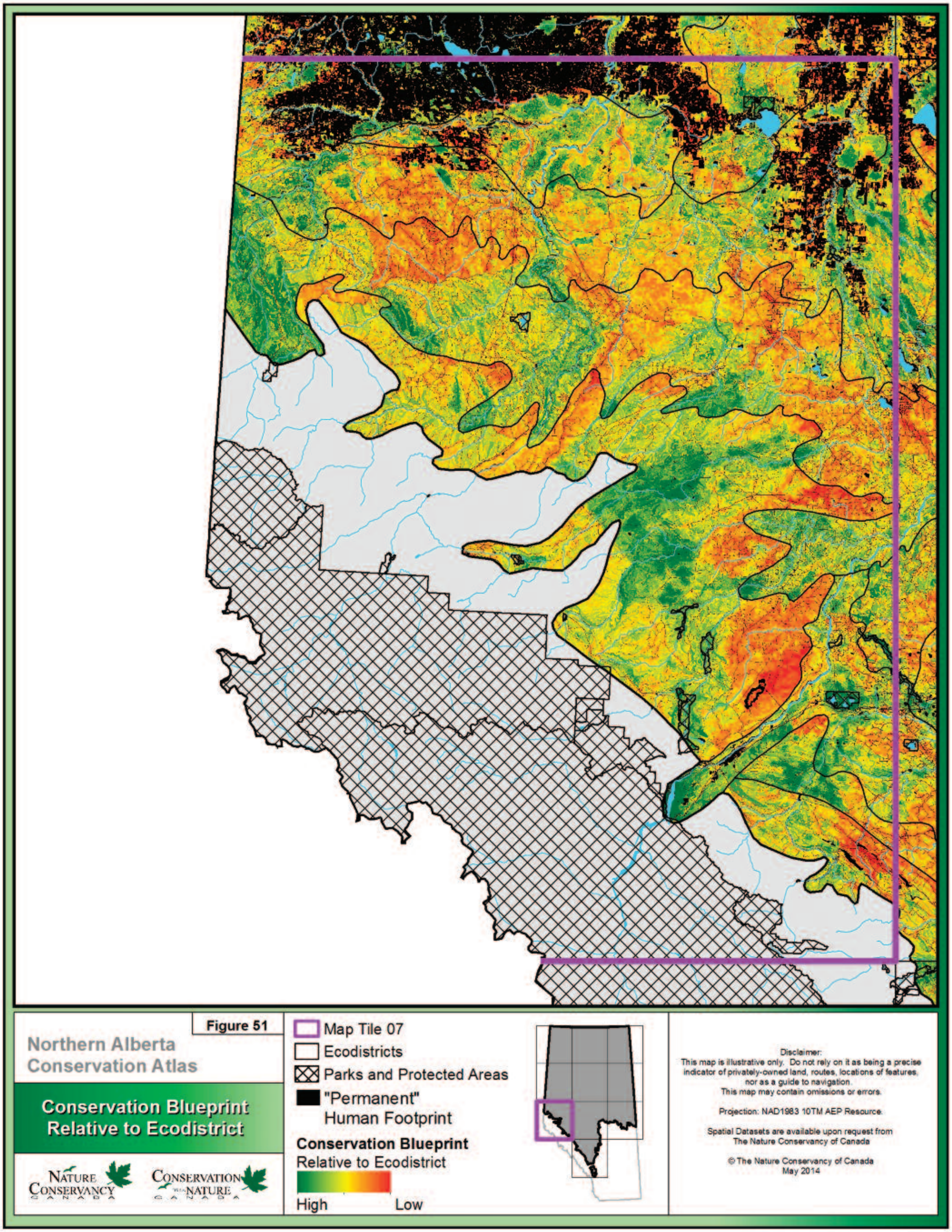


Figure 51. Map Tile 7.

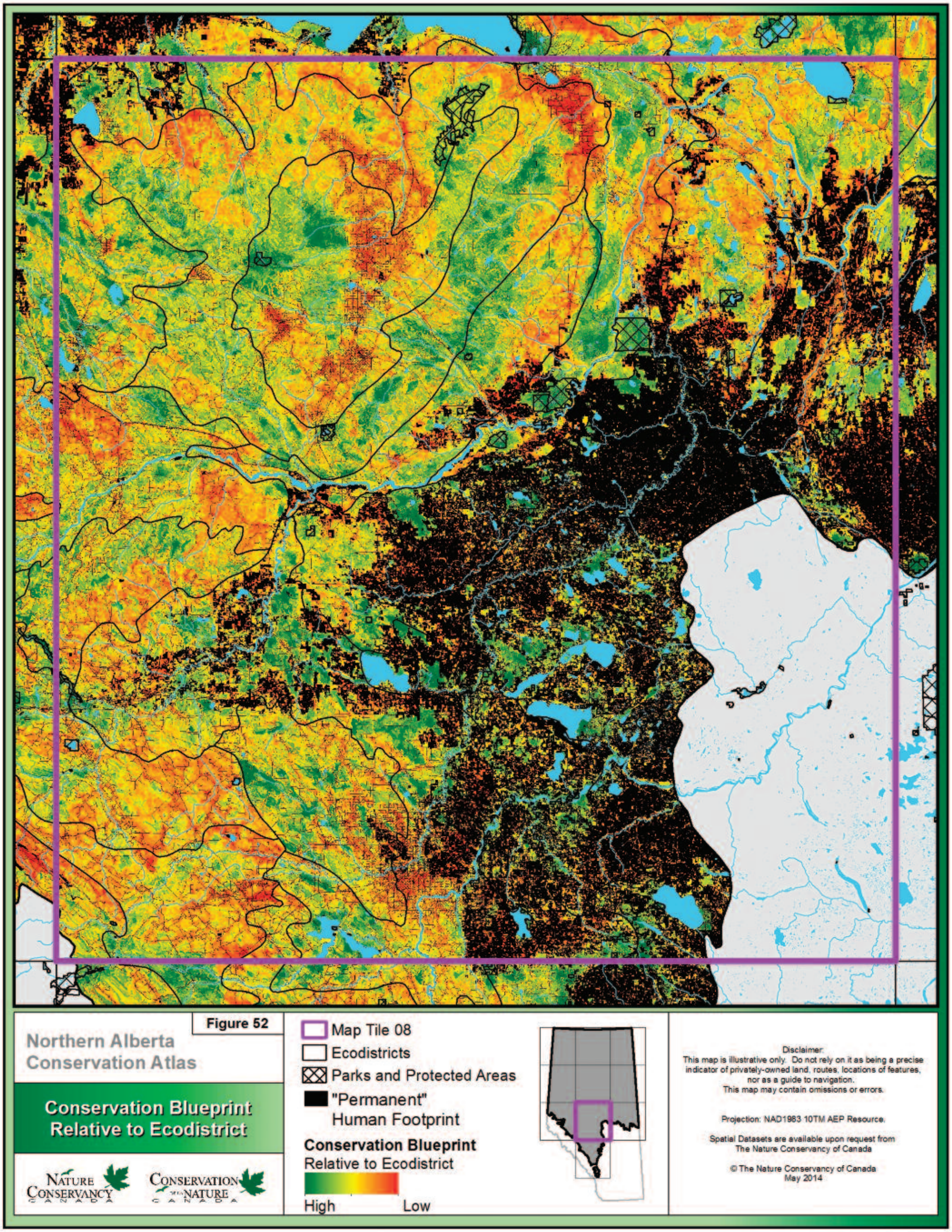


Figure 52. Map Tile 8.

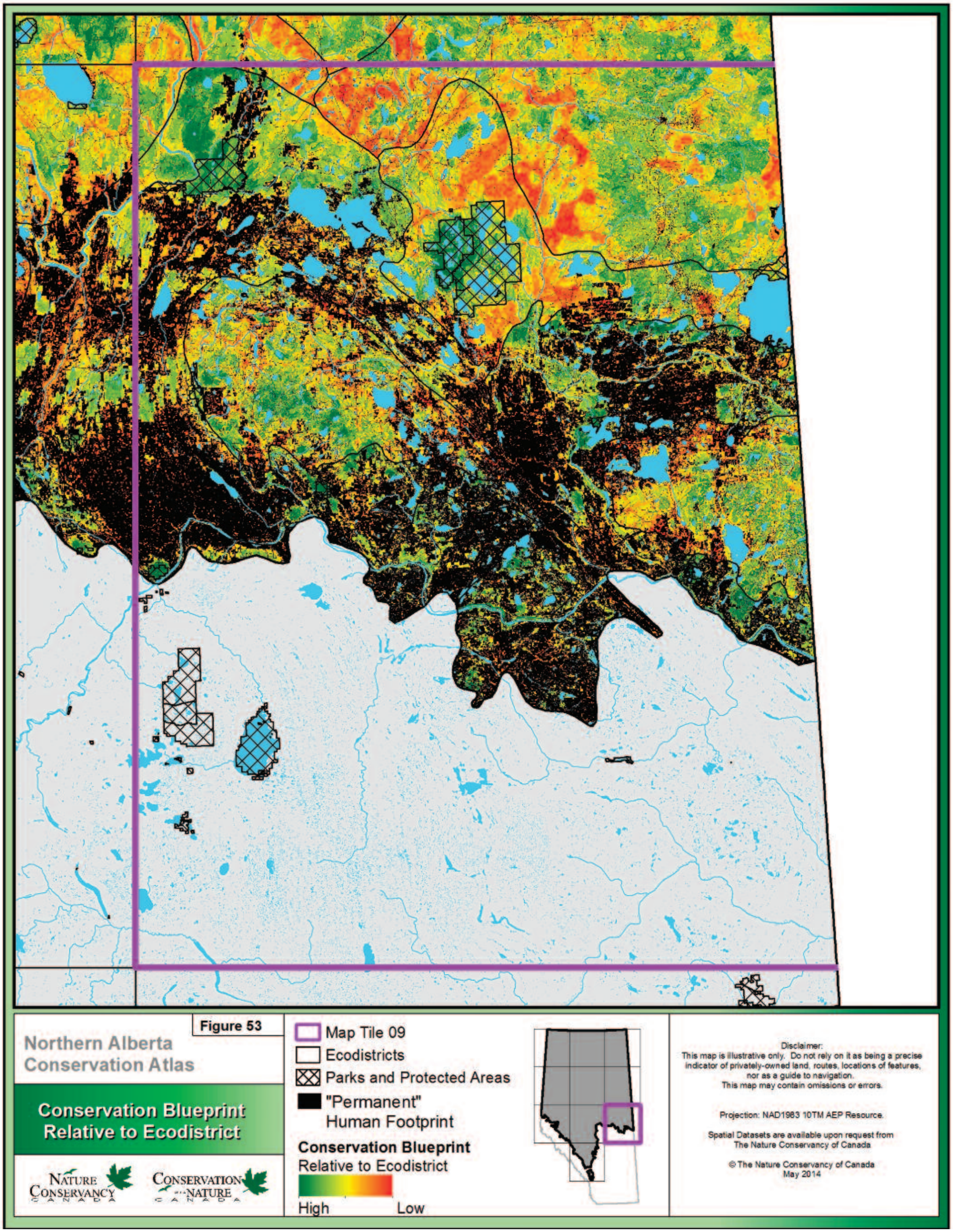


Figure 53. Map Tile 9.

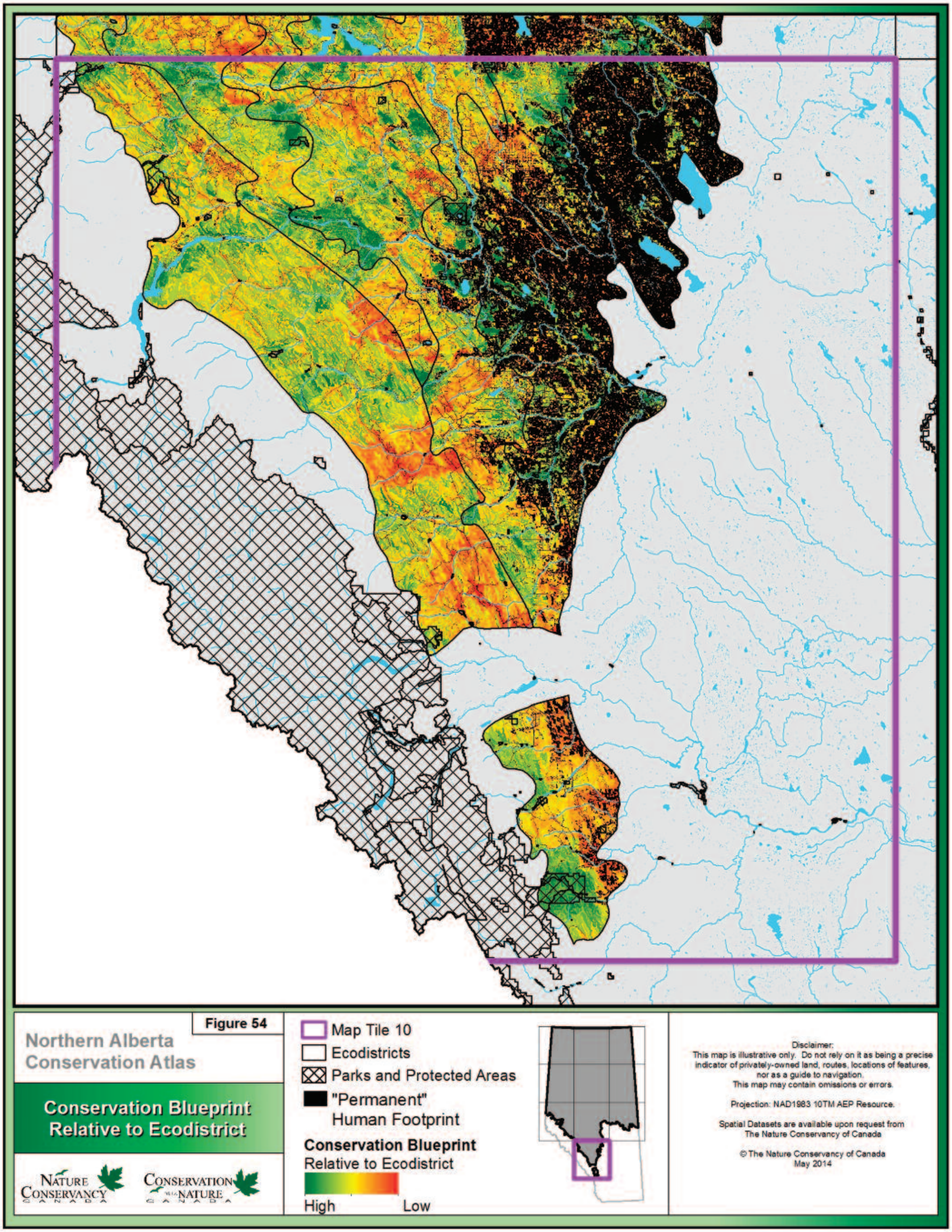


Figure 54. Map Tile 10.

Athabasca River north of Ft. McMurray Global Forest Watch Canada

3.0 Related Information

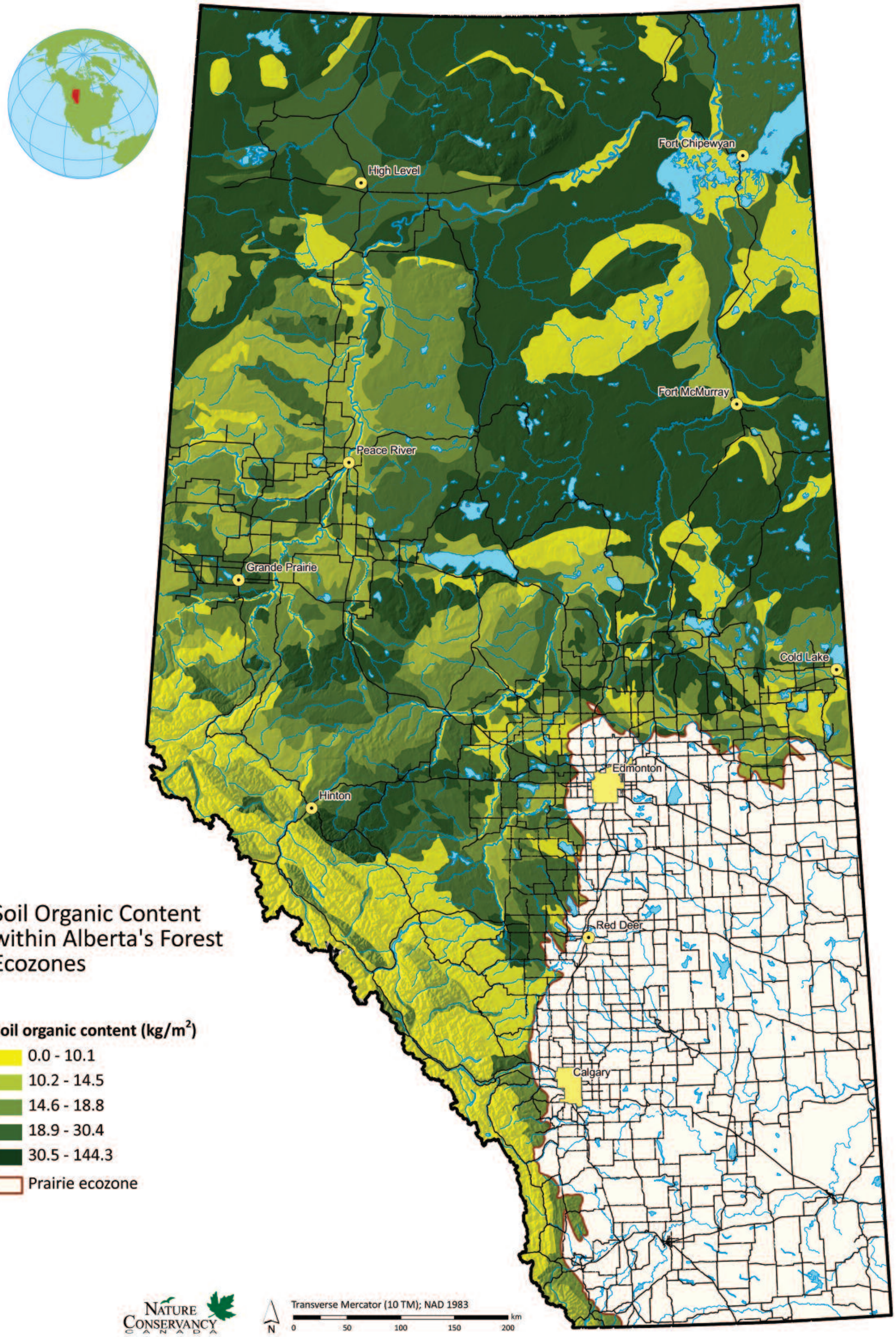
The Nature Conservancy of Canada (NCC) undertook an exploratory reconnaissance project prior to final analysis, *Mapping Ecological Values within Alberta's Forest Ecozones*, in 2010, also in collaboration with Global Forest Watch Canada. The project used coarser-resolution ecological datasets to rank key natural areas across northern Alberta. The project concluded that further work was needed, which comprises Sections 1.0 and 2.0 of this report.

Peatland north of Ft. McMurray storing organic carbon. Global Forest Watch Canada

3.1 Soil Organic Content

It is estimated that almost 30 percent of the Earth's soil organic carbon is locked in tundra and boreal ecosystems. Approximately 75 percent of Canada's land base consists of these ecosystems, which suggests that Canada contains a very significant portion of the Earth's stored carbon. Most of this occurs at mid to high latitudes, where cryosolic and organic soils dominate. Forest landscapes are important repositories of soil organic carbon, especially in peatlands and, consequently, soil organic carbon is a key ecological value.

Illustrated here is the distribution of soil organic carbon in northern Alberta, measured in kilograms of carbon per square metre and is classified into five categories (Tarnocai and Lacelle 1996).


Soil Organic Content within Alberta's Forest Ecozones
Soil organic content (kg/m^2)
0.0 - 10.1
10.2 - 14.5
14.6 - 18.8
18.9 - 30.4
30.5 - 144.3
Prairie ecozone
Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
NATURE CONSERVANCY CANADA
Transverse Mercator (10 TM); NAD 1983
N
0
50
100
150
200
km

Wetlands and mixedwood forests north of Hinton. Global Forest Watch Canada

3.2 Net biome productivity

Net biome productivity (NPB) is a measure of the carbon balance on the forest landscape, the difference between carbon assimilation and carbon dioxide loss through plant and soil respiration. Areas with a positive NPB balance are carbon sinks, which withhold carbon from the release into the atmosphere.

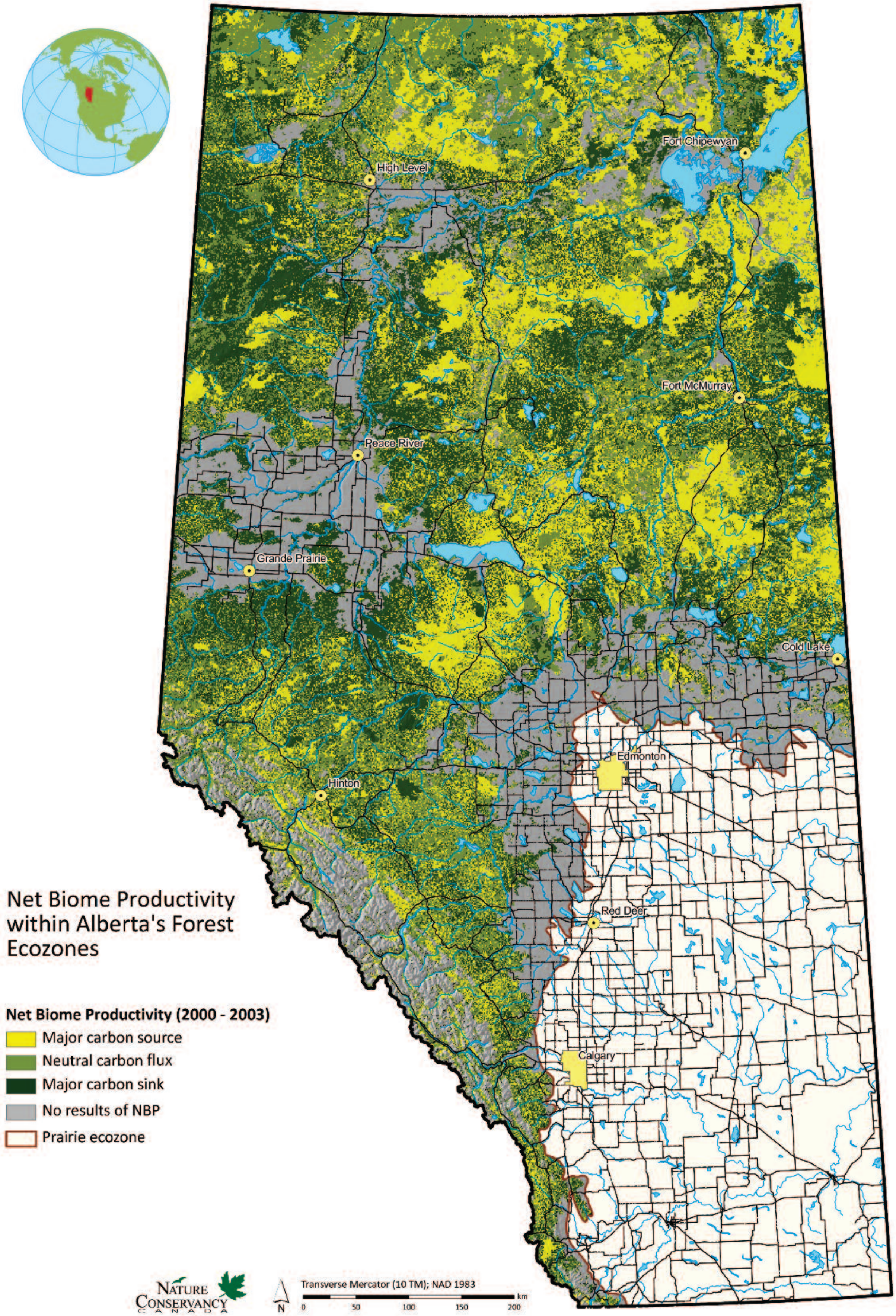
Chen and others (2003) have calculated the spatial distribution of carbon sources and sinks in forests at 1-km resolution for the period 1901 to 1998 using ecosystem models that integrate remote sensing data with gridded climate, soils and forest-inventory data. GIS-based fire scar maps were used to refine the mapping, based on burned areas in the 25 years prior to 1998. Empirical data on NPB and tree ages were used to simulate the annual forest growth and carbon balance in 1-km pixels. The carbon value is adjusted to forest-stand age in 1998.

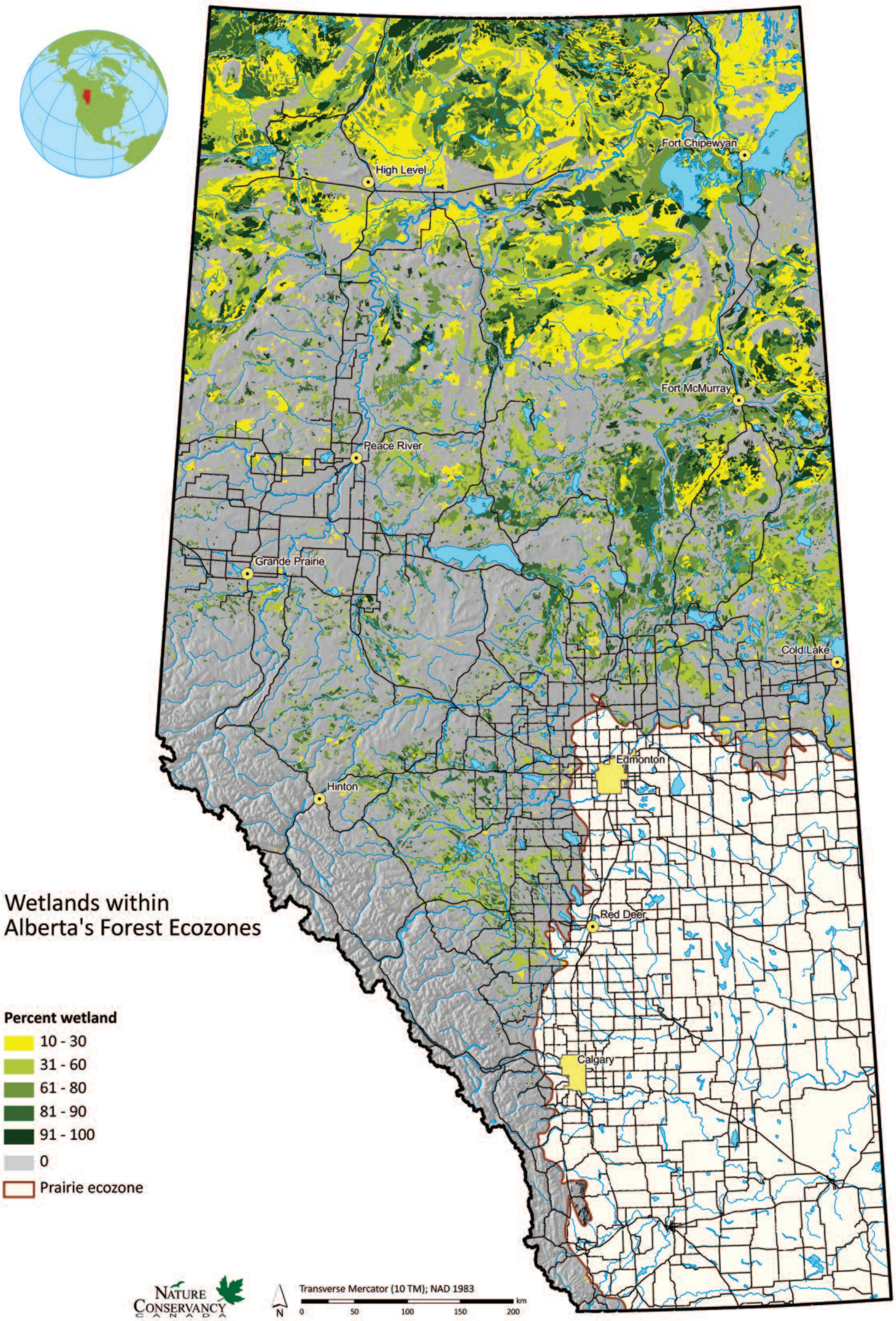
3.3 Wetlands

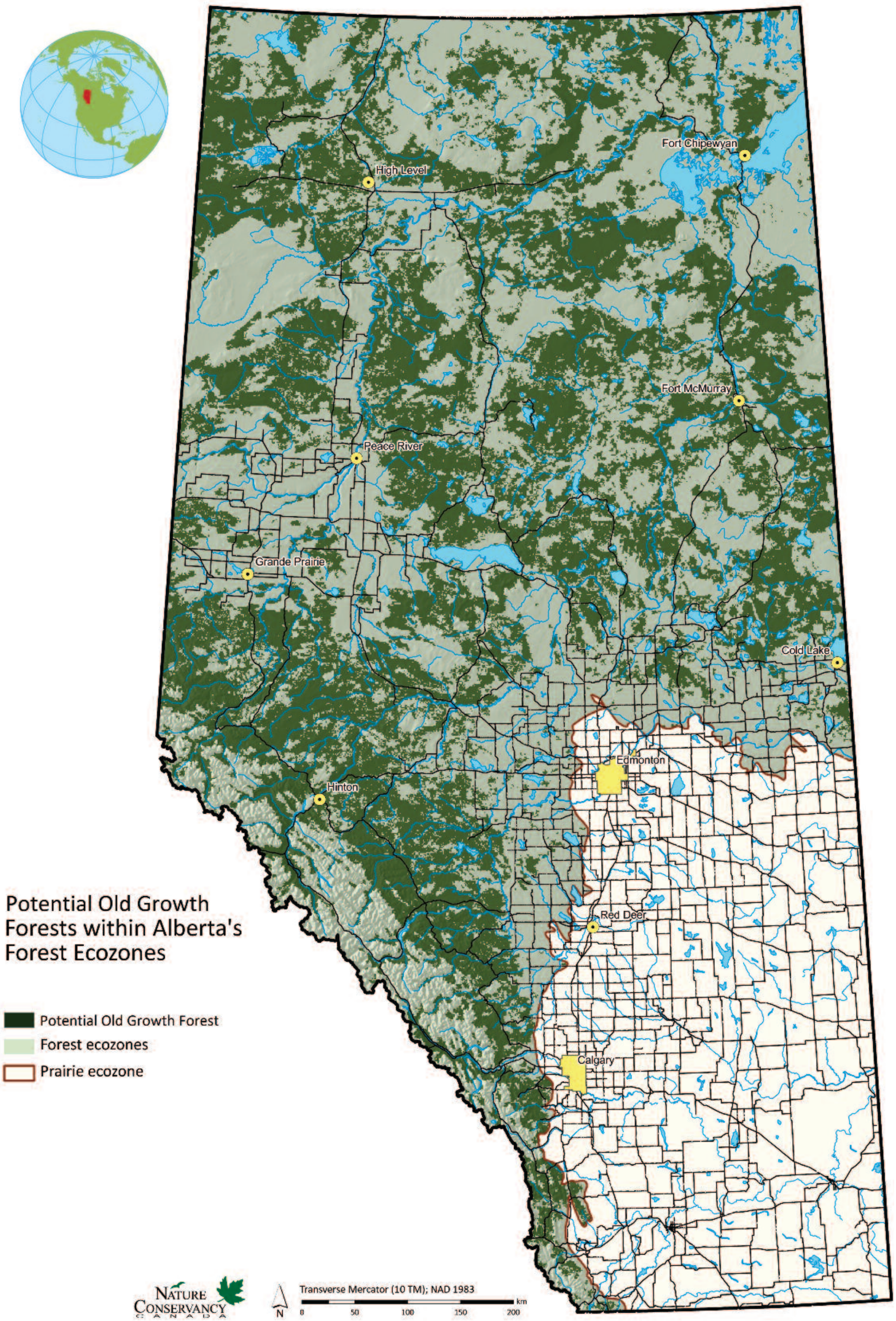
On balance, wetlands sustain more life than other ecosystems. They provide critical breeding, rearing and feeding habitat for wildlife of all kinds. Canada harbours 14 percent of global wetlands (Atlas of Canada 2004). Wetland mapping is available from Alberta Environment (Halsey and Vitt 1966).

3.4 Potential old growth forests

Old growth forests are increasingly rare native ecosystems, and sites of atmospheric carbon storage. Potential deciduous, conifer and mixed old growth forests have been mapped by Global Forest Watch Canada (also see Land Cover of Canada 1985-2000), excluding non-treed land-cover categories and areas burned between 1931 and 2009 (fire data from AGSRM 2010). Recent anthropogenic changes during a varying period but generally between 1990 and 2006 were deleted from the data layer (also Global Forest Watch Canada internal data). Areas remaining are considered potential old-growth forest.


Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Net Biome Productivity within Alberta's Forest Ecozones
Net Biome Productivity (2000 - 2003)
Major carbon source
Neutral carbon flux
Major carbon sink
No results of NBP
Prairie ecozone
Nature Conservancy Canada
N
Transverse Mercator (10 TM); NAD 1983
0 50 100 150 200
km


Wetlands within
Alberta's Forest Ecozones
Percent wetland
10 - 30
31 - 60
61 - 80
81 - 90
91 - 100
0
Prairie ecozone
Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Nature Conservancy Canada
Transverse Mercator (10 TM); NAD 1983
N
0 50 100 150 200 km


Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Potential Old Growth Forests within Alberta's Forest Ecozones
Potential Old Growth Forest
Forest ecozones
Prairie ecozone
Nature Conservancy Canada
N
Transverse Mercator (10 TM); NAD 1983
0 50 100 150 200 km

Indian Paintbrush. Global Forest Watch Canada

3.5 Combined species diversity

The maintenance of native biological diversity is a key conservation objective. One measure of this is species diversity, and Environment Canada (1999) has developed a dataset that incorporates mapping, by ecodistrict unit, of common and rare native reptiles, amphibians, birds, mammals, and trees (1999).

3.6 Reptile and amphibian species diversity

Lands and waters with the greatest reptile and amphibian diversity (more than 9 species per ecodistrict) are in the foothills and mountain of southern Alberta (Environment Canada 1999).

3.7 Bird species diversity

Lands and waters with the highest bird species diversity are located in the foothills and mountain of southern Alberta (Environment Canada 1999).

3.8 Mammal species diversity

Lands with the highest mammal species diversity are in the foothills and mountain of southern Alberta (Environment Canada 1999).

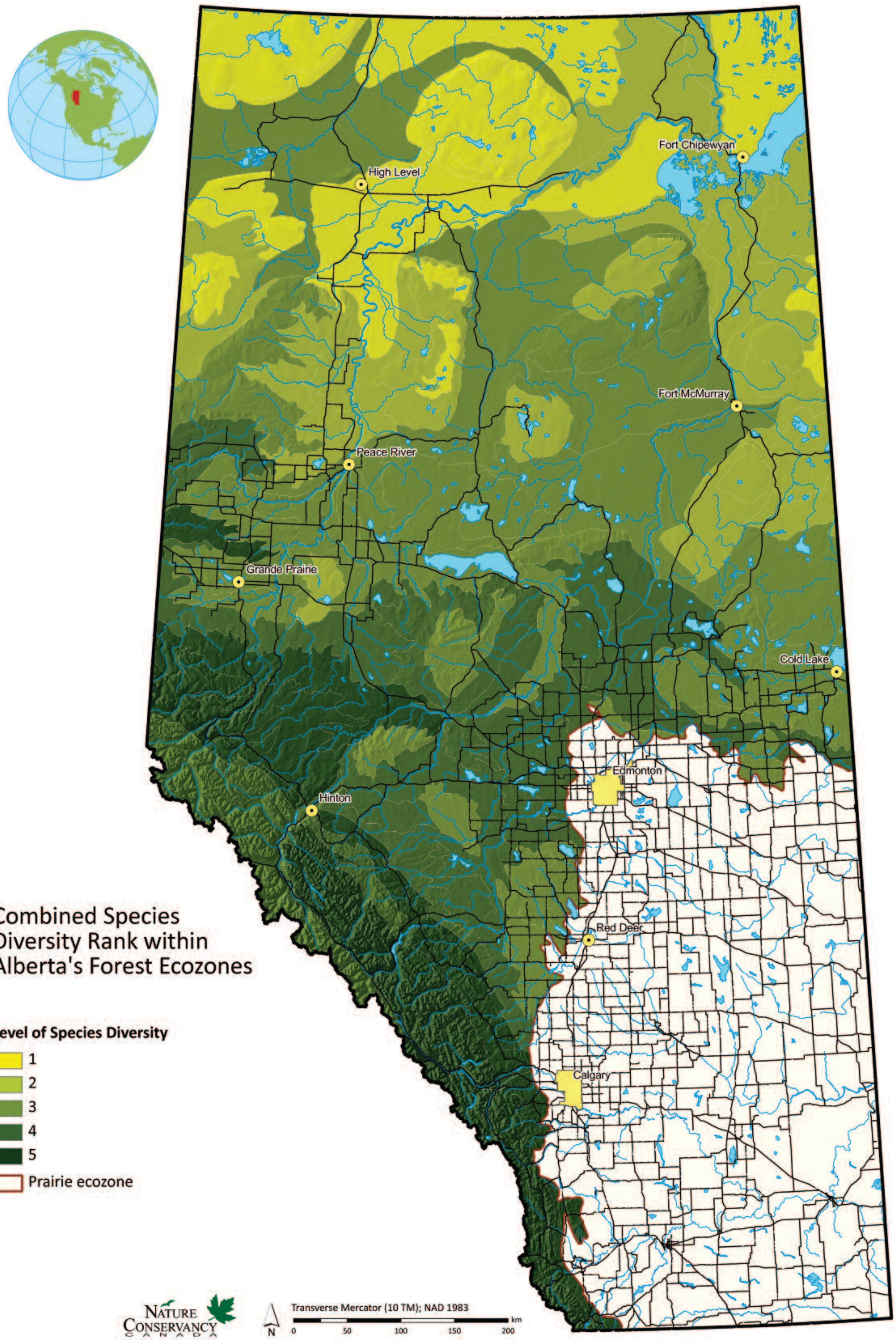
3.9 Tree species diversity

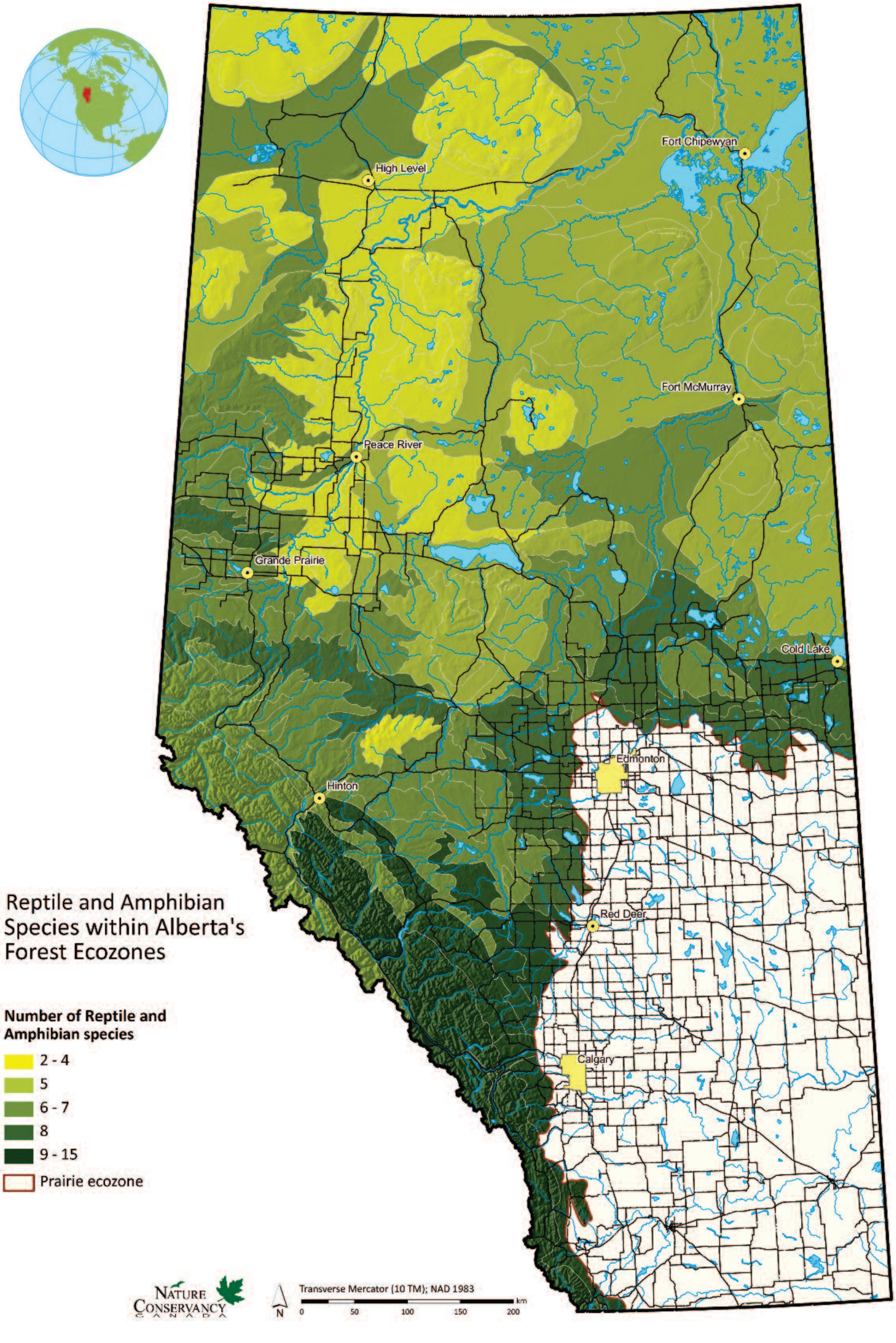
Lands with the highest tree species diversity are in the foothills and mountain of southern Alberta (Environment Canada 1999).

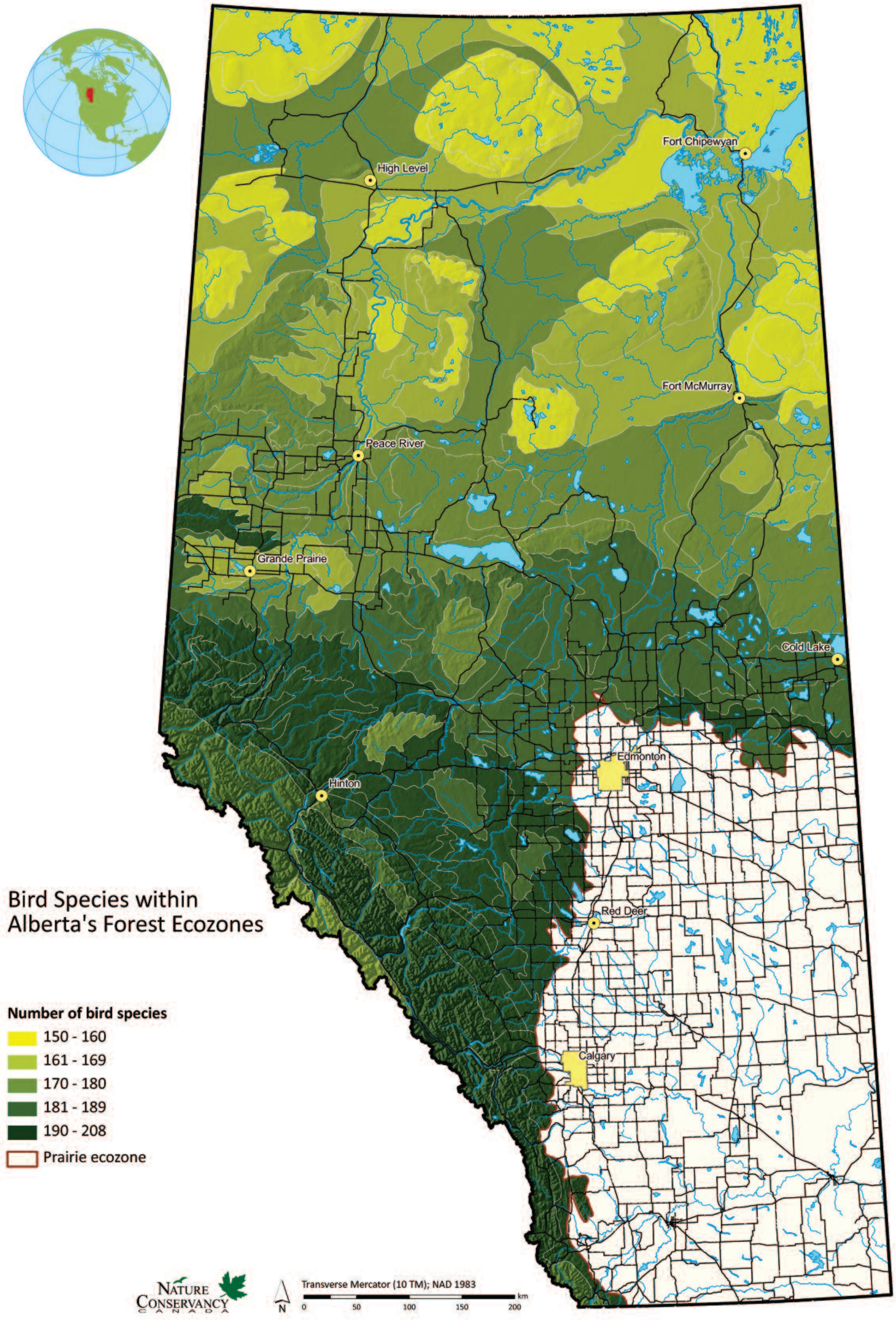
Opposite: Black-backed Woodpecker. Janice Melendez, Red-sided Garter Snakes. Chris Helzer /The Nature Conservancy, Boreal Toad. John P. Clare, Female Moose. Ann Brokelman, Great Gray Owl. Janice Melendez

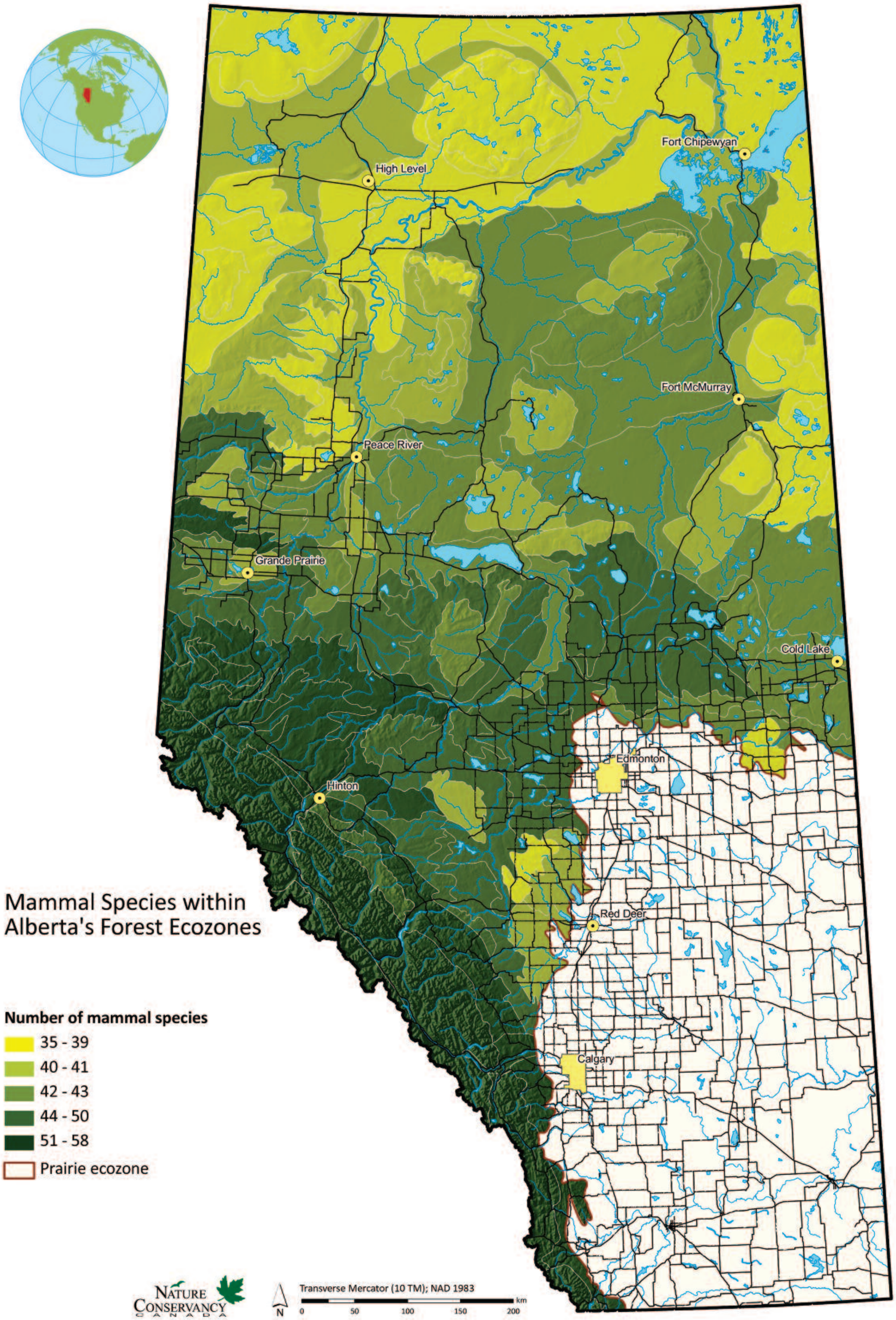


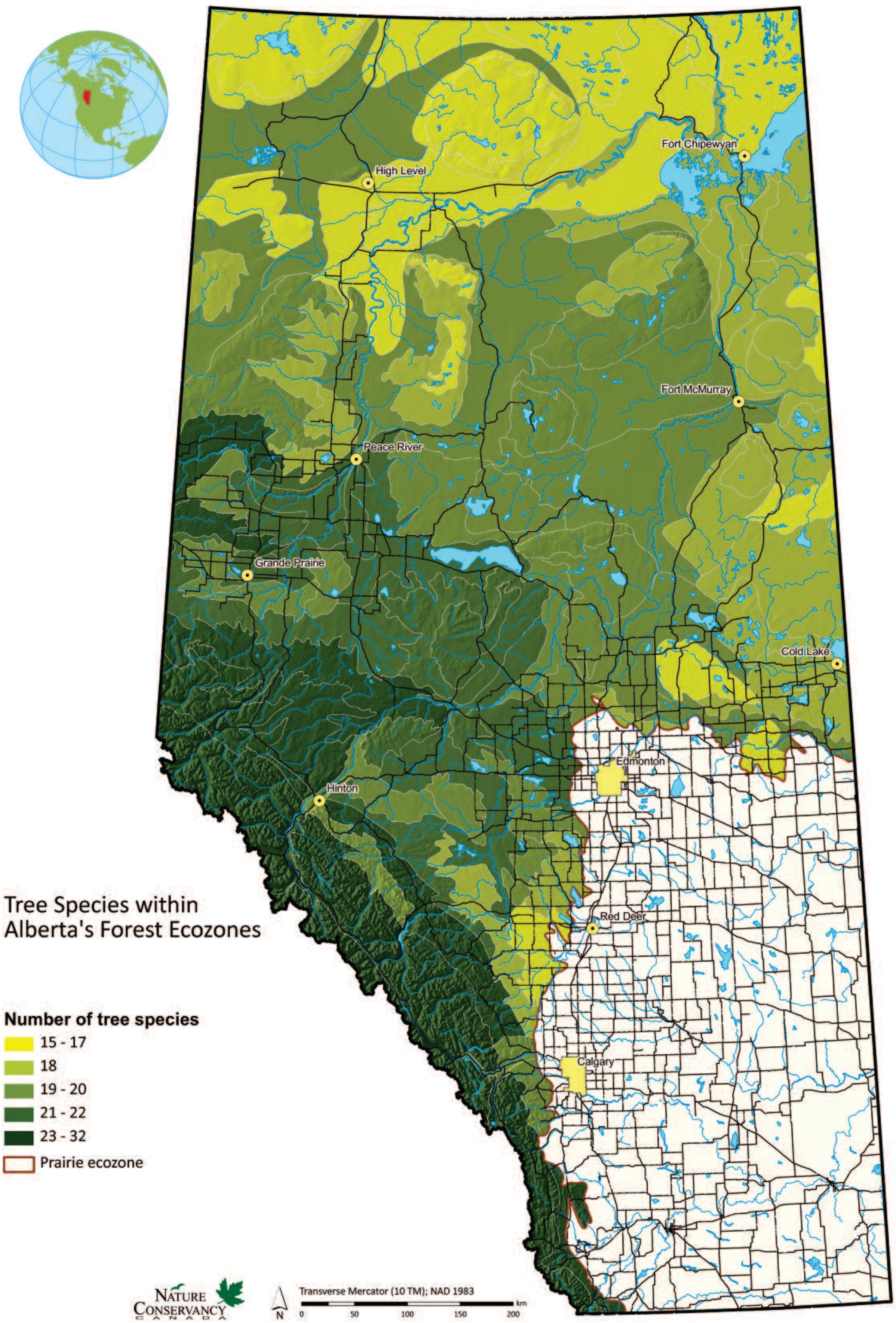



Combined Species Diversity Rank within Alberta's Forest Ecozones
Level of Species Diversity
1
2
3
4
5
Prairie ecozone
High Level
Fort Chipewyan
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Nature Conservancy Canada
Transverse Mercator (10 TM); NAD 1983
N
0
50
100
150
200
km


Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Reptile and Amphibian Species within Alberta's Forest Ecozones
Number of Reptile and Amphibian species
2 - 4
5
6 - 7
8
9 - 15
Prairie ecozone
Nature Conservancy Canada
Transverse Mercator (10 TM); NAD 1983
N
0
50
100
150
200
km


Bird Species within Alberta's Forest Ecozones
Number of bird species
150 - 160
161 - 169
170 - 180
181 - 189
190 - 208
Prairie ecozone
High Level
Fort Chipewyan
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
NATURE CONSERVANCY CANADA
Transverse Mercator (10 TM); NAD 1983
N
0 50 100 150 200 km


Mammal Species within Alberta's Forest Ecozones
Fort Chipewyan
High Level
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Number of mammal species
35 - 39
40 - 41
42 - 43
44 - 50
51 - 58
Prairie ecozone
Nature Conservancy Canada
N
Transverse Mercator (10 TM); NAD 1983
0 50 100 150 200 km



Tree Species within
Alberta's Forest Ecozones
Number of tree species
15 - 17
18
19 - 20
21 - 22
23 - 32
Prairie ecozone
High Level
Fort Chipewyan
Fort McMurray
Peace River
Grande Prairie
Cold Lake
Edmonton
Hinton
Red Deer
Calgary
Nature Conservancy Canada
Transverse Mercator (10 TM); NAD 1983
N
0 50 100 150 200 km

3.10 Scoring Ecological Values

A simple method of assessing relative ecological value is to score discrete parts of the landscape in relation to selected (and weighted) ecological values. Ecological values can include physical or biological components, species occurrences, or values associated with ecosystem services, or wetland, aquatic and terrestrial values.

The ecological values for which coarse-resolution geospatial data were available were:

- Soil Organic Carbon
- Net Biome Productivity
- Species Diversity – Combined Trees, Birds, Mammals, Reptiles and Amphibians
- Key focal species – Woodland Caribou, Grizzly Bear
- Potential Old-growth
- Riparian length per watershed
- Wetlands (see Table 1 for weighting)

Other important ecological value layers were not available at the time (e.g., Sections 2.1, 2.2), thus the following analysis of datasets was considered a test only of a particular scoring approach.

Geospatial data for each ecological value was clipped to the boundary of Alberta's forest landscapes, and then subjected to a ranking and weighting process that assigned relative values to a 1-km grid. The resulting values were then summed into a conservation value index. (A perceived drawback was the differing resolutions of coverages, reducing spatial accuracy of outputs.)

Key ecological values were ranked, based on an assumed even spread of relative values, between 1 (lowest) and 5 (highest). Ecological values were thus ranked into a maximum of 5 quantile classes (each class, or quantile, contains an approximately equal number, or count, of features). (There are, of course, other ways to establish classes (e.g., equal interval; standard deviation; natural breaks). The simplicity of the approach taken may well assign unwarranted equivalencies to classes, for example, equating a Rank 1 of carbon with a Rank 1 of number of species.)

Trembling aspen forest, slopes of the Swan Hills.
Global Forest Watch Canada

Individual relative scores were then combined into a single conservation score by summing their geographical coincidence; the 1-km grids of each ecological value were overlayed and summed.

(There is an implicit bias when the values are combined into a single index. For example, a portion of Caribou range that intersects other values receives a high ranking but loses its value for caribou if treated in isolation.)

The resulting range of numerical sums within the ecological value index grid was then grouped into five quantile classes in order to illustrate focal areas that may warrant conservation consideration.

Table 12. Summary of values, scoring ranks, and relative weighting

Key Ecological Value	Categories	Ranking	Relative Weight	Scaled Weight (max value = 1)
Soil Organic Carbon	5	1 to 5	1	0.03
Net Biome Productivity	3	1 to 5	1	0.03
Potential Old Growth Forests	1	1 to 5	1	0.03
Species Diversity - Combined Trees, Birds, Mammals, Reptiles and Amphibians	5	1 to 5	2	0.05
Key focal species	1	1 to 5	1	0.03
Aquatic density per watershed	5	1 to 5	1	0.03
Wetlands	5	1 to 5	1	0.03
			8	**0.2**

Table 13. The seven key ecological values and their categorization and ranking

Key Ecological Value	Units	Description	Categories	Ranking
Soil Organic Carbon	kg of carbon / m2	Amount of carbon in the soils	0 - 10.1	1
			10.1-14.5	2
			14.5 - 18.8	3
			18.8 - 30.4	4
			30.4 - 144.3	5
Net Biome Productivity	g of carbon / m2/ year	Net carbon balance of forest landscapes	major carbon source (-854 - 18)	1
			neutral carbon flux (-19 - 52)	3
			major carbon sink (53 - 784)	5
Old Growth Forests	Treed land cover older than 76 years	Based on the "Forest Land" class of the "Multi-temporal land cover map of Canada (2000) using NOAAAVHRR 1km data." Areas within the Alberta wildfire database (1931-2009) and disturbances mapped by GFWC were excluded.	All areas	5
Species Diversity Combined Trees, Birds Mammals, Reptiles and Amphibians	Average species diversity rank	Nearest whole value of the average species diversity rank. Individual diversity ranking was derived from quantile classification of number of species as shown below.	average combined spp. diversity rank	1
			average combined spp. diversity rank	2
			average combined spp. diversity rank	3
			average combined spp. diversity rank	4
			average combined spp. diversity rank	5
Key Focal Species	Grizzly or Caribou	Present Range	All Grizzly or Caribou range	5
Shoreline Length per Watershed	Length per hectare by watershed	Rivers and lake perimeters (river lengths were multiplied by 2)	0 - 1.93	1
			1.93 - 2.38	2
			2.38 - 2.86	3
			2.86 - 3.43	4
			3.43 - 20.03	5
Wetlands	Percent wetland	Bogs, fens, swamps and marshes	10 - 30	1
			30 - 60	2
			60 - 80	3
			80 - 90	4
			90 - 100	5
			190-208	5

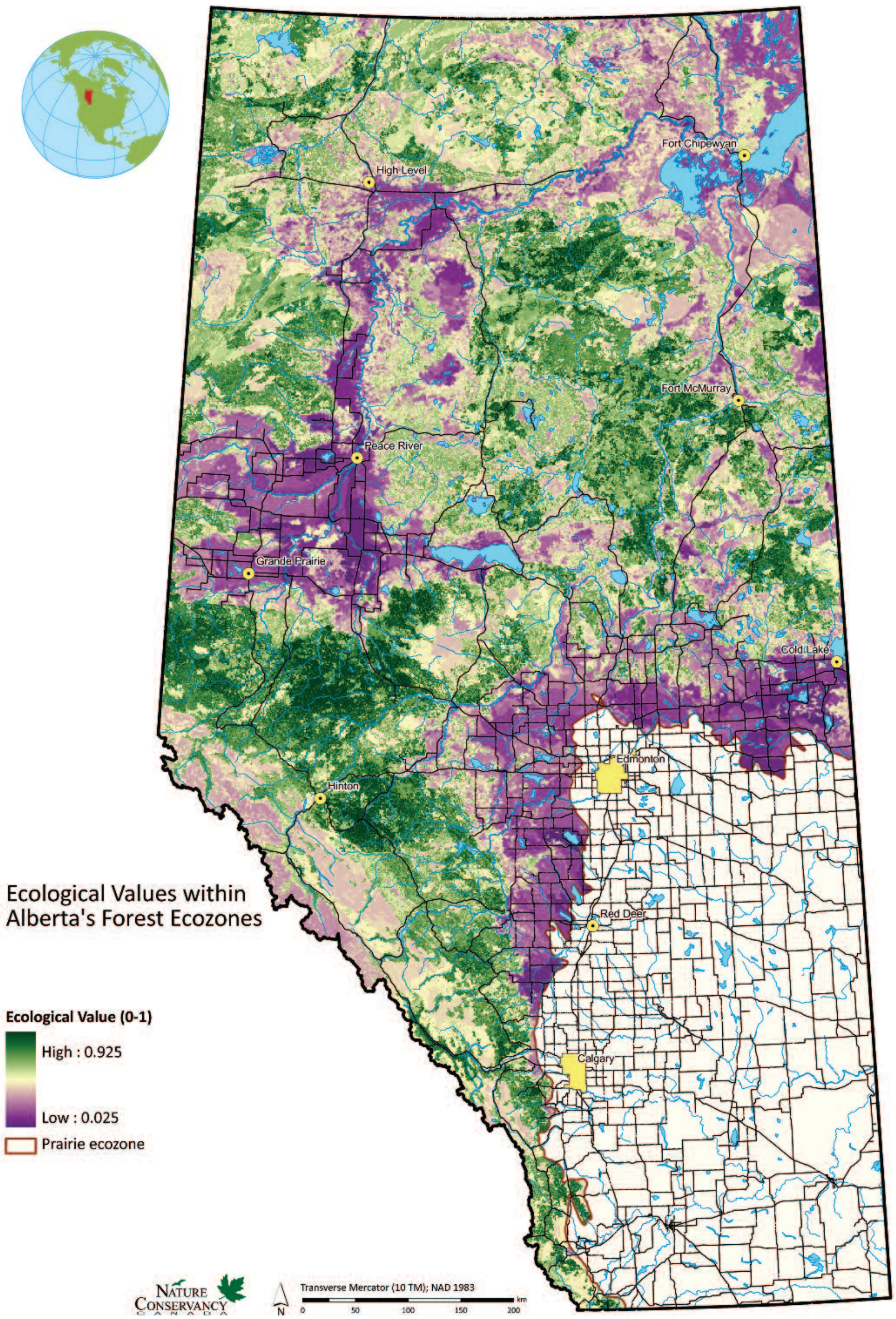
Northern Shoveler. Ann Brokelman

Table 14. Individual species diversity ranking

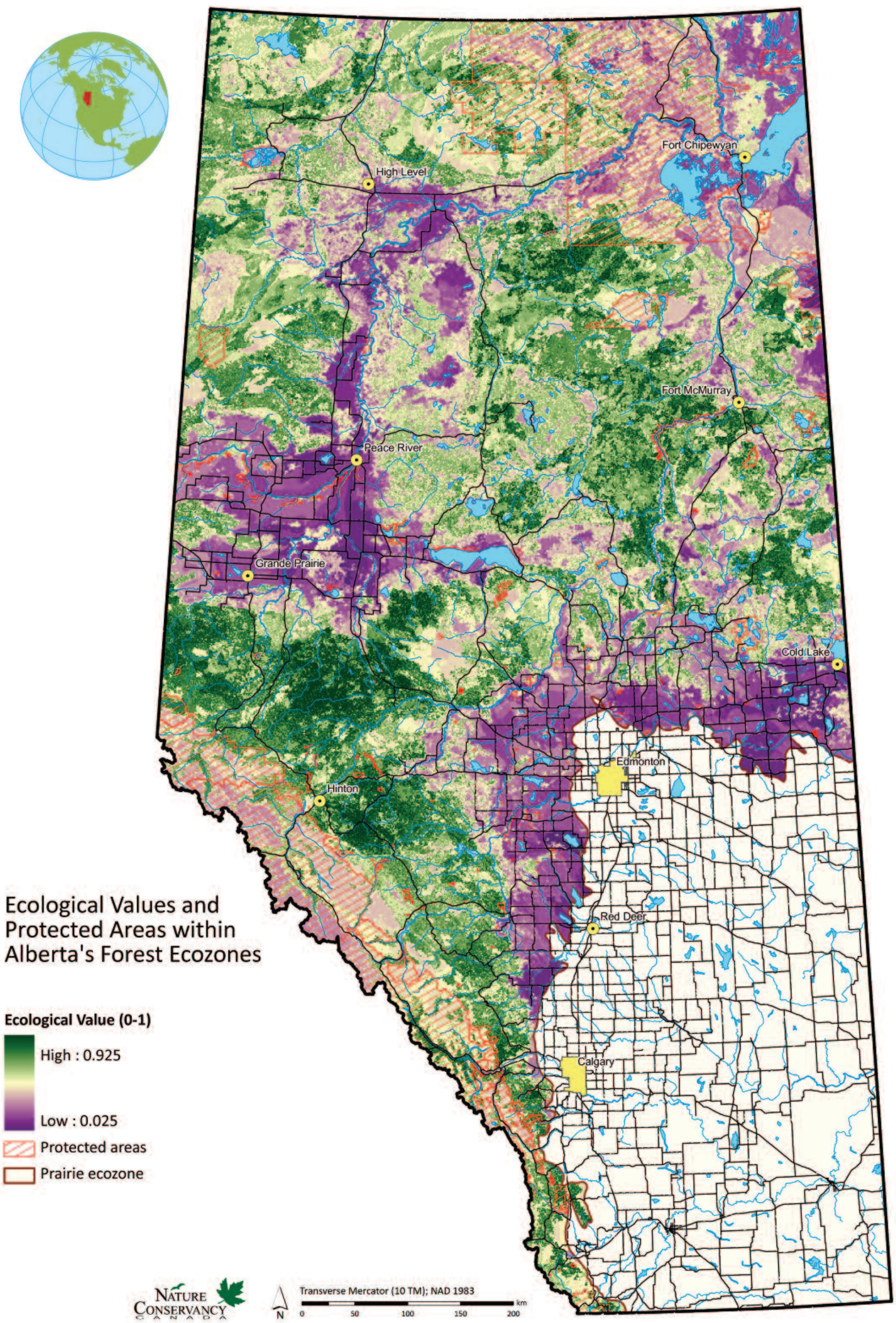
		Categories	Ranking
Trees	Based on ranges	15-17	1
Number of species		18	2
		19-20	3
		21-22	4
		23-32	5
Birds	Based on ranges	150-160	1
Number of species		161-169	2
		170-180	3
		181-189	4
		190-208	5
Mammals	Based on ranges	35-39	1
Number of species		40-41	2
		42-43	3
		44-50	4
		50-58	5
Reptiles and Amphibians	Based on ranges	2-4	1
Number of species		5	2
		6-7	3
		8	4
		9-15	5

3.10.1 GENERAL MAPPING

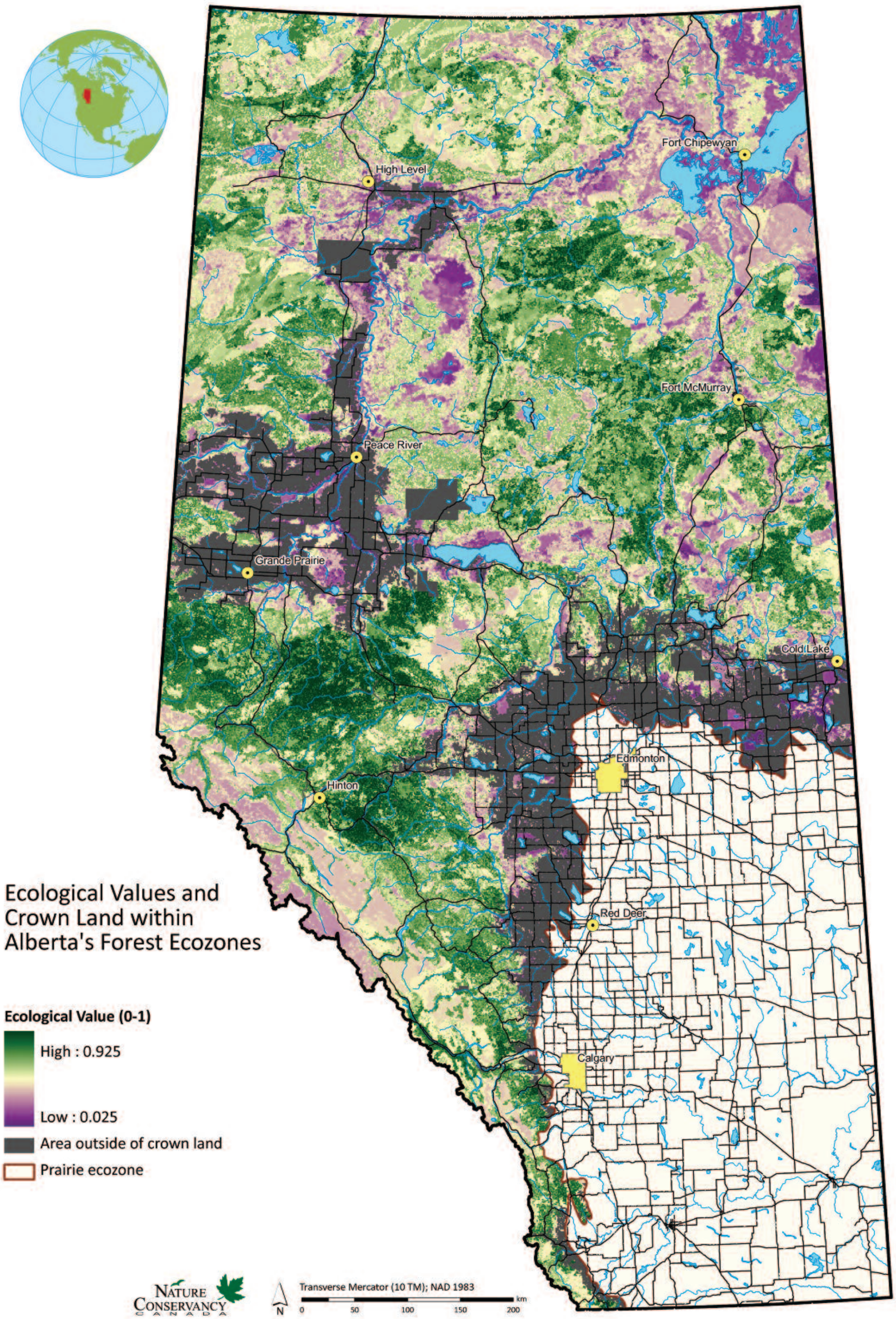
Based on this scoring, the foothills of the Rockies and parts of the central and northern boreal forest support the largest areas with the highest index of combined ecological values.



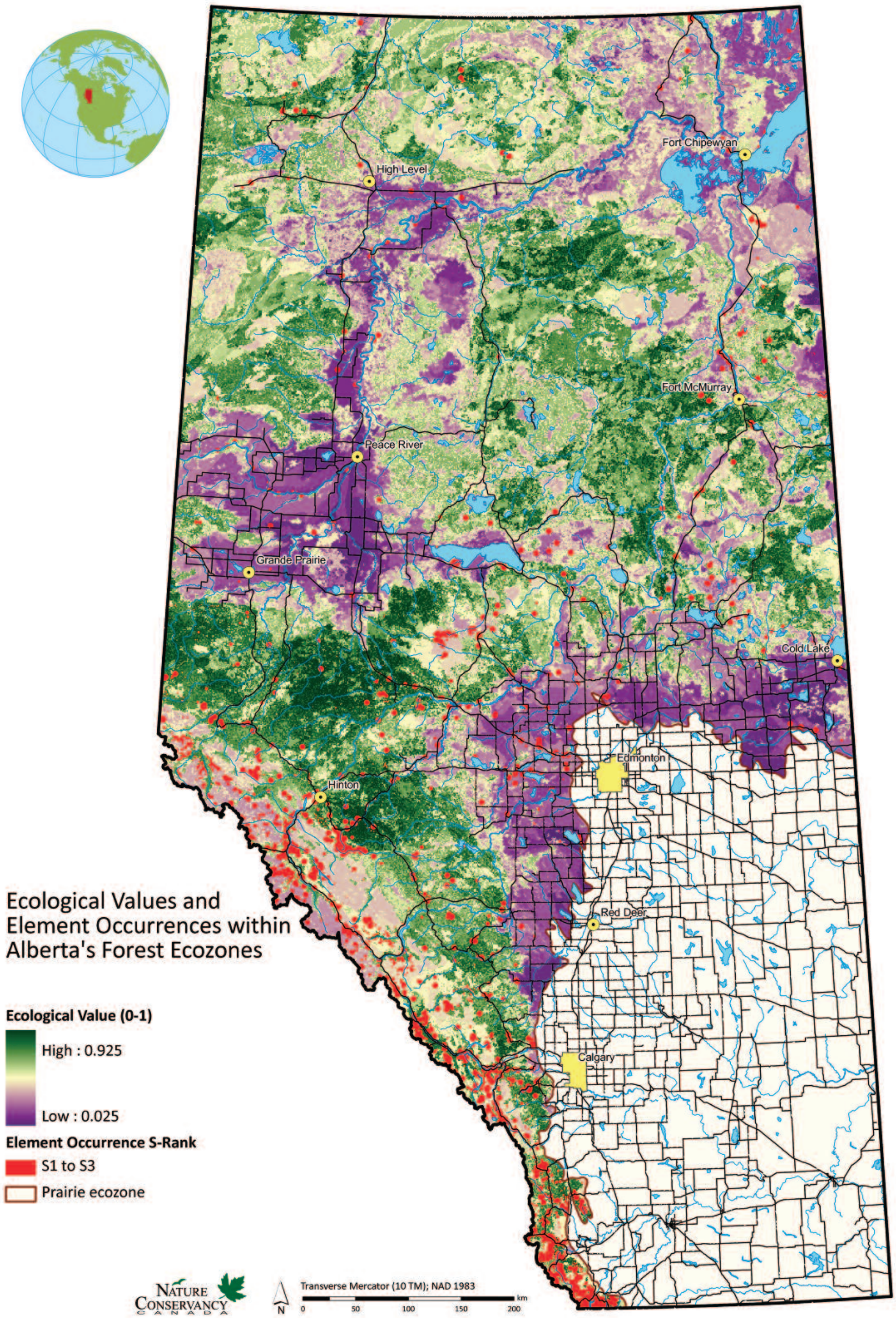
3.10.2 PROTECTED AREAS (see Lee *et al.* 2013)



3.10.3 PUBLIC LANDS



3.10.4 KEY ELEMENT OCCURRENCES



Emergent riparian marsh. Nature Conservancy of Canada

4.0 References

AGRSM (Alberta Government, Sustainable Resource Management) 2010. Spatial Wildfire Data. On line http://www.srd.alberta.ca/UpdatesFireAlerts/Wildfire Status/HistoricalWildfireInformation/SpatialWildfire Data.aspx

ASRD and ACA (Alberta Sustainable Resources Development and Alberta Conservation Association) 2010a. *Status of the Grizzly Bear* (Ursus arctos) *in Alberta*. Wildlife Status Report 37. Edmonton, AB. 44pp.

ASRD and ACA (Alberta Sustainable Resource Development and Alberta Conservation Association 2010b. *Status of the woodland caribou* (Rangifer tarandus caribou) *in Alberta*. Wildlife Status Report 30. Edmonton, AB.

Anderson, M. *et al.* 2006. *Supplementary information on the 90m raster dataset created for the Northern Appalachian-Acadian Ecoregion*. The Nature Conservancy (U.S.), Eastern Region, Boston. (As referenced in 2012 NCC internal paper "Supplementary information on the content and construction of the ELU30m raster dataset for the Labrador Conservation Blueprint")

Atlas of Canada. 2004. Wetlands. On line http://atlas.nrcan.gc.ca/site/english/learningresources/theme_modules/wetlands/index.html

Bird Studies Canada and The Canadian Nature Federation. 2004. I*mportant Bird Areas of Canada Database.* Port Rowan, Ontario: Bird Studies Canada.

Burrough, P. A. 1989. *Fuzzy mathematical methods for soil survey and land evaluation*. Journal of Soil Sciences 40:477-492.

Chen, J.M., W.Ju, J.Cihlar, D.Price, *et al.* 2003. *Spatial distribution of carbon sources and sinks in Canada's forests*. Tellus B. 55-2: 622-641.

Ducks Unlimited Canada. 2012. *Mapping spatial distribution of waterfowl pairs in the Canadian Western Boreal Forest: Overview of methodology, results and interpretation. MS.*

Environment Canada. 1999. Dataset and report (K.Freemark, H.Moore, D.M.Forsyth *et al.* 1999. *Identifying minimum sets of conservation sites for representing biodiversity in Canada: a complementarity approach*. Technical Report, Canadian Wildlife Service, Ottawa, ON. On line ftp://ftp.geogratis.gc.ca/Ecosystems/

Environment Canada. 2011. *Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou* (Rangifer tarandus caribou), *Boreal Population*, In Canada: 2011 Update. Ottawa, ON. 102 pp. + app.

ESWG (Ecological Stratification Working Group.) 1999. *Ecozones, Ecoregions and Ecodistricts [vector digital data]*. Created by Agriculture and Agri-Foods Canada, Environment Canada. http://sis.agri.gc.ca/cansis/hsdb/ecostrat/gis_data.html.

Fulton, R.J. 1995. Surficial Materials of Canada. Geological Survey of Canada, Map 1880A.

Halsey, L. and D.H.Vitt. 1996. *Alberta Wetlands Inventory*. Available on request from Alberta Environment.

Land Cover of Canada: Multi-tempral Land Cover Maps of Canada using NOAA AVHRR 1-km data from 1985-2000. On line http://geodiscover.cgdi.ca/wes/Record Summary-Page.do;jsessionid=2D7C4AD10527814AB1C97F924BD7186D.gdp2?uuid=B5ABF13A-B3F4-7421-35C8-32D1C7D4C3BF&recordLocale=en_US&view=summary&entryPoint=jsMap&mode=unmappable

Lee, P., M. Hanneman, R. Cheng. 2013. Rapid Ecological Assessment of Northern Alberta. Draft Report prepared for the Nature Conservancy of Canada.

MacMillan, R.A., W.W. Pettapiece, S.C. Nolan and T.W. Goddard. 2000. *A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic*. Fuzzy Sets and Systems 113 (1): 81-109.).

MacMillan, R.A. 2003. *LandMapR© Software Toolkit- C++ Version: Users manual*. LandMapper Environmental Solutions Inc., Edmonton, AB. 110 pp.

NEF (*National Ecological Framework for Canada*, by Marshall, I.B., P.H. Schut, M. Ballard.) 1999. Agriculture and Agri-Food Canada, and Environment Canada. Ottawa/Hull.

Nielsen, S.E., J. Cranston, and G.B. Stenhouse. 2009. *Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada*. Journal of Conservation Planning 5:38–60.

Notzl, L., R. Greene and J.L. Riley. 2013. *Labrador Nature Atlas.* Vol. I. Nature Conservancy of Canada, Toronto, Ontario, Canada. 204pp.

Riley, J.L., S.E. Green and K.E. Brodribb. 2007. *A Conservation Blueprint for Canada's Prairies and Parklands.* Nature Conservancy of Canada, Ontario, Canada. 226pp. plus DVD-ROM.

Riley, J.L., L.Notzl and R.Greene. 2013. *Labrador Nature Atlas*. Vol. II. *Ecozones, Ecoregions and Ecodistricts*. Nature Conservancy of Canada, Toronto, ON. 128pp.

Tarnocai, C. and B. Lacelle. 1996. *Soil Organic Carbon Digital Database of Canada*. Personal communication.

Beaver ponds north of Ft. McMurray.
Global Forest Watch Canada

Technical Appendices

A. Land Cover Analysis

B. Crosswalk Table of Surficial Geology Classes

C. Analysis of Landscape Facets

Appendix A. **Land Cover Analysis**

Land cover, or vegetation, describes the habitats that species select and make use of for particular parts of their life cycles. Legend units correspond generally to broad ecological systems. (Section 1.2, Figure 4)

Land-cover data are regularly used as the biological attributes of a mapped layer of Ecological Land Units, but land-cover mapping adequate for this purpose was not available for the entire study area. The adequacy of available land-cover data was assessed in the following manner.

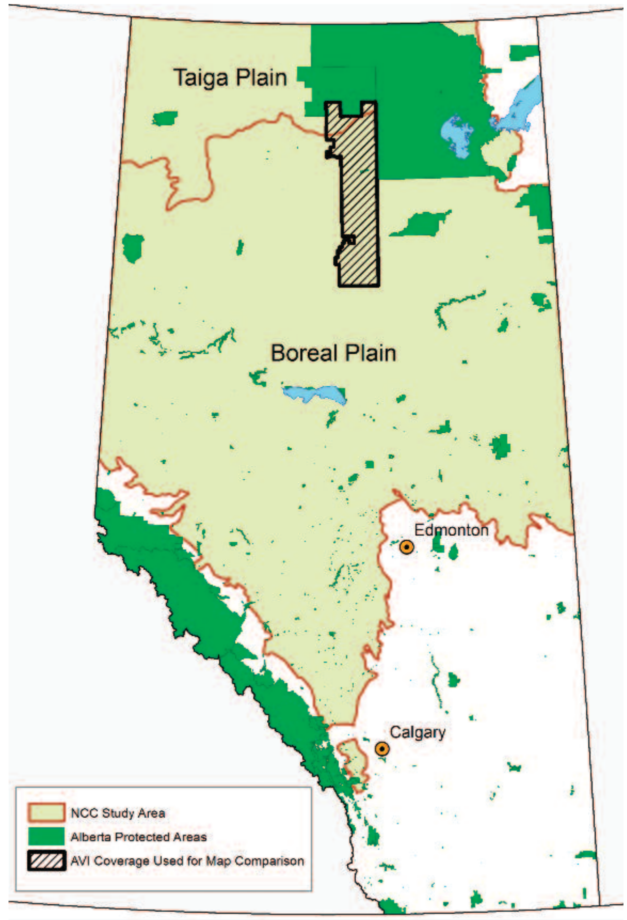
Available land-cover datasets

In the absence of Alberta-wide, available, detailed, multi-category mapping, a more generalized Canada-wide land-cover data set was considered (ca. 2000, EOSD) (http://www.geobase.ca/ geobase/en/data/land-cover/csc2000v/description.html). However, during the course of the project, the Alberta Biodiversity Monitoring Institute (ABMI) developed a land-cover map referred to as *ABMI Wall-to-Wall Land Cover* (LC) Map (ABMIw2wLCV2000v2.1) (http://www. abmi.ca/abmi/rawdata/geospatial/gisdownload.jsp?categoryId=2). ABMI made available a pre-release version of these data. In addition, Dr. G. Arturo Sanchez-Azofeifa of the University of Alberta kindly made available a land-cover dataset titled "AGCC." (The latter dataset was not used because it is not yet published and lacked metadata at the time of this project.)

Comparison of land-cover datasets

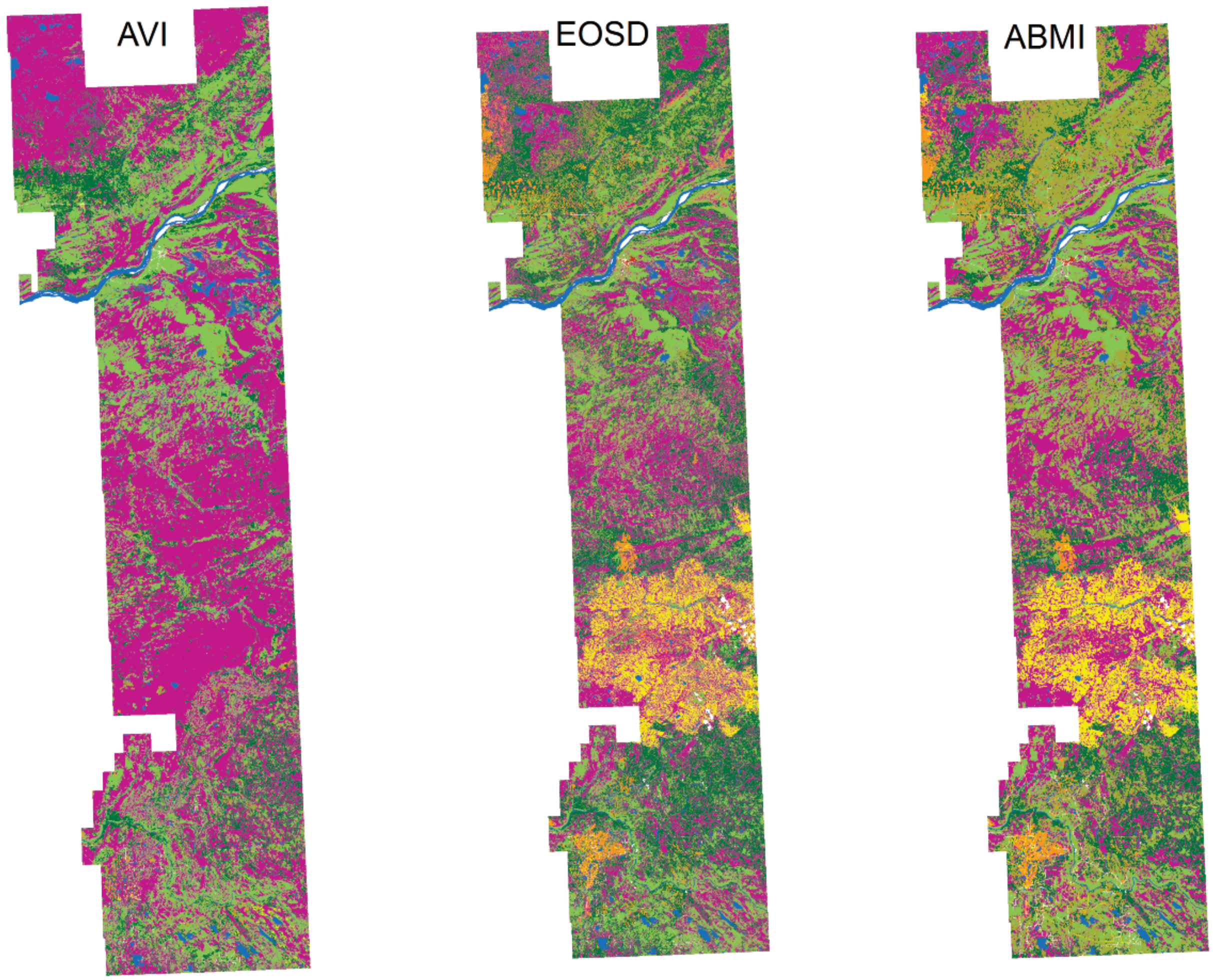
For the two publically available datasets noted above, we compared each of them to each other and to a widely-accepted forest inventory dataset available for a portion of the study area, titled Alberta Vegetation Inventory (AVI). For the comparisons, we used Map Comparison Kit software (http://www.riks.nl/mck/).

For these comparisons, a cross-section of northern Alberta was selected, which was also mapped by the Alberta Vegetation Inventory (AVI). The selected area (figure below) encompasses both the highlands and south-facing slopes of the Caribou Mountains in the north, through the lowlands of Peace River valley, south to the burned and developed mixed forests in the south.



Assessment area selected for land cover comparisons.

The land-cover classes used by the three land-cover datasets was generalized and standardized to the degree possible using the three classifications, and resulting three land-cover classifications were then subject to *Map Comparison Kit* software (http://www.riks.nl/mck/) which compared them with each other. The following figure shows the generalized, consistent land-cover classes that were the subject of the comparison.



Land cover for three land cover datasets (AVI, EOSD, ABMI).

- coniferous dense / coniferous open
- deciduous dense / deciduous open
- exposed land
- grassland
- mixedwood dense
- shrubland
- water
- wetland - treed/wetland - shrub/wetland - herb

The comparisons with the AVI dataset illustrated obvious differences. The Grassland, Shrubland and Mixedwood land-cover classes are much more expansive in the EOSD and ABMI land cover datasets than in the AVI dataset. The land-cover classes with the highest correlations between EOSD and AMBI datasets are Water, Conifer, Deciduous, Exposed Land and Wetland; and the lowest are Grassland and Shrubland (Mixedwood is also fairly low).

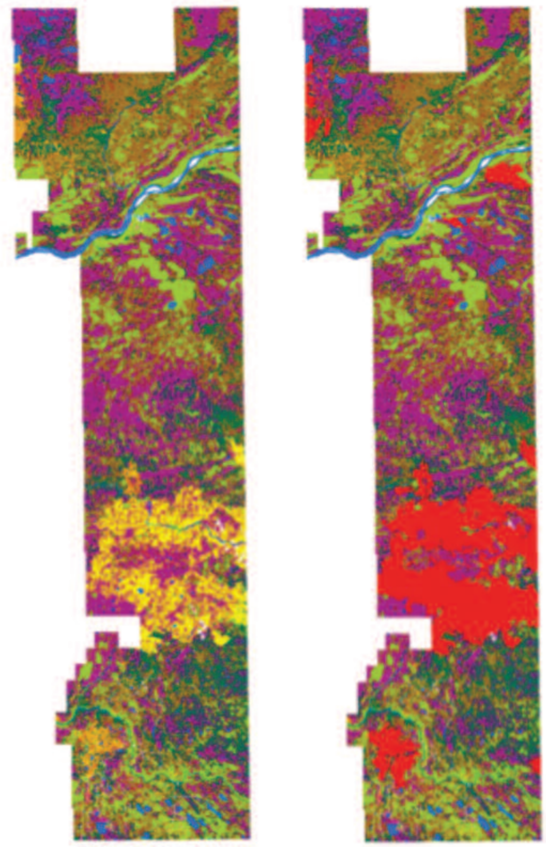
The reason for the low correlation for Grassland and Shrubland classes is likely the recent burn in the area. The National Forest Fire Database displays fairly recent fire polygons over much of this Grassland and Shrubland area (see next figure). How the different land-cover datasets treat fire has a major impact on how such areas are classified. As detailed as AVI is, it does not include many recent fires, likely due to the currency of data updates. Finally, the lack of correlation of Mixedwood cover classes is likely a result of how the different approaches define Mixedwood.

There is a high correlation of EOSD and ABMI datasets, for example, a greater than 90 percent correlation for Wetland, Water, and Grassland classes, an 80 to 90 percent correlation for the Deciduous class, and 70 to 80 percent for the Conifer class. (The Mixedwood and Exposed land classes are only +/- 50 percent correlated.)

The high correlations are attributable to the derivation of the ABMI dataset from the combination of two raster datasets, the Canadian Forest Service EOSD Land Cover dataset, and Agriculture and Agri-Food Canada Land Cover dataset. In turn, both datasets are derived from digital classifications of Landsat 5 and Landsat 7 ortho-images acquired ca. 2000, and both share the same land cover classes. In the development of the ABMI dataset, the EOSD data were given priority in tiles dominated by forest, and AAFC data in tiles dominated by farm lands. As well, in the development of the ABMI dataset hydrographic features from Government of Alberta (GoA) GIS data, such as water bodies, major rivers and wetlands, were 'burned in.' The same process was used for roads, railways, power lines and pipelines, based on GoA's access layer.

The comparison led us to conclude the ABMI dataset was the best-available land-cover data for Alberta, with the following observations:

- Wetlands, and especially peatlands, are ecological features not adequately distinguished or mapped;
- Forest disturbance results in areas in transitional classes. For examples: forest harvest areas are commonly classed as Deciduous whereas surrounding forests are Conifer; pipeline rights-of-way are often classed as grassland whereas adjacent areas are Conifer or Mixedwood.
- Fire suppression results in areas mapped in classes that would be different in its absence.



ABMI land cover (left) and ABMI land cover with recent burns in red (right).

As a consequence of these land cover classification issues, we decided not to use a land cover dataset for incorporation as the biotic component in the development of an abiotic-biotic Ecological Land Units coverage. Instead, we developed an abiotic "landscape facet" dataset that reflected the more enduring features of the study area and that also have ecological relevance. (Appendix C, below).

Appendix B. **Crosswalk Table of Surficial Geology Classes**

Final Category	Category 2	Category 3	Category 4	Labels
REMOVED	Anthropogenic	Anthropogenic	Anthropogenic	A
Bedrock	Bedrock	Bedrock	Bedrock	R
Glaciofluvial/Valley	Glaciofluvial / Valley	Glaciofluvial deposits	Glaciofluvial deposits	FG
			Ice-contacted deposits	FGI
			Glaciofluvial delta	GFD
			Undivided glaciofluvial deposits; Undivided glaciofluvial and glaciolacustrine complex	FG FLG
			Undivided Recent fluvial deposits	F
		Valley Complex	Colluvium; Undivided colluvial deposits	Cs CE
			Fluvial	F FP
			Alluvial; Alluvial fan (active and inactive forms); Alluvial fans and aprons; Alluvium; Coarse stream alluvium; Fine stream alluvium	A Ap
			Talus	
			Rockslide deposits; Landslide deposits	
			Valley train	
			Doughnut moraine;	MSD
			Eroded slope;	CE
			Eroded moraine;	ME
			Esker complex	
			Delta	
			Kame, kame moraine, small esker and related ice-contact deposits Kames, kame terraces and kame moraines	
			Lag gravel	
			Meltwater channel deposits	
			Outwash; Outwash gravel; Outwash plains; Outwash sand; Outwash sand and gravel; Pitted outwash; Pitted outwash deposits	
			Slump deposits	CS
			Thrust moraine	MT
			Undivided moraine	MU
			Stagnant ice moraine; undivided	MS-FG
Glaciolacustrine Coarse	Glaciolacustrine Coarse	Glaciolacustrine Coarse	Deltaic sediments	
			Ice-contact Lacustrine and Fluvial, undivided	
			Glaciolacustrine deposits - gravel, sand, silt and clay, local till	LGL
			Littoral and nearshore sediments; Littoral and nearshore sediments (glaciolacustrine)	LGL LL
			Undivided Recent lacustrine deposits	L

Final Category	Category 2	Category 3	Category 4	Labels
Glaciolacustrine Fine	Glaciolacutrine Fine	Glaciolacutrine Fine	Glaciolacustrine deposits - Silt, clay and sand; Glaciolacustrine deposits: Off-shore (distal)	LG
			Lacustrine Deposits - clay, silt and sand laminated in places	
			Ice-contacted Lacustrine	LGI
REMOVED	Lake	Lake	Lake	L
		Glacier	Glacier	
Moraine	Moraine Plain	Moraine Plain	Moraine; Ground moraine; Moraine draped; Fluted moraine; Undifferentiated moraine	M MF M
			Drumlinoid moraine	
			Moderately leached till, Continental provenance; Slightly leached till, Continental provenance	
	Moraine Ridged/ Hummocky	Moraine Hummocky	Moraine	Mh
			Stagnant ice moraine Ice-thrust moraine	MS MT
		Moraine Ridged	Fluted moraine; Ridged moraine; Stagnant ice moraine; Ice-Thrust moraine; Ridged End moraine;	M
	Moraine Undulating	Moraine Undulating	Moraine; Undivided moraine	M M
			Stagnant ice moraine; Ice-thrust moraine; Drumlinoid moraine;	
		Moraine Veneer	Moraine; Ice-thrust moraine	M
			Deeply leached till, Cordilleran provenance; Slightly leached till, Cordilleran provenance; Schist till, Cordilleran provenance; Ground moraine (locally derived); Moraine-colluvium undifferentiated	
Organic	Organic	Organic	Organic - woody, fibrous and mucky peat; Bog, fen: peats developed from sedges and mosses	O OB OF
Sand	Eolian Plain	Eolian Plain	Eolian; Undivided eolian deposits; Cryoturbated Eolian (loess) and Fluvial	E
	Sand Hills	Sand Hills	Eolian; Aeolian sand, dunes	E

Mixedwood boreal forest north of Ft. McMurray. Global Forest Watch Canada

Table 15. Landscape facets used to generate Ecological Land Units

Landscape Facet	Code
Steep slope/cliff (cool)	STC
Steep slope/cliff (warm)	STW
Upper gentle slopes	UGS
Upper depression	UPD
Upper flats	UPF
Mid slope (cool)	SDC
Mid slope (warm)	SDW
Lower gentle slopes	LGS
Lower depressions	LWD
Lower flats	LWF

Appendix C. **Analysis of Landscape Facets**

Based on the following analysis, ten landscape facets that were considered to reflect the major variation in ecological processes on northern Alberta landscapes. They combine terrain attributes of slope, aspect, landscape position, curvature, and wetness index (Table 15; see Figures 19, 20, above).

Most terrain attributes can be deduced from digital elevation models (DEM), using a variety of GIS tools. Various methods are available that use these attributes to model spatial landform or ecological units, such as landscape facets. Three software tools were used in this analysis. The primary software used was the *LandMapR©* suite of programs, here referred to as *LandMapR*, developed by Dr. Robert MacMillan of LandMapper Environmental Solutions Inc. *LandMapR* processes digital elevation data (DEMs) to automatically extract a variety of user-defined hydrological, ecological and landform spatial entities (see *LandMapR* Users' Manual). The program offers a heuristic, rule-based, classification approach. Fuzzy logic rules are applied to convert absolute terrain measures into relative concepts such as very steep, high wetness, near peak/divide, etc. These conceptual attributes are then formulated into definitions of landform classes.

The second software used was a batch shell utility titled *Process DEM data input and outputs for LandMapR Utility v2.0*, here referred to as the *Batch LandMapR Utility*, developed by Dr. Thomas Mayr of the National Soil Research Institute at Cranfield University, UK. This was designed to batch-process the *LandMapR* suite of programs for a set of DEM watershed subunits. In addition to its ability to batch-process the *LandMapR* programs, it contributed in two other ways. First, it automatically subsetted a DEM by a predefined watershed vector file and converted it to the file format required by *Land MapR*. Second, it automatically calculated the upslope area thresholds required by *LandMapR*, based on app - roximating the length of blue-line hydrology within the watershed unit.

The third software was the *Hydrologic Modeling System* (HEC-HMS) extension for ArcGIS 10 version 5.0 developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC). This extension was used to apply terrain re-conditioning to the SRTM data and to delineate watershed units used to subset the SRTM data for subsequent *LandMapR* processing.

DEM Preprocessing

The elevation data used were derived from the CGAIR-CSI SRTM 3-arc-second digital elevation model (DEM). The SRTM data is provided globally in 5-by-5-degree tiles extending north to the 60th parallel. The 3-arc-second resolution translates to approximately 50x90 metres in the study area, for which 8 tiles were mosaicked and re-projected on to a Transverse Mercator projection with a cell size of 50 metres.

Local "noise" occurs in all DEMs, and can mask features of interest and lead to erroneous classification. SRTM data can also contain stripping noise at regular wavelengths, which can produce errors in DEM derivatives. Therefore, the SRTM data were smoothed using 3x3 and 5x5 successive mean filters to reduce short-range signal noise and minimize the effects of artificial regular scan errors.

Local hydrologic features such as river channels are not very well captured by the medium resolution of SRTM data. Smoothing filters were applied, which have the unwanted effect of smoothing out some small channels. To improve the hydrological accuracy of the SRTM data, it was re-conditioned to force or "burn in" the blue line hydrology features of the Natural Resources Canada 1:50,000 National Hydrologic Network (www.GeoBase.ca). This was accomplished using the terrain re-conditioning tool from the HEC-HMS extension. which works by lowering the elevation of the cells by a user-specified amount along linear stream features. It does this in two separate ways, but first a sharp drop at the stream cell and then with a gradual (smooth) drop in a specified neighbourhood using the AGREE method. In this case, a neighbourhood of five cells (250m) was used with a smooth drop of 3m from the overbank to the stream. A sharp drop of 1 metre was applied to the stream cells. A 3x3 mean filter was applied to the re-conditioned DEM to smooth the transition along the edge of the re-conditioned stream cells.

DEM Preparation for Landscape Facet Classification

The *LandMapR* programs have a maximum processing size of approximately 6 million square cell units, which equals a square DEM grid dimension of approximately 2500x2500 pixels. Inputs larger than this can cause errors related to insufficient memory. This means that a DEM with a 50m resolution across the study area (460,000 km^2) must be divided into at least 30 equal-size subunits. *LandMapR* then works by deriving terrain attributes calculated from local catchments based on an upslope area threshold.

Therefore, the most logical division of the landscape would be an appropriately scaled watershed unit. With no watershed data available at the scale needed, watersheds were instead delineated directly from the SRTM data using hydrologic processing tools from the HEC-HMS extension. An adequate scale of watersheds was determined, by trial and error, by setting an appropriate stream accumulation threshold in the 'stream definition' calculation. A larger threshold value results in a larger catchment size. To limit the number of watershed units, watershed units less than 1000 ha were merged with adjacent units. The final number of watershed units was 195, ranging in size from about 1,000 to 6,500 ha.

The *Batch LandMapR Utility* was used to subset the SRTM data into the delineated watershed units. One of the primary functions of this utility is to automatically subset or clip an input DEM by a watershed-boundary vector file and convert it to the DBF file format required by LandMapR. Once the SRTM data was subset into watershed units and converted to DBF format they were then ready for the first processing stage of *LandMapR*.

LandMapR Processing

HYDROLOGIC FLOW

LandMapR© has four C++ programs that extract spatial entities, three of which were used to classify landscape facets. The programs (FlowMapR, FormMapR, and FacetMapR) perform three distinct steps. FlowMapR is the first step, and computes flow topology from an input DEM to simulate surface water flow in both the down-slope and up-slope directions (MacMillan 2003). It does this by applying a succession of hydrologic flow models beginning with a pit (sink) removal procedure. The default threshold values were used for the initial pit removal procedures. The initial pit removal step significantly improves processing time by eliminating the many smaller pits (sinks) below the threshold. Flow MapR then automatically executes each watershed unit from the *Batch LandMapR Utility*.

TERRAIN DERIVATIVES

FormMapR is the second step. *The FormMapR component computes a number of terrain derivatives that describe surface form, orientation, wetness index, relative and absolute relief and relative and absolute slope lengths. These terrain derivatives are used as the primary (or sole) inputs to the subsequent FacetMapR program for classifying landforms or ecological spatial entities* (MacMillan 2003; see *LandMapR* User Manual for details of calculations and outputs).

The threshold values for upslope and down-slope flow accumulations have a large impact on the subsequent calculations of absolute and relative relief and slope position. These thresholds identify which grid cells belong to channels (for down-slope flow) and ridges (for upslope flow). These thresholds must represent true channels and ridges in an area, based on the classification objectives. A recommended method is to select a down-slope area threshold that, when visualized, resembles that of a mapped blue-line network. The threshold for each of the 195 watershed subunits against a blue-line network was done using the *Batch LandMapR Utility*, which automatically calculated this threshold based on a mapped blue-line network, specifically the Natural Resources Canada 1:50,000 National Hydrologic Network. This is performed by, first, clipping the blue-line network to the watershed unit and calculating its total length. Next, based on an initial threshold value, it converts the down-slope flow to a vector line (simulated line network) and calculates its total length. This length is then compared with the mapped blue-line length and iteratively adjusted until the length is within a 1% difference. The *Batch LandMapR Utility* thus executed the FormMapR program for each watershed subunit.

LANDSCAPE FACET CLASSIFICATION

The final step in landscape-facet classification was performed using FacetMapR. *FacetMapR is a custom program written expressly to facilitate automated classification of landform, ecological or soil spatial entities using heuristic fuzzy logic rule bases* (MacMillan 2003). FacetMapR is driven by two fuzzy rule files defined by the user that ultimately determine the likelihood or probability that a grid cell belongs to a particular landform or ecological spatial entity.

The first fuzzy rule files uses the DEM derivatives generated by FormMapR to define "fuzzy attributes," which are rules that express landform attributes in fuzzy semantic terms, such as the likelihood that a slope value is considered to be very steep, mid sloped, gently sloped, flat, etc. The DEM derivatives are converted into a continuous scale from 0-100 representing the likelihood that a cell belongs to a particular attribute. The fuzzy attributes that were defined for this study, which are stored in a DBF file format, are presented in Table 16.

The "MODEL_NO" field tells the program which fuzzy model to use to rescale the raw input values. Three of the five distinct model types defined by Burrough (1989) to convert terrain derivatives into fuzzy landform attributes are used to classify fuzzy attributes. The fields B (central concept) and D (dispersion index) are key parameters used by the fuzzy model that define the value above or below which is fully likely (100%) and half as likely (50%), respectively, of belonging to the fuzzy

Table 16. Fuzzy attributes.

SORTORDER	FILE_IN	ATTR_IN	CLASS_OUT	MODEL_NO	B	B_LOW	B_HI	B1	B2	D
1	formfile	PROF	CONVEX_D	4	2.0	0.0	0.0	1.0	0.0	1.0
2	formfile	PROF	CONCAVE_D	5	-2.0	0.0	0.0	0.0	-1.0	1.0
3	formfile	PROF	PLANAR_D	1	0.0	0.0	0.0	-0.5	0.5	0.5
4	formfile	PLAN	CONVEX_A	4	2.0	0.0	0.0	1.0	0.0	1.0
5	formfile	PLAN	CONCAVE_A	5	-2.0	0.0	0.0	0.0	-1.0	1.0
6	formfile	PLAN	PLANAR_A	1	0.0	0.0	0.0	-0.5	0.5	0.5
7	formfile	QWETI	HIGH_WI	4	12.8	0.0	0.0	10.3	0.0	2.5
8	formfile	QWETI	LOW_WI	5	8.5	0.0	0.0	0.0	10.0	1.5
9	formfile	SLOPE	NEAR_LEVEL	5	3.0	0.0	0.0	0.0	5.0	2.0
10	formfile	SLOPE	GEN_SLOPE	1	7.0	7.0	7.0	4.0	10.0	3.0
11	formfile	SLOPE	MID_SLOPE	1	18.0	18.0	18.0	8.0	28.0	10.0
12	formfile	SLOPE	V_STEEP	4	30.0	0.0	0.0	28.0	0.0	2.0
13	formfile	ASPECT	NE_ASP	1	45.0	45.0	45.0	315.0	135.0	45.0
14	formfile	ASPECT	SW_ASP	1	225.0	225.0	225.0	135.0	315.0	45.0
15	relzfile	PCTZ2ST	VNR_DIV	4	95.0	0.0	0.0	90.0	0.0	5.0
16	relzfile	PCTZ2ST	NEAR_DIV	1	80.0	0.0	0.0	70.0	90.0	10.0
17	relzfile	PCTZ2ST	NEAR_HALF	1	50.0	50.0	50.0	30.0	70.0	20.0
18	relzfile	PCTZ2ST	NEAR_CHAN	1	20.0	20.0	20.0	10.0	30.0	10.0
19	relzfile	PCTZ2ST	VNR_CHAN	5	5.0	0.0	0.0	0.0	10.0	5.0
20	relzfile	PCTZ2PIT	NEAR_PEAK	4	90.0	0.0	0.0	75.0	0.0	15.0
21	relzfile	PCTZ2PIT	NEAR_MID	1	50.0	50.0	50.0	25.0	75.0	25.0
22	relzfile	PCTZ2PIT	NEAR_PIT	5	5.0	0.0	0.0	0.0	10.0	5.0
23	relzfile	Z2PIT	HI_ABOVE	4	2.0	0.0	0.0	1.0	0.0	1.0

attribute. For instance, for the "NEAR_LEVEL" class, using model type 5, slope gradient values less than or equal to the central concept (B) 3.0 fully meet the criteria for being "NEAR_LEVEL" (likelihood = 100). The dispersion index (D) of 2.0 is added to B (in this case 5.0) to indicate that slope gradient value at which it is half as likely to be "NEAR_LEVEL" (likelihood = 50). Refer to the *LandMapR* User Manual (MacMillan 2003) for details on fuzzy models and parameter definitions.

Expert judgment is used to select appropriate values for B and D and the values used in this study were based on the standard fuzzy attribute rules for use by the *LandMapR* LSM procedures. These were modified where appropriate for northern Alberta to generate the attributes required for the landscape-facet classes. For instance, slope values were based on previous NCC slope classes (Notzl *et al.* 2013), and some values were modified based on various sample areas to improve landscape-facet results.

Foothills stream, Swan Hills. Global Forest Watch Canada

The second fuzzy rule file makes use of one or more fuzzy attributes to determine the likelihood that a cell belongs to a "fuzzy class" (i.e., landscape facet). The fuzzy attributes for each fuzzy class have a weighted sum of 100, such that each grid cell is given a scaled value from 0-100 representing the likelihood of it belonging to that fuzzy class. A particular grid cell is then assigned to the fuzzy class that has the highest value or likelihood. This procedure has been documented by MacMillan *et al*. (2000).

The fuzzy rule file used for this study is presented in Table 17. The "F_NAME" field is a coded value for each landscape facet. The "FUZATTR" field is the list of fuzzy attributes that define the landscape facet class. Each fuzzy attribute is given weighted value in the "ATTRWT" field for a combined sum of 100. The concept of how these fuzzy rules interact to define a class is provided in the *LandMapR* User Manual (MacMillan 2003), excerpted below:

…if the value for the fuzzy attribute (FUZATTR) is multiplied by the weighting factor for that attribute (ATTRWT) and a weighted sum is computed for all fuzzy attributes used to define a class, one arrives at an overall likelihood value that a defined class will occur at given cell with a given set of attributes. The defined class with the highest likelihood of occurring at a particular site is selected as being the most likely correct classification for that site… Landform classes may be defined as having overlapping characteristics such that two or more elements may both be described as relatively steep but differentiated on the basis of another attribute such as being relatively convex or relatively concave. An added advantage is the ability to manage and resolve situations where the value of one or more input variables used to define a class falls just outside what would otherwise be a class boundary using a classed approach and Boolean logic…

Table 17. Fuzzy rule file

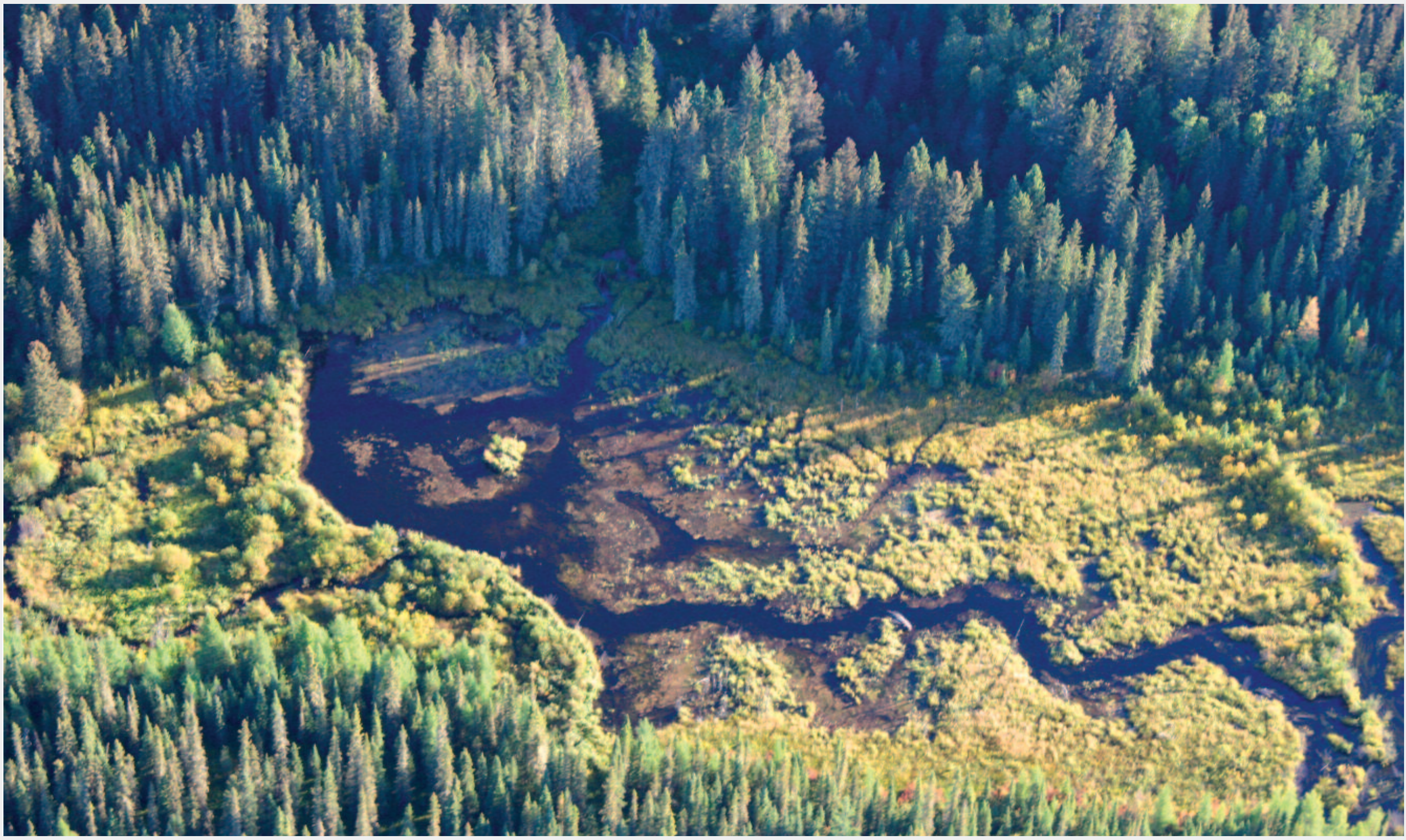
F_NAME	FUZATTR	ATTRWT	FACET_NO	F_CODE
STC	V_STEEP	80	1	41
STC	NE_ASP	20	1	41
STW	V_STEEP	80	2	42
STW	SW_ASP	20	2	42
UGS	NEAR_PEAK	30	3	31
UGS	NEAR_DIV	20	3	31
UGS	LOW_WI	10	3	31
UGS	GEN_SLOPE	40	3	31
UPD	NEAR_PEAK	30	4	33
UPD	NEAR_DIV	20	4	33
UPD	NEAR_LEVEL	30	4	33
UPD	HIGH_WI	20	4	33
UPF	NEAR_PEAK	30	5	34
UPF	NEAR_DIV	20	5	34
UPF	NEAR_LEVEL	30	5	34
UPF	PLANAR_D	10	5	34
UPF	PLANAR_A	5	5	34
UPF	LOW_WI	5	5	34
SDC	MID_SLOPE	80	6	21
SDC	NE_ASP	20	6	21
SDW	MID_SLOPE	80	7	22
SDW	SW_ASP	20	7	22
LGS	NEAR_CHAN	30	8	13
LGS	NEAR_PIT	20	8	13
LGS	GEN_SLOPE	40	8	13
LGS	HIGH_WI	10	8	13
LWD	VNR_CHAN	40	9	11
LWD	NEAR_PIT	20	9	11
LWD	NEAR_LEVEL	20	9	11
LWD	HIGH_WI	20	9	11
LWF	NEAR_CHAN	30	10	12
LWF	NEAR_PIT	20	10	12
LWF	NEAR_LEVEL	30	10	12
LWF	PLANAR_D	10	10	12
LWF	PLANAR_A	5	10	12
LWF	HIGH_WI	5	10	12

FacetMapR was not incorporated into the Batch *LandMapR Utility*, so each of the 195 watershed subunits was processed individually using the original *LandMapR* suite of programs. The outputs of FacetMapR are in DBF file format, so the max class value for each output was converted to an ESRI Float grid. The grids were converted to an integer value, mosaicked, and clipped to the study area.

LANDSCAPE FACET POST-PROCESSING

A series of steps were performed to generalize and smooth the initial landscape facets. Two successive majority filters were performed in ArcMap 10 to smooth the class edges and generally reduce pixel noise. The Majority Filter tool replaces cells based on the majority value in their contiguous neighbourhoods (ArcGIS 10 Help).

The result was further cleaned in ArcMap 10 by eliminating all cell groups less than or equal to 3. This was done by applying a 'Region Group' and computing a 'Lookup grid' on the cell count of each group. Groups of 3 or less cells were set to null using raster calculator and then applying the 'Nibble' tool to replace the no data cells with the values of their nearest neighbour. Figures 55 and 56 illustrate the landscape facets before and after the cleaning procedure.



Beaver flood meadow marsh and thickets. Global Forest Watch Canada

Outline of procedures used in developing Landscape Facet dataset

1. **Pre-process SRTM DEM**
    - **a.** Mosaic Hole-filled seamless SRTM data V4 (Jarvis *et al.*, 2008)
        - *i.* 8 - 5x5 degree tiles from 60°N and 125°W to 50°N and 105°W
    - **b**. Project DEM to Transverse Mercator projection resampled to 50m cell size
    - **c**. Smooth DEM using 3x3 and 5x5 successive mean filters
    - **d**. Perform hydrologic reconditioning of the DEM using blue line hydrology (NHN)
        - *i.* Merge NHN data intersecting study area
        - *ii.* Remove NLFLOW features that are isolated waterbodies or that were an alternate path with a direction of -1
        - *iii.* ("ISOLATED" = 1 OR "TYPE" <> 2) AND ("DIRECTION" <> -1 OR "PRIORITY" = 1)
        - *iv.* Apply HEC-GeoHMS terrain reconditioning tool to lower the elevation of the stream cell and gradually lower the 5 cells neighboring the stream
            1. Stream buffer = 5 cells
            2. Smooth drop = 3 metres (neighboring cells)
            3. Sharp drop = 1 metre (stream cells)
    - **e**. Smooth reconditioned DEM with 3x3 mean filter

2. **Delineate catchment units for batch *LandMapR* processing**
    - **a**. Apply HEC-GeoHMS v5.0 terrain preprocessing functions to generate catchments that are smaller than the recommended processing size of *LandMapR* software
        - *i.* Create depressionless dem grid (fill sinks) from reconditioned SRTM DEM
        - *ii.* Create Flow Direction grid from filled DEM
        - *iii.* Create Flow accumulation grid from Flow direction grid
        - *iv.* Create stream definition grid from flow accumulation grid
            1. Via trial and error, set stream accumulation threshold values to delineate catchments of adequate scale
        - *v*. Create catchment grid from stream definition
        - *vi*. Convert catchment grid to polygon

3. **Run the batch script "Process DEM data input and outputs for *LandMapR* Utility v2.0" on each catchment unit to create the outputs necessary for FacetMapR classification (landscape facets)**
   - **a**. Pre-process DEM to batch clip each catchment unit (buffered by 2km) as a separate DEM and converts to dbf file for use in FlowMapR
   - **b**. Batch execute *LandMapR* tool FlowMapR for each catchment unit using default pit removal thresholds
     - *i.* The FlowMapR component processes an input DEM to compute flow topology for simulated surface water flow in both the down-slope and up-slope directions (MacMillan 2003)
   - **c.** Calculate the upslope area threshold for use in FormMapR for each catchment
     - *i.* The upslope area threshold is automatically estimated to approximate the length of blue line hydrology (NHN) within the catchment
       1. NHN hydrology data is clipped to the catchment and the total length is calculated
       2. The upslope area output from FlowMapR is converted to a line vector using an initial threshold value (1000) and the resulting length is summed
       3. This length is compared with the NHN length and iteratively adjusted until the length is within 1% difference.

4. **Define Landscape Facet classes using *LandMapR* tool: FacetMapR**
   - **d**. Select a set of ecologically relevant landform classes based on previous NCC blueprints and default *LandMapR* classification rules
   - **e**. Construct and modify rule files for use in FacetMapR
     - *i.* Use DEM derivatives generated by FormMapR to define "fuzzy attributes", which are rules that express landform attributes in terms of fuzzy semantic constructs, such as the likelihood that a slope value is considered to be very steep, mid sloped, gently sloped, flat, etc. The DEM derivatives are converted into a continuous scale from 0-100 representing the likelihood that a cell belongs to a particular attribute. Fuzzy attributes are created in a DBF attribute rule file. The Model_no field tells the program which fuzzy model (defined by Burrough (1989)) to use to rescale the raw input values. The fields B and D (dispersion index) are key parameters used by the fuzzy model that define the value above or below which it is 100 percent likely and ½ as likely, respectively, of belonging to the fuzzy attribute.
     - *ii.* Use 1 or more fuzzy attributes to define the likelihood that a cell belongs to a fuzzy class (ie. landscape facet). The fuzzy attributes for each fuzzy class have a weighted sum of 100, such that each cell is given a scaled value from 0-100 representing the likelihood of it belonging to that fuzzy class. A particular cell is then assigned to the fuzzy class that has the highest value or likelihood.
   - **f.** Execute FacetMapR using the fuzzy rule files for each buffered catchment DEM
   - **g**. Convert FacetMapR outputs to ESRI integer grid clipped to catchment boundary
     - *i.* Use GridReadWriteUtility.exe to convert DBF FacetMapR output field 'Max_Value' to ESRI Float grid
     - *ii.* Batch convert ESRI Float grid to ESRI integer grid
     - *iii.* Batch extract by mask each Integer grid to its catchment boundary
   - **h**. Mosaic FacetMapR clipped integer grids and clip to study area
   - **i.** Apply 2 successive majority filters to smooth the landscape facets
     - *i.* Replacement threshold (number of contiguous (spatially connected) cells that must be of the same value before a replacement will occur) = MAJORITY
       Neighbors (number of neighboring cells to use in the kernel of the filter) = EIGHT
     - *ii.* Replacement threshold = HALF
       Neighbors = FOUR
   - **j**. Further clean output by replacing all landscape facet classes with 3 or less cells
     - *i.* Apply a region group and compute a lookup grid on the cell count of each group
     - *ii.* Set to null all groups of 3 or less cells
     - *iii.* Use ESRI 'nibble' tool to replaces the no data cells with the values of the nearest neighbors of the original grid.

Table 18. Fuzzy logic attributes used for developing Landscape Facets.

DEM derivative	Fuzzy Attribute Class	Fuzzy Model Type	50% likelihood (B1)	100% likelihood (B)	50% likelihood (B2)	Dispersion Index (D)
Profile Curvature	Convex (down)	4	1.0	2.0	0.0	1.0
Profile Curvature	Concave (down)	5	0.0	-2.0	-1.0	1.0
Profile Curvature	Planar (down)	1	-0.5	0.0	0.5	0.5
Plan Curvature	Convex (across)	4	1.0	2.0	0.0	1.0
Plan Curvature	Concave (across)	5	0.0	-2.0	-1.0	1.0
Plan Curvature	Planar (across)	1	-0.5	0.0	0.5	0.5
Wetness Index	High Wetness	4	2.5	5.0	0.0	2.5
Wetness Index	Low Wetness	5	0.0	0.7	2.2	1.5
Slope gradient	Near Level	5	0.0	3.0	5.0	2.0
Slope gradient	Gentle slope	1	4.0	7.0	10.0	3.0
Slope gradient	Medium slope	1	8.0	18.0	28.0	10.0
Slope gradient	Steep	4	28.0	30.0	0.0	2.0
Aspect	Northeast	1	315.0	45.0	135.0	45.0
Aspect	Southwest	1	135.0	225.0	315.0	45.0
% distance from ridge to stream	Near divide	4	75.0	90.0	0.0	15.0
% distance from ridge to stream	Near half	1	25.0	50.0	75.0	25.0
% distance from ridge to stream	Near channel	5	0.0	10.0	25.0	15.0
% distance from peak to pit	Near peak	4	75.0	90.0	0.0	15.0
% distance from peak to pit	Near middle	1	25.0	50.0	75.0	25.0
% distance from peak to pit	Near pit	5	0.0	5.0	10.0	5.0
Distance from peak to pit	High above	4	1.0	2.0	0.0	1.0

Landform facet	Fuzzy Attribute Class	Fuzzy Attribute weight	Facet number
Lower gentle slopes	Near channel	30	8
	Near pit	20	8
	Gentle slope	40	8
	High Wetness	10	8

Landscape Facets before and after the cleaning procedure

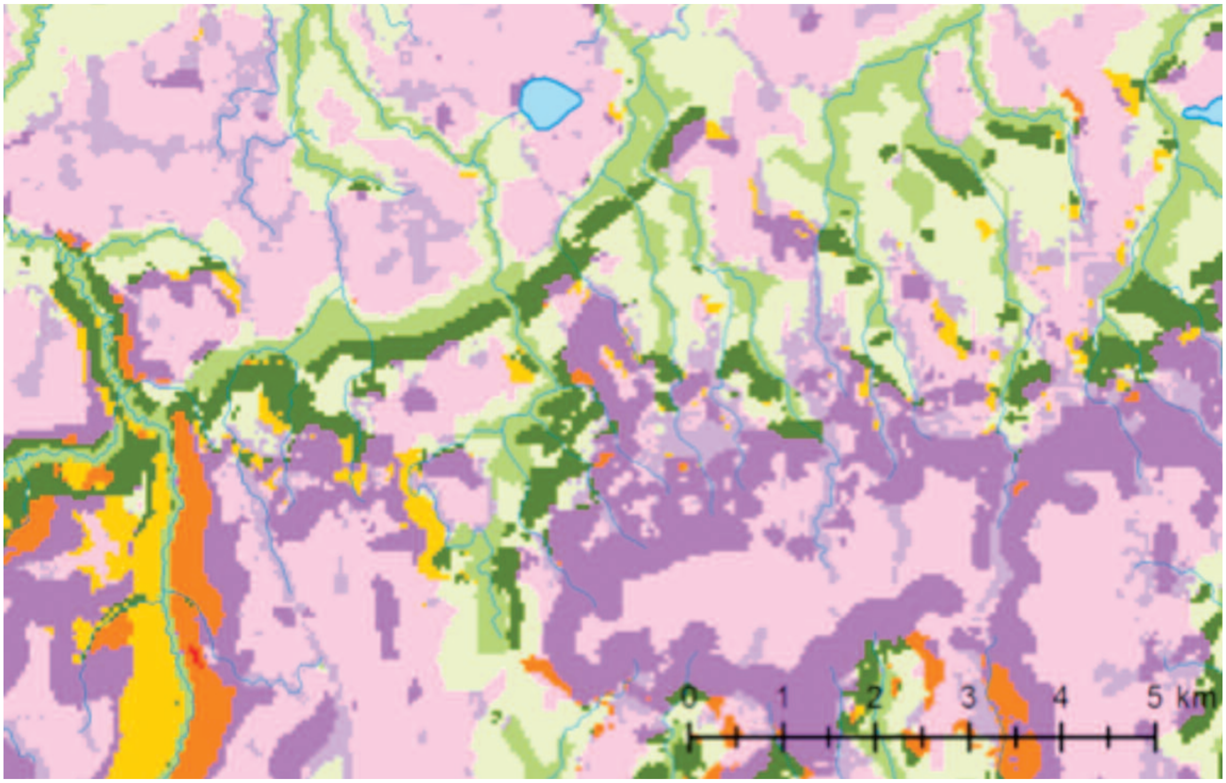


Figure 55. Landscape Facets: sample area before cleaning

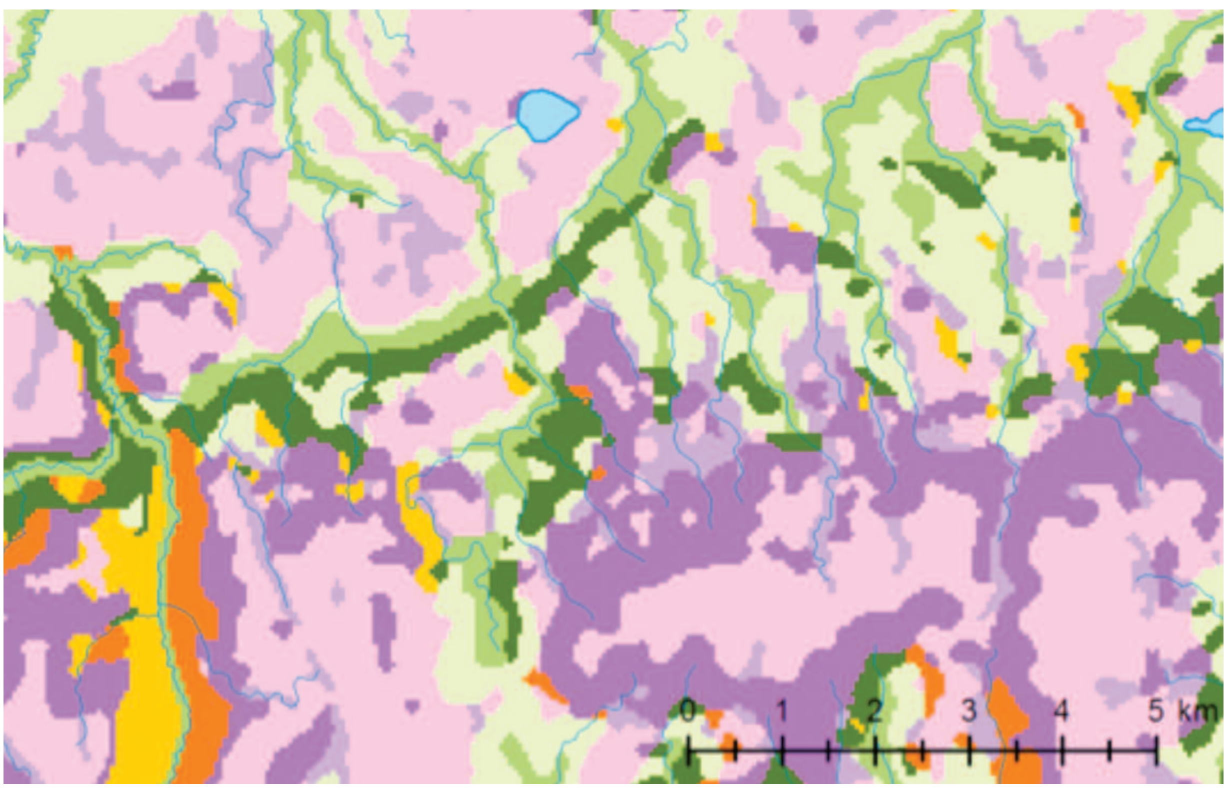


Figure 56. Landscape Facets: same sample area after cleaning

The *Northern Alberta Conservation Atlas* is a report of a partnership from 2010 to 2013 led by the Nature Conservancy of Canada (NCC).

The goal was to assemble, map and share the highest-quality, best-available information on the geography and biological features of northern Alberta, to support superior resource stewardship and conservation, and to share project results widely. This report summarizes map-based information that describes the natural geographic variability of northern Alberta.

Northern Alberta covers 460,000 square kilometres, larger than Newfoundland and Labrador combined. It supports major farming, ranching, oil and gas, and forestry industries, but remains a relatively undeveloped landmass. The datasets assembled and mapped for northern Alberta include first-ever mapping of many features, including ecological land units and areas of special conservation concern, and updates of mappng of wildlife, landform, wetlands, geology, protected areas and other conservation lands.

The link to download datasets is at www.geodiscover.alberta.ca <http://www.geodiscover.alberta.ca>, search for 'Northern Alberta Conservation Atlas'.

Athabasca River north of Ft. McMurray. Global Forest Watch Canada
Western Grebe. Ann Brokelman
Steep incised valley, Athabasca region. Nature Conservancy of Canada

Nature Conservancy Canada

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