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GEOLOGICAL SURVEY OF CANADA
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Historical land-use changes and lichen-rich ecosites near Fox Creek, Alberta

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Executive Summary

This report focuses on changes in land use by comparing major land cover between the 1950s and 2020s in areas near Fox Creek, Alberta. The Study Watershed, covering 706 square kilometers, is located within the southern portion of the Smoky/Wapiti sub-watershed of northwestern Alberta, southwest of Fox Creek. The Local Study Area covers an area of 90 square kilometers in the center of the Study Watershed.

Historical aerial photos from Alberta Biodiversity Monitoring Institute (ABMI) taken in the 1950s were processed and analyzed. Three main land use classes were identified: Open Water, Wetland, and Forest. The Wetland class was further divided into the Fen and Swamp sub-classes. The Forest class was divided into sub-classes of Broadleaf and Conifer. The current (2020s) land cover was classified into seven main classes and fourteen sub-classes by referencing the 2021 Crop Inventory (CI), 2019 Human Footprint Inventory (HFI), and 2021 Wetland Inventory (WI).

In the Study Watershed, Forest was the dominant class covering 617 km^2 (87%) in the 1950s. By the 2020s, Forest only covered 397 km^2 (56%) of the Study Watershed, representing the single, most significant decline of 220 km^2 or 36% after 70 years. Cutblock accounts for 184 km^2 or 84% of the total lost Forest cover. Industry and Other Disturbances account for 12 km^2 (5%) and 23 km^2 (10%) of the Study Watershed, respectively. By contrast, Open Water and Wetland cover were almost unchanged between the 1950s and 2020s, with approximately 11 km^2 and 90 km^2, respectively.

In the Local Study Area, Forest was the dominant class, covering 84 km^2 or 93% of the area. It dropped to only 47 km^2 or 52% by the 2020s. Open Water and Wetland declined by 22% and 20% between the 1950s and 2020s. Cutblock gained the most, accounting for 93% of the loss of Forest, Wetland, and Open Water. Other Disturbances and Industry account for 8% and 3% of the land use change, respectively.

There are 3934 km (6 km/km^2) of linear features in the Study Watershed and 448 km (5 km/km^2) in the Local Study Area. Seismic Line dominates the Study Watershed (61%) and Local Study Area (63%). Pipeline is the second most abundant linear feature, accounting for 23% of all linear features in the Study Watershed and 22% in the Local Study Area. Various roads account for 14% and 15% of the Study Watershed and Local Study Area, respectively. By contrast, Railway is the least prevalent linear feature, accounting for 1% of the Study Watershed, and is absent in the Local Study Area.

A caribou-preferred lichen ecosite phase map was created for the study areas, including the overlapping area with the Little Smoky Caribou Range to the west of the Study Watershed. Treed bog (k1) is the most abundant site type across the study areas, followed by shrubby bog (k2). K1 and k2 combined cover about 20% of the overlapping Little Smoky Caribou Range, significantly lower than the 65% threshold of undisturbed habitat in order for caribou population to have a 60% likelihood of maintaining self-sustaining levels outlined in the federal boreal caribou recovery strategy. Ecosite phases h1 and b1 each account for a fraction of the study areas, while ecosite phase b2 is likely not a preferred caribou habitat due to the presence of deciduous shrubs.

Table of Contents

List of Tables

List of Figures

1. Background

The Geological Survey of Canada of the Lands and Minerals Sector of Natural Resources Canada (NRCan) is carrying out a project on land cover change in the Fox Creek area in west-central Alberta. The study area extends over 700 km^2 and is located just southwest of the Town of Fox Creek. The initial objective of the project was to study the potential impacts of oil and gas activities on shallow groundwater. In late 2019, however, different sectors within NRCan identified the industrial area of Fox Creek as a region of interest for developing regional cumulative effects evaluation methods in support of new impact assessment legislation. Therefore, the project's scope was expanded to include the long-term assessment of changes in vegetation, forests, wetlands, and the landscape.

To meet the study objective, NRCan approached the project team from NAIT and the University of Saskatchewan to compile land cover maps for evaluating the evolution of the landscape in the Fox Creek area over the past 50 years using remote sensing data (including aerial archive photos). This project team is very familiar with the west-central Alberta region and has expertise in wetlands, forests, vegetation, and remote sensing.

This information is of utmost importance, as forest disturbances and fragmentation, including the creation of oil and gas well pads and linear features, such as seismic lines, access roads, and pipelines, affect all the different components of the hydrologic cycle (i.e., runoff, infiltration, evapotranspiration) and wildlife. For example, linear features are a leading cause of the population decline of woodland caribou (*Rangifer tarandus caribou*) across the boreal region (Latham et al. 2011, DeMars and Boutin 2018). Seismic lines and roads are preferred travel corridors for predators, thus exposing caribou (an endangered species) to increasing predatory pressure. Networks of roads can also significantly alter flow patterns, affect vegetation growth, and ultimately change the regional water balance and hydrologic cycle.

The report is divided into two parts: historical land use change (referred to as the "Land Use" report hereinafter) and lichen-rich ecosites (referred to as the "Lichen" report hereinafter).

The Land Use report deliverables include (1) two land cover maps (one from the 1950s and one from the 2020s) and (2) change matrices reported in area (ha) and proportion (%) by land cover components, such as forest, wetland, linear feature, and vegetation. To achieve these goals, the project developed a workflow to:

1) Create a historical land cover map
2) Create current land cover maps
3) Quantify changes in land cover

The Lichen report aims to identify lichen-rich ecosites within the study area, particularly in the area overlapping with the Little Smoky Caribou Range in the western portion of the study area.

2. Study Areas

The study area is located within the southern portion of the Smoky/Wapiti sub-watershed of northwestern Alberta, southwest of the town of Fox Creek (Figure 1). This area covers 706 square kilometers and will be referred to as the "Study Watershed". The "Local Study Area" covers 90 square kilometers in the center of the Study Watershed. This is the area where intensive field monitoring campaigns took place by other project teams. The Little Smoky Caribou Range overlaps the western portion of the Study Watershed, an area of approximately 166 square kilometers or 5.4% of the entire caribou range. See Ingram et al. 2021 for detailed descriptions and wetland coverage of the study areas.

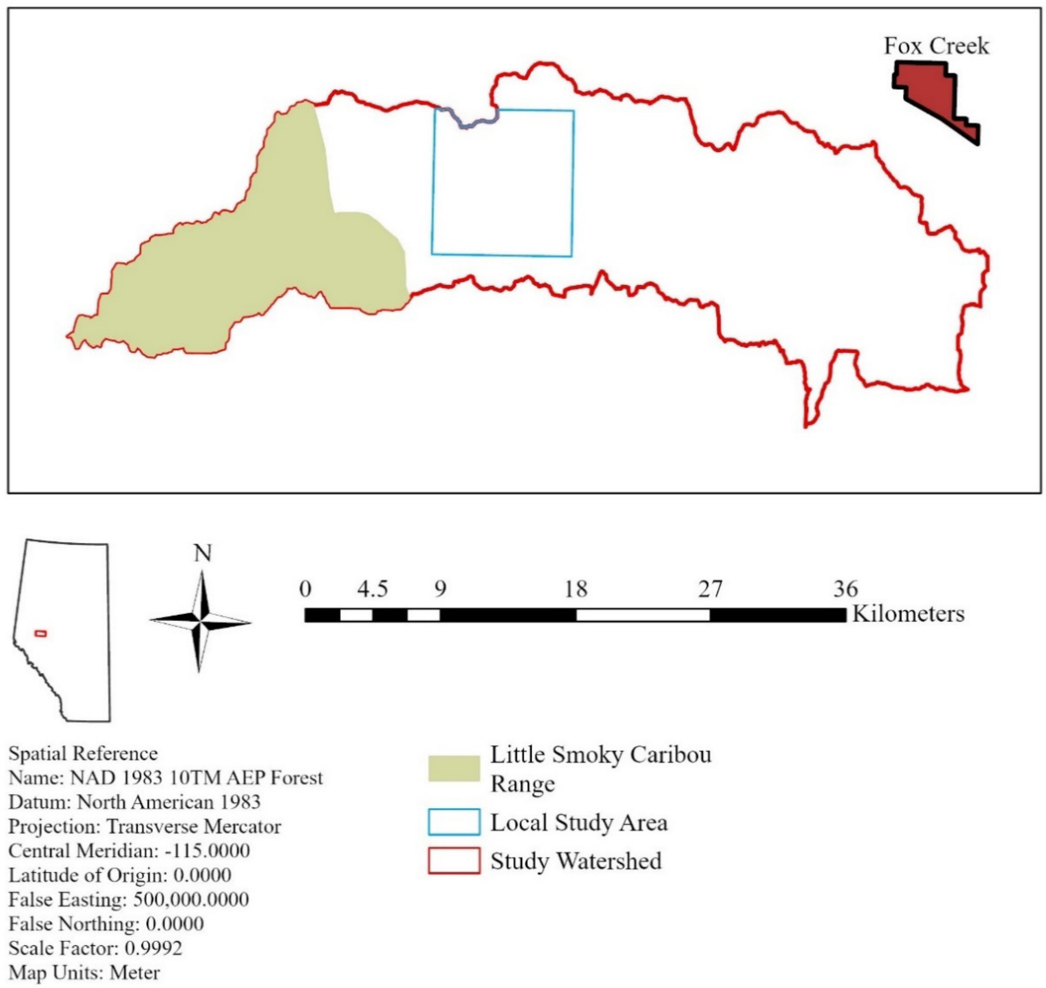


Figure 1. Study areas. Red: Study Watershed (706 km^2); Blue: Local Study Area (90 km^2); Olive: overlapping Little Smoky Caribou Range.

3. Data collection

3.1. Historical aerial photos and DEM

Six historical aerial photos, 83K02, 83K03, 83K04, 83K05, 83K06, and 83K07, that cover the Study Watershed were collected from the Alberta Biodiversity Monitoring Institute (ABMI) website[1]. These

[1] https://abmi.ca/home/data-analytics/da-top/da-product-overview/Other-Geospatial-Land-Surface-Data/Historical-Orthophotos.html

photos were taken in 1949, and each photo covers a 1:50,000 NTS sheet at a scale of 1:63,360 (Alberta Biodiversity Monitoring Institute (ABMI) 2015). Figure 2 shows an example of a historical aerial photo.

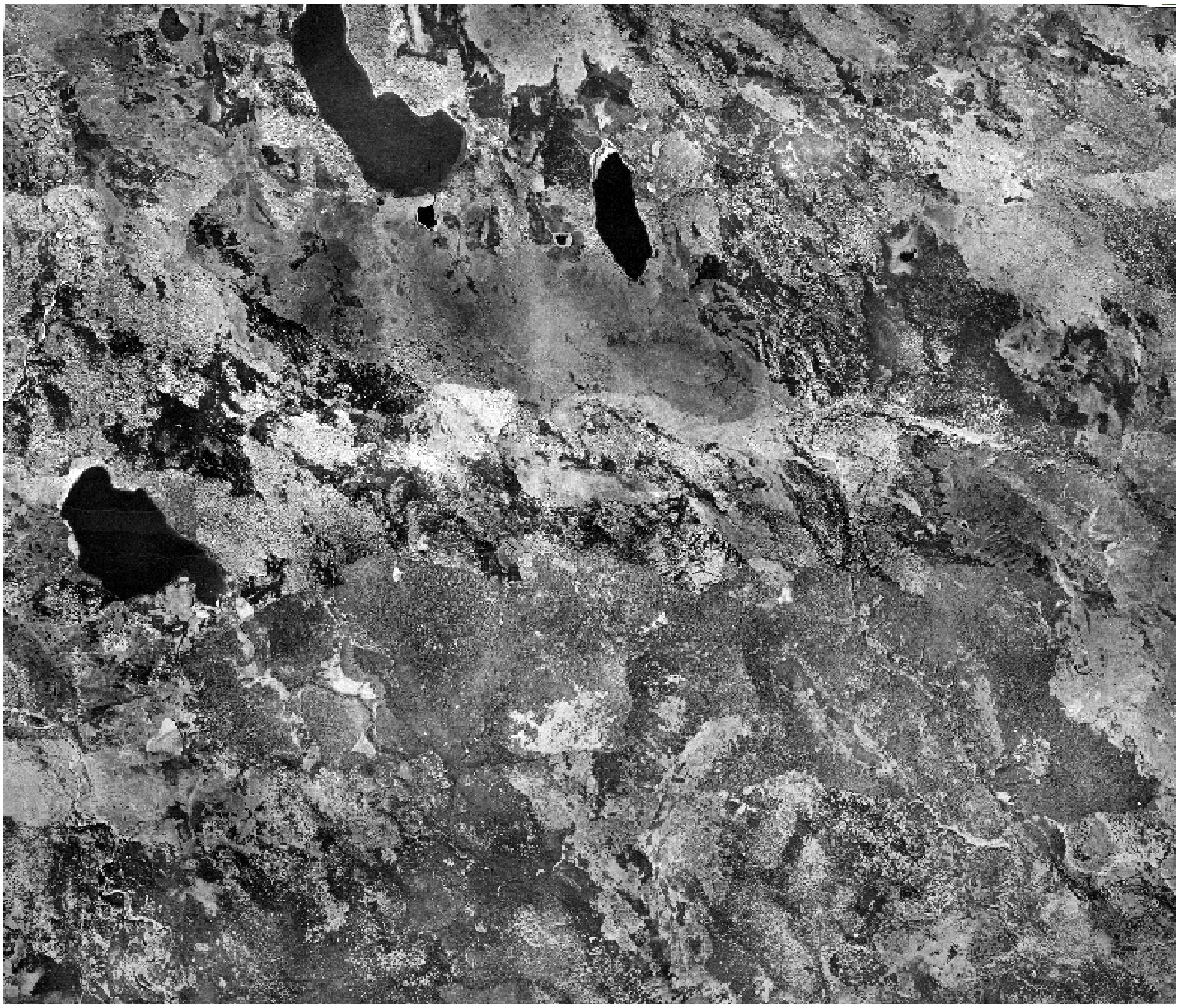


Figure 2. Historical air photo 83K07 covering part of the Study Watershed.

Most of the photos were provided by Alberta Tourism, Parks and Recreation and scanned by Alberta Innovates Technology Futures at the University of Alberta Map Library in 2008. Additional photos provided by Alberta Environment and Sustainable Resource Development (AESRD) were scanned by the ABMI with an HP DesignJet 820 MFP scanner at a resolution of 1,000 DPI in 2015. The output resolution was 1.22 metres (Alberta Biodiversity Monitoring Institute (ABMI) 2015). LIDAR 15 m Digital Elevation Models (DEM) were provided by the NRCan project team to support mapping the 1950s land cover of the Study Watershed.

3.2. Ancillary land cover inventory

Current land cover maps, including the 2021 Crop Inventory (CI) map[2], 2019 Human Footprint Inventory (HFI)[3], and 2021 Wetland Inventory (WI)[4], were collected to create the 2020s land cover map. The 2021 WI map provided by the ABMI was created based on three datasets, Sentinel-1 (S1) Synthetic Aperture Radar (SAR) data, Sentinel-2 (S2) optical data, and Advanced Land Observing Satellite (ALOS) Digital Surface Model (DSM) (DeLancey 2021). It classifies wetlands into five categories: open water, fen, bog, marsh, and swamp.

The 2019 HFI map provided by the ABMI has 20 layers: (1) Reservoirs; (2) Borrow Pits, Sumps, Dugouts, and Lagoons; (3) Non-Vegetated Impermeable Surfaces (Roads); (4) Rail Lines Hard Surface; (5) Canals; (6) Vegetated Surfaces of Roads, Trails, and Railways; (7) Mine Sites; (8) Industrial Sites; (9) Well Sites (Energy) ACTIVE; (10) Landfill; (11) Other Vegetated Facilities and Recreation; (12) Wind Generation Facilities; (13) Transmission Lines; (14) CFO and other High-Density Livestock; (15) Urban and Rural Residential; (16) Well Sites (Energy) ABANDONED; (17) Cultivation; (18) Cutblocks; (19) Pipelines; and (20) Seismic Lines. Furthermore, the 2021 CI map from Agriculture Agri-Food Canada (AAFC) maps 71 layers of forest, crop, and other land covers in Alberta.

4. Methods

4.1. 1950s Land Cover Map

Aerial photos and DEM were used as inputs for creating the historical (1950s) land cover map. Data processing steps were compiled in a workflow so that they could be repeated. The major data processes are (1) data pre-processing, (2) label collection, (3) image classification, and (4) output evaluation and spatial statistics (Figure 3).

[2] https://open.canada.ca/data/en/dataset/199e4ab6-832b-4434-ac39-e4887d7cc4e5
[3] https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html
[4] https://abmigc.users.earthengine.app/view/abmi-wetland-inventory

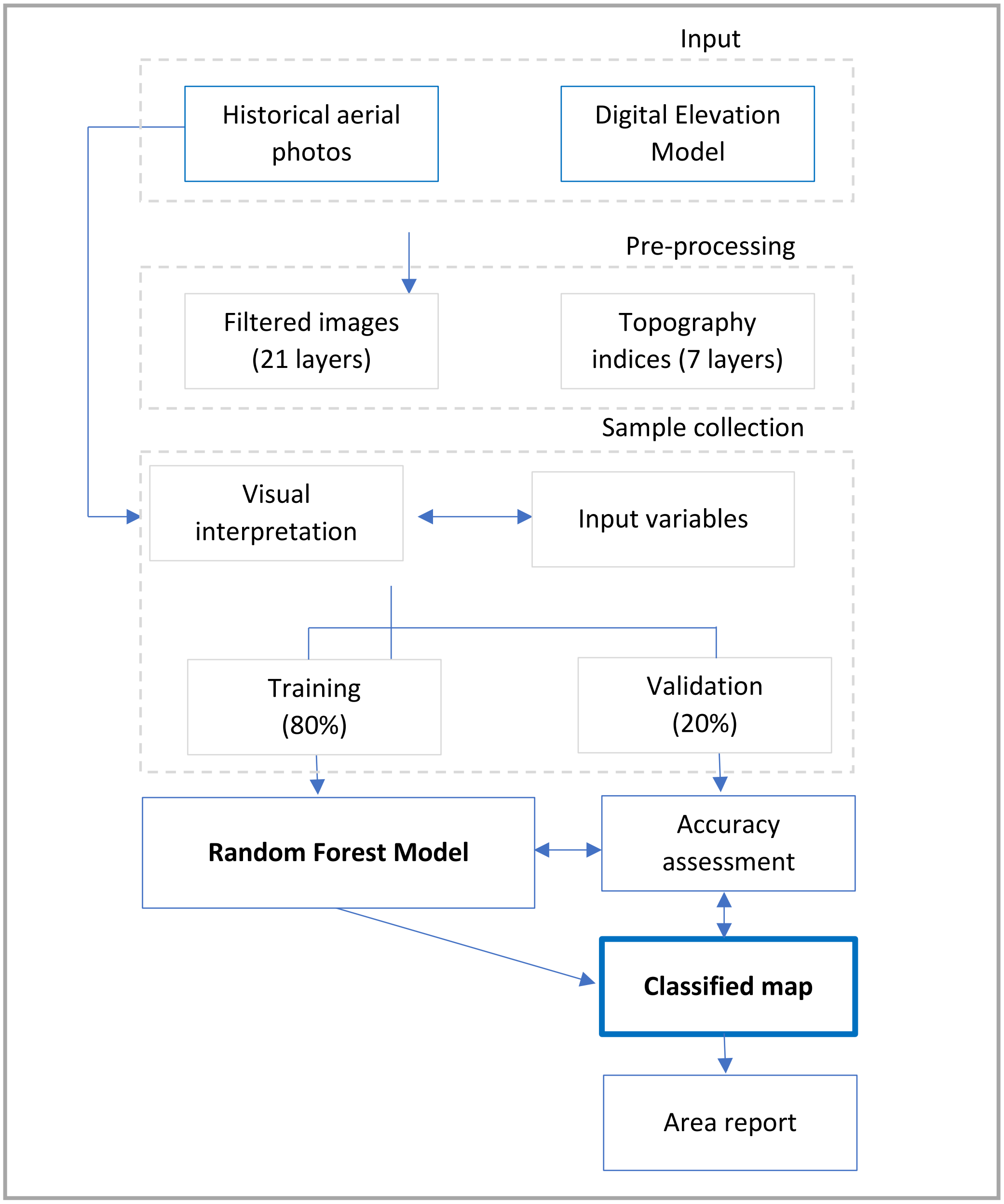


Figure 3. Workflow of data pre-processing, label collection, and image classification (using Random Forest model) procedures for land cover mapping using historical aerial photos and DEM as inputs.

4.1.1. Data Pre-Processing

Data pre-processing of historical imagery involves aerial photo orthorectification, mosaicking, and data cleaning. For the purposes of map overlaying, orthorectification is an important initial step to convert aerial photos so they spatially align with other data sources. Each scene was visually clipped to remove pixels without data. Mosaicking, which involves joining all overlapping images to form a uniform image (hereinafter "orthophotos"), was necessary as the aerial photos were provided as individual scenes. These pre-processing steps were conducted in ArcGIS Pro v10.6 software by Esri. As aerial photos have a low spectral resolution (single band in black and white), data enrichment is required. Image filtering using max/min, entropy, and texture filters (GLCM tool) was conducted. This pre-processing step generated 21 by-product map layers from the aerial photos. Data pre-preprocessing of DEM includes a process to extract topographic indices. The outputs from this step are seven map layers describing topographic characteristics of the Study Watershed, such as aspect, slope, sink, and valley depth. Detailed information about these map layers can be found in the next section.

4.1.2. Label Collection

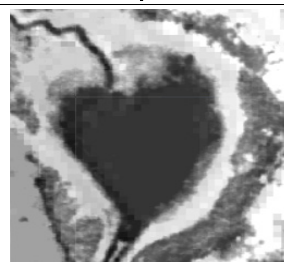
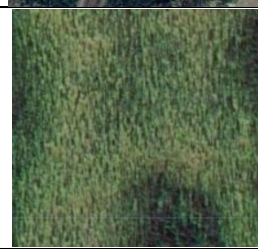
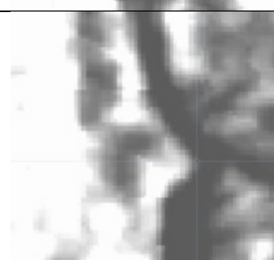
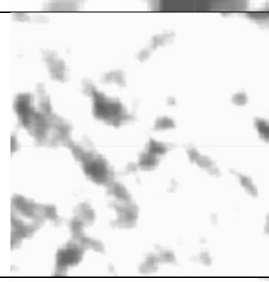
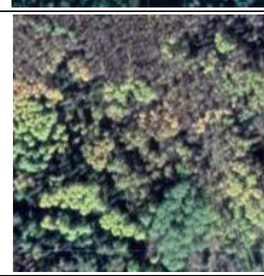
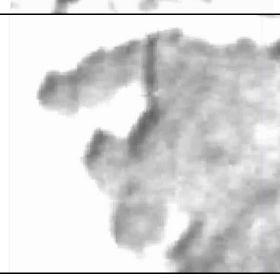
Label collection is an important step to collect reference land cover types for model training and validation in the succeeding steps. As no field verification data of the 1950s land cover in the Study Watershed is available, the label collection process was performed based on orthophoto properties, the experience of experts, and current Googles Earth images.

Areas without nearby disturbances (e.g., roads, well pads, and cutblocks) were selected using Google Earth to identify their land cover type. These areas were chosen based on the assumption that without nearby disturbances, the land cover would have remained the same since the 1950s. However, we acknowledge that this assumption may not hold true in some cases. The land cover was then matched to the same area on the orthophotos through an on-screen visual image interpretation technique by experts (the NAIT project team) who are familiar with the Study Watershed and the boreal landscape of northern Alberta.

Because historic orthophotos have lower resolution and retain fewer details than Google Earth images, the classifications were consolidated into three main land cover (LC) classes: Open Water, Wetland, and Forest. The Wetland and Forest classes were further divided to yield five sub-classes, Open Water, Fen, Swamp, Coniferous Forest, and Broadleaf Forest (Table 1). These land cover classes were validated by comparing their size and shape between the orthophotos and Google Earth images.

Open Water was easily identified in the orthophotos based on its black colour and smooth texture. In Google Earth, Fens have a bright brown colour (likely due to high moss ground cover) and a low density of conifer trees. These areas were found to have a smooth, white appearance in the orthophotos. Bogs and marshes account for less than 1% of the Study Watershed (Ingram et al. 2021) and therefore were included with Fens as they are indistinguishable in the orthophotos. Swamps are found in the transitional areas between uplands and open water. These areas are dark green with a high density of conifer trees in Google Earth and were identified as smooth, dark grey areas in the orthophotos. Broadleaf Forests have multiple bright colours (e.g., yellow and orange) and distinctly rounded to oval-shaped crowns in Google Earth. In the orthophotos, Broadleaf Forests were detected by a rough white background with sporadic grey patches. In contrast, Coniferous Forests have trees with green, conical/pyramid-shaped crowns in Google Earth and were identified as light to dark grey areas on orthophotos.

Table 1. Land cover (LC) classes and sub-classes in the 1950s orthophotos and current Google Earth images within the Study Watershed.

LC Class	LC Sub-Class	1950s Orthophotos	Current Googles Earth Images	No. of Samples
Open Water	Open Water			35
Wetland	Fen			314
	Swamp			76
Forest	Broadleaf Forest			127
	Coniferous Forest			246

Based on the properties, abundance, and distribution of the five land cover sub-classes in the orthophotos, as well as our experience and reference to Google Earth images in the study area, 798 sampling points were collected (Table 2) for the subsequent analysis steps.

4.1.3. Image Classification

Image classification refers to the task of extracting information classes from the orthophotos. This process can be performed using different approaches with various models. Random Forest (RF) was chosen as it generally has high accuracy and can handle large datasets. RF also provides an estimate of variable importance and can handle overfitting on large, estimated features, which gives it an advantage over other models.

Out of the 798 sampling points, 80% were used for training the model, and the remaining 20% were used to validate the classified map. Sample selection for training and validation was random. No cross-validation approach was used, but two hyper-parameters, the number of trees (ntree) and the number of features considered in each split (mtry), were tuned to generate an optimum model.

4.1.4. Output Evaluation, Predictive Performance and Variable Importance

Output evaluation aims to assess the model's performance and the quality of the output map and rank the importance of variables (predictors) that contribute to the accuracy. Hence, accuracy matrices using overall training accuracy, a validation error matrix, and validation accuracy (also overall accuracy) were used.

Predictive performance was evaluated using model validation accuracy via hyperparameter tuning and a confusion matrix, while variable importance was assessed using the Mean Decrease Accuracy (MDA) technique.

Hyperparameter tuning was performed to select the optimal number of predictors (mtry) used to build each tree and the number of trees grown in the forest (ntree). This step was taken with the goal of improving the model's accuracy, preventing overfitting, reducing training time, and enhancing model robustness. The results, shown in Figure 4, indicate that the best model was achieved with ntree = 100 and mtry = 4.

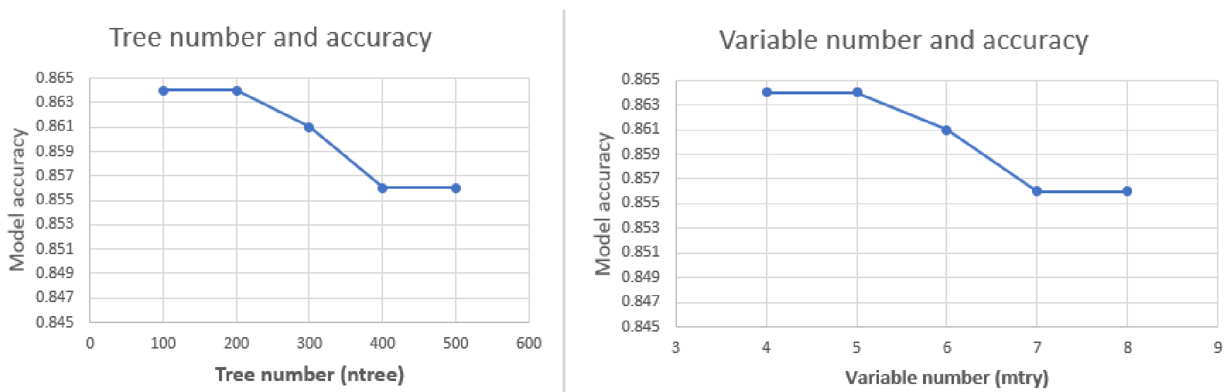


Figure 4. Hyperparameter tuning of ntree and mtry for model optimization.

The accuracies of the model were evaluated by comparing the predicted class labels with the true class labels and presented in a confusion matrix. The overall accuracy, user's accuracy, producer's accuracy (Congalton 1991), and kappa coefficient (Stehman 1997) were computed from 369 random validation points.

Table 2. Confusion matrix and classification accuracy assessment of the classified map.

		Ground truth classes						
		Water	Fen	Conifer	Broadleaf	Swamp	Total	UA
Predicted classes	Water	7	0	2	0	2	9	0.77
	Fen	1	84	1	6	5	95	0.88
	Conifer	0	0	159	9	1	193	0.82
	Broadleaf	0	7	16	44	0	60	0.73
	Swamp	1	4	15	1	4	12	0.33
	Total	11	97	169	67	25	369	
	PA	0.63	0.86	0.94	0.66	0.16		
	Overall accuracy: 0.807 Kappa: 0.708 Note. UA: Users' accuracy; PA: Producers' accuracy							

Based on the information provided, it seems that the classification model achieved a relatively good overall accuracy of 0.807, indicating that the model correctly classified 80.7% of the samples (Table 5). The kappa value of 0.708 suggests that the agreement between the predicted and ground truth (validation) labels is substantial. The user's accuracy and producer's accuracy columns indicate that some classes were easier to separate than others. For example, all classes except Swamp could be separated relatively well, as evidenced by the high user's and producer's accuracy values. However, there were some errors of commission (false positives) with the Conifer class. It is important to note that the performance of the model may have been affected by the low and unbalanced sample number among classes and the non-standardized gray-scale air photo imagery. Addressing these issues may improve the model's performance in the future.

For variable importance evaluation, Mean Decrease Accuracy (MDA) was used to find out how much each feature contributed to the accuracy of the model. This tool has been widely used for feature selection or dimensionally reduction. According to the results presented in Figure 5, the most important variable in the model was air-photo (black and white), followed by DEM, and then sink_smooth (a topographic index from DEM). Following these is a group with very similar values in which the variables of valDepth (valley depth), slope (in percentage), and Lfactor (length factor) were found. Finally, the variables of less importance in the model were aspect and dem_TWI (terrain wetness index from DEM).

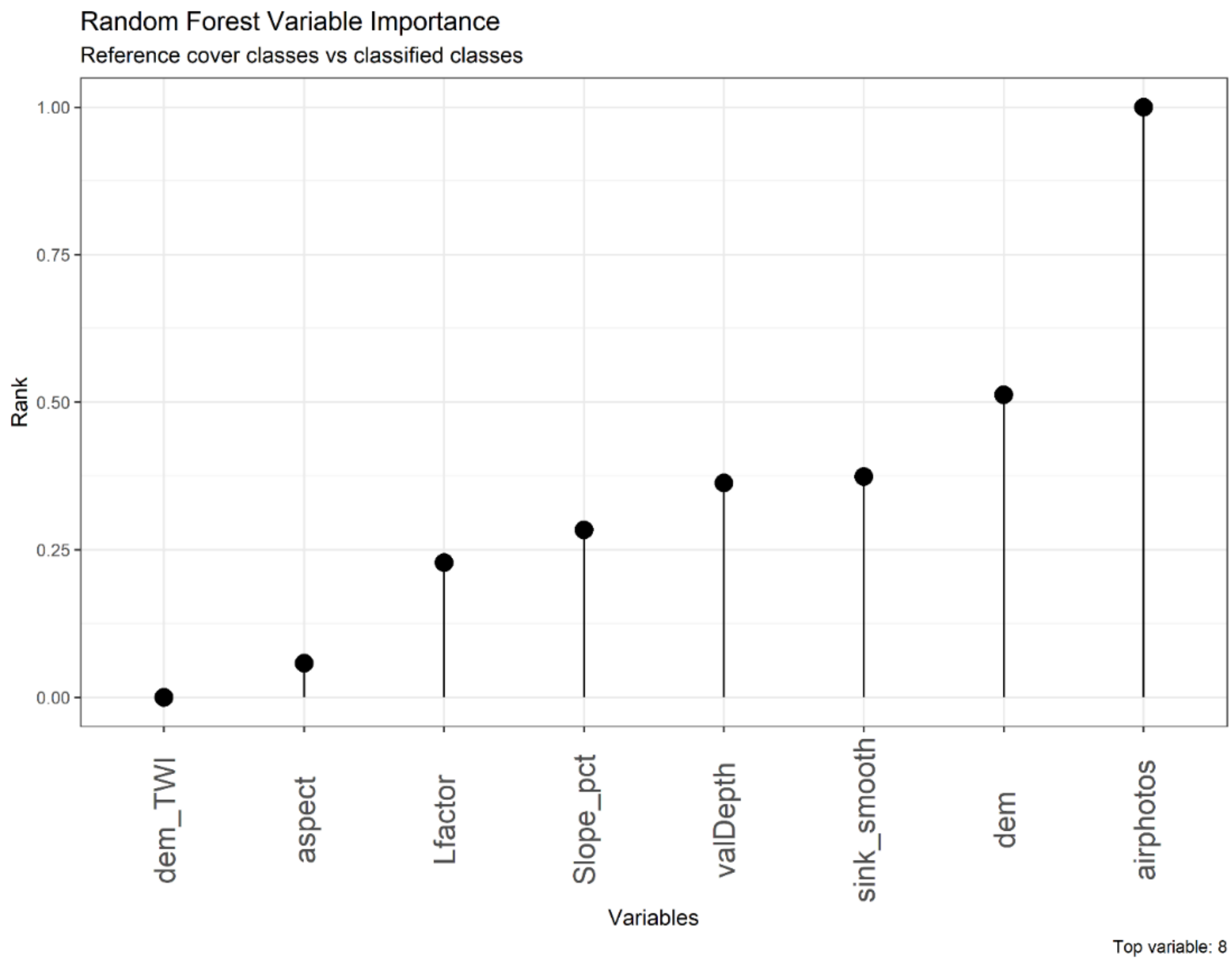


Figure 5. Mean Decrease Accuracy value for the variables used in the Random Forest model.

4.1.5. Spatial Statistics

From the classified map, area, in hectares and proportion of the total area, was quantified using spatial statistics technique. All the steps in label collection, image classification, output evaluation, and spatial statistics were implemented in Google Earth Engine, a cloud-based computing platform of Google. Figure 3 depicts the major steps of land cover mapping using historical aerial photos.

4.2. Current (2020s) Land Cover Map

Government agencies have made a lot of effort since the early 2000s to create land use and land cover maps. Based on the land cover classifications outlined in the 2021 Crop Inventory (CI) map, 2019 Human Footprint Inventory (HFI), and 2021 Wetland Inventory (WI), seven main LC classes and fourteen sub-classes were used for the 2020s map (Table 3). All input maps were converted into raster format, and pixel masking techniques were used to update the new layer onto the base map. In short, the current land cover map was created using ABMI's WI map as the base, and agriculture and forestry features were added from additional data sources.

The Cutblock class/sub-class is defined as areas where forestry operations have occurred. Similarly, the Industry class/sub-class is defined as areas where industrial activities (e.g., mining, oil and gas) other than forestry have taken place. Both are classified based on the 2019 HFI.

The 2021 WI map classifies wetlands into five categories, shallow open water, fen, bog, marsh, and swamp. For the current land cover map, the same wetland classifications as in the WI map were used, with the exception of shallow open-water wetlands. These are wetlands with less than 2 meters of water and are usually vegetated with emergent and aquatic species. Shallow open-water wetlands are difficult to distinguish, so they were included in the Marsh class. On the other hand, Open Water are areas with a water depth greater than 2 meters and lack vegetation. It is classified as a stand-alone class.

Forest (both Broadleaf and Conifer) land cover was classified using the Agriculture Agri-Food Canada's CI map published in 2021. There are areas that do not fall under any of the land cover classes. These included areas that were disturbed as part of the industrial activities (e.g., cutblock, well pads, roads) but have undergone either natural regeneration or reclamation. They are usually vegetated, with early seral communities dominated by shrubs and small trees. These features were grouped into the "Other Disturbances" class based on the 2021 CI (Table 3).

The 2019 HFI separates linear features (e.g., seismic lines) from the associated industrial activities (e.g., oil and gas extraction) due to the linear nature and how they are mapped. We adopted the same methodology for classifying linear features, further divided into four main classes: Pipeline, Railway, Road, and Seismic Line (Table 4).

Table 3. 2020s land cover class and sub-class definitions and their corresponding data sources.

LC Class	LC Sub-Class	Definition	Primary Data Source
Cutblock	Cutblock	Areas where forestry operations have occurred, such as clear-cut, selective harvest, salvage logging, etc.	2019 HFI
Forest	Broadleaf	Predominantly broadleaf/deciduous forests.	2021 CI
	Conifer	Predominantly coniferous forests.	2021 CI
Industry	Industry	Areas where mining and oil and gas activities occur. Mining includes the extraction of sand and/or gravel. Oil and gas sites include camps, well pads, central processing facilities, power plants and utilities, and urban industrial sites.	2019 HFI
Open Water	Open Water	Areas of open water > 2 m in depth.	2021 WI
Wetland	Bog	Ombrogenous peatlands receiving water and nutrients from precipitation only, *Sphagnum* dominated ground layer.	2021 WI
	Fen	Minerougenous peatlands with mineral-rich water sources, ground layer of *Sphagnum* and true mosses.	2021 WI
	Marsh	Non-peat forming wetlands, graminoid dominated, no mosses or trees; includes shallow open water wetlands.	2021 WI
	Swamp	Mineral wetlands with > 25% woody cover.	2021 WI
Other Disturbances	Other Disturbances	Areas disturbed by human activities, such as access roads and timber harvest, that do not fall under any of the above land cover classes. Most have regenerating woody vegetation of relatively low height (< 2 m).	2021 CI

Table 4. 2020s linear feature class and sub-class definitions and their corresponding data sources.

Class	Sub-Class	Definition	Primary Data Source
Pipeline	Pipeline	Lines of underground and over-ground pipes of substantial length and capacity used for the conveyance of petrochemicals.	2019 HFI
Railway	Abandoned	An abandoned road or track for trains, consisting of parallel steel rails supported on wooden crossbeams that are no longer in use.	2019 HFI
	Track	A road or track for trains consisting of parallel steel rails supported on wooden crossbeams. The single track consists of one parallel set of tracks.	2019 HFI
Road	ATV Trail	An off-road corridor surfaced with low vegetation for ATV travel.	2019 HFI
	Gravel-1L	A roadway surfaced with gravel and constituted a main access route. The road surface is about 6 m in width, and the road clearing is about 20 m or greater in width. The surface, ditches, bridges, and intersections are in good condition.	2019 HFI
	Gravel-2L	A roadway surfaced with gravel and constituted a main access route. The road surface is 7 m or greater in width, and the road clearing is 30 m or greater in width. The surface, ditches, bridges, and intersections are in good condition.	2019 HFI
	Paved-UNDIV-2L	A roadway paved with asphalt or concrete and consisting of two adjacent lanes, with no median to separate them.	2019 HFI
	RIS-Road	Roads in oil sands mining areas that are not specifically part of other disturbed features.	2019 HFI
	Truck Trail	A roadway surfaced with dirt or low vegetation and constituted a minor access route.	2019 HFI
	Unclassified	A temporary coding for an unknown class of road, which will be updated after a field check or verification.	2019 HFI
	Unimproved	A roadway surfaced with dirt and constituted a minor access route. The road surface is up to 7 m in width, and the road clearing is up to 20 m in width. The surface and ditches are poorly maintained, and the bridges are narrow.	2019 HFI
Seismic Line	Low Impact	A polygon feature class derived from a 1.5 m buffer (3 m total width) of a pre-low-impact-seismic centerline.	2019 HFI
	Conventional	A polygon feature class derived from a 3 m buffer (6 m total width) of a pre-low-impact-seismic centerline.	2019 HFI
	Trail	A polygon feature class derived from a 2 m buffer (4 m total width) of a pre-low-impact-seismic centerline.	2019 HFI

4.3. 1950s to 2020s Land Cover Change

After producing two land cover maps (the 1950s and 2020s) in raster format, change detection was conducted to map locations of change and create a change matrix. To accomplish this task, the change detection wizard in ArcGIS Pro was used, and a smoothing neighborhood of 5x5 pixels was applied to reduce the 'salt and pepper' issue in the detection map. Post-processing of the image clipped to the area of interest and resampling of the pixel size to 30 m to match the current land cover map was applied. To calculate land cover changes, the historical land cover map was used as the reference and compared to the 2020 land cover map. Any changes from the 1950s to the 2020s were calculated by type and area and presented in a matrix table showing the source and destination of all changes (e.g., from land cover A in the 1950s to land cover B in the 2020s).

5. Results

5.1. 1950s Land Cover

Forest is the dominant land cover class, covering 617 km^2 (87%) of the Study Watershed and 83 km^2 (93%) of the Local Study Area (Table 5). Wetland covers 78 km^2 (11%) of the Study Watershed and 6 km^2 (7%) of the Local Study Area. Open Water accounts for 11 km^2 (2%) of the Study Watershed and is negligible in the Local Study Area. The spatial distribution of the three main classes are presented in Figure 6 for the Study Watershed and in Figure 8 for the Local Study Area.

Among the five sub-classes, Conifer Forest is the largest, covering 395 km^2 (56%) of the Study Watershed and 46 km^2 (52%) of the Local Study Area. Broadleaf Forest is the second largest, covering 222 km^2 (31%) of the Study Watershed and 37 km^2 (42%) of the Local Study Area. Fen covers 65 km^2 (9%) of the Study Watershed and 4 km^2 (5%) of the Local Study Area. Swamp covers 12 km^2 (2%) of the Study Watershed and 2 km^2 (2%) of the Local Study Area. The spatial distribution of the sub-classes is presented in Figure 7 for the Study Watershed and in Figure 9 for the Local Study Area.

Table 5. 1950s land cover (area and percent cover) of the Study Watershed and Local Study Area by main and sub-class.

LC Class	**LC Sub-Class**	**Study Watershed**		**Local Study Area**	
		Area (km^2)	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
Forest	Broadleaf	222	31	37	42
	Conifer	395	56	46	51
	Total	*617*	*87*	*84*	*93*
Open Water	*Open Water*	*11*	*2*	*0*	*0*
Wetland	Fen	65	9	4	5
	Swamp	12	2	2	2
	Total	*78*	*11*	*6*	*7*
Total		**706**	**100**	**90**	**100**

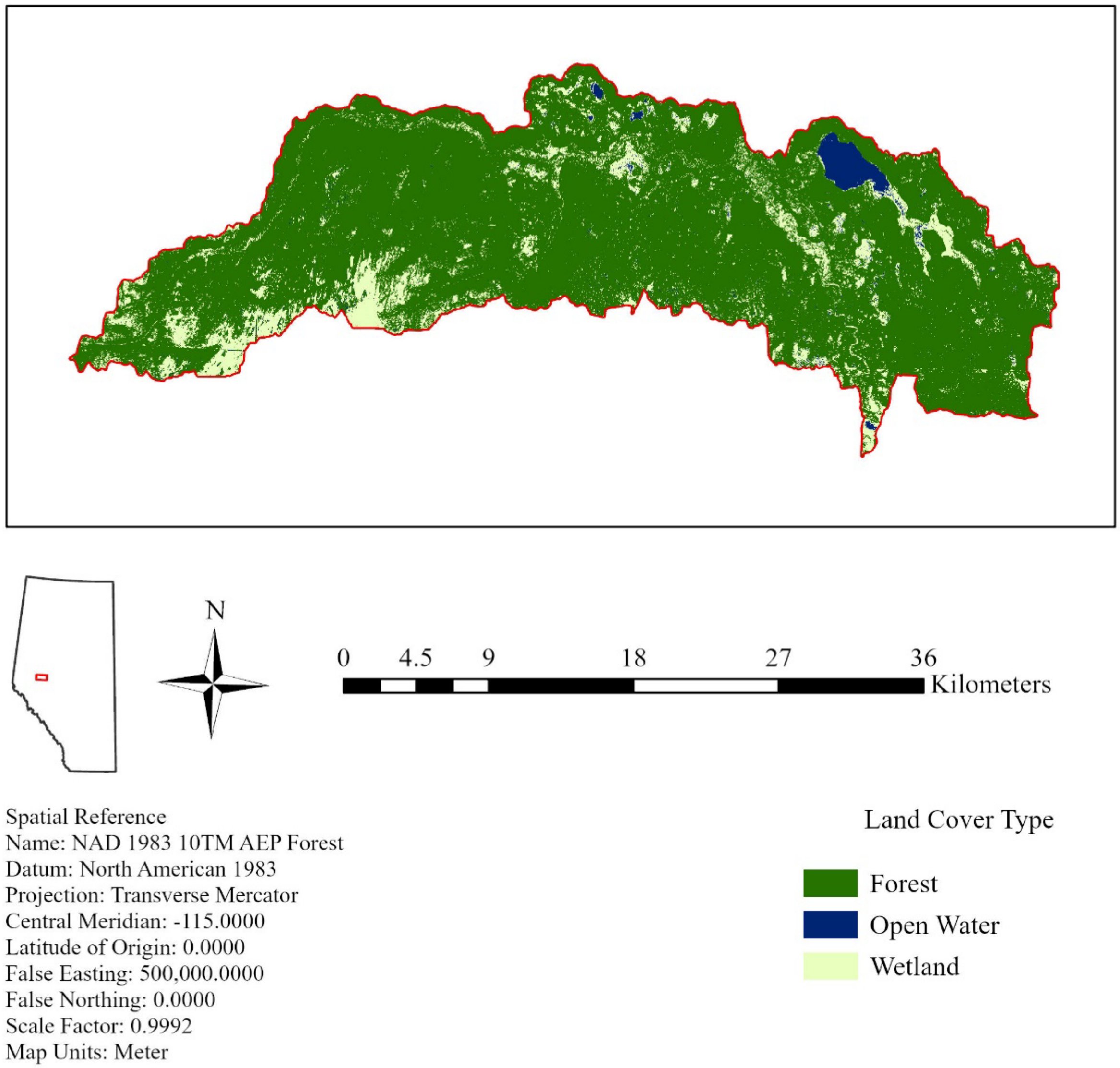


Figure 6. 1950s land cover map of the Study Watershed by main class.

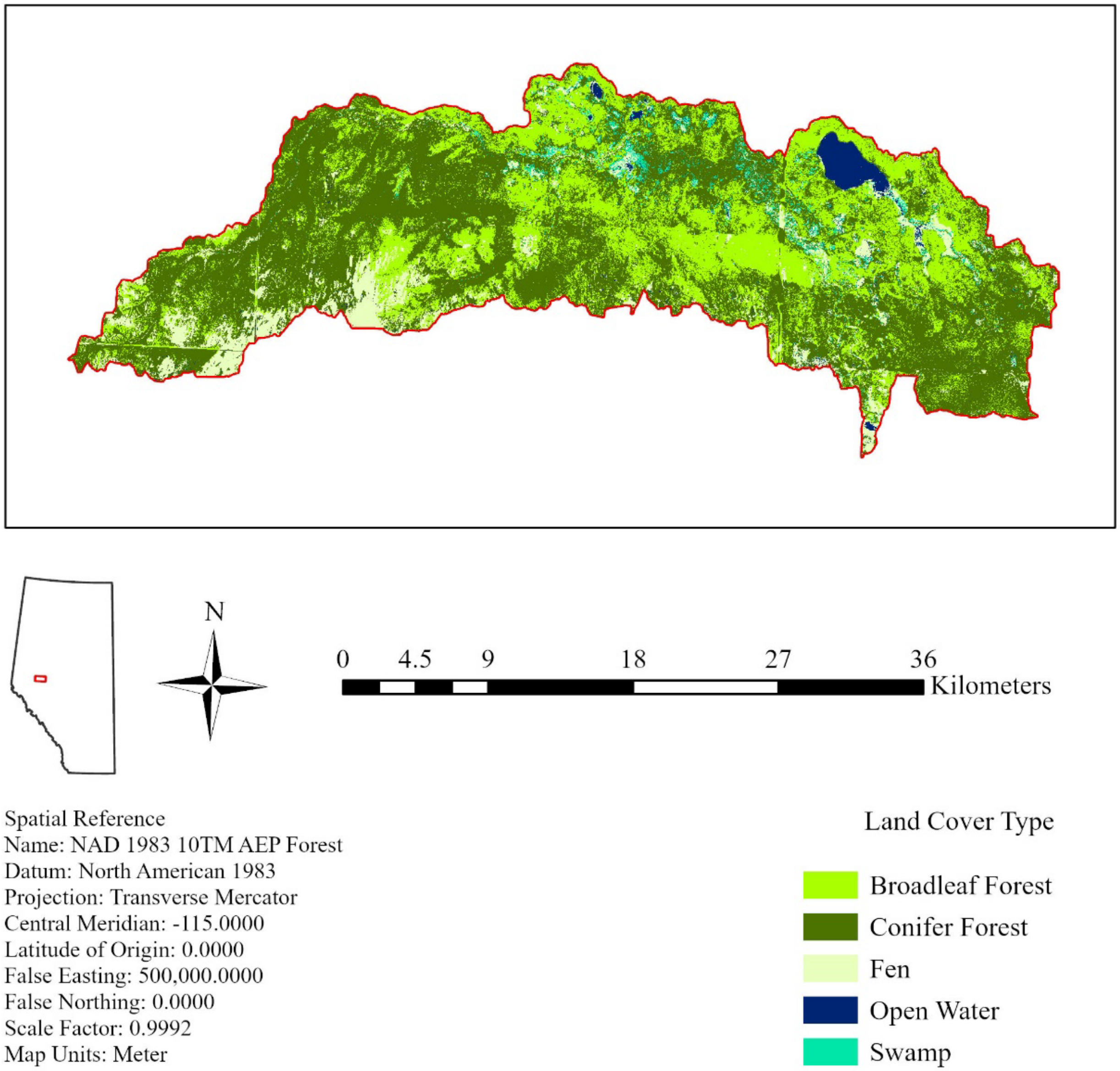


Figure 7. 1950s land cover map of the Study Watershed by sub-class.

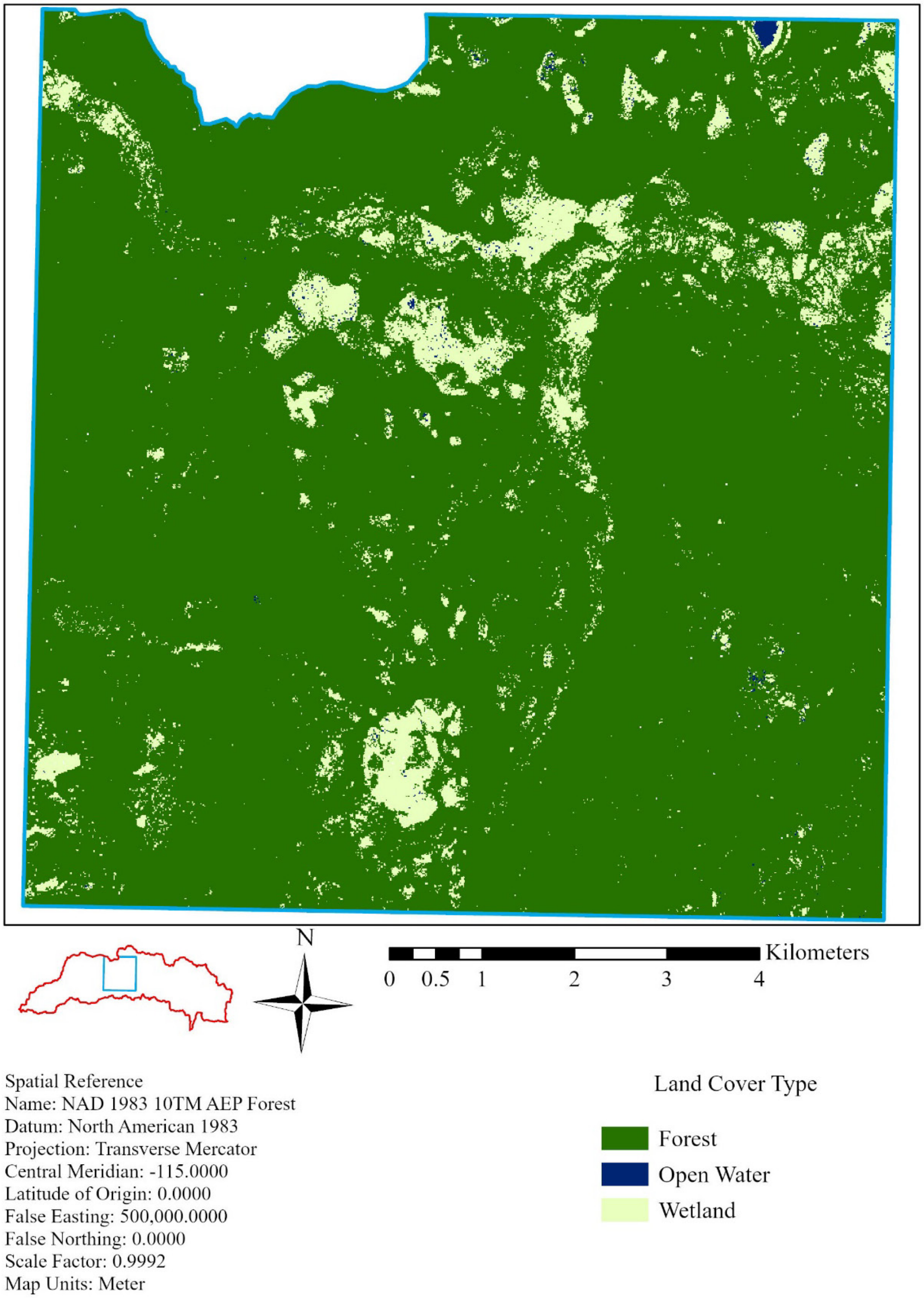


Figure 8. 1950s land cover map of the Local Study Area by main class.

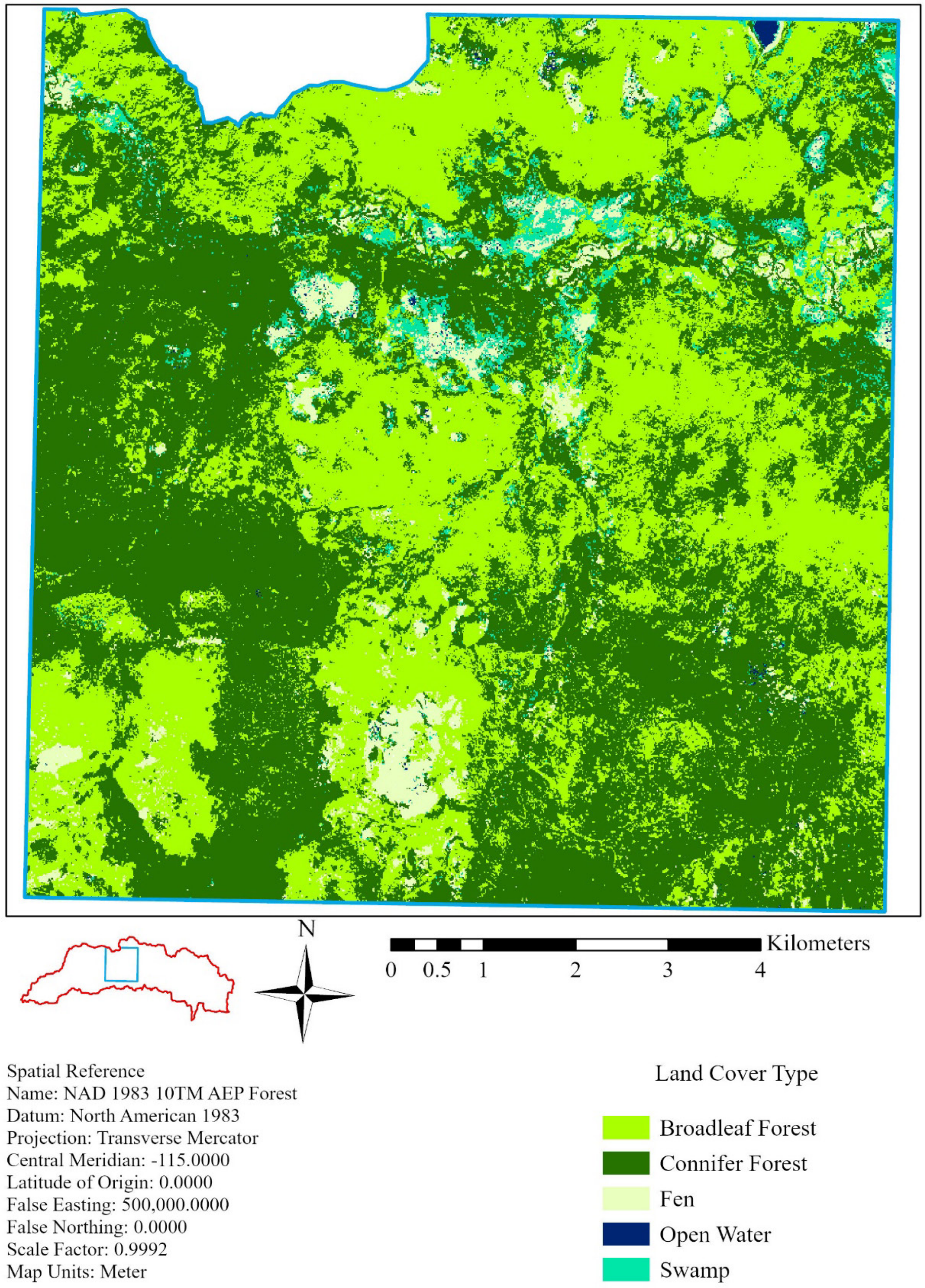


Figure 9. 1950s land cover map of the Local Study Area by sub-class.

5.2. 2020s Land Cover

Forest is the dominant land cover in the 2020s, covering 397 km^2 (56%) of the Study Watershed and 47 km^2 (52%) of the Local Study Area. Cutblock is the second largest land cover, accounting for 184 km^2 (26%) of the Study Watershed and 34 km^2 (38%) of the Local Study Area. Wetland covers 80 km^2 (11%) of the Study Watershed and 5 km^2 (6%) of the Local Study Area. Other Disturbances account for 23 km^2 (3%) of the Study Watershed and 3 km^2 (3%) of the Local Study Area. Open Water and Industry cover 12 km^2 (2%) and 10 km^2 (1%) of the Study Watershed, respectively. Within the Local Study Area, Open Water is negligible, while Industry is 1 km^2 (1%). The spatial distribution of the six main classes is shown in Figure 10 for the Study Watershed and in Figure 12 for the Local Study Area.

Among the sub-classes, Conifer Forest has the highest land cover at 297 km^2 (42%) of the Study Watershed and 36 km^2 (41%) of the Local Study Area (Table 6). Cutblock is the second largest land cover, followed by Broadleaf Forest at 100 km^2 (14%) of the Study Watershed and 10 km^2 (11%) of the Local Study Area. The spatial distribution of the 10 sub-classes is presented in Figure 11 for the Study Watershed and in Figure 13 for the Local Study Area.

Table 6. 2020s land cover (area and percent cover) in the Study Watershed and Local Study Area by main and sub-class.

LC Class	**LC Sub-Class**	**Study Watershed**		**Local Study Area**	
		Area (km^2)	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
Cutblock	*Cutblock*	*184*	*26*	*34*	*38*
Forest	Broadleaf	100	14	10	11
	Conifer	297	42	36	41
	Total	*397*	*56*	*47*	*52*
Industry	*Industry*	*10*	*1*	*1*	*1*
Open Water	Open Water	12	2	0	0
Wetland	Bog	0	0	0	0
	Fen	76	11	4	5
	Marsh	0	0	0	0
	Swamp	4	1	0	1
	Total	*80*	*11*	*5*	*6*
Other Disturbances	*Other Disturbances*	*23*	*3*	*3*	*3*
Total		**706**	**100**	**90**	**100**

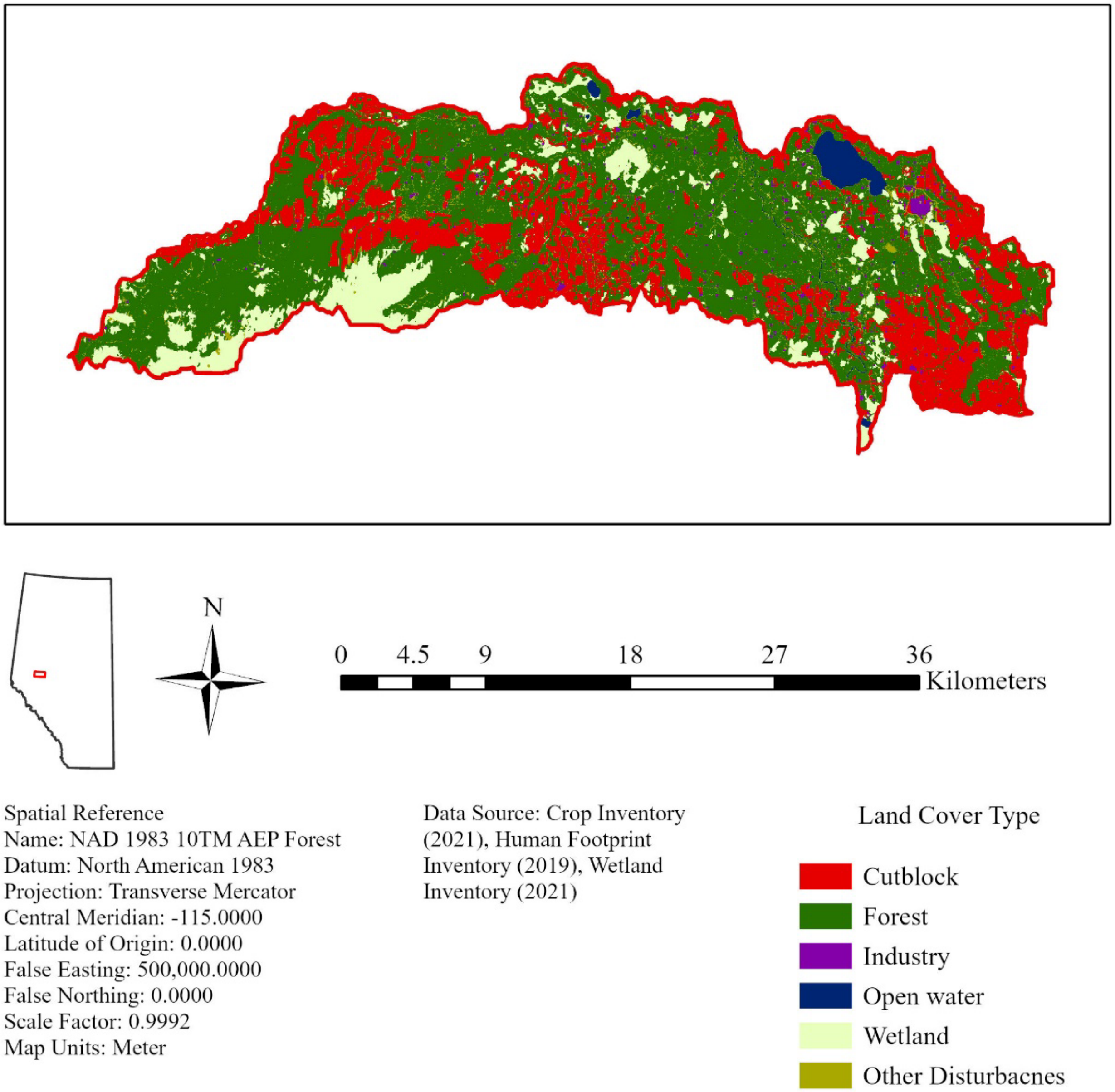


Figure 10. 2020s land cover map of the Study Watershed by main class.

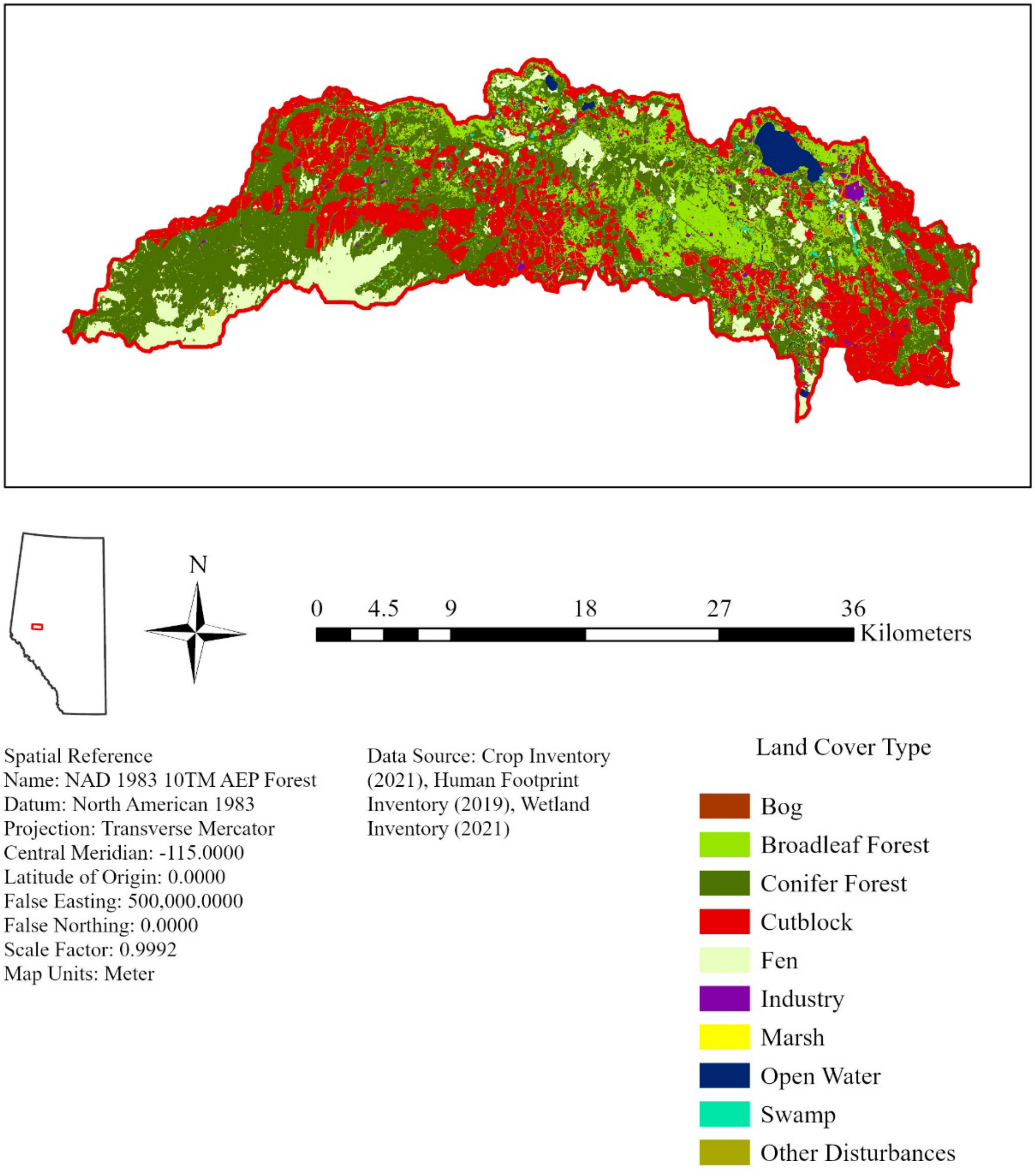


Figure 11. 2020s land cover map of the Study Watershed by sub-class.

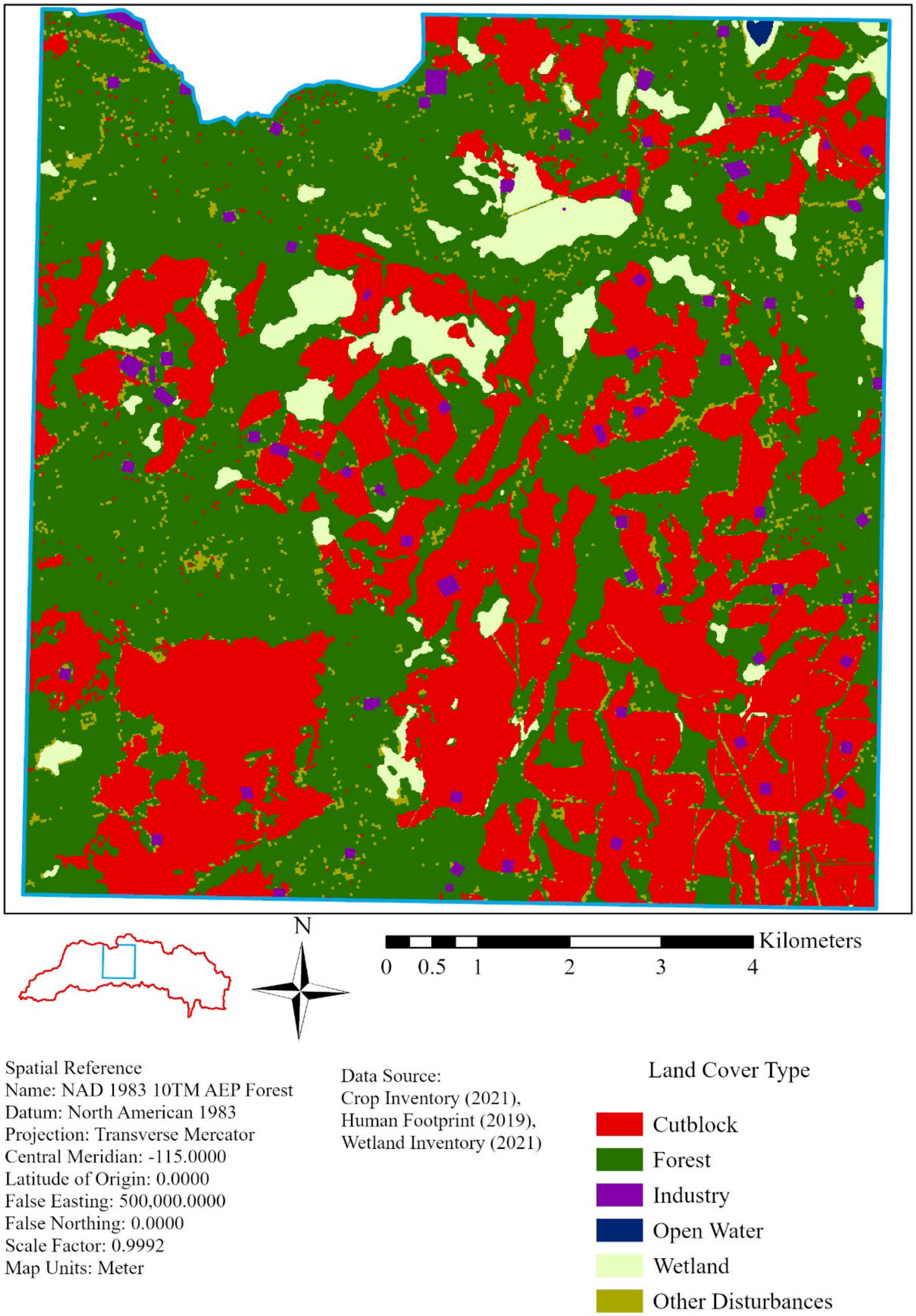


Figure 12. 2020s land cover map of the Local Study Area by main class.

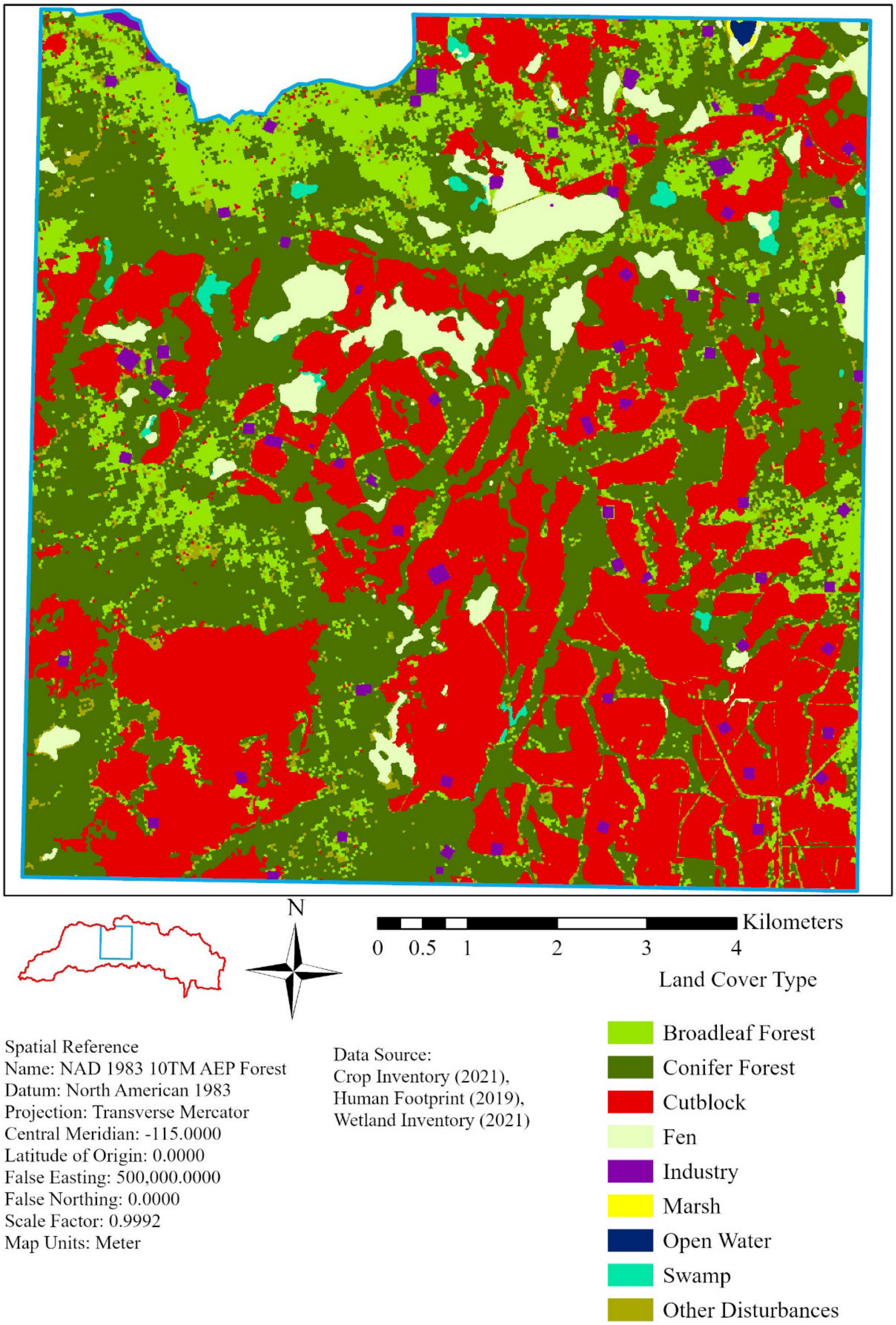


Figure 13. 2020s land cover map of the Local Study Area by sub-class.

5.3. Linear Features

There are 3934 km of linear features in the Study Watershed and 448 km in the Local Study Area (Table 7, Figures 14 to 17). The density of linear features is 6 km/km^2 in the Study Watershed and 5 km/km^2 in the Local Study Area. Seismic Line is the dominant class, accounting for 61% of all linear features in the Study Watershed and 63% in the Local Study Area. Pipeline is the second most abundant linear feature, accounting for 23% in the Study Watershed and 22% in the Local Study Area. Various roads account for 14% and 15% of the Study Watershed and Local Study Area, respectively. By contrast, Railway is the least abundant linear feature, accounting for 1% of the Study Watershed and being absent in the Local Study Area.

Table 7. 2020s linear features by main and sub-class in the Study Watershed and the Local Study Area.

Class	**Sub-Class**	**Study Watershed**			**Local Study Area**		
		Length (km)	**Percentage (%)**	**Density (km/km^2)**	**Length (km)**	**Percentage (%)**	**Density (km/km^2)**
Pipeline	*Pipeline*	*922*	*23*	*1*	*97*	*22*	*1*
Railway	Abandoned	11	0	0	0	0	0
	Track	39	1	0	0	0	0
	Total	*51*	*1*	*0*	*0*	*0*	*0*
Road	ATV Trail	1	0	0	1	0	0
	Gravel-1L	342	9	0	46	10	1
	Gravel-2L	36	1	0	0	0	0
	Paved-UNDIV-2L	3	0	0	0	0	0
	RIS Road	11	0	0	5	1	0
	Truck Trail	52	1	0	3	1	0
	Unclassified	0	0	0	0	0	0
	Unimproved	101	3	0	13	3	0
	Total	*546*	*14*	*1*	*68*	*15*	*1*
Seismic Line	Conventional	1739	44	2	186	42	2
	Low Impact	103	3	0	24	5	0
	Trail	574	15	1	74	16	1
	Total	*2415*	*61*	*3*	*283*	*63*	*3*
Total/Average		**3934**	**100**	**6**	**448**	**100**	**5**

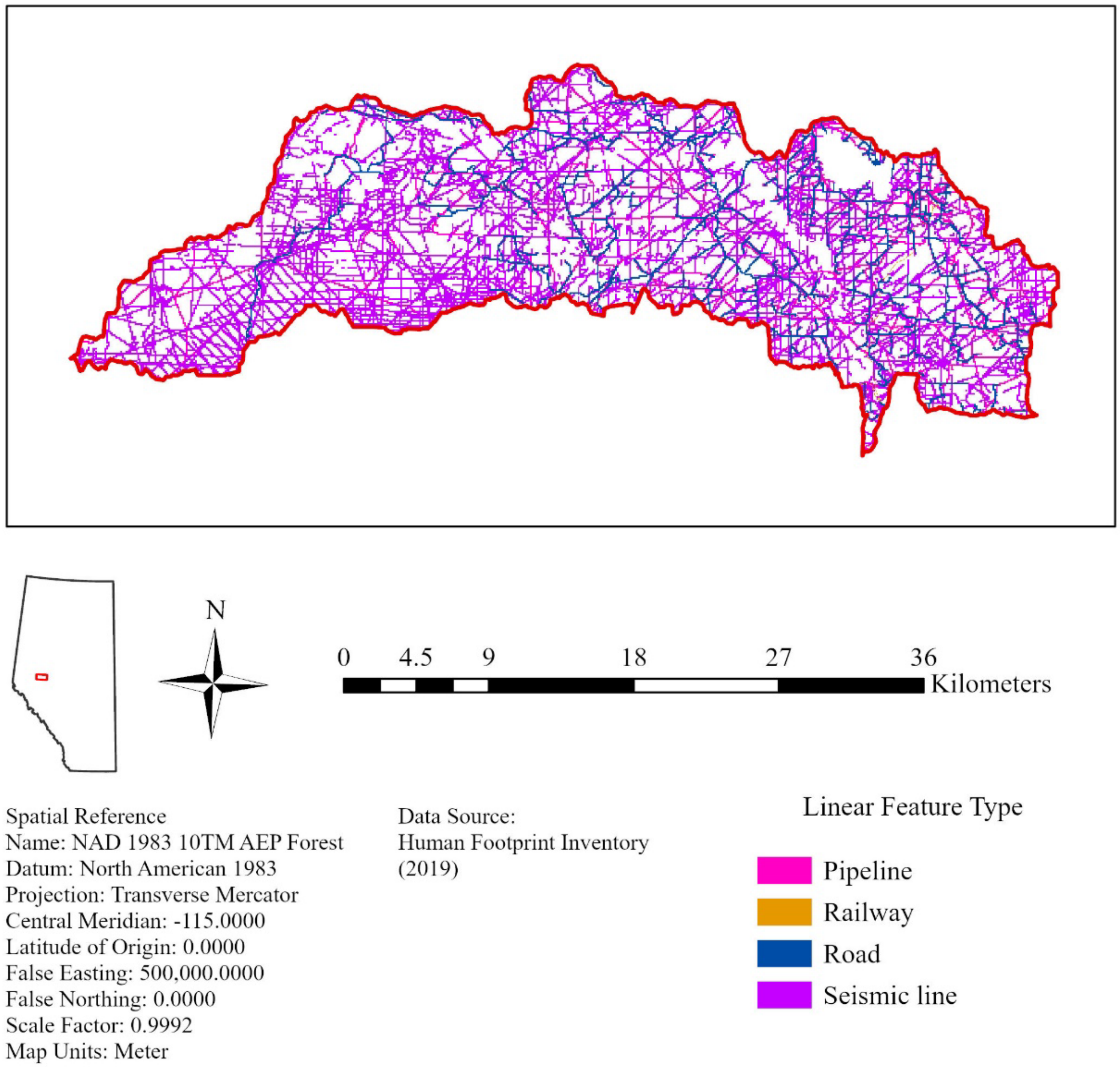


Figure 14. 2020s linear feature map of the Study Watershed by main class (retrieved from 2019 HFI).

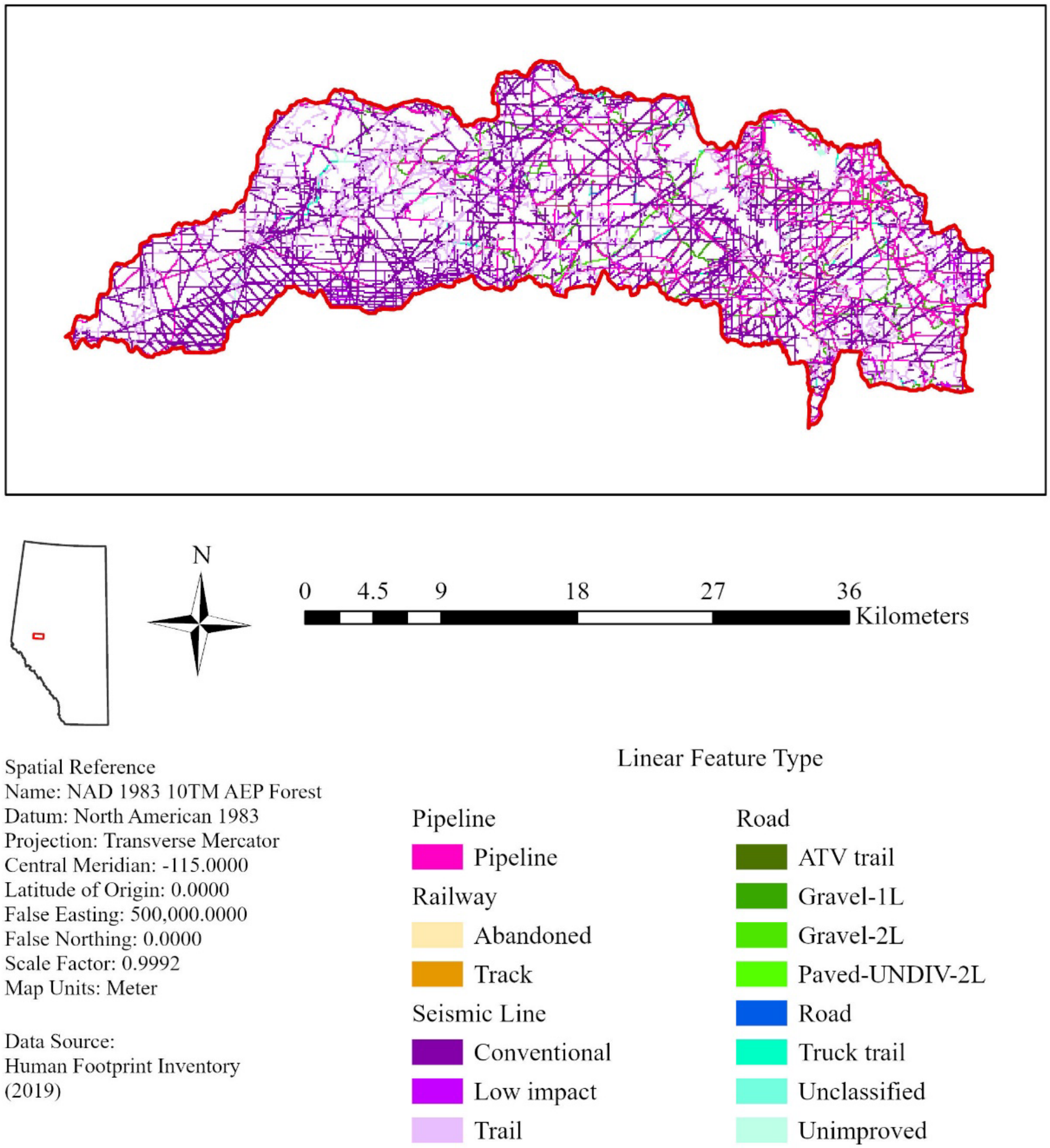


Figure 15. 2020s linear feature map of the Study Watershed by sub-class.

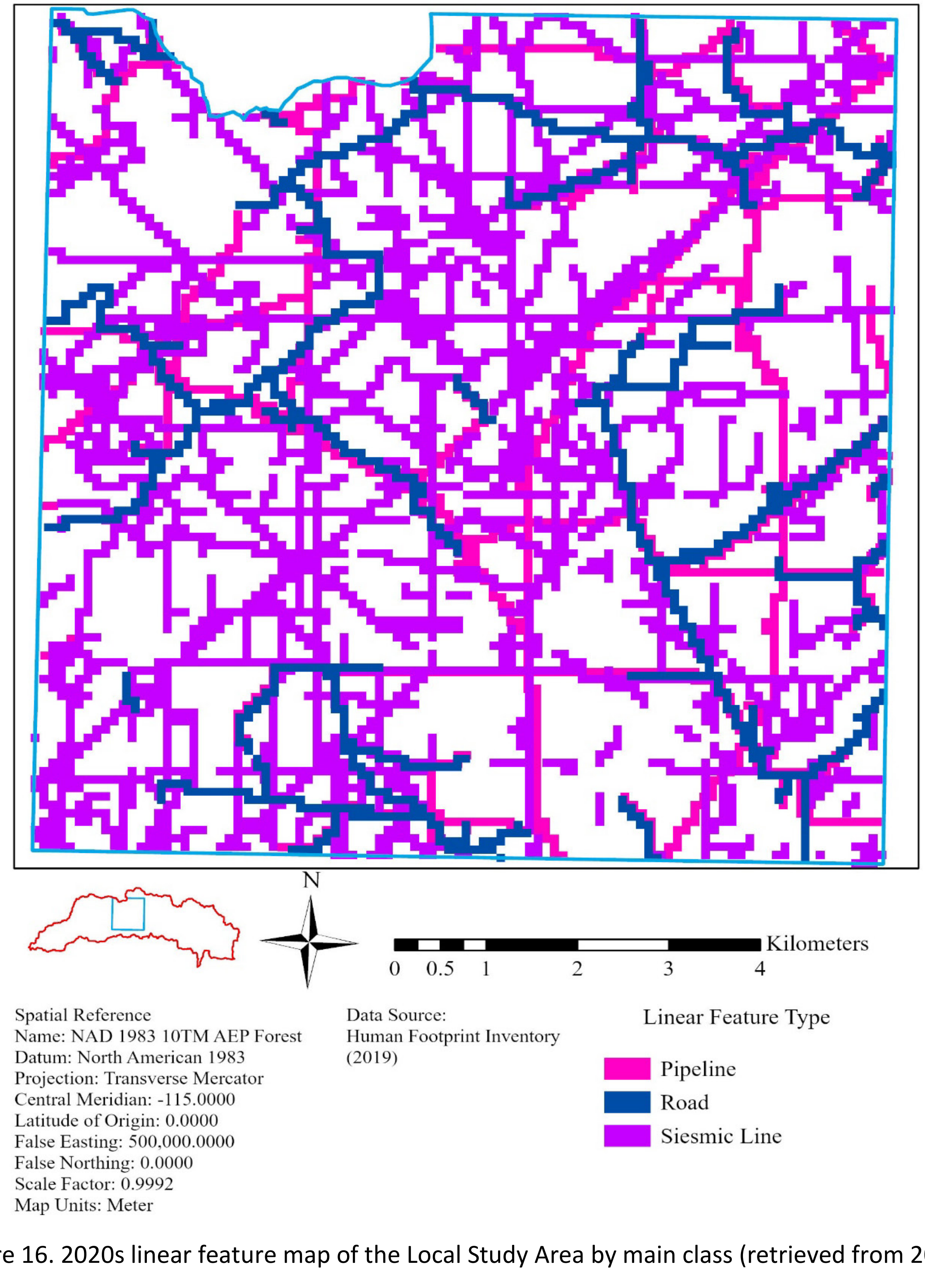


Figure 16. 2020s linear feature map of the Local Study Area by main class (retrieved from 2019 HFI).

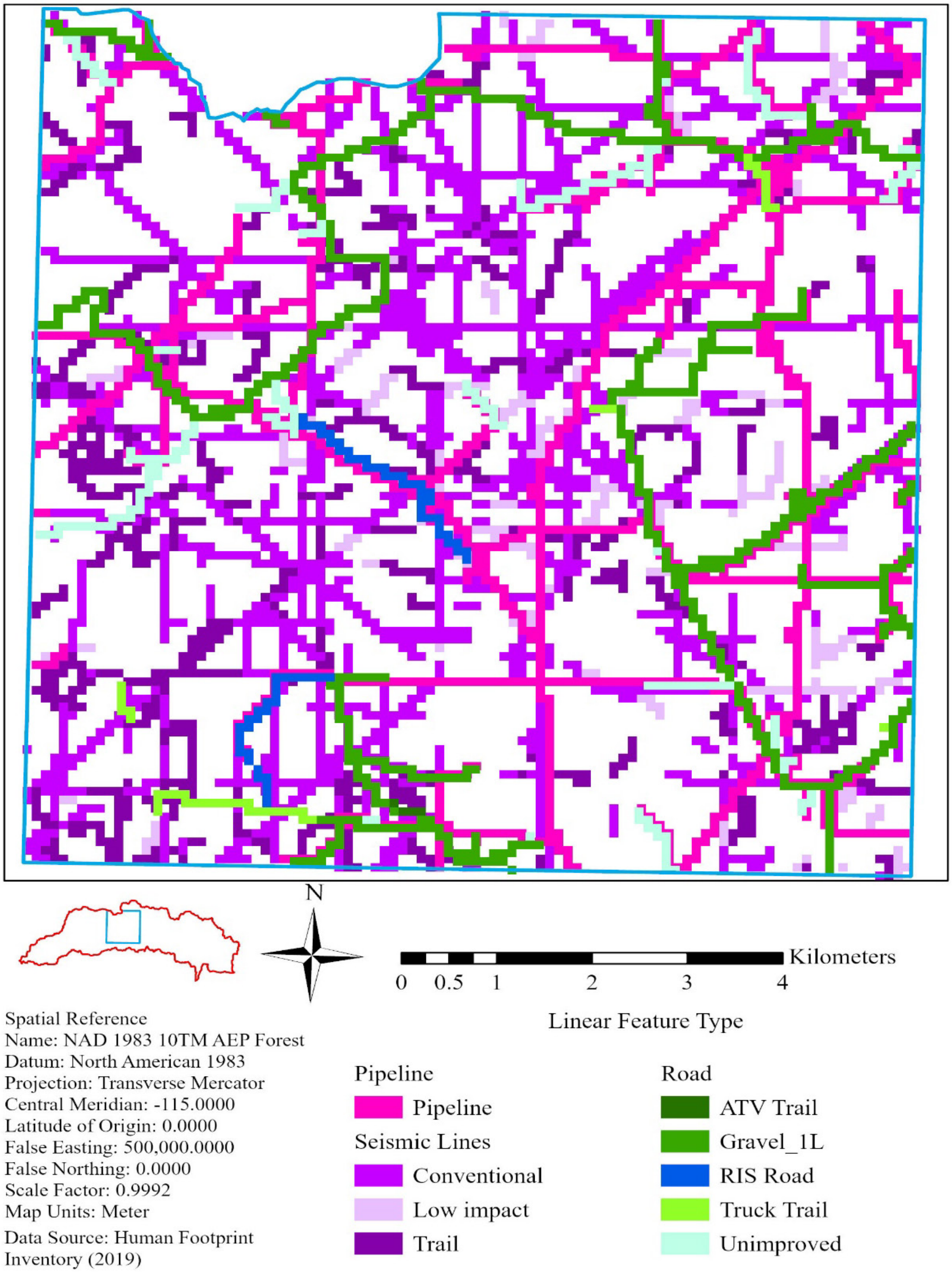


Figure 17. 2020s linear feature map of the Local Study Area by sub-class (retrieved from 2019 HFI).

5.4. Land Cover Changes from the 1950s to 2020s

For this report, we assume that without the change in total area, the total loss in certain land use classes (e.g., Forest) should equal total gains in other land use classes (e.g., Cutblock + Industry). We acknowledge that there are exceptions to this assumption, and there are errors in the land cover estimates. However, these exceptions and errors shouldn't change the overall trend in land use change presented here.

In the Study Watershed, Forest was the dominant class covering 617 km^2 (87%) of the total area in the 1950s (Table 8). By the 2020s, Forest only covered 397 km^2 (56%) of the study watershed, representing the single, most significant decline of 220 km^2 or 36% after 70 years. Cutblock accounts for 184 km^2 or 84% of the total land use loss. Industry and Other Disturbances account for 12 km^2 (5%) and 23 km^2 (10%) of the Study Watershed, respectively. By contrast, Open Water and Wetland cover were almost unchanged between the 1950s to the 2020s, with approximately 11 km^2 and 90 km^2, respectively. The spatial distribution of changes in Forest cover is shown in Figure 18, while changes in Wetland cover are presented in Figure 20.

In the Local Study Area, Forest was the dominant class, covering 84 km^2 or 93% of the area (Table 8). It dropped to only 47 km^2 or 52% by the 2020s. Open Water and Wetland declined by 22% and 20% between the 1950s and 2020s. Cutblock is the main factor for land use change, accounting for 93% of the loss of Forest, Wetland, and Open Water. Other Disturbances and Industry account for 8% and 3% of the land use change respectively. Changes in Forest cover are illustrated in Figure 19 and changes in Wetland cover in Figure 21.

Table 8. Land cover changes from the 1950s to 2020s.

LC Class	**Study Watershed (km^2)**				**Local Study Area (km^2)**			
	1950s	**2020s**	**Change**		**1950s**	**2020s**	**Change**	
			km^2	**%**			**km^2**	**%**
Cutblock	-	184	184	84*	-	34	34	93*
Forest	617	397	-220	-36	84	47	-37	-44
Industry	-	10	10	5*	-	1	1	3*
Open Water	11	12	1	0*	0	0	0	-22
Wetland	89	92	3	1*	6	5	-1	-20
Other Disturbances	-	23	23	10*	-	3	3	8*
Total	**706**	**706**			**90**	**90**		

Note: * land use gains as a percentage of the total land use loss (underscored numbers): -220 km^2 of Forest in the Study Watershed and -38 km^2 of Forest + Open Water + Wetland in the Local Study Area.

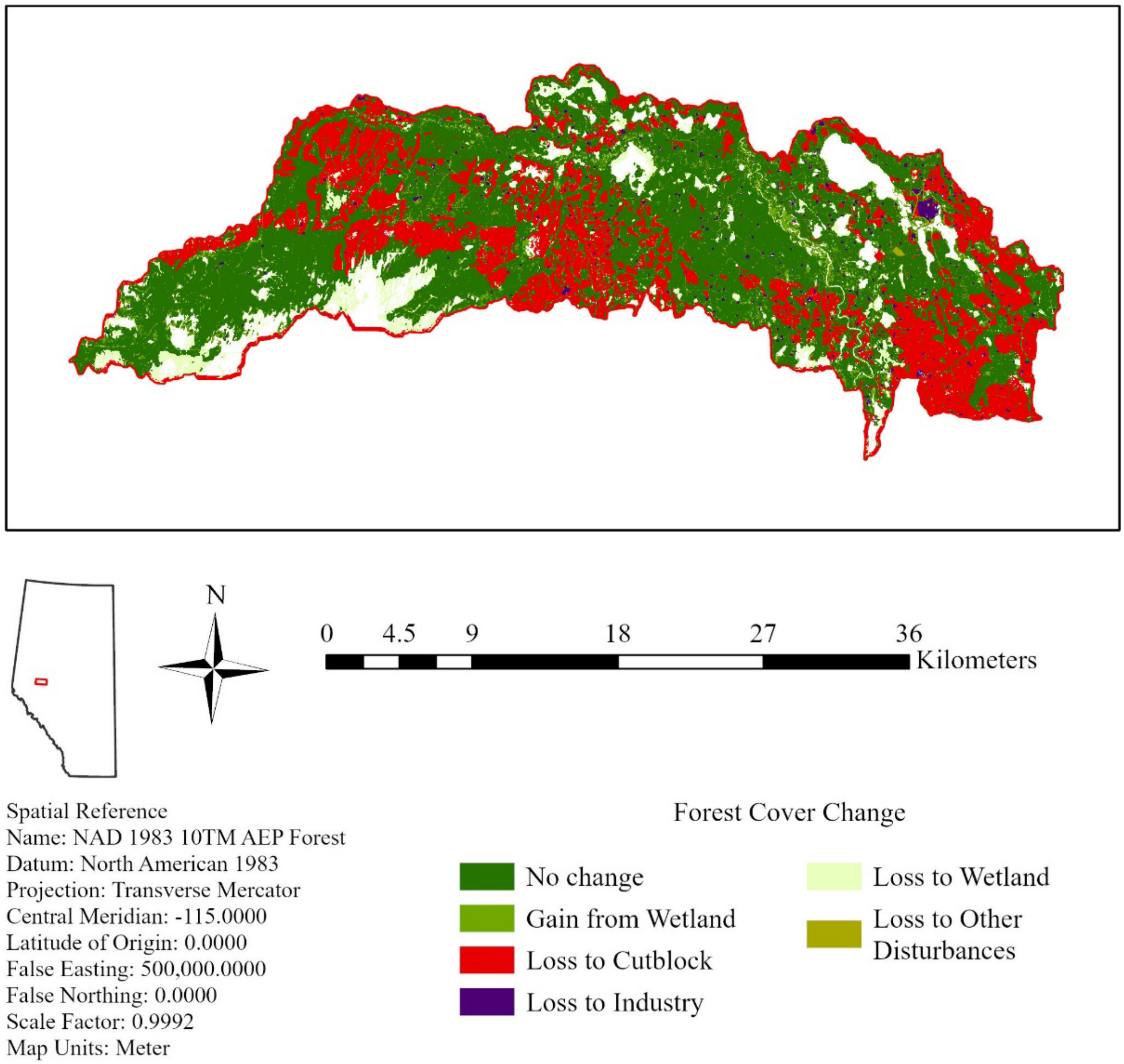


Figure 18. Changes in Forest cover in the Study Watershed from the 1950s to 2020s. Blank area (white colour) indicates Wetland or Open Water.

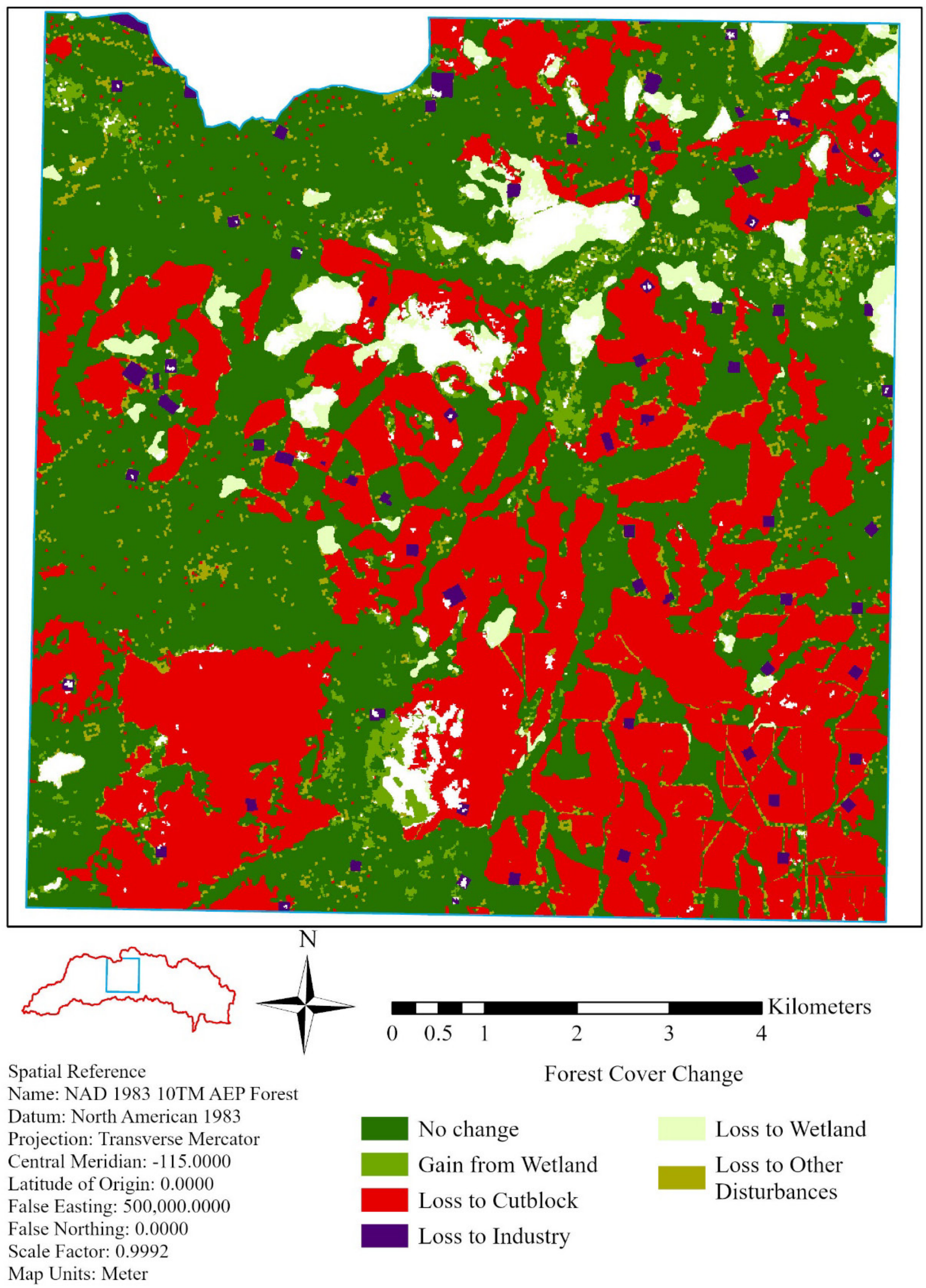


Figure 19. Changes in Forest cover in the Local Study Area from the 1950s to 2020s. Blank area (white colour) indicates Wetland or Open Water.

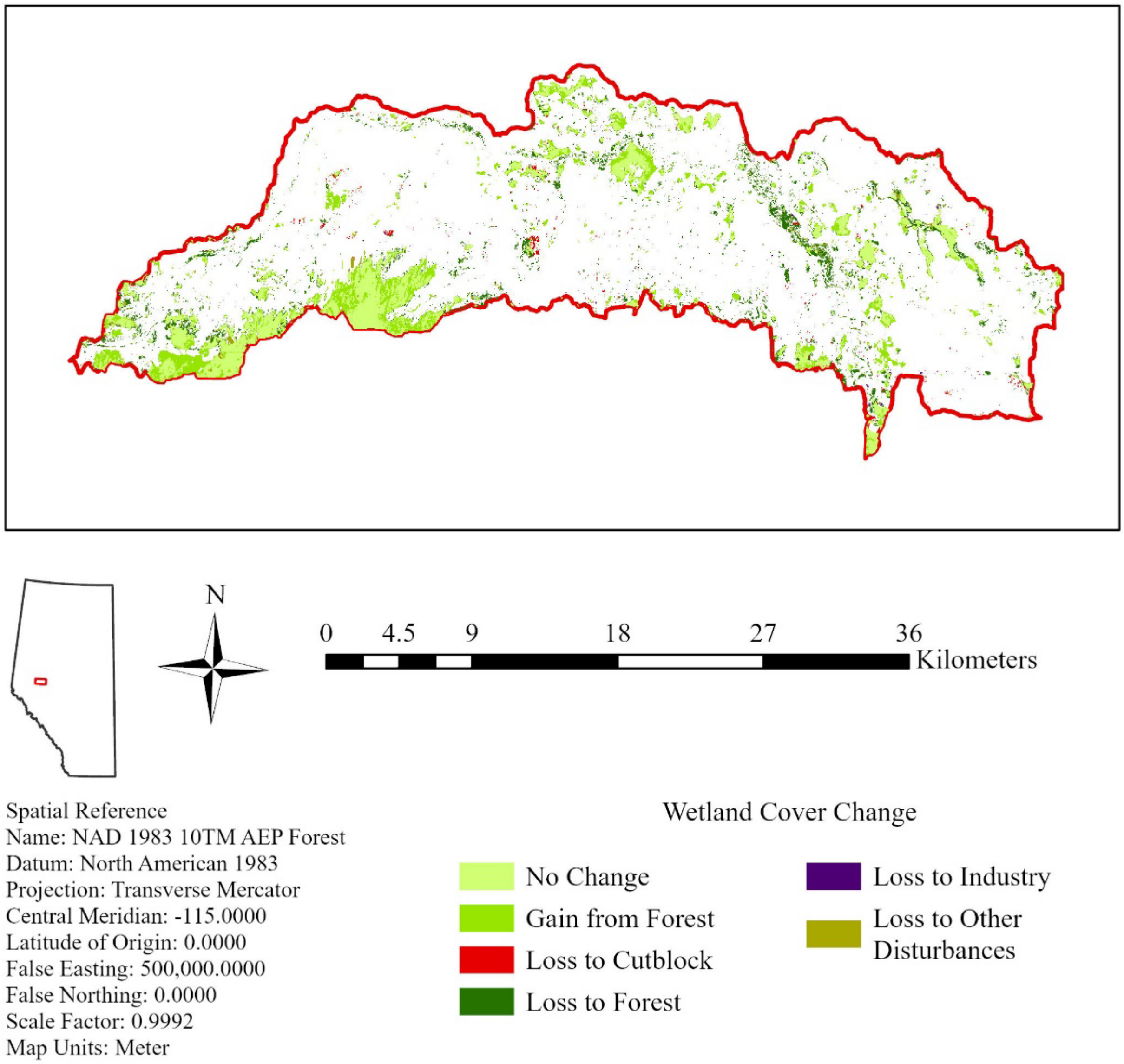


Figure 20. Changes in Wetland cover in the Study Watershed from the 1950s to 2020s. Blank area (white colour) indicates Forest or Open Water.

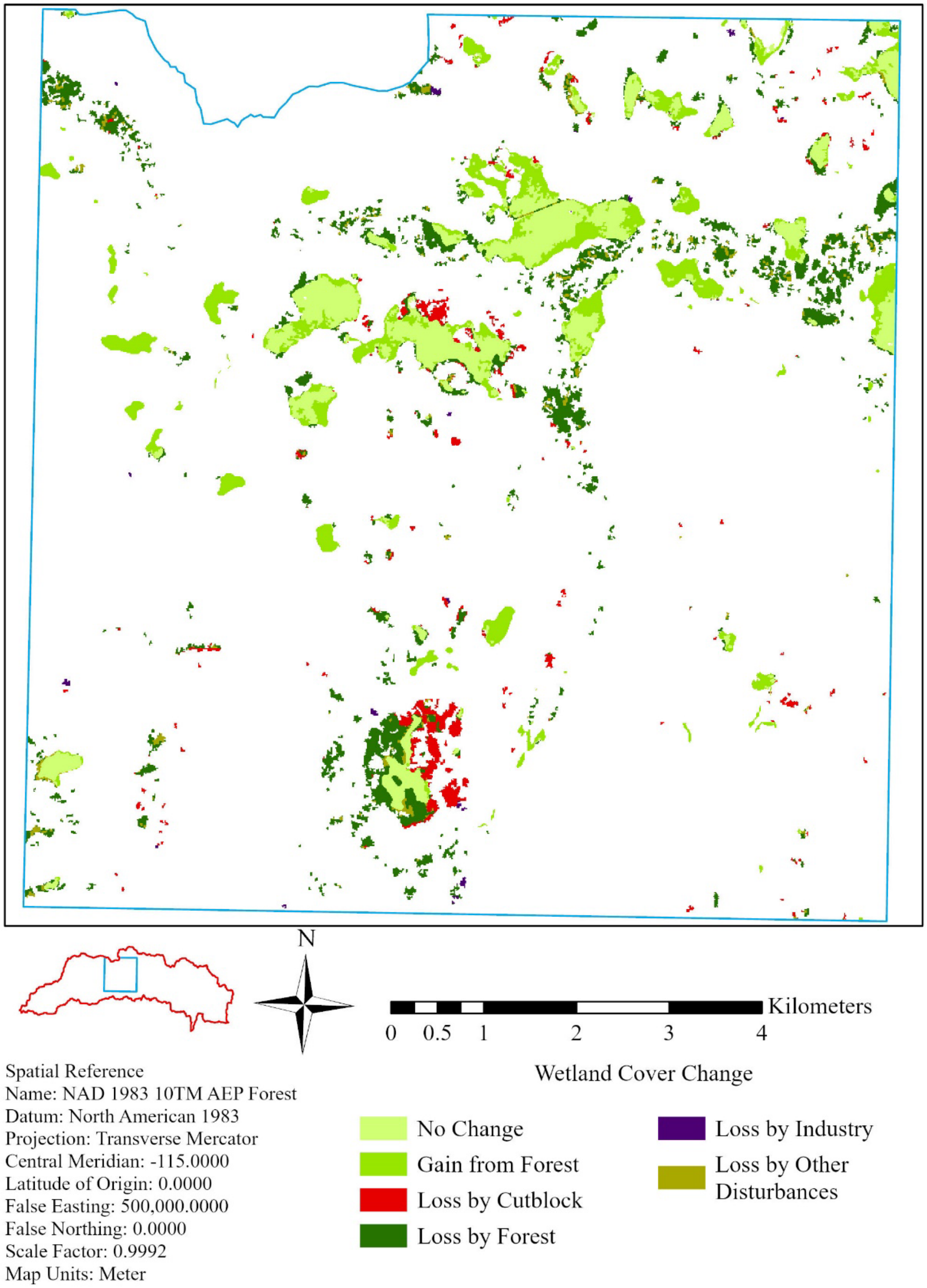


Figure 21. Changes in Wetland cover in the Local Study Area from the 1950s to 2020s. Blank area (white colour) indicates Forest or Open Water.

6. Lichen Ecosites

This part of the report is to identify the distribution of lichen-rich sites within the Fox Creek study region. The goal is to support a Canada-wide study assessing the ability of caribou to access lichen led by Julie Lovitt and Wenjun Chen. To achieve this goal, a two-step approach was developed.

The first step was to use Alberta's Derived Ecosite Phase database to screen for sites with a lichen (particularly Reindeer Lichen, *Cladina mitis,* and *rangiferina*) understory. The Fox Creek region straddles both the Upper and Lower Foothills subregions. Therefore, the published ecosite guides for both regions were used to compile a list of lichen ecosite types.

The second step was to evaluate additional parameters, such as trees and shrubs, to narrow down the lichen sites to habitats preferred by caribou. The final product was a "Caribou-Preferred Lichen Ecosite Phase Map of the Study Areas".

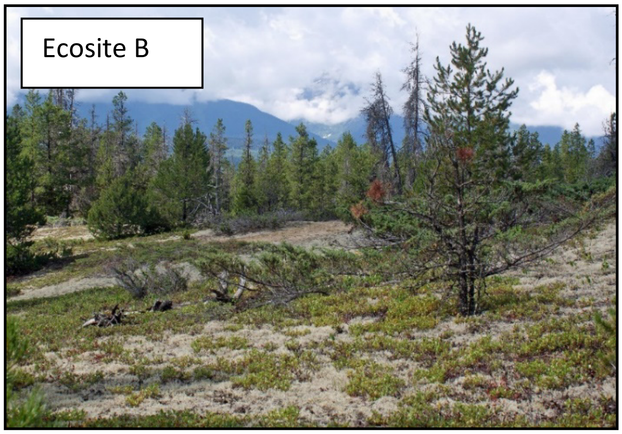
6.1. Methods and Results

Generally speaking, caribou prefer old-growth forests where the understory is dominated by ericaceous shrubs such as Labrador tea and bog cranberry (Willoughby et al. 2018, 2021). Early seral sites tend to have deciduous shrubs that can attract other prey, like deer. In the boreal regions of Alberta, woodland caribou strongly prefer treed bogs and fens and avoid well-drained habitats (Bradshaw et al. 1995).

The Ecological Sites of the Upper Foothills Subregion and Ecological Sites of the Lower Foothills Subregion Reference Guides were used to generate a map of lichen habitat in the Study Watershed. A list of ecosite phases that contained *Cladina mitis* and/or *Cladina rangiferina* as an indicator species was compiled (Table 9).

To determine which lichen-rich ecosite phases are caribou-preferred habitats, other factors, such as dominant canopy and understory species, had to be considered. Following Ray 2014, the caribou-preferred habitat was determined to be lichen-rich, with relatively pure stands of conifer trees and few deciduous shrubs.

While lichen-rich bogs (Figure 22) are known caribou habitats, neither ecosite guides of the Upper and Lower Foothills listed lichens in the ground layer of bog ecosites k1, k2, and k3. On the other hand, literature often refers to treed fens as the preferred caribou habitat (Bradshaw et al. 1995). However, based on our experience and field observation, poor, moderate-rich, and rich fens in boreal Alberta do not have a ground layer of terrestrial lichens preferred by caribou. Given the discrepancy between peatland literature and the two ecosite guides, we chose to include treed (k1) and shrubby (k2) bogs as lichen-rich ecosite phases in the final list (Table 9).



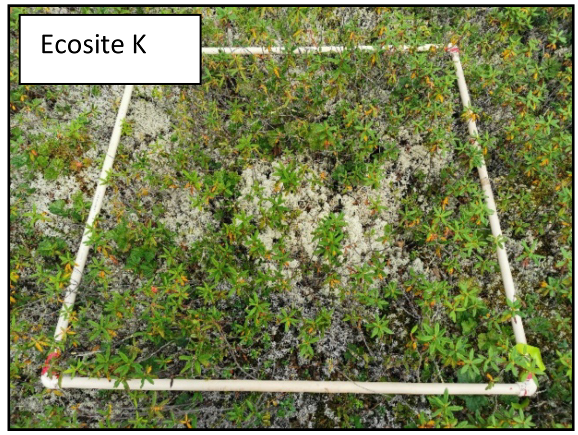


Figure 22. Left: Example of Ecosite B of the Upper Foothills Subregion. Photo by Nina Munteanu, from https://themeaningofwater.com/2022/09/04/jackman-flats-a-strange-and-unique-beauty. Right: Lichen ground layer of a continental bog (ecosite K).

Table 9 lists lichen-rich ecosite phases within the Upper and Lower Foothills subregions. Ecosite phase b1 has dry conditions with rapidly drained, acidic soil due to coarse-textured material. It has a canopy dominated by *Pinus contorta* and an understory of ericaceous shrubs, including *Arctostaphylos uva-ursi, Vaccinium vitis-idaea, Rhododendron groenlandicum,* and *Vaccinium myrtilloides* (Figure 22). In ecosite phase b2, *Populus tremuloides* is the dominant canopy species, and *Rosa acicularis,* and *Shepherdia canadensis* are prevalent in the understory.

Ecosite phase h1 in the lower foothills has a nutrient-poor substrate with poorly drained soil. This community is dominated by *Rhododendron groenlandicum,* feather mosses, and lichen in the understory and *Pinus contorta* and *Picea mariana* in the canopy.

Ecosite phase k1 represents treed bogs dominated by *Picea mariana*, *Rhododendron groenlandicum*, and *Sphagnum* mosses. Ecosite phase k2 is the shrubby phase of a bog with small trees. It is dominated by shrubs such as *Vaccinium vitis-idaea, Rhododendron groenlandicum,* and *Sphagnum* mosses. Both communities can have abundant lichen mixed in the ground layer (Figure 22 right).

Table 9. Ecosite phases with terrestrial lichen in the ground layer preferred by woodland caribou.

Ecoregion	Ecosite	Ecosite Phase	Reference Plant Community
Upper Foothills	**b** bearberry/lichen (subxeric/medium)	**b1** bearberry/lichen Pl	ufe17 Pl/Labrador tea/Bog cranberry
			ufe1 Pl/Bog cranberry
		b2 bearberry/lichen Aw	ufd1 Aw/Rose/Bearberry
	k bog (subhydric/poor)	**k1** treed bog	ufe5 Sb/Labrador tea/Cloudberry/Peat moss
		k2 shrubby bog	ufb15 Labrador tea/Cloudberry/Peat moss
Lower Foothills	**b** bearberry/lichen (subxeric/poor)	**b1** bearberry Aw-Sw-Pl	LFj1 Pl/Bearberry/Hairy wild rye
			LFj22 Pl/Blueberry/Lichen
	h Labrador tea (subhygric/poor)	**h1** Labrador tea-subhygric Sb-Pl	LFj27 Sb-Pl/Labrador tea/Feather moss
			LFj28 Sb-Pl/Green alder/Feather moss
	k bog (subhydric/poor)	**k1** treed bog	LFj19 Sb/Labrador tea/Cloudberry/Peat moss
		k2 shrubby bog	LFc14 Labrador tea/Peat moss

6.2. Caribou-Preferred Lichen Ecosite Map of the Study Areas

The caribou-preferred lichen ecosite phases within the study watershed were mapped in QGIS using the Derived Ecosite Phase v2.0 package from the Government of Alberta. Figure 23 and Table 10 show ecosite phases b1, b2, h1, k1, and k2 within the study areas.

Overall, treed bog (k1) is the most abundant type, covering 117.9 km^2 or 14.8% of the 795 km^2 Study Watershed, 12.8 km^2 or 6.5 % of the 195 km^2 Local Study Area, and 57.6 km^2 or 19.7% of the 292 km^2 overlapping Little Smoky Caribou Range.

Shrubby bog (k2) is the distant second most abundant site type, covering 3.9 km^2 or 0.5% of the Study Watershed, 0.9 km^2 or 0.5% of the Local Study Area. It is negligible (<0.1%) in the Little Smoky Caribou Range.

Ecosite phases h1 and b1 cover 0.9 km^2 (0.1%) and 0.6 km^2 (0.1%) of the Study Watershed, respectively. In the overlapping Little Smoky Caribou Range, ecosite phase b1 covers 0.1 km^2 (0.1%), and h1 covers 0.1 km^2 (<0.1%) of the 166 km^2 area. Within the Local Study Area, ecosite phases b1 and h1 are negligible (<0.1%).

Ecosite phase b2 covers 1.8 km^2 or 0.2% of the Study Watershed. These ecosites are concentrated in areas along the flow path of the Upper Little Smoky River near Smoke Lake (Figure 23). However, ecosite phase b2 is technically not a caribou-preferred site type.

The Little Smoky Caribou Range is the southernmost remaining caribou habitat within Alberta. It lies within the Foothills, Subalpine, and Alpine Natural Regions and within the Lower Foothills and Upper Foothills Subregions of the province, constituting the last boreal caribou range on the eastern slopes of Alberta (Government of Alberta 2017). Over the last half-century, the population of the Little Smoky herd has steadily declined to qualify for species at immediate risk of extirpation (Russell et al. 2016).

As of 2017, 99% of the Little Smoky range was disturbed by anthropogenic sources; 97% of the range area was leased to oil and gas companies, while 100% of the range was allocated to forestry companies, and 1% was leased to metallic and industrial mineral companies (Russell et al. 2016, Government of Alberta 2017). Treed and shrubby bogs account for roughly 20% of the overlapping Little Smoky Caribou Range. As the amount of undisturbed habitat within this range is currently far less than the 65% required by the federal caribou recovery strategy (Environment Canada 2012), all habitat that currently exists in the area and will contribute to the achievement of 65% undisturbed habitat in time is considered critical habitat (Russell et al. 2016). In order for caribou to persist within the Little Smoky range, conservation of the existing habitat and restoration of anthropogenic disturbances will need to be prioritized within this area (Government of Alberta 2017).

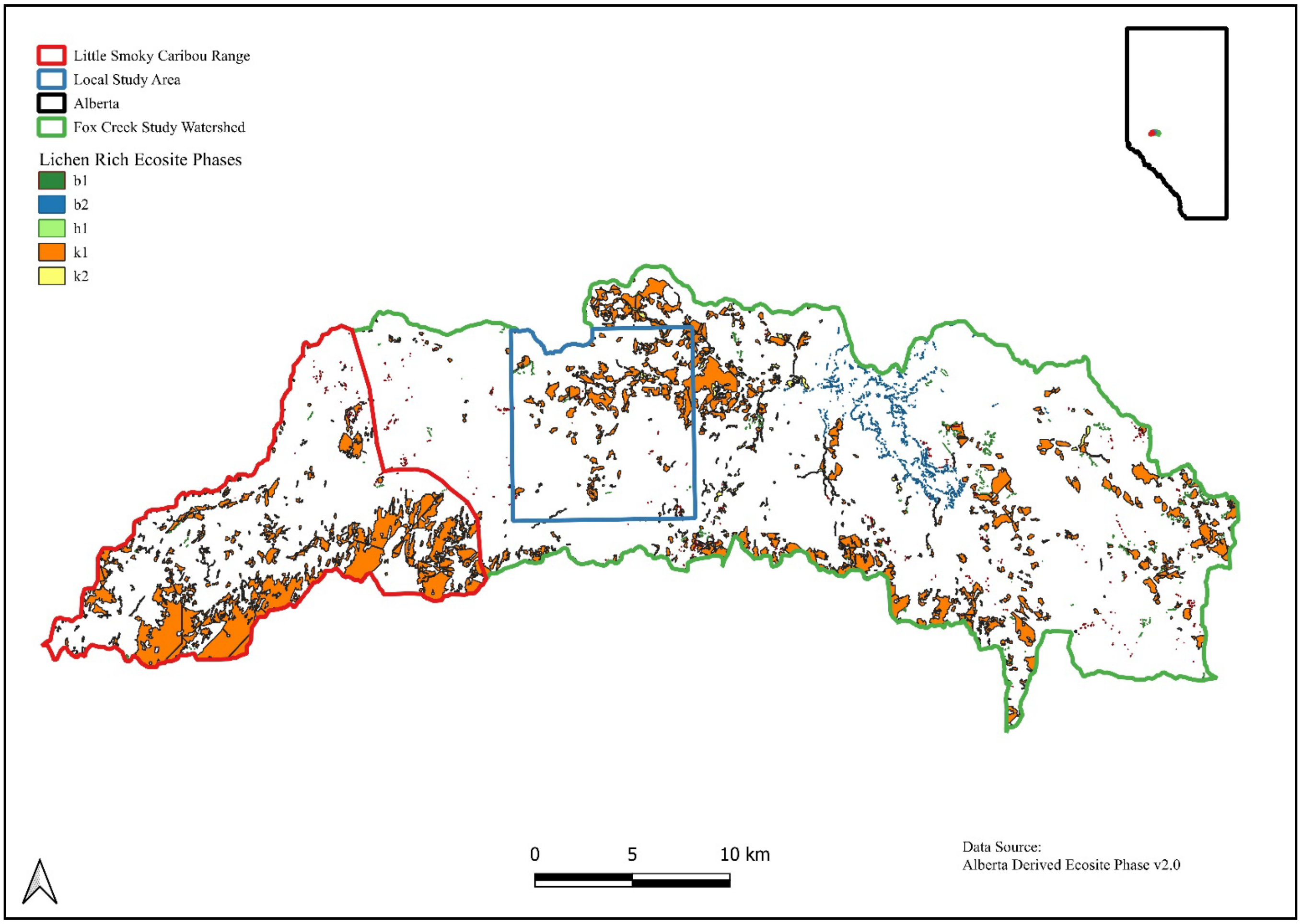


Figure 23. Map of caribou-preferred lichen ecosite phases of the study areas.

Table 10. Area and percentage of ecosite phase b1, b2, h1, k1 and k2 within the study areas. See table 9 for ecosite phase code.

Study Area	EcoSite Phase Code	Area (km^2)	Total Area (km^2)	Percentage of Total Area
Study Watershed	b1	0.6	**795.0**	0.1%
	b2	1.8		0.2%
	h1	0.9		0.1%
	k1	117.9		14.8%
	k2	3.9		0.5%
	Sum	**125.2**		**15.8%**
Local Study Area	b1	0.1	**195.0**	0.0%
	h1	0.1		0.0%
	k1	12.8		6.5%
	k2	0.9		0.5%
	Sum	**13.8**		**7.0%**
Little Smokey Caribou Range (overlapping)	b1	0.1	**292.0**	0.0%
	h1	0.1		0.0%
	k1	57.6		19.7%
	k2	0.0		0.0%
	Sum	**57.9**		**19.8%**

7. References

Alberta Biodiversity Monitoring Institute (ABMI). 2015. Historical Ortho Imagery Circa 1950-1960 Version 1.0.

Bradshaw, C. J. A., D. M. Hebert, A. B. Rippin, and S. Boutin. 1995. Winter peatland habitat selection by woodland caribou in northeastern Alberta. Canadian Journal of Zoology 73:1567–1574.

DeLancey, E. 2021. ABMI Wetland Inventory-Technical documentation ABMI Geospatial Centre March, 2021.

DeMars, C. A., and S. Boutin. 2018. Nowhere to hide: Effects of linear features on predator–prey dynamics in a large mammal system. Journal of Animal Ecology 87:274–284.

Environment Canada. 2012. Recovery Strategy for the Woodland Caribou (Rangifer tarandus caribou), Boreal population, in Canada. Ottawa.

Government of Alberta. 2017. Provincial Woodland Caribou Range Plan: Alberta's Approach to Achieve Caribou Recovery (Draft).

Ingram, R., Munir, T.M., Xu, B. 2021. Regional wetland status and sensitivity to disturbances near Fox Creek, Alberta; Geological Survey of Canada, Open File 8812, 2021, 66 pages, https://doi.org/10.4095/328584

Latham, A. D. M., M. C. Latham, M. S. Boyce, and S. Boutin. 2011. Movement responses by wolves to industrial linear features and their effect on woodland caribou in northeastern alberta. Ecological Applications 21:2854–2865.

Ray, J. C. 2014. Defining Habitat Restoration for Boreal Caribou in the Context of National Recovery: A Discussion Paper. Prepared by the Wildlife Conservation Society Canada, Toronto, Ontario for Environment and Climate Change Canada, Ottawa, Ontario.

Russell, T., D. Pendlebury, and A. Ronson. 2016. Alberta's Caribou: A Guide to Range Planning Vol 2: Little Smoky. Page 36. Edmonton, AB.

Willoughby, M., J. H. Archibald, G. D. (Grant D. Klappstein, I. G. W. (Ian G. W. Corns, J. D. (John D. Beckingham, T. L. France, D. J. Downing, and Alberta. 2018. Ecological sites of the Upper Foothills subregion : second approximation.

Willoughby, M. G., J. H. Archibald, G. D. Klappstein, I. G. W. Corns, J. D. Beckingham, and T. L. France. 2021. Ecological Sites of the Lower Foothills subregion (Fourth Approximation).