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Monitoring Canada's forests. Part 1: Completion of the EOSD land cover project

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Abstract. Capture of land cover information is a key requirement for supporting forest monitoring and management. In Canada, provincial and territorial forest stewards use land cover information to aid in management and planning activities. At the federal level, land cover information is required to aid in meeting national and international reporting obligations. To support monitoring of Canada's forests, the Earth Observation for Sustainable Developments of Forests (EOSD) project was initiated as a partnership between the Canadian Forest Service (CFS) and the Canadian Space Agency (CSA), with provincial and territorial participation and support. The EOSD project produced a 23 class land cover map of the forested area of Canada representing circa year 2000 conditions (EOSD LC 2000). Including image overlap outside of the forested area of Canada, over 480 Landsat-7 Enhanced Thematic Mapper Plus (ETM+) images were classified and more than 80% of Canada was mapped, culminating in the production of 630 1:250 000 map sheet products for unfettered sharing. EOSD LC 2000 is the most detailed and comprehensive map of the forested area of Canada ever produced. The objectives of this communication are to provide background on the project and associated methods, summarize the process of product development and dissemination, and provide a synopsis of the resultant land cover tabulations. Finally, key lessons learned from undertaking such a large, multipartner, collaborative project are provided.

Résumé. L'acquisition d'information sur le couvert est un élément essentiel pour le suivi et la gestion de la forêt. Au Canada, les gestionnaires de la forêt tant au niveau provincial que territorial utilisent l'information sur le couvert en soutien aux activités de gestion et de planification. Au plan fédéral, l'information sur le couvert est nécessaire pour remplir les obligations nationales et internationales du Canada en matière de préparation de rapports. Le projet OTDD (Observation de la Terre pour le développement durable des forets), projet de partenariat entre le Service canadien des forêts (SCF) et l'Agence spatiale canadienne (ASC) avec la participation et le soutien des autorités provinciales et territoriales, a été mis sur pied pour aider au suivi des forêts canadiennes. Le projet OTDD a produit une carte du couvert comportant vingt-trois classes de la zone forestière du Canada représentant les conditions de l'année 2000 (EOSD LC 2000). Si l'on inclut la zone de superposition des images située en dehors de la zone proprement forestière du Canada, plus de 480 images de ETM+ de Landsat-7 ont été classifiées et plus de 80 % du territoire canadien a été cartographié, le tout s'étant soldé par la production de 630 feuillets topographiques à l'échelle du 1:250 000 à partager librement. Le produit EOSD LC 2000 représente la carte la plus détaillée et la plus complète de la zone forestière du Canada à ce jour. L'objectif de la présente communication est de donner des informations générales sur le projet et les méthodes utilisées, de résumer la procédure de développement et de dissémination du produit et de fournir une synthèse des calculs de couvert résultants. Enfin, nous donnons un aperçu des leçons apprises au cours de la réalisation de ce projet de collaboration de grande envergure faisant appel à de nombreux partenaires.
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Introduction

Canada is a large country, approaching one billion hectares in size, with approximately 402.1 million hectares (Mha) of forest and other wooded land (Power and Gillis, 2006). Canada's forests contribute CAN$28.1 billion to the national balance of trade (Canadian Forest Service, 2007), and reliable information on the amount and location of forests is required to ensure effective management of this resource. In support of national and international reporting requirements (e.g., climate change,

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sustainable forest management), the Canadian Forest Service (CFS), in partnership with the Canadian Space Agency (CSA), and with the support and participation of provincial and territorial agencies, is using space-based Earth Observation (EO) technologies to monitor the sustainable development of Canada's forests through an initiative called Earth Observation for Sustainable Development of Forests (EOSD; http://eosd.cfs.nrcan.gc.ca/).

The EOSD project was designed to provide the following: land cover maps (Wulder et al., 2003); methods for estimating biomass using satellite and forest inventory data (Luther et al., 2006; Hall et al., 2006); techniques for identifying and mapping disturbed areas; methods for enabling data distribution and sharing; and opportunities for research and development focused on new technologies (Wood et al., 2002), with research teams targeted to specific themes, including land cover, forest change, biomass, and automated processing. The land cover component of the EOSD project was initiated in 2000, with an initial research and development phase followed by a regionally based national implementation. The primary project objective was to produce (by 2006) a land cover map of the forested ecozones of Canada, representing circa year 2000 conditions (Wulder et al., 2003).

The completed EOSD land cover product (hereafter referred to as EOSD LC 2000) is an important data source in the National Forest Carbon Accounting Framework and in Canada's new plot-based National Forest Inventory (NFI) (Wulder et al., 2004c; Gillis et al., 2005). In addition, EOSD LC 2000 forms an integral part of a national-level cross-sector land cover map currently being developed for inclusion in the National Topographic Data Base (NTDB). Following a rule-base for class dominance in overlap areas, EOSD LC 2000 is being combined with the land cover products being produced by Agriculture and Agri-Foods Canada for the National Land and Water Information Service (NLWIS) for Canada's agricultural areas (Fisette et al., 2006), and the Canada Centre for Remote Sensing for the Arctic ecozones (Olthof and Fraser, 2007). This combined product will provide a complete Landsat-based land cover map of Canada, with the data integration and dissemination effort being led by the Centre for Topographic Information (CTI) of Natural Resources Canada (NRCan), aided by funding from the CSA. The National Wetlands Inventory, led by Environment Canada, is focused on producing detailed information on wetlands from remotely sensed data and has used the EOSD LC 2000 data for stratification purposes and to identify priority areas on which to focus mapping efforts (Fournier et al., 2007).

The objectives of this communication are to provide background on the project and associated methods, summarize the process of product development and dissemination, and provide a synopsis of the resultant land cover tabulations. Finally, we also provide some key lessons learned from undertaking such a large, multipartner, collaborative project.

Methods

Figure 1 provides an overview of the methods and data used to generate the EOSD product, from image acquisition and preprocessing, through to post-classification quality assurance, accuracy assessment, and final production and distribution of the 1:250 000 National Topographic System (NTS) product tiles. In the following section we present the key elements of the map production process, with additional details available in the referenced project documentation. The Landsat data used for EOSD LC 2000 and the resulting products are available freely through a distributed computational grid infrastructure called the System of Agents for Forest Observation Research with Advanced Hierarchies (SAFORAH) at http://www.saforah.org (Goodenough et al., 2007).

Project area

Canada's forests occupy 10% of the total global forest area and 20% of the total global boreal forest area (Wulder et al., 2007a). Canada's forest cover varies nationally according to drivers such as climate, precipitation, soils, and topography. Land use and disturbance regimes also influence the composition of Canada's forests, and commercial activities (e.g., road construction, forest harvesting, mineral extraction, oil and gas exploration, and urban development) alter landscape patterns and influence land cover composition and structure in areas where access and economic opportunities are available. In other areas of the country, fire and insects are the key agents of disturbance (Volney and Hirsch, 2005), with fire playing an especially important role in the modification of land cover in more northern, less actively managed locations (de Groot et al., 2007). The 10 forested ecozones of Canada (**Figure 2**) represent broad mosaics formed by the interaction of macroscale climate, human activity, vegetation, soil, and geologic and physiographic features (Ecological Stratification Working Group, 1996).

Image data

A consortium of Canadian federal, provincial, and territorial government agencies, led by the Center for Topographic Information (CTI) of Natural Resources Canada (NRCan), produced Landsat-7 Enhanced Thematic Mapper Plus (ETM+) 30 m orthoimage coverage for Canada (Ortho-7). Through the application of standardized methods and use of best available elevation data, this orthoimage coverage of Canada provided a data source that is temporally, spatially, and geometrically consistent (Wulder et al., 2002). Commencing in 1999, the Ortho-7 project acquired Landsat-7 ETM+ images until complete coverage of Canada was obtained in 2002. All Ortho-7 project images were obtained prior to the Landsat-7 Scan Line Corrector (SLC) malfunction on 31 May 2003 (Maxwell, 2004). The images selected for classification by the EOSD analysts were assessed for cloud cover and phenology (e.g., as cloud-free as possible and collected between the months of

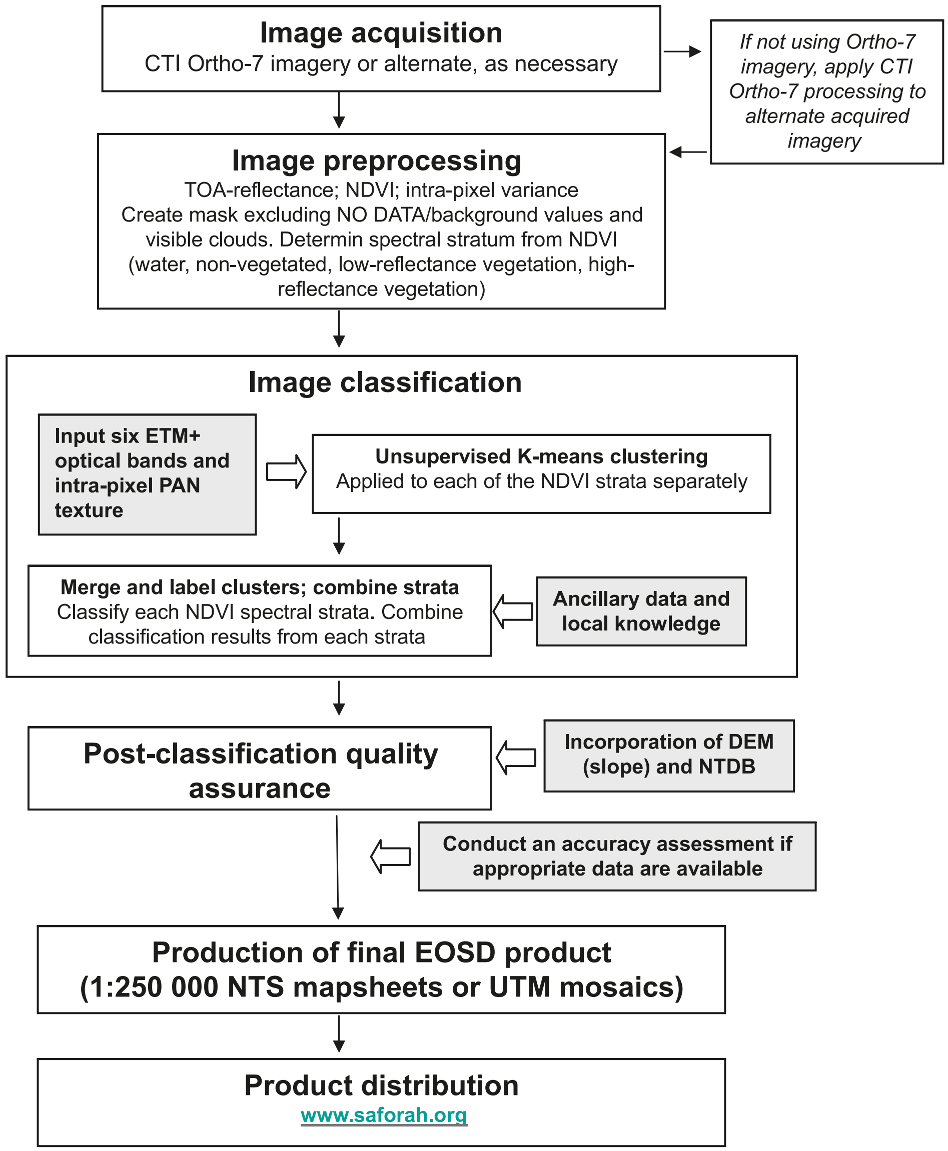


Figure 1. A summary of the EOSD classification workflow, from image preparation to final product generation.

May and October). Of the Landsat-7 ETM+ images used for Ortho-7, 90% were acquired within 1 year of the EOSD year 2000 target (**Table 1**). When the Landsat-7 ETM+ images used for Ortho-7 had excessive cloud cover or an unsuitable collection date for the EOSD project, Landsat-5 TM images were substituted as required. Radiometric and geometric processing of these Landsat-5 scenes corresponded closely to that of the Ortho-7 imagery.

Following the collection of Landsat-7 ETM+ imagery, pre-approved commercial agents were contracted by CTI to complete the image orthorectification (Wulder et al., 2002). The Ortho-7 project released imagery as it was acquired and processed; this intermittent delivery of source imagery, combined with the desire to begin preprocessing and classifying images for the EOSD project in a timely manner (and prior to the completion of the Ortho-7 project), precluded the use of a mapping zone approach such as that used by Homer et al. (2004) when developing the National Land Cover Database for the United States. Rather, EOSD methods were applied to single scenes or small groups of scenes as the images became available from CTI. This implementation strategy

Table 1. Summary of Landsat-7 ETM+ acquisition dates for Ortho-7 product generation.

Year	No. of Landsat-7 ETM+ images acquired
1999	101
2000	202
2001	184
2002	55

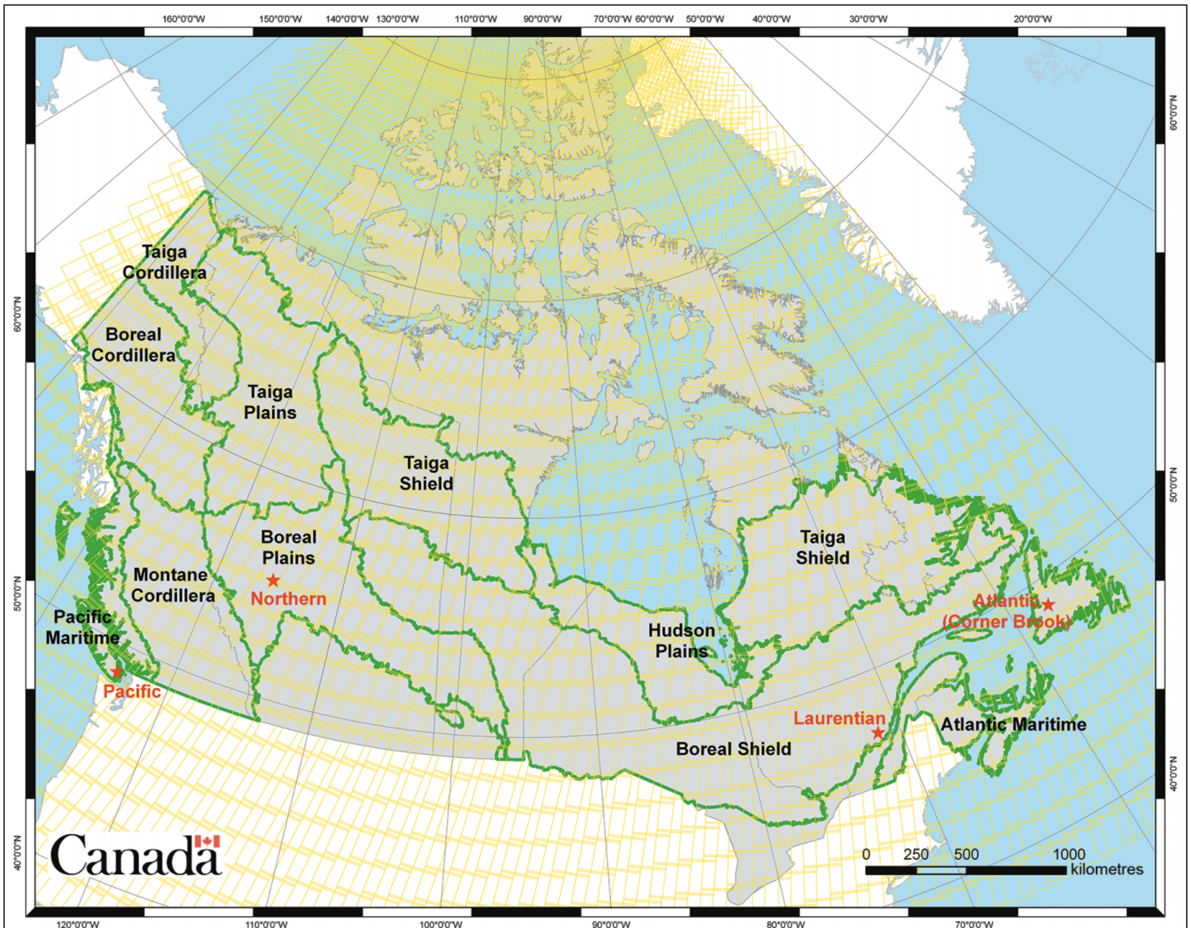


Figure 2. WRS-2 frames (in yellow) and the forested ecozones of Canada (in green). A total of 486 Landsat scenes were used in the production of the EOSD land cover product. CFS regional centres active in EOSD project implementation are indicated in red.

facilitated early commencement of EOSD classification efforts and enabled economies to emerge, whereby neighbouring scenes were used to aid in classification (by taking advantage of image overlap, which is approximately 40% at Canada's southern border and 80% in the far north (Wulder and Seemann, 2002)) (**Figure 2**). A total of 486 Landsat scenes were classified for the EOSD project.

Radiometric preprocessing

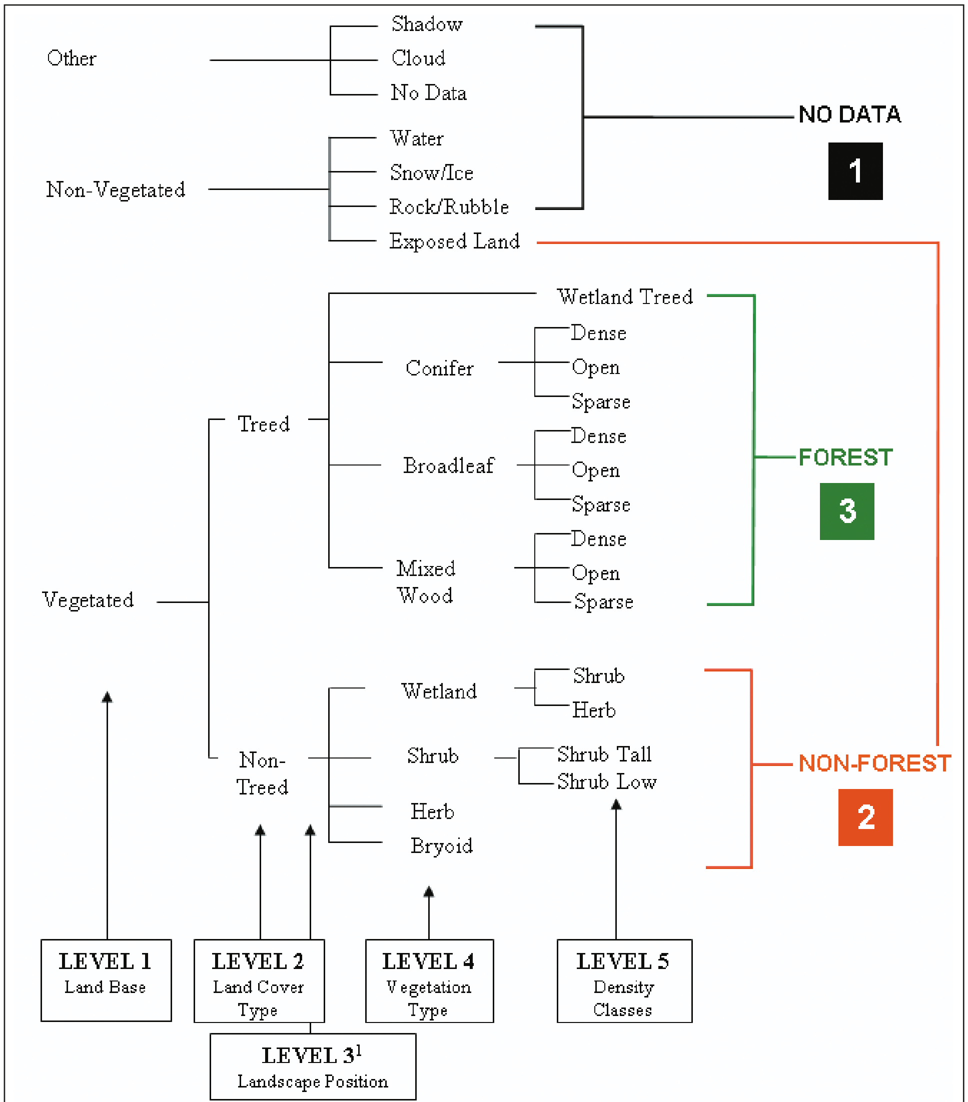
Following acquisition of the Ortho-7 imagery from CTI, a conversion from at-sensor radiance values to top-of-atmosphere (TOA) reflectance was undertaken using software developed at the Canada Centre for Remote Sensing (R. Landry, personal communication, 2001; ftp://ftp.ccrs.nrcan.gc.ca/ad/landry/). The TOA-reflectance correction procedure, as described in Peddle et al. (2003), is an implementation largely based on equations and theory originally posited by Markham and Barker (1986). This approach accounts for the influence of sun illumination on pixel radiometric response, with fewer data requirements than those associated with absolute atmospheric correction procedures (Liang et al., 2001).

Classification legend

The legend used for EOSD was developed to fit with the hierarchical classification of the NFI (Wulder and Nelson, 2003). **Figure 3** provides a schematic of the class hierarchy and a listing of the 23 class codes (included in parentheses). The level of detail captured in the NFI hierarchy is greater than what can be obtained from Landsat imagery, and therefore a legend was developed that was both compatible with the NFI class structure and considered realistically feasible given the spatial and spectral resolution of Landsat data (Wulder et al., 2003). As detailed in Wulder and Nelson (2003), the EOSD legend has been cross-walked to a number of common legends, both national and international, including the Land Cover Classification System (LCCS), produced by the Food and Agriculture Organization of the United Nations (Di Gregorio and Jansen, 2000).

Classification methods

Using single scenes of Landsat data to produce land cover information is not uncommon; however, combining several or even hundreds of Landsat scenes for the development of a large



[1]Level 3 is not illustrated here as this level does not exist in the same manner in the EOSD and NFI classification systems. In the NFI land cover classification scheme, this level refers to landscape position (e.g. alpine, upland, or wetland).

Figure 3. EOSD land cover legend (based on the NFI level 4 classes and level 5 density descriptors).

area land cover map is relatively uncommon (Franklin and Wulder, 2002). To completely cover the forested ecozones of Canada, approximately 800 Mha were mapped (**Figure 2**). The classification approach for EOSD was based upon an unsupervised hyperclustering, cluster merging, and labelling method (Wulder et al., 2004a). With this method, more spectral groupings than unique classes were created through the *k*-means clustering process, from which spectrally similar groups were merged and subsequently labelled into meaningful classes conforming to the 23 class legend.

To provide additional spectral discrimination ability, without having too many pixels assigned to spectrally dominant clusters, we used the normalized difference vegetation index (NDVI) (Myneni et al., 1995) to initially stratify the imagery into four broad groups expected to contain classes with spectral similarity (i.e., water, non-vegetated, low-reflectance vegetation, high-reflectance vegetation). This stratification facilitated hyperclustering within a narrow and spectrally similar assemblage of classes. The same *k*-means parameters (12 iterations, 241 clusters, 50% of pixels under the mask sampled, and a movement threshold of 0.1) were applied to each NDVI stratum (Wulder et al., 2004a). Input channels for the *k*-means clustering algorithm included ETM+ bands 1–5, 7, and a texture channel generated from the intra-pixel variance derived from a 3 × 3 pixel window applied to the 15 m ETM+ panchromatic band. The intra-pixel variance was used to capitalize upon the finer-scale structural information; to avoid the introduction of edge effects, the texture channel was resampled to 30 m prior to clustering, using a bilinear interpolation algorithm. Classes that were not expected in a given NDVI stratum (the above spectral similarity groupings) were also identified and labelled appropriately. After cluster merging and labelling, the NDVI strata were reassembled to form a seamless classification on a scene-by-scene basis. The classification of a given scene was used to aid in the classification of neighbouring images.

Ancillary data

Forest inventory information was the primary data source used in the interpretation and labelling of the *k*-means spectral clusters. As available, field data from provincial and territorial inventory and land management programs, as well as aerial photographs, were used to aid in cluster labelling. Interpreters were mindful of the temporal difference between the Landsat data used for the EOSD and many of the ancillary data sources. Overlapping image areas with adjacent classified Landsat images were used to further aid the cluster labelling process. Additional ancillary data sources were used to facilitate quality control once the initial cluster labelling was complete. For example, digital elevation models (DEMs) were used to generate a slope surface, which in turn was used to check for areas of topographic shadow that had been misclassified as water. Other data sources such as the NTDB, or provincial data sources such as British Columbia's Baseline Thematic Mapping data (Geographic Data BC, 2001), were used to detect systematic issues in labelling associated with rare or spatially heterogeneous classes such as bryoids and wetlands.

Project implementation

The CFS operates from five regional centres and a headquarters in Ottawa. Four of the regional centres were actively involved in the implementation of the EOSD project (Pacific Forestry Centre (PFC), Northern Forestry Centre (NoFC), Laurentian Forestry Centre (LFC), and Atlantic Forestry Centre (AFC); **Figure 2**), thereby facilitating provincial/territorial partnerships, data sharing, local knowledge of land cover characteristics, linkages to local mapping agencies, and leveraging of existing mapping and monitoring programs. Concerted efforts were followed to maintain consistent methodologies across implementation centres; however, there were slight regional variations in implementation. For example, at LFC, methods from Beaubien et al. (1999) were used in Quebec to address regional concerns and maintain consistency with previous classification efforts undertaken in the province.

Limited resources necessitated the incorporation of ongoing land cover mapping activities, as undertaken by provinces and territories, with the EOSD project. For example, the Alberta Ground Cover Classification (AGCC) (Sánchez-Azofeifa et al., 2005) was already in progress when the EOSD project was initiated, thereby providing an opportunity to partner, share expenses, and incorporate the results of the AGCC into the EOSD product. Similarly, the Northwest Territories (NWT) and Ontario had ongoing land cover mapping programs that were appropriate for integration with EOSD. We worked with the Forest Management Division of NWT Environment and Natural Resources to determine which classifications were appropriate for cross-walking and which required reclassification, largely to account for image acquisition dates (either outside of the EOSD LC circa year 2000 objective or those containing seasonal artefacts, such as snow cover). Approximately one-third of the NWT was appropriate for cross-walking from pre-existing classification initiatives to meet EOSD specifications. All these initiatives followed approaches that were similar to the EOSD project, thus enabling the post-classification cross-walk of these products to the EOSD legend (Wulder and Nelson, 2003).

Classification accuracy assessment

A readily available pool of data suitable for map calibration and validation is not common—or consistent—across Canada, and most of the available data were used for calibration and cluster labelling. Furthermore, the nature of the available data (i.e., temporal disparities, data types (point or polygon), attributes, geolocational mismatches, minimum mappable units, availability) precluded the use of these data in a traditional accuracy assessment framework (Wulder et al., 2006a). Ideally, purpose-acquired data would be preferable for accuracy assessment (Wulder et al., 2007c); however, the cost and time associated with such a massive data collection effort was prohibitive for this project. Forest inventory data were the most promising data source for assessment of the EOSD product. In Canada, forest inventory data are typically polygonal, with a 2 ha minimum mappable unit for vegetated polygons (Leckie and Gillis, 1995).

To be used in an accuracy assessment framework, the land cover class associated with a forest inventory polygon would carry a single category for an area that was at least 2 ha in size. However, as a single EOSD pixel has an area of 0.0625 ha, approximately 32 classified EOSD pixels would be found within a minimum sized forest inventory polygon. Typically, the polygon class label was compared with the label of the single pixel that corresponded to the location of the polygon centroid. The class labels of forest inventory polygons are considered average expressions of the forest type at the polygonal level, and as a result, there is typically much greater variation in the vegetation than what can be captured within a minimum mapping unit of 2 ha. Because this inherent variability in vegetation will translate into heterogeneity of land cover as represented in remotely sensed data, it is unreasonable to assume that this scenario would provide a useful assessment of EOSD product accuracy. Methods do exist, however, for making raster and vector data more compatible for the purposes of accuracy assessment (e.g., use the modal or the majority land cover class of the pixels that fall within a polygon; only use polygons that satisfy some predefined homogeneity criterion) (Wulder et al., 2006b). As a result of these limitations to a national-scale accuracy assessment, the quality assessment procedures followed during map production were the primary means for ensuring classification consistency and quality, making the best use of available support data and the combined knowledge of the classification analysts (Wulder et al., 2004a). Training and regular team meetings, including cross-calibration of interpreters, were undertaken to aid in the consistency of cluster labelling and to provide a quality control stage.

To aid in building confidence in the accuracy of the EOSD product, a regional accuracy assessment was completed for Vancouver Island, British Columbia, using purpose-acquired airborne video data (Wulder et al., 2007c). The collection of airborne image data enabled the use of a systematic stratified random sampling approach (Wulder et al., 2006a) and categorization of the extracted image chips to EOSD specific classes by experienced interpreters (Wulder et al., 2007c). The EOSD classification of Vancouver Island was composed of six Landsat images. In this trial, agreement between the EOSD product and the airborne video data was defined as a match between the mode land cover class of a 3 × 3 pixel neighborhood surrounding the sample pixel and the primary or secondary choice of land cover for the interpreted video.

Products and distribution

EOSD land cover products are based upon the NTDB's NTS map sheet framework. There are 986 1:250 000 map sheets covering the totality of Canada's landmass, and of these, 630 represent the forested ecozones of Canada (**Figure 2**). NTS-based provision of the classification results enables use of an existing spatial framework and an established nomenclature. Each map sheet represents an area of approximately 14 850 km^2 (although area varies slightly with latitude). The EOSD products are available in a paletted GeoTIFF format, with a disabled TIFF world file, and bilingual United States Federal Geographic Data Committee (FGDC) compliant metadata in text and HTML formats. To integrate well with other geospatial products and nest within the Universal Transverse Mercator (UTM) projection, final products are resampled to a 25 m spatial resolution. As a single EOSD product tile may have been generated from a number of images, Environmental Systems Research Institute (ESRI) shapefiles are provided to communicate source image information and actual mosaic lines (example shown in **Figure 4**). The spatial metadata include information on the source imagery used to produce the classification for each NTS map sheet, including Landsat WRS-2 path/row and image acquisition date.

All 630 NTS map sheets that comprise the EOSD product are complete and available for download through the National Forest Information System (NFIS) and SAFORAH. SAFORAH is a networking data grid that enables distributed data storage and access (http://www.saforah.org). FTP download of bundled and compressed collections of entire provincial or territorial coverages, as well as EOSD mosaics by UTM zone, are also available from SAFORAH (e.g., http://www4.saforah.org/eosdlcp/ntsprov.html).

Figure 4. A sample of a 1:250 000 NTS map sheet (093F; Nechako River, British Columbia). Mosaic lines are shown, along with the source path and row of the corresponding Landsat image used to fill each portion of the NTS map sheet. This information is delivered with the product as an ESRI shapefile, enabling the user to know the source image and the date the source image was acquired. See **Figure 5** for class listing and related colour coding.

Results and discussion

Figure 5 shows the complete EOSD land cover product for the forested ecozones of Canada with 23 land cover classes with a pixel size of 25 × 25 m. A complete description of the EOSD land cover classes is provided in Wulder and Nelson (2003). **Figure 6** summarizes the proportional distribution of EOSD land cover classes at level 4 of the NFI classification hierarchy (**Figure 3**). Note that the coniferous forest class dominates, with over 30% of Canada's forested area classified as coniferous forest, followed by shrub (11.88%), water (11.52%), and mixedwood forest (9.46%). Combined, forested classes represent >53% of the EOSD project area. The rarest vegetated class was bryoids (2.3%).

Each of Canada's forested ecozones have different proportions of the EOSD classes (**Figure 7**), supporting the basis for the ecozone characterizations (Ecological Stratification Working Group, 1996). For example, the Hudson Plains ecozone is dominated by the wetland class, whereas the Montane Cordillera ecozone is dominated by the coniferous class. More northerly ecozones contain a greater amount of shrub and wetland, whereas southerly ecozones are dominated by coniferous and mixedwood classes. Coniferous forests dominate coastal forests in both the Pacific Maritime and Atlantic Maritime ecozones; however, on the east coast, coniferous forests are balanced by an equal amount of broadleaf and mixedwood forests.

The EOSD land cover classes have been summarized by ecozone for both levels 4 and 5 of the NFI classification

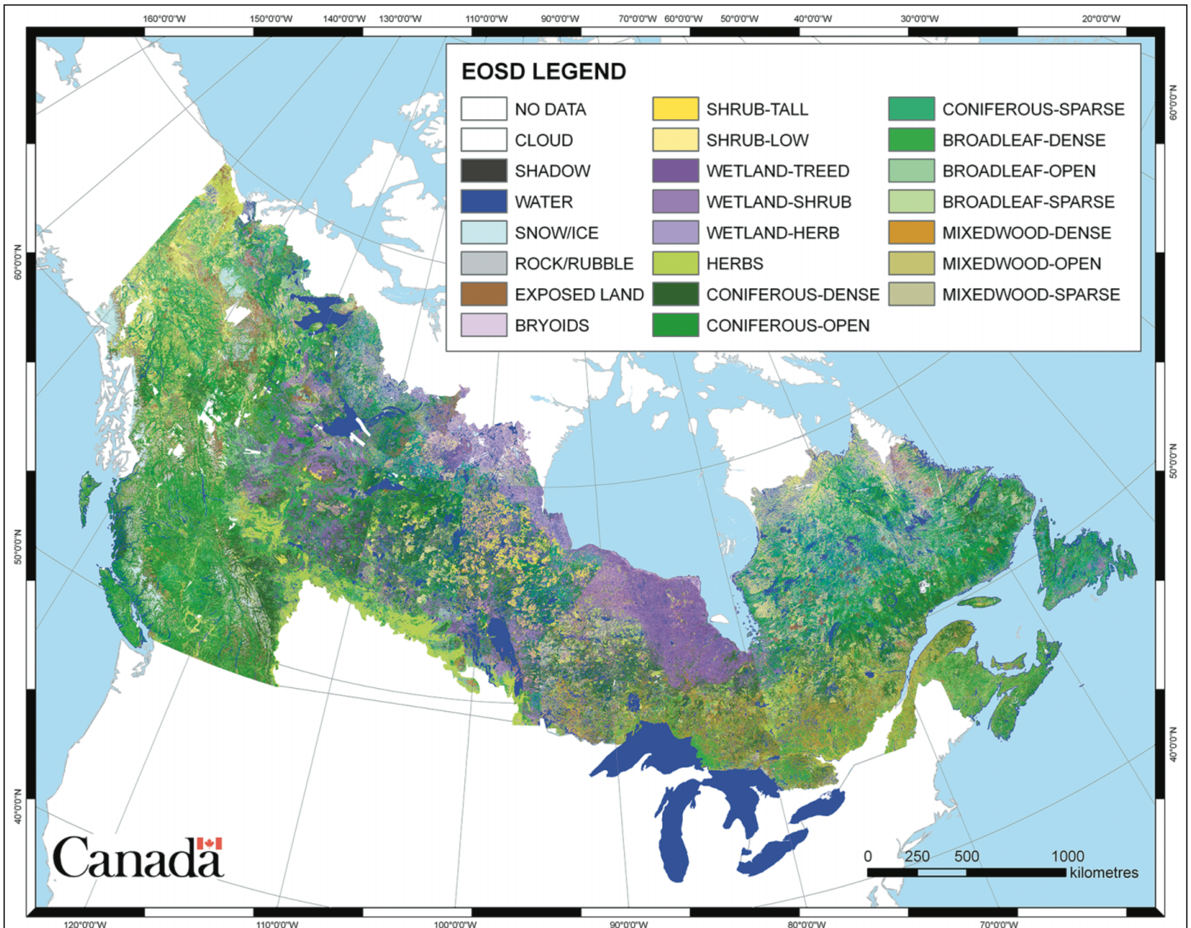


Figure 5. The final EOSD product representing circa 2000 conditions of the forested ecozones of Canada.

hierarchy (**Tables 2 and 3**). Given that the data sources and methods used to generate the EOSD product differ significantly from the forest inventory data sources used to compile Canada's National Forest Inventory (CanFI), it is not expected that the areas of the various land cover classes will be directly comparable with those reported by CanFI. As summarized by Wulder et al. (2006b), pixel-based classifications and vector-based forest inventories characterize land cover in a different manner. Pixel-based detail versus polygon-based generalizations will result in the mapping of different class areas. Even though the results are expected to be different based upon issues related to data capture, depiction, and classification, a comparison to ensure general similarity is useful to build confidence in the categoric trends and area representations found. Based on Canada's 2001 Forest Inventory report (Power and Gillis, 2006), the total area of forest is estimated to be 310 133 820 ha. The total area of other wooded land is estimated to be 91 950 910 ha. In the summaries of the EOSD product represented in **Tables 2 and 3**, the area of forest (calculated as the sum of the coniferous, broadleaf, and mixedwood classes) was estimated to be 315 039 865 ha. The amount of other wooded land (see **Table 2**; wetland treed and shrub) from the EOSD is estimated to be 108 239 253 ha. Given the aforementioned differences between the EOSD and CanFI datasets, the estimates of Canada's forest area differ by less than 2%. Estimates of other wooded land vary by approximately 18%, and this may, in part, be attributed to differences in how other wooded land is defined in CanFI relative to the EOSD LC 2000.

In this communication, we have presented the status of land cover over the forested area of Canada. The availability of the land cover also provides opportunities for investigation of the spatial patterns and inter-relationships of the mapped classes. In a companion communication (Wulder et al., 2008a), we describe the development and trends regarding forest fragmentation generated from the EOSD LC 2000.

Product accuracy

Purpose-acquired airborne video data were collected to assess the accuracy of the EOSD classification for Vancouver Island. Following a systematic design, a target accuracy of 80% was achieved, with the overall accuracy of the Vancouver Island EOSD product estimated at 77% (90% confidence intervals: 74%–80%) for level 4 of the classification hierarchy (Wulder et al., 2007c). The coniferous treed class, which represented 71%

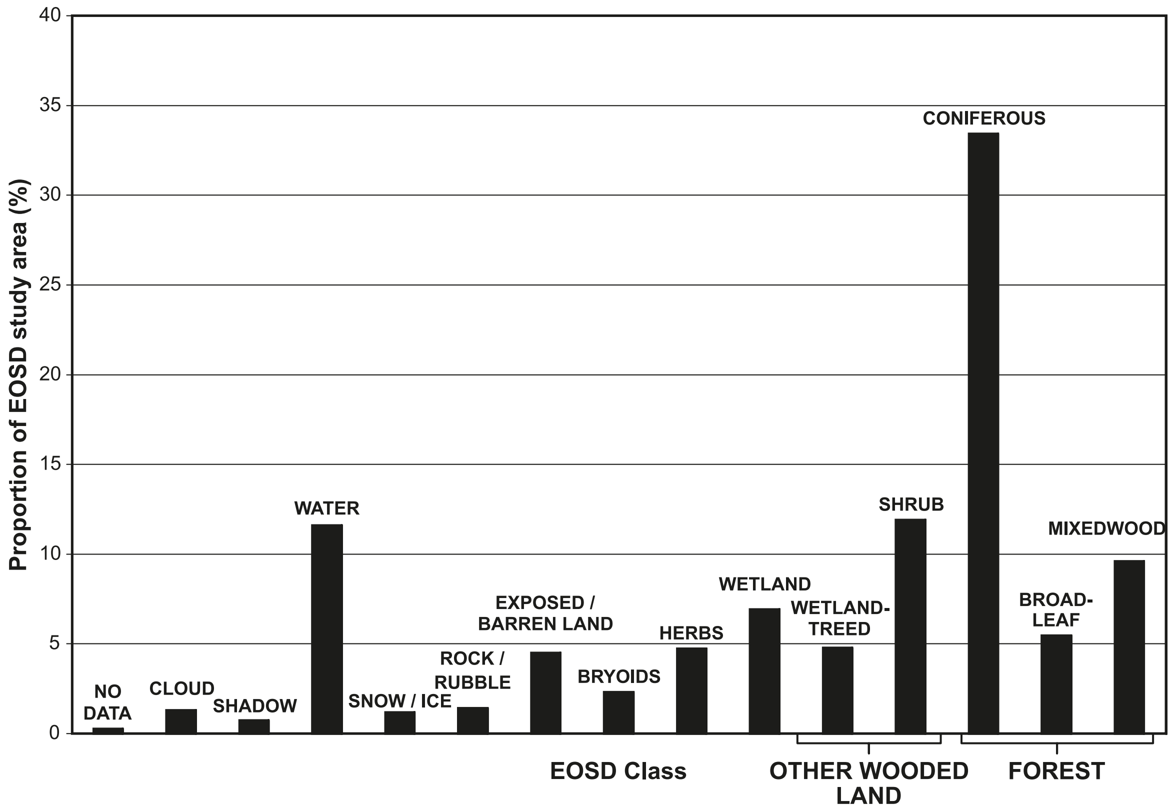


Figure 6. National summary of EOSD land cover classes (level 4), by proportion of EOSD study area.

of Vancouver Island's area, had an estimated user's accuracy of 86%. These findings are also supported by the results of this regional product accuracy assessment, as well as on an earlier map agreement exercise (Remmel et al., 2005). Furthermore, the areas of the forest classes mapped by EOSD LC 2000 are corroborated by the areas reported in CanFI 2001 (Power and Gillis, 2006).

The EOSD metadata include statements regarding product accuracy to remind users that the EOSD product is to be used as appropriate and at the user's own risk, to divest the Crown of liability, and to facilitate data sharing. These statements do not indicate a lack of diligence or appropriate effort in producing quality classifications. Classifications, which by nature are generalizations, are never free of error. Transparency in map development protocols allows map users to pass professional judgement, on a project-specific and information-needs basis, in order to determine the suitability of EOSD (or any) land cover product for a given application (Foody, 2002; 2008).

Lessons learned

Access to imagery that was already orthorectified reduced image acquisition and geometric processing requirements for the project. Furthermore, the purchase of Landsat imagery as a federal, provincial, and territorial consortium reduced costs and enabled access to "best available" DEMs on a jurisdictional basis (Wulder et al., 2002). The use of the Ortho-7 imagery as a common base for EOSD enabled and promoted the use of a standard geographic framework for facilitating spatial comparisons and integration of derived spatial data products. However, a limitation to using an image database intended to meet the needs of a broad range of applications is that the acceptable date range for collecting imagery is beyond that which is considered ideal for vegetation studies. The range of dates used to generate the CTI Ortho-7 project resulted in some images with unsuitable phenological characteristics, low sun angles, and, in other cases, snow and ice on the ground. Ortho-7 imagery that was considered unacceptable for EOSD project needs was replaced with imagery acquired closer to the date of peak photosynthetic period (i.e., summer months). Newly acquired imagery was subject to the same geometric and radiometric processing as the Ortho-7 imagery. Research has demonstrated that the use of imagery from a different year is preferred over the use of imagery with unsuitable phenological conditions (Wulder et al., 2004b).

From an image classification and project execution perspective, the regional CFS establishments across Canada resulted in a distributed framework for implementation of the EOSD project. At each establishment, a regional project leader was able to build the required partnerships with appropriate provincial or territorial stakeholders. These partnerships facilitated access to data for classification calibration and quality control, and integration of EOSD with other ongoing mapping programs, and ensured that EOSD classification and labelling was done by individuals familiar with the geographic region being mapped. Our management structure allowed us to

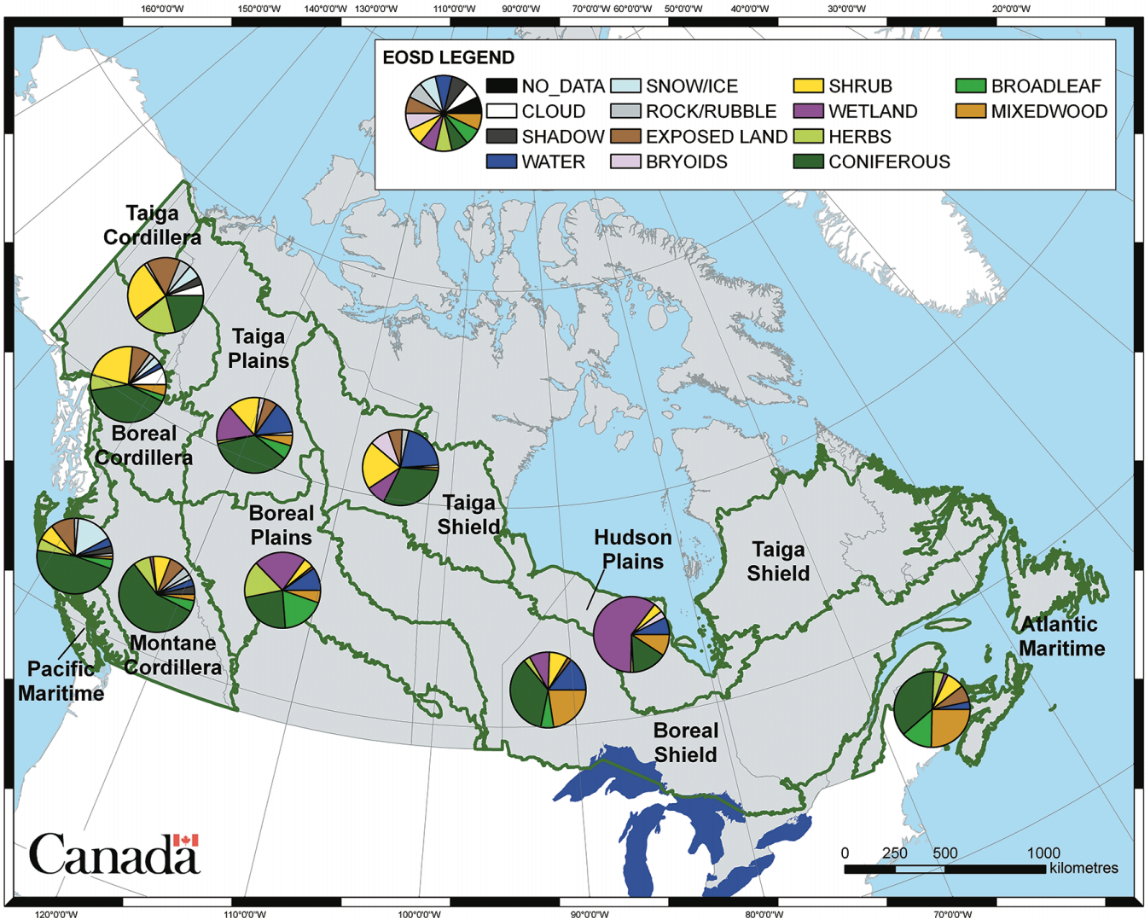


Figure 7. The distribution of EOSD land cover classes (level 4), by forested ecozone.

deal with issues such as continuity, which arose from the use of a temporary workforce in a project that spanned several years. Training manuals, regular meetings, and analyst cross-collaboration mitigated issues related to staff turnover and multiple contractors.

A shortcoming with the regional implementation approach was the introduction of edge effects between some of the implementation regions. These edge effects have been minimized and addressed through the application of a quantitative protocol for relabelling of classes. As summarized in Wulder et al. (2007b), where edge effects were visually evident along a mapping region boundary, the classes on one side of the discontinuity were used, in a distance-weighted fashion, to perform class-specific quantitative relabelling on the other side of the discontinuity. Typically, these visual discontinuities at boundary regions were related to differences in density classes (Wulder et al., 2007b). In some cases, wetlands (as an often dynamic land condition and not a pure land cover) were difficult to map and led to some instances of discontinuities across mapping regions. Furthermore, changes in water levels apparent across years and seasons manifest as a classification discontinuity when water features occur at scene boundaries.

The development of the EOSD classification legend in accordance with the NFI classification scheme (Wulder and Nelson, 2003) provided for a meaningful link across government programs and ensured that the information needs of provincial and territorial agencies were met. The EOSD-NFI legend classes (**Figure 3**) represent land cover categories that are appropriate for capture and depiction with the spatial and spectral resolutions available from the Landsat-7 ETM+ imagery used to generate the EOSD product, and facilitate compatibility between EOSD and NFI projects (Wulder et al., 2004c).

For future implementation of similar nationwide land cover mapping efforts, it is highly recommended to collect, following consistent specifications and standards, photography or video from an airborne platform to aid with classification calibration and validation. As described in Wulder et al. (2007c), purpose-acquired data are useful for quality assurance and map accuracy assessment. High spatial resolution satellite imagery may also be used for calibration or validation (Morisette et al., 2003). Regardless of the data source selected for calibration and validation, data collection should be planned so that it is temporally coincident with the collection of the medium spatial resolution EO data to be used for land cover classification, in

Table 2. Summary of EOSD class area, by ecozone (at NFI level 4).

	Ecozone area (ha)										
EOSD class	Pacific Maritime	Montane Cordillera	Boreal Cordillera	Boreal Plains	Taiga Cordillera	Taiga Plains	Taiga Shield	Boreal Shield	Hudson Plains	Atlantic Maritime	Total
No data	95	866	20	15 192	52	42	194 447	1 059 134	301 265	133 135	**1 704 248**
Cloud	240 738	353 914	3 251 270	364 400	1 192 960	912 092	1 396 315	589 992	24 717	34 071	**8 360 469**
Shadow	620 522	1 672 710	437 517	62 019	831 242	176 355	515 462	298 652	8 649	100 206	**4 723 334**
Water	729 003	1 417 510	902 082	6 909 708	225 805	8 291 120	26 520 287	26 979 942	2 667 190	663 489	**75 306 136**
Snow / ice	3 141 610	1 023 530	1 475 630	1 931	1 380 960	232 884	398 454	16 181	0	961	**7 672 141**
Rock / rubble	328 694	1 750 670	1 039 180	26 097	1 189 470	367 934	3 771 638	662 486	22 515	40 023	**9 198 706**
Exposed / barren land	2 061 390	3 184 810	3 447 190	759 878	3 501 280	3 438 800	7 744 929	3 252 615	314 195	1 457 320	**29 162 406**
Bryoids	314	5	101 580	16	329 470	1 382 260	10 918 300	1 101 555	1 072 600	32 024	**14 938 123**
Shrub	1 391 555	3 571 628	9 826 940	3 057 859	6 244 149	8 369 100	26 716 915	15 123 794	1 455 581	1 528 536	**77 286 057**
Herbs	1 019 040	3 471 530	2 923 530	11 149 560	4 393 570	795 224	504 572	5 206 382	409 256	892 584	**30 765 247**
Wetland	3 870 613	2 441 040	2 377 712	6 911 639	1 606 765	8 524 004	26 918 741	26 996 123	2 667 190	664 450	**44 892 515**
Wetland-treed	62 766	82 375	117 063	7 548 622	21 313	3 763 560	2 271 664	6 367 421	10 662 000	56 412	**30 953 196**
Coniferous	9 422 424	27 144 000	17 375 810	16 348 326	5 101 311	21 897 960	40 523 765	66 590 946	5 331 700	7 478 450	**217 214 692**
Broadleaf	812 234	2 307 944	1 200 137	13 107 968	247 072	3 752 505	1 144 684	10 175 633	65 590	2 673 316	**35 487 081**
Mixedwood	278 908	1 254 027	2 059 200	3 821 243	238 142	2 725 485	1 557 754	42 021 732	3 289 679	5 091 922	**62 338 091**
Total	**23 979 905**	**49 676 558**	**46 534 861**	**70 084 456**	**26 503 562**	**64 629 325**	**151 097 926**	**206 442 588**	**28 292 126**	**20 846 899**	**650 002 443**

order to minimize discrepancies in land cover between the EO data and ancillary data sources. Waiting until project completion to collect validation data, when funds and enthusiasm are waning, precludes use of these data for calibration, and can compromise validation efforts in dynamic areas experiencing ongoing changes in land cover.

Both trained personnel and financial resources are imperative for a national land cover mapping effort to be realized. This project would have been difficult, if not impossible, to undertake without the collaborative partnerships that were utilized in this project. The potential benefits of EOSD LC 2000 extend beyond those of federal information needs through its potential use as framework data for developing a range of value-added applications. An extensive technology transfer effort was undertaken across Canada with the training of high-quality personnel at federal and provincial agencies and at several universities. To systematically and repeatedly monitor Canada's forests, it is clear that technological, administrative, and financial structures must be in place to support the continuation of this or a similar program.

Conclusions

The goal of the EOSD land cover project was to produce a land cover map of the forested area of Canada with Landsat-7 ETM+ data, in order to provide timely and useful information for use within, and external, to Canada. A key accomplishment has been the use of EOSD products in support of the Canadian National Forest Inventory. Although not free of issues, the final EOSD land cover 2000 product will provide an invaluable depiction of circa 2000 land cover conditions for the forested area of Canada for present and future generations. EOSD LC 2000 is an unprecedented characterization of Canada's forested area; the spatial extent and level of detail afforded by the EOSD product will make it useful for a wide range of applications. We have endeavoured to be transparent at all project stages, from initial communication of options and planned approaches, through to a detailed description of methods followed and products developed. This transparency was intended to assist users in understanding what particular operational decisions were made and why, and how these decisions, or operational realities, formed the final EOSD product.

The lessons learned in the implementation of EOSD LC 2000 will serve as the basis for guiding any subsequent update or mapping efforts. Building upon the baseline of circa year 2000 conditions captured in the EOSD LC 2000 product, an update that includes and labels changes (i.e., Wulder et al., 2008b) can provide a basis for the systematic monitoring of Canada's forests. Although the use of Landsat imagery for land cover update would be ideal, we acknowledge that the presence of technical issues with Landsat-7 (i.e., the 2003 SLC malfunction) and the age of Landsat-5 (launched in 1984 with a 3-year design life) may condition this data choice until the launch of the next Landsat instrument (Wulder et al., 2008c). As an update option, a cross-sensor approach for land cover update has been developed (Wulder et al., 2008b), which

Table 3. Summary of EOSD class area, by ecozone (at NFI level 5).

	Ecozone area (ha)										
EOSD class	Pacific Maritime	Montane Cordillera	Boreal Cordillera	Boreal Plains	Taiga Cordillera	Taiga Plains	Taiga Shield	Boreal Shield	Hudson Plains	Atlantic Maritime	Total
No data	95	866	20	15 192	52	42	194 447	1 059 134	301 265	133 135	**1 704 248**
Cloud	240 738	353 914	3 251 270	364 400	1 192 960	912 092	1 396 315	589 992	24 717	34 071	**8 360 469**
Shadow	620 522	1 672 710	437 517	62 019	831 242	176 355	515 462	298 652	8 649	100 206	**4 723 334**
Water	729 003	1 417 510	902 082	6 909 708	225 805	8 291 120	26 520 287	26 979 942	2 667 190	663 489	**75 306 136**
Snow / ice	3 141 610	1 023 530	1 475 630	1 931	1 380 960	232 884	398 454	16 181	0	961	**7 672 141**
Rock / rubble	328 694	1 750 670	1 039 180	26 097	1 189 470	367 934	3 771 638	662 486	22 515	40 023	**9 198 706**
Exposed / barren land	2 061 390	3 184 810	3 447 190	759 878	3 501 280	3 438 800	7 744 929	3 252 615	314 195	1 457 320	**29 162 406**
Bryoids	314	5	101 580	16	329 470	1 382 260	10 918 300	1 101 555	1 072 600	32 024	**14 938 123**
Shrub tall	16 925	717 948	1 549 190	2 386 416	509 569	1 390 700	5 979 865	8 081 751	903 856	145 286	**21 681 505**
Shrub low	1 374 630	2 853 680	8 277 750	671 443	5 734 580	6 978 400	20 737 050	7 042 043	551 725	1 383 250	**55 604 552**
Wetland-treed	62 766	82 375	117 063	7 548 622	21 313	3 763 560	2 271 664	6 367 421	10 662 000	56 412	**30 953 196**
Wetland-shrub	64 226	286 794	204 044	5 739 301	84 632	3 904 800	5 616 578	8 124 825	9 382 100	229 691	**33 636 991**
Wetland-herb	41 324	263 984	110 802	2 465 241	143 290	1 984 160	3 096 184	1 679 864	1 412 320	58 356	**11 255 524**
Herbs	1 019 040	3 471 530	2 923 530	11 149 560	4 393 570	795 224	504 572	5 206 382	409 256	892 584	**30 765 247**
Coniferous-dense	1 696 210	5 473 930	2 890 810	12 081 082	327 131	4 656 990	6 180 725	32 888 288	2 525 050	2 421 190	**71 141 406**
Coniferous-open	6 751 410	19 476 500	10 139 300	4 050 027	2 110 610	12 748 000	18 458 478	24 634 230	1 761 950	3 922 800	**104 053 305**
Coniferous-sparse	974 804	2 193 570	4 345 700	217 218	2 663 570	4 492 970	15 884 562	9 068 427	1 044 700	1 134 460	**42 019 981**
Broadleaf-dense	150 217	399 702	454 715	10 339 929	62 512	1 433 800	577 527	8 446 200	62 729	1 459 360	**23 386 690**
Broadleaf-open	631 346	1 681 980	675 030	2 748 662	168 521	2 155 880	526 808	1 644 841	2 861	1 150 870	**11 386 799**
Broadleaf-sparse	30 671	226 262	70 392	19 377	16 039	162 825	40 349	84 591	0	63 086	**713 592**
Mixedwood-dense	13 211	61 077	44 884	1 782 714	340	872 017	340 161	25 081 714	687 825	3 440 220	**32 324 165**
Mixedwood-open	251 960	1 024 990	1 844 540	2 017 774	228 341	1 839 210	971 881	6 431 498	25 194	1 498 460	**16 133 847**
Mixedwood-sparse	13 737	167 960	169 776	20 755	9 461	14 258	245 711	10 508 519	2 576 660	153 242	**13 880 079**
Total	**20 214 842**	**47 786 296**	**44 471 995**	**71 377 359**	**25 124 719**	**61 994 281**	**132 891 947**	**189 251 154**	**36 419 356**	**20 470 495**	**650 002 443**

employs a simple change detection method to facilitate the use of imagery from different sensors to identify changes that can subsequently be mapped using time-2 image spectral and contextual information.

EOSD LC 2000 is an example of what can be achieved with targeted federal funding and collaboration across federal, provincial, and territorial agencies, to produce useful products to satisfy regional, national, and international information needs. The completion of the EOSD product would not have been possible without generous federal (CSA, CFS) funding and in-kind and real contributions from provincial and territorial agencies. Co-operation and communication both within and between various levels of government provided an opportunity to share resources and to work towards common objectives. Products generated from this project are vital for the monitoring of Canada's forests and will assist the public and interested organizations in understanding the composition, distribution, and dynamics of Canada's forests.

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