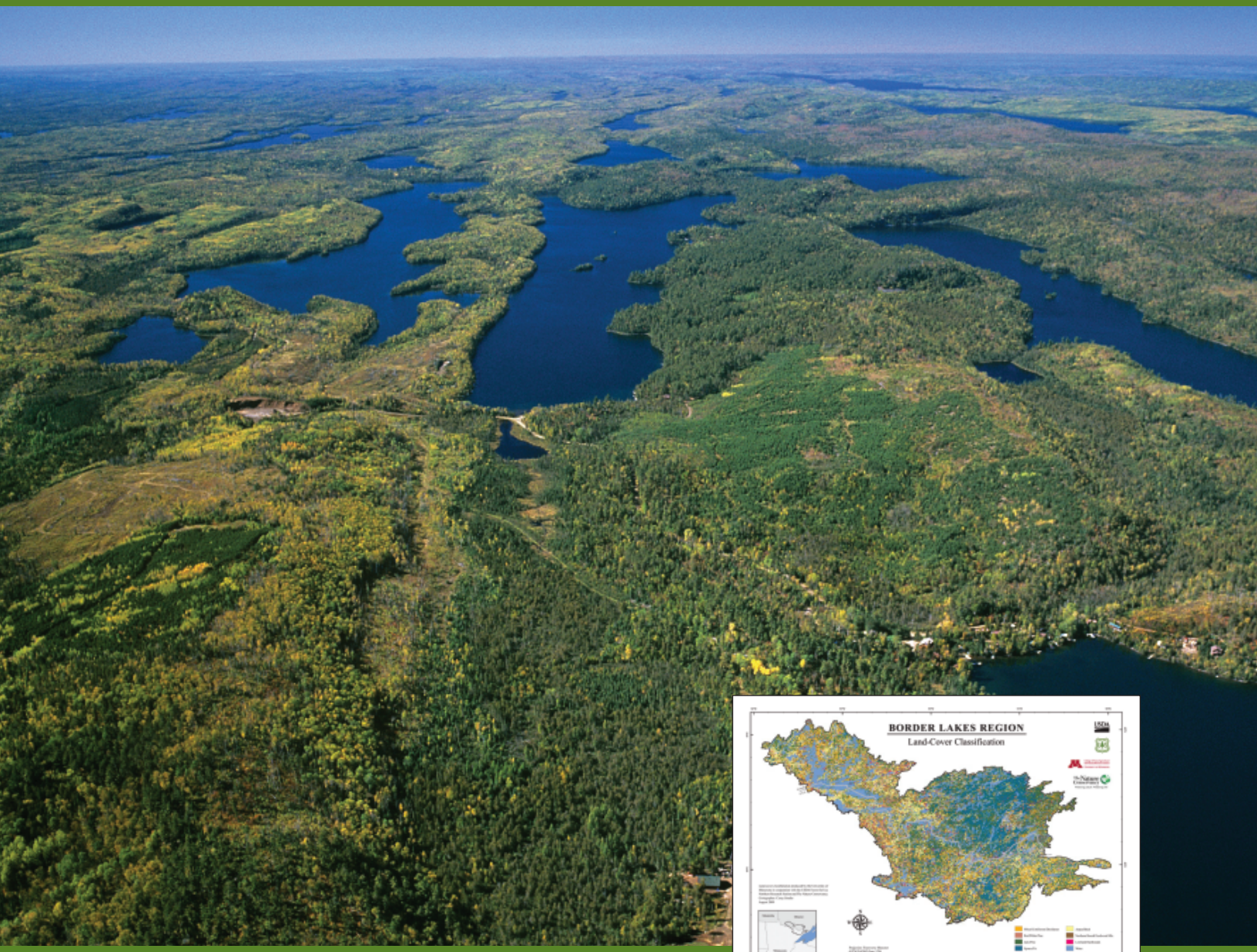
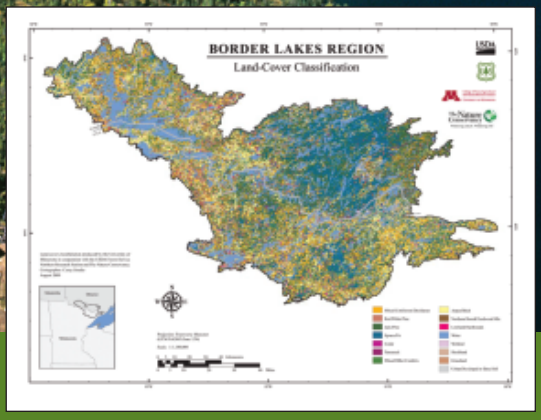
Border Lakes Land-Cover Classification

Metadata, description of land-cover classification methods, fold-out map, and digital versions of the classification





United States Department of Agriculture

Forest Service

Research Map NRS-1

Abstract

This document contains metadata and a description of land-cover classification for an approximate 5.1 million acre (2.1 million hectare) landscape bordering Minnesota, U.S.A., and Ontario, Canada. The product was created by the University of Minnesota-Geospatial Analysis Laboratory under grant by, and in collaboration with, the U.S. Forest Service Northern Research Station acting as a representative for the Border Lakes Partnership. The classification focused on the separation and identification of specific forest-cover types. Some separation of the nonforest classes also was performed. The classification was derived from multi-temporal Landsat TM/ETM+ imagery (collected from the years 1999-2001) using eCognition segmentation software to identify stands and the kNN algorithm to perform the spectral classification. Reference data sites were obtained for Minnesota from the Forest Inventory and Monitoring (FIM) program dataset and for Ontario from the Forest Resource Inventory (FRI) program. This dataset was created for use in a forest landscape model (LANDIS-II) that was designed to simulate future forest disturbance and compositional changes over the Border Lakes landscape.

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Cover photo: Clearwater Lake, Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, U.S.A. Photo copyright Airphoto–Jim Wark, all rights reserved, used with permission.

Border Lakes Land-Cover Classification

Metadata, description of land-cover classification methods, fold-out map, and digital versions of the classification

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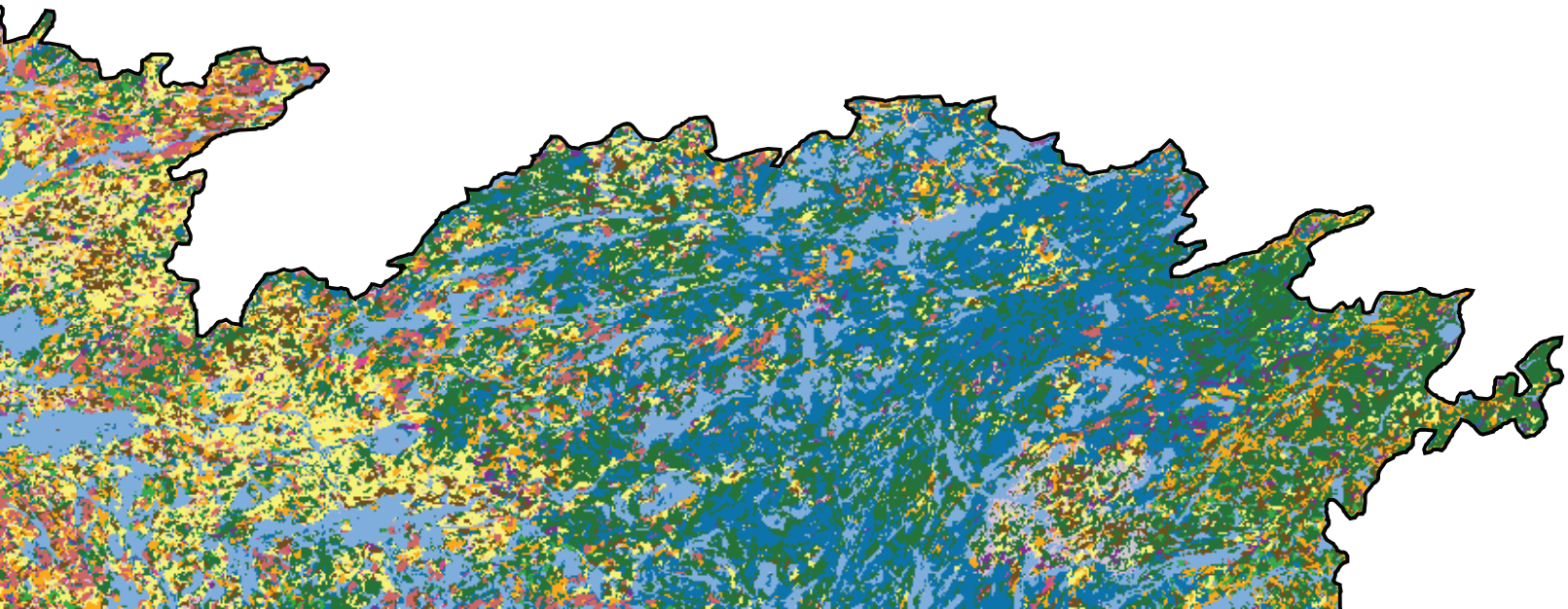

About this Publication

This map product is derived from a Landsat land-cover classification for the Border Lakes Region in northern Minnesota and northwestern Ontario—a lake-filled landscape in the southern boreal forest that covers 5.1 million acres (2.1 million hectares) and includes Voyageurs National Park, Quetico Provincial Park, the Boundary Waters Canoe Area Wilderness, other public (state, provincial, county), First Nation/tribal, and private lands. The classification was developed by the University of Minnesota for the U.S. Forest Service Northern Research Station and The Nature Conservancy. The classification was used as a key map layer for an ecological modeling research project, known as the Border Lakes Project (BLP). The BLP was designed to help land management agencies and other organizations understand the effects of long-term disturbance dynamics, especially fire and timber harvest, on forest ecosystems. The BLP used a forest landscape computer model, called LANDIS-II, to simulate various management scenarios, including collaborative, cross-boundary strategies to manage forest resources, reduce hazardous fuels, and conserve biodiversity.

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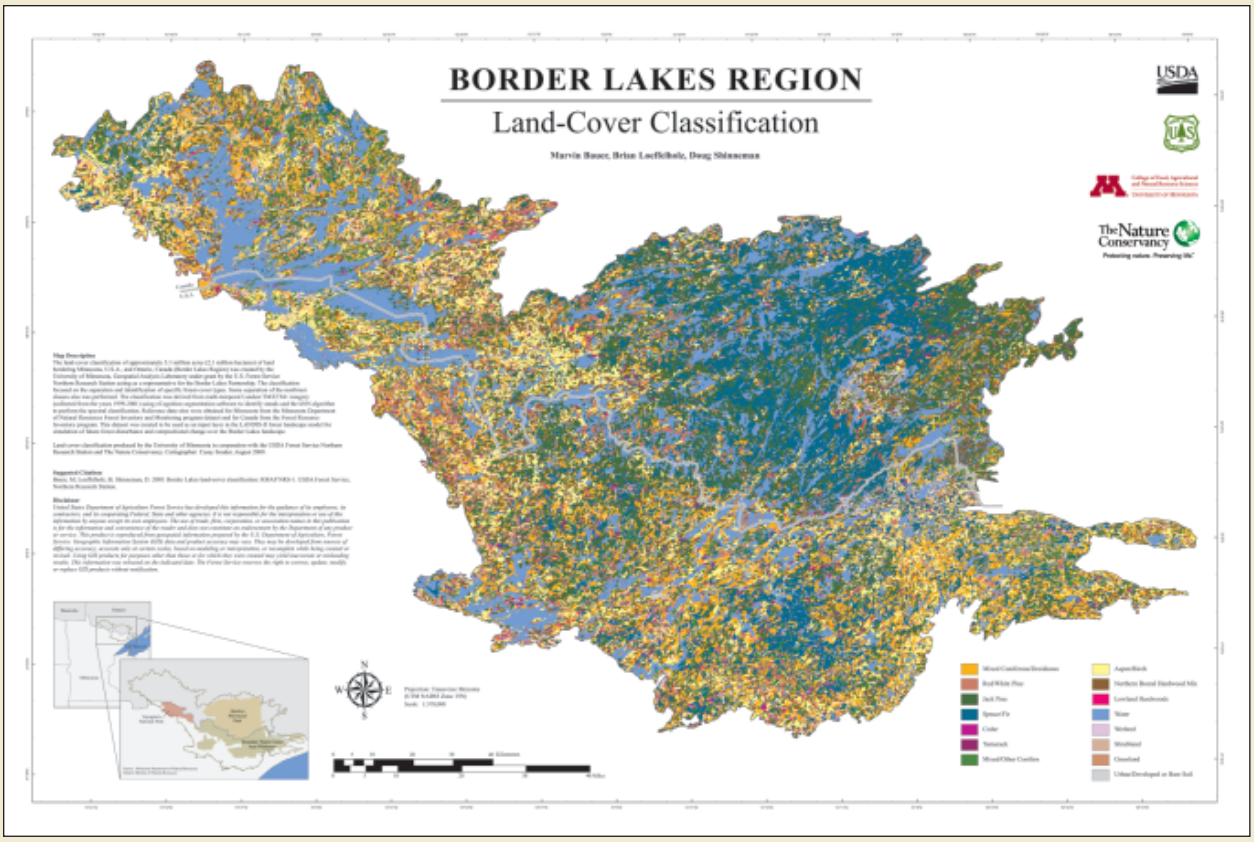
DVD Contents:

- Map in PDF format
  Software required: Adobe Acrobat Reader
- Map in GeoTIFF format
  Software required: Geographic Information System software (e.g., ESRI ArcGIS)
- Documentation Booklet in PDF format



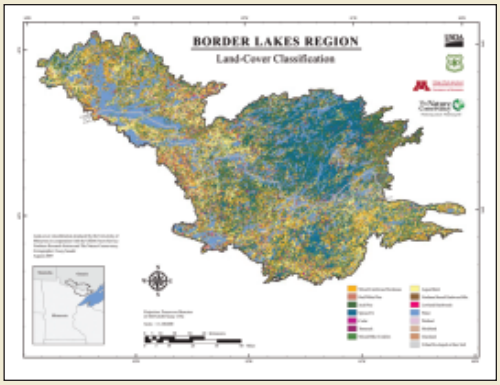
About the Dataset

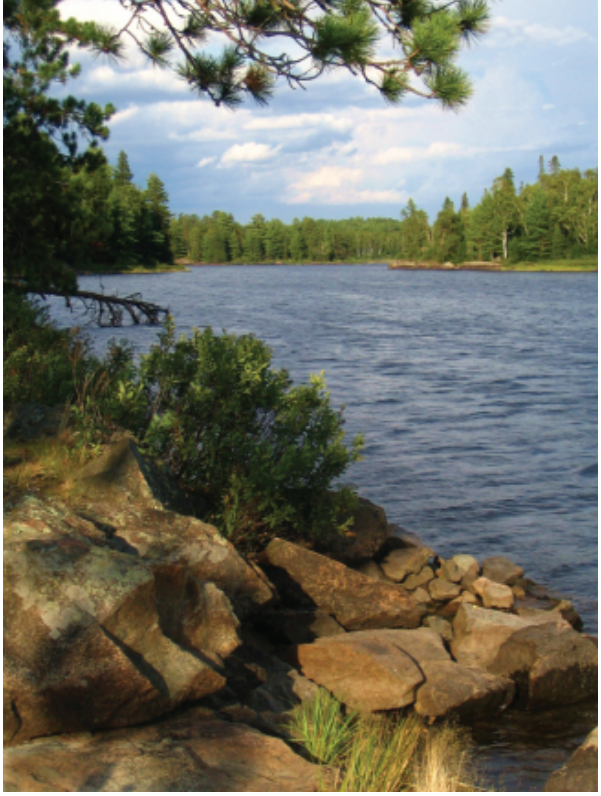
This dataset is provided in three digital formats (on a DVD) and as two hard-copy maps (specifications listed below). The maps and DVD are located in the back of this publication.

1) A GeoTIFF (*.tif) file. This file format is a georeferenced raster image that can be viewed, edited, queried, and manipulated using a geographic information system (GIS). The GeoTIFF data also includes an attribute table with cover-type category names and classification codes (refer to the metadata for details), and FGDC-compliant metadata (available in both XML and HTML formats).

2) A 21 inch x 32 inch poster with a locator map and a legend indicating major cover types. This product is provided as both a printable PDF file and a folded paper poster.

3) An 8 1/2 inch x 11 inch poster with a locator map and a legend indicating major cover types. This product is provided as both a printable PDF file and an attached paper map (page 14).





Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, U.S.A. Photo by Doug Shinneman, used with permission.

Introduction

The land-cover classification of approximately 5.1 million acres (2.1 million hectares) of land bordering Minnesota, U.S.A. and Ontario, Canada (Border Lakes Region) was created by the University of Minnesota, Geospatial Analysis Laboratory under grant by the U.S. Forest Service Northern Research Station acting as a representative for the Border Lakes Partnership. The classification focused on the separation and identification of specific forest-cover types. Some separation of the nonforest classes also was performed. The classification was derived from multi-temporal Landsat TM/ETM+ imagery (collected from the years 1999-2001) using eCognition segmentation software to identify stands and the kNN algorithm to perform the spectral classification. Reference data sites were obtained for Minnesota from the Minnesota Department of Natural Resources (MNDNR) Forest Inventory and Monitoring (FIM) program dataset used in forest resource management plans (Minnesota Department of Natural Resources 2005) and for Canada from the Forest Resource Inventory (FRI) program (Ontario Ministry of Natural Resources 2004). This dataset was created to be used as an input layer in the LANDIS-II forest landscape model for simulation of future forest disturbance and compositional change over the Border Lakes landscape.

There were four objectives: (1) to divide the Landsat imagery into groups of pixels that represent areas of continuous cover types on the ground, referred to as stands; (2) to produce a land-cover classification that separated the land cover into forest, nonforest, and water classes; and (3) to delineate the forest areas into more specific forest-cover-type classes (i.e., white pine, jack pine, spruce/fir, aspen/birch, etc).

The spatial extent of the data is the ecologically defined Border Lakes Region, which includes most of the Boundary Waters Canoe Area Wilderness (BWCAW), Quetico Provincial Park (Ontario, Canada), and Voyageurs National Park.

About the Border Lakes Partnership

The Border Lakes Partnership is an interagency team of natural resource professionals from land-owning agencies and other organizations concerned with the management of the Border Lake region's resources. The overarching goal of the group is to develop collaborative, cross-boundary strategies for managing forest resources, reducing hazardous fuels, and conserving biodiversity. The group plans to identify a variety of land management options that will help agencies to achieve mutual goals. A number of technical experts have contributed, including: U.S. Forest Service Northern Research Station and Superior National Forest; Minnesota Department of Natural Resources; Voyageurs National Park; Quetico Provincial Park; The Nature Conservancy; The Nature Conservancy of Canada; Legacy Forest Project (Canada); Canadian Forest Service; and Ontario Ministry of Natural Resources. The Partnership also cooperates with other interagency organizations, including the Minnesota Forest Resources Council.

Classification

Two levels of classification were performed. The first classification, Level 1, had three classes: forest, nonforest, and water. The second classification, Level 2, was performed separately on the Level 1 forest and nonforest classes.

The Level 2 forest classification focused on identifying and separating forest-cover types.
The Level 2 nonforest classification focused on separating nonforest cover types (i.e. wetland, shrubland, grassland, and urban/soil).

Cover types for the Level 1 and Level 2 classifications are defined in the cover-type classification scheme listed on page 11.

Data Quality

Level 2 classification accuracy is assessed with a traditional error matrix. Accuracy assessment sites were randomly selected for each Level 2 class from field verified datasets. Points were generated from the existing datasets and the points were then visually compared to high resolution imagery for location and adjusted when necessary. A total of 738 accuracy test points were generated. Level 2 accuracy assessment data were only available for the individual forest-cover-type classes. Nonforest cover types were only assessed as a whole.

Accuracy

Producer's Accuracy — This refers to the proportion of reference points for each category that were accurately classified. (Cover-type categories listed below and the numbers in parentheses correspond to the cover-type category in the attribute table of the GeoTIFF dataset included on the DVD in this publication.)

- Mixed coniferous/deciduous (1) – 31.7 percent
- Red pine/white pine (2) – 42.4 percent
- Jack pine (3) – 45.3 percent
- Spruce/fir (4) – 29.8 percent
- Cedar (5) – 41.7 percent
- Tamarack (6) – 44.8 percent
- Mixed/other coniferous (7) – 15.0 percent
- Aspen/birch (8) – 32.8 percent
- Northern boreal hardwood mix (9) – 22.9 percent
- Lowland hardwoods (10) – 24.3 percent
- Water (11) – 98.9 percent
- Nonforest (12) – 34.9 percent

User's Accuracy — This refers to the proportion of the pixels assigned to each category that were accurately classified.

- Mixed coniferous/deciduous (1) – 17.9 percent
- Red pine/white pine (2) – 44.6 percent
- Jack pine (3) – 24.0 percent
- Spruce/fir (4) – 32.1 percent
- Cedar (5) – 66.7 percent
- Tamarack (6) – 48.2 percent
- Mixed/other coniferous (7) – 17.7 percent
- Aspen/birch (8) – 19.2 percent
- Northern boreal hardwood mix (9) – 15.7 percent
- Lowland hardwoods (10) – 60.0 percent
- Water (11) – 100.0 percent
- Nonforest (12) – 86.9 percent

Overall Accuracy

- 41.3 percent

Kappa 0.42

Horizontal positional accuracy

- RMS error <7.5 m or $^1/_4$ pixel

Vertical positional accuracy

- RMS error <7.5 m or $^1/_4$ pixel

Imagery and Imaging Preprocessing

To obtain an acceptable level of classification accuracy at the species level requires the use of multi-temporal image classification which utilizes the seasonal phenological variability in land covers to aid in spectral identification. The Landsat TM and ETM+ images acquired for this project were multi-temporal image sequences of spring, summer, and fall imagery. To cover all of the Border Lakes Region, a minimum of five images for each date were needed. The Landsat imagery used for the project are as follows:

Patch(P):28 Row(R):26
Spring: 20 April, 2000 - ETM+
Summer: 26 August, 2000 - ETM+
Fall: 21 October, 2000 - TM

P:27 R:26
Spring: 29 April, 2000 - ETM+
Summer: 18 July, 2000 - ETM+
Fall: 22 October, 2000 - ETM+

P:26 R:26
Spring: 25 April, 2001 - ETM+
Summer: 13 September, 2000 - ETM+
Fall: 13 October, 1999 - ETM+

P:27 R:27
Spring: 29 April, 2000 - ETM+
Summer: 12 September, 2000 - TM
Fall: 05 November, 1999 - ETM+

P:26 R:27
Spring: 28 April, 1999 - TM
Summer: 07 August, 2001 - TM
Fall: 13 October, 1999 - ETM+

Imagery was rectified to the Universal Transverse Mercator (UTM) coordinate and projection system to an root mean square (RMS) error of less then 1/4 pixel (7.5 meters) using approximately 25 ground control points per image. The base layer used was the Minnesota Department of Transportation map of major roads map and the Ontario roads map. The imagery was nearest neighbor resampled to a 30-meter pixel size and the coordinates of the final image were adjusted to values evenly divisible by 30. Format of rectified imagery is unsigned 8-bit in the UTM, spheroid GRS80, datum NAD83, Zone 15 coordinate system.

Following rectification the imagery was then mosaicked by season. The five images necessary for complete coverage of the Border Lakes Region by season were mosaicked to produce a single image for three seasons (spring, summer, fall) with six bands each (1, 2, 3, 4, 5 and 7).

During the mosaicking process we established spectrally consistent classification units (SCCUs) to identify where the image boundaries were located. This is essential when classifying a large area with imagery from multiple dates and years. Five SCCUs were identified for the Border Lakes project. The SCCUs will be used for stratification during the classification process.

Computation of an additional feature, normalized difference vegetation index (NDVI), was then performed on the separate mosiacked imagery. NDVI is a spectral radiometric transformation that is sensitive to the amount of green vegetation. This created three new images with a single layer of NDVI for each.

Sample from Landsat 7 ETM+ data used to classify the Border Lakes Region land cover. This image was created using bands 1, 2, and 3 to create a natural color image. Source: Landsat 7 ETM+ P27 R26 July 18, 2000.

The mosaicked Landsat imagery as well as the NDVI imagery was then layer stacked to produce a single 21-band image. This image consisted of the six spectral bands (1, 2, 3, 4, 5, and 7) from each season (spring, summer, and fall) as well as the three texture layers from the NDVI images. The layer order is as follows:

band01: Spring/band1
band02: Spring/band2
band03: Spring/band3
band04: Spring/band4
band05: Spring/band5
band06: Spring/band7
band07: Summer/band1
band08: Summer/band2
band09: Summer/band3
band10: Summer/band4
band11: Summer/band5
band12: Summer/band7
band13: Fall/band1
band14: Fall/band2
band15: Fall/band3
band16: Fall/band4
band17: Fall/band5
band18: Fall/band7
band19: Spring/NDVI
band20: Summer/NDVI
band21: Fall/NDVI

Voyageurs National Park, Minnesota, U.S.A. Photo by Cory Mcnulty, Voyageurs National Park Association, used with permission.

Image Segmentation:

We used eCognition image software to separate the mosaicked layer-stacked imagery into areas of consistent cover type that represented stands. This software groups pixels into areas where the spectral values are the most alike within the group and least like those out outside the group. The parameter settings for eCognition segmentation were as follows:

Scale Parameter - 10
Shape Factor - 0.1
Smoothness - 0.5
Compactness - 0.5

These setting were chosen after several trial segmentations were performed and the resulting segments compared to stand size statistics from the Minnesota Department of Natural Resources (MNDNR) Forest Inventory and Monitoring (FIM) data and Ontario Forest Resource Inventory (FRI) datasets. The MNDNR-FIM dataset had mean stand size of 7.2 acres, standard deviation of 10.5 acres, maximum stand size of 177.1 acres, and minimum stand size of less then 0.1 acre. The Ontario-FRI dataset had mean stand size of 10.8 acres, standard deviation of 253.5 acres, maximum stand size of 911.0 acres, and minimum stand size of less then 0.1 acre. Using the previously mentioned parameter settings, the resulting segmentation stand statistics were mean stand size of 32.88 acres, standard deviation of 30.97 acres, maximum stand size of 368.3 acres, and minimum stand size of 0.2 acre.

The SCCU data also were included as a thematic layer in eCognition during the segmentation process. This ensured that image segment boundaries stopped at the edges of the SCCUs.

When the image segmentation was complete, the data were exported from eCognition as a shapefile, creating a polygon for each image segment. Attributes of the segments retained during the export were: (1) the mean spectral value within the individual segments for each of the 21 layers; (2) the standard deviation of the spectral value within the individual segments for each of the 21 layers; and (3) the SCCU the segment was within.

Classification Techniques

The Level 1 classification was performed using ERDAS Imagine maximum likelihood image classification software. The maximum likelihood algorithm assigns each unknown (target) pixel the field attributes of the most spectrally similar reference object from the field reference data. The similarity is defined in terms of the feature space. The Level 1 classification was performed for each individual SCCU separately and then combined to create a coverage of the entire Border Lakes Region. This was performed four times to create classifications based on the four time combinations: spring/summer/fall, spring/summer, summer/fall and spring/fall. Of these four, the primary classification was the three-date classification. Areas in the three-date classification that had clouds were substituted with clear portions of the corresponding two-date classification. This created a complete, cloud-free, Level 1 classification with classes of forest, nonforest, and water.

The Level 2 forest classification was restricted to the area identified in the Level 1 classification as forest. This classification was performed using the University of Minnesota's kNN image classification software. The kNN software assigns each unknown (target) object the field attributes of the most similar reference object(s) for which field data exists. The similarity is defined in terms of the feature space, typically measured as Euclidean distance. The nonparametric algorithm of this unique method overcomes low sampling intensity limitations to produce truly useful maps of forest attributes collected through field inventory (Franco-Lopez et al. 2001). The classification was again performed for the four time combinations: spring/summer/fall, spring/summer, summer/fall, and spring/fall. Of these four, the primary classification was the three-date classification. Areas in the three-date classification that with clouds were substituted with portions of the corresponding clear areas from the two-date classification. This created a complete, cloud-free, Level 2 classification of the specific forest cover types. Following classification, the Level 2 forest vector cover type classification was converted to raster format. The data was converted to 30-meter by 30-meter pixels. Following the conversion, the raster data set was spatially adjusted to have coordinates divisible by 30. This ensured that the Level 2 cover-type pixels would overlap with other 30-meter pixel datasets.

The Level 2 nonforest classification was restricted to the area identified in the Level 1 classification as nonforest. This classification was performed using ERDAS Imagine maximum likelihood image classification software. Each SCCU was classified separately as well as for the four time combinations. Of these four, the primary classification was the three-date classification. Areas in the three-date classification with clouds were substituted with portions of the corresponding clear areas from the two-date classification. This created a complete, cloud-free, Level 2 classification of the specific nonforest cover types.

Readers should note that forest training sites (used to derive classification parameters) for Minnesota were obtained from the MNDNR-FIM dataset and from the Ontario–FRI dataset. We made an effort to match the cover-type descriptions between the inventory datasets and the remotely sensed cover type within the limitations of remote sensing capabilities. Examples: white pine, red pine, oak, mixed conifer and mixed deciduous.

Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, U.S.A. Photo by Doug Shinneman, used with permission.

Cover-type Classification Scheme

Forest: An upland or lowland area of land covered with woody perennial plants, the tree reaching a mature height of at least 6 feet with a definite crown. To be considered a forested cover type the stand must have a combined species minimum volume of 3 cords/acre or 1,251 board feet/acre or 251 stems/acre depending on size class (MN Common Cooperative Stand Assessment [CCSA] standards)

Coniferous: Upland areas whose canopies have a distinct crown closure of which no less than two-thirds (67 percent), based on volume measures, should be of the coniferous tree group. If the broad-leaved deciduous species group is present, it should not exceed one-third (33 percent) of the canopy), based on volume measures, (Examples: jack pine, red pine, white spruce, balsam fir, tamarack.)

Red pine/white pine: No less than 80 percent of the conifer stand volume should be red pine, white pine or a combination of the two species.

Jack pine: No less than 80 percent of the conifer stand volume should be jack pine.

Spruce/fir: No less than 80 percent of the conifer stand volume should be composed of a single or a mix of black spruce, white spruce and/or balsam fir.

Cedar: No less than 80 percent of the conifer stand volume should be northern white cedar.

Tamarack: No less than 80 percent of the conifer stand volume should be tamarack.

Mixed/other conifers: In the case of mixed conifers, no less than 80 percent of conifer stand volume is not of a single coniferous species but rather a mix of coniferous species, but not a mix listed previously.

Broad-leaved deciduous: Upland areas whose canopies have a distinct crown closure of which no less than two-thirds (67 percent), based on volume measures, should be of the broad-leaved deciduous tree group. If the coniferous species group is present, it should not exceed one-third (33 percent) of the canopy, based on volume measures. (Examples: aspen, oak, maple, birch.)

Aspen/birch: No less than 80 percent of the deciduous stand volume should be composed of quaking aspen, big-toothed aspen, balsam poplar, and paper birch.

Northern boreal hardwood mix: No less than 80 percent of the deciduous stand volume should be composed of a single or a mix of quaking aspen, bigtoothed aspen, balsam poplar, paper birch, red maple, sugar maple, silver maple, basswood, red oak, northern pin oak, burr oak and/or boxelder. No more than 79 percent of the deciduous stand volume should be composed of a single or mix of aspen (*Populus* spp.) and/or birch (*Betula* spp.).

Lowland hardwoods: No less than 80 percent of the deciduous stand volume should be composed of a single or a mix of black ash and elm.

Mixed coniferous/deciduous: In the case of mixed broad-leaved deciduous/coniferous forest, canopy percent must have a distinct canopy closure, of which no more than two-thirds (67 percent), based on volume measures, should be from the coniferous or broad-leaved deciduous.

Nonforest

Urban/developed or bare soil: An area of any amount of impervious cover of manmade solid materials or compacted soils including areas with interspersed vegetation. Examples: parking lots, shopping malls, warehouses, industrial parks, highways, sparse development, single family residential developments, single lane roads, and mines. Also, any sparsely vegetated exposures of soil, sand, or rock (less than 33 percent coverage). If vegetation is present, it is low density and not uniformly distributed throughout the stand.

Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, U.S.A. Photo by Doug Shinneman, used with permission.

Grassland: An upland or lowland area covered by cultivated or noncultivated herbaceous vegetation predominated by grasses, grass-like plants and forbs. Includes nonagricultural upland vegetation dominated by short manicured grasses and forbs as well as noncultivated herbaceous vegetation dominated by native grasses and forbs. Examples: golf courses, lawns, athletic fields, wet and dry prairies, and pastures.

Wetland: A lowland area with a cover of persistent and nonpersistent herbaceous plants standing above the surface of wet soil or water. Examples: cattails, marsh grass, sedges, and peat.

Shrubland: An upland or lowland area with vegetation that has a persistent woody stem, generally with several basal shoots, low growth of less than 20 feet in height. Area has less than 251 stems/acre of commercial tree species, the shrub species are fairly uniformly distributed throughout and the density of the coverage is moderate to high. (Examples: alder, willow, buckthorn, hazel, sumac, and scrub oak) Note: all scrubland training sites were obtained from the MNDNR CCSA data and thus an effort was made to match the cover-type descriptions between the two data sets within the limitations of remote sensing capabilities.

Water: An area of open water with none or very little above surface vegetation. Example: lakes, streams, rivers, and open wetlands.

Reference Sites

Reference sites (used to assess classification accuracy) were generated from the Minnesota FIM, the Ontario FRI cover type, and the MNDNR digital line graph (DLG) data. These are polygon datasets that offered detailed stand-level information about cover types as well as when and how the data were collected. This dataset was created as an input layer in the LANDIS forest landscape model for simulation of future forest disturbance and compositional change over the Border Lakes landscape. Both Level 1 (forest, nonforest, and water) as well as detailed Level 2 forest-cover-type data was extracted from these datasets along with forest stand age information.

Processing of these datasets was needed to make them suitable for use as spectral signature references for a Landsat image classification. First, all the available reference sites were buffered internally by 30 meters. This ensured that there would not be edge pixels included in the spectral signature extracted from the Landsat images for the reference sites. Second, the area of the buffered reference sites was calculated and retained only those stands that were 1.0 hectare or greater. This ensured that several Landsat pixels would be contained within the reference site.

Adjustments also had to be made to the attributes of the reference datasets before utilization. The reference data originated from several sources which classified the cover types based on different definitions, thus a standardization process was needed to create reference data that were consistent across the entire Border Lakes Region. This was particularly the case for the forest reference sites. The reference sites were standardized to cover type definitions specifically defined for the Border Lakes Project. Standardization was based on forest species composition information supplied in the attribute data. The MNDNR-FIM data was standardized using forest-volume attributes and the Ontario-FRI was standardized using species composition attributes.

Selection of sites was performed randomly with a goal of 10 to 20 reference sites per cover type for each SCCU. Sites were selected at the lowest cover-type level and included the following cover types:

- Forest (10 types): red pine, white pine, jack pine, spruce/fir, cedar, tamarack, mixed/other conifers, aspen/birch, northern boreal hardwood mix, lowland hardwoods, and mixed coniferous/deciduous.
- Nonforest (five types): urban/bare soil, agriculture, grassland, wetland, and shrubland.
- Water

For those cover types which had fewer then 10 reference sites, all available sites were used. Also, several cover types did not have any reference sites for one of several SCCUs due to little or no presence of the particular cover type in that region.

Spectral information for each reference site was extracted from the Landsat imagery using the zonal attributes function in the ERDAS Imagine software. Spectral information calculated from the imagery for each reference site included the mean spectral value within each reference site for all 21 spectral layers as well as the standard deviation of the spectral values within each reference site for all 21 spectral layers.

Clouds and cloud shadows were identified by visual interpretation of the Landsat imagery. Once identified, the boundaries of the clouds/cloud shadows were digitized. This was performed separately for each mosaicked date of Landsat imagery.

Map

This dataset found on the DVD in the back of this publication is provided in three formats:

- A GeoTIFF (*.tif) file. This file format is a georeferenced raster image that can be viewed, edited, queried, and manipulated using a geographic information system (GIS). The GeoTIFF data also includes an attribute table with cover-type category names and classification codes (refer to the metadata for details), and FGDC-compliant metadata (available in both XML and HTML formats).
- A 21 inch x 32 inch poster with a locator map and a legend indicating major cover types. This product is provided as both a printable PDF file and a folded paper poster.
- An 8 1/2 inch x 11 inch poster with a locator map and a legend indicating major cover types. This product is provided as both a printable PDF file and an attached paper map.

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We would like to thank Ebrahim Abdela (University of Minnesota) for assisting with datasets used to produce this classification; Casey Souder (The Nature Conservancy) for his data assistance and cartographic contributions; and Brian Sturtevant (U.S. Forest Service Northern Research Station), Mark White (The Nature Conservancy), and others (anonymous) for reviewing earlier iterations of this classification. We would also like to thank the many organizations and agencies in Ontario and Minnesota who were engaged in the Border Lakes Partnership and provided reference data and advice.

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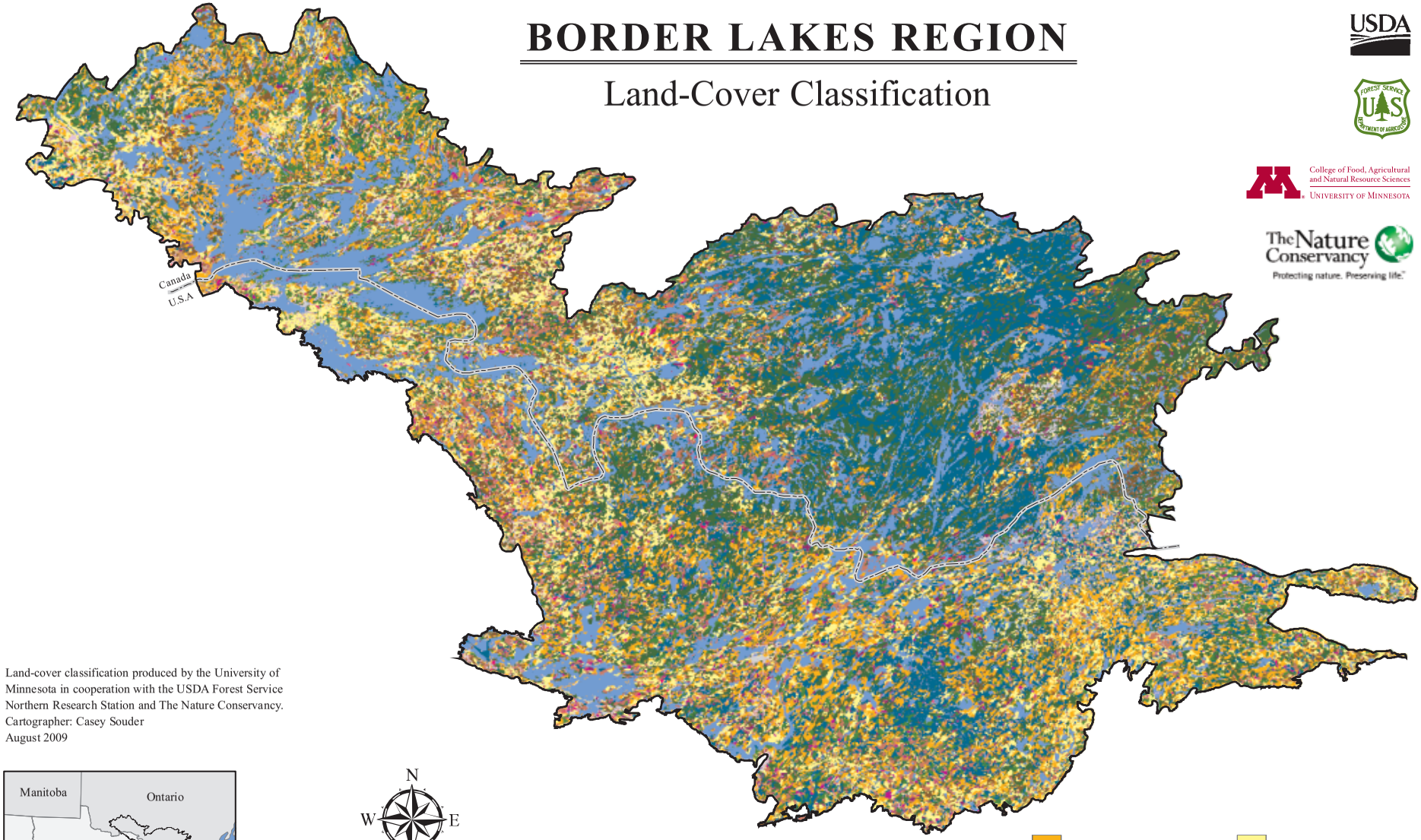
BORDER LAKES REGION

Land-Cover Classification



Land-cover classification produced by the University of Minnesota in cooperation with the USDA Forest Service Northern Research Station and The Nature Conservancy.
Cartographer: Casey Souder
August 2009

N
W E
S

Projection: Transverse Mercator
(UTM NAD83 Zone 15N)

Scale: 1:1,180,000

0 5 10 20 30 40 Kilometers

0 5 10 20 30 40 Miles

- Mixed Coniferous/Deciduous
- Red/White Pine
- Jack Pine
- Spruce/Fir
- Cedar
- Tamarack
- Mixed/Other Conifers
- Aspen/Birch
- Northern Boreal Hardwood Mix
- Lowland Hardwoods
- Water
- Wetland
- Shrubland
- Grassland
- Urban/Developed or Bare Soil

USDA

College of Food, Agricultural and Natural Resource Sciences
University of Minnesota

The Nature Conservancy
Protecting nature. Preserving life.

Bauer, Marvin; Loeffelholz, Brian; Shinneman, Doug. 2009. **Border Lakes land-cover classification.** Research Map NRS-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 14 p. [DVD and printed map included].

This document contains metadata and description of land-cover classification of approximately 5.1 million acres of land bordering Minnesota, U.S.A. and Ontario, Canada. The classification focused on the separation and identification of specific forest-cover types. Some separation of the nonforest classes also was performed. The classification was derived from multi-temporal Landsat TM/ETM+ imagery (collected from the years 1999-2001) using eCognition segmentation software to identify stands and the kNN algorithm to perform the spectral classification. Reference data sites were obtained for Minnesota from the Forest Inventory and Monitoring program dataset and for Ontario from the Forest Resource Inventory program. This dataset was created as an input layer in the LANDIS-II forest landscape model for simulation of future forest disturbance and compositional change over the Border Lakes landscape.

KEY WORDS: Minnesota, Ontario, Quetico Provincial Park, Boundary Waters Canoe Area Wilderness, Voyageurs National Park, land-cover type, Landsat, forest

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