

The Petawawa Research Forest: Establishment of a remote sensing supersite

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ABSTRACT

The pace of technological change in forest inventory and monitoring over the past 50 years has been remarkable, largely as a result of the increased availability of various forms of remotely sensed data. Benchmarking sites, with the requisite reference and baseline data for evaluating the capacities of new technologies, algorithms, and approaches, can be extremely valuable for sparking innovation, as well as for enabling transparent and scientifically sound assessments of technologies, new data streams, and associated information outcomes. Herein we describe the establishment of a remote sensing supersite at the Petawawa Research Forest (PRF) in southern Ontario, Canada, and summarize the open access datasets that have been compiled and made available to the public. The PRF is approximately 10 000 ha in size and represents a complex assemblage of tree species and forest structures. More than 1900 data records, including multiple airborne laser scanning datasets and associated derivatives (i.e., digital terrain model, canopy height model), airborne imagery, satellite remote sensing time series, and ground plot data, among others, have been made openly available for download from Canada's National Forest Information System. We identify issues and present opportunities associated with the establishment of a remote sensing supersite at the PRF, as well as share some of the lessons learned to foster the establishment and open data sharing for other national and international remote sensing supersites. The PRF supersite can be accessed from the following link: <https://opendata.nfis.org/mapserver/PRF.html>.

Keywords: forest, inventory, open data, LiDAR, Landsat, time series, Sentinel, monitoring

RÉSUMÉ

La vitesse des changements technologiques en matière d'inventaire forestier et de suivi au cours des 50 dernières années a été remarquable, principalement à la suite de la disponibilité accrue des différentes formes de données acquises par télédétection. Les sites d'analyse comparative, comprenant des informations de référence et des données de base destinées à l'évaluation des capacités des toutes nouvelles technologies, algorithmes et approches, peuvent s'avérer extrême précieux lors du développement d'une innovation, tout en permettant des évaluations transparentes et scientifiquement fondées des technologies, des nouveaux ensembles de données et des retombées connexes en matière d'information. Nous décrivons dans cet article la mise en place d'un supersite de télédétection dans la Forêt expérimentale de Petawawa (FEP) située dans le sud de l'Ontario au Canada et nous présentons un condensé des ensembles de données de libre accès qui ont été compilés et rendus disponibles au public. La FEP couvre approximativement 10 000 ha et constitue un assemblage complexe d'espèces d'arbres et de structures forestières. Plus de 1 900 ensembles de données, incluant de nombreux ensembles de données provenant de balayage scanner par des lasers aéroportés, ainsi que leurs dérivés connexes (par ex., des modèles numériques du terrain, des modèles de la hauteur des cimes), des représentations aéroportées, des ensembles de données chronologiques provenant de télédétections par satellite et des données terrestres tirées de parcelles, entre autres, sont facilement accessibles pour téléchargement à partir du Système d'information sur les forêts nationales du Canada. Nous avons identifié les enjeux et les opportunités présentes associées à la mise en place d'un supersite de télédétection dans la FEP, en plus de présenter les leçons reliées à la sensibilisation envers la mise en place et le partage des données pour les autres supersites nationaux et internationaux de télédétection. Le supersite de la FEP peut être accédé en suivant le lien : <https://opendata.nfis.org/mapserver/PRF.html>.

Mots clés : forêt, inventaire, données libres, LiDAR, séries chronologiques, Sentinel, suivi

Introduction

Established in 1918 to generate and transfer knowledge that could be used to improve the quality, productivity, and health of Canada's forests, the Petawawa Research Forest (PRF) is the oldest, continuously operated research forest in Canada (Place 2002). Over the 100-year history of the PRF, numerous ground sample plots and research trials have been established. For example, the PRF is known to have hosted approximately 500 growth and yield permanent sample plots (PSPs), 100 silvicultural field studies, 125 research planta-

tions, 1100 intensive forest management plots, 300 genetic trials, 100 forest fire experimental sites, 13 ecological reserves, and 300 remote sensing sites (D'Eon 2006). These data holdings, long-term infrastructure, and ease of accessibility make the PRF an ideal location for facilitating long-term research (Burgess and Robinson 1988), as well as collaboration among government researchers, universities, and industry (Place 2002).

Remotely sensed data, specifically aerial photography, has played a critical role in the development of forest inventories.

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Recently, new remote sensing technologies, including airborne laser scanning (ALS) or airborne Light Detection and Ranging (LiDAR), and digital aerial photogrammetry (DAP), are increasingly used to enable detailed, accurate forest inventories over large areas (White *et al.* 2016). Over time, the PRF has been the site of numerous operational and experimental remotely sensed data acquisitions (Leckie 1990). More recently, airborne LiDAR data have been acquired, and used in conjunction with ground plot data to develop an Enhanced Forest Inventory (EFI) for the PRF (White *et al.* 2013a, 2017). Collectively, these available data holdings make the PRF an ideal location for the development, testing, and validation of algorithms, approaches, and applications of remotely sensed data for forest management.

This communication describes the establishment of a remote sensing supersite and innovation incubator at the PRF. Supersites are foci for data acquisition and analysis, providing critical reference data that enable new technologies and approaches to be benchmarked and evaluated objectively and transparently. The remote sensing supersite at the PRF was established to facilitate the compilation and consolidation of available data holdings and associated metadata into an accessible platform, with the objective of providing efficient and open access to data in order to stimulate innovation and enable ongoing research and development. In this communication we introduce the supersite concept, summarize the datasets that have been compiled and made available for the PRF to-date, and indicate lessons learned and opportunities for the establishment of other similar remote sensing supersites in Canada and beyond.

The Supersite Concept

Supersites are spatial foci for measurement and long-term observation of phenomena. The supersite concept is not new; in 1980, the National Science Foundation established the Long Term Ecological Research (LTER) Network, which now includes more than 28 sites across the United States (Hobbie *et al.* 2003). Similarly, the Australian Supersite Network was established in 2009 as a series of 10 terrestrial monitoring supersites where data collection and research efforts are focused on biodiversity and ecosystem function (Karan *et al.* 2016). In Canada, the Boreal-Atmosphere BOREAS project established remote sensing supersites, with locations in Saskatchewan and Manitoba selected to represent the boreal forest ecotone (Hall *et al.* 1993). Although the BOREAS supersites were not maintained, the data acquired via the BOREAS project are openly available through the ORNL DAAC¹, including 40 remotely sensed datasets. More recently, a remote sensing supersite was established in Hekla, South Iceland for retrospective monitoring of the Hekla volcano eruptions (Pedersen *et al.* 2019). Hekla is one of 10 such supersites established by the Group on Earth Observations (GEO) as part of their Geohazard Supersite and Natural Laboratory initiative. Similar to the PRF supersite described herein, the GEO supersites seek to make data openly accessible and provide interactive data visualization capabilities to end users.

¹ <https://daac.ornl.gov>

The Petawawa Research Forest

The PRF extends over an area of approximately 10 000 ha and is situated in Ontario, approximately two-hours northwest of Canada's capital city, Ottawa (Fig. 1). Located in the mixed-wood forests of the Great Lakes–St. Lawrence Forest region, common tree species include white pine (*Pinus strobus* L.), trembling aspen (*Populus tremuloides* Michx.), red oak (*Quercus rubra* L.), red pine (*P. resinosa* Ait.), white birch (*Betula papyrifera*), maple (*Acer* spp.), and white spruce (*Picea glauca*), among others (Wetzel *et al.* 2011). The Great Lakes–St. Lawrence forest region is considered a transition zone between the boreal forests to the north, which are dominated by coniferous species, and the deciduous-dominated forests to the south. The species diversity, combined with a long-term history of silvicultural treatments, contributes to the structural complexity of the forests found in the PRF, which are currently actively managed by the Canadian Wood Fibre Centre of the Canadian Forest Service.

Remotely sensed and ancillary datasets

The remotely sensed and ancillary data compiled for the PRF supersite are detailed in Tables 1–5, organized by data type (e.g., ALS, aerial photography, ground) and where appropriate, by sensor.

Airborne laser scanning data

The PRF has been the subject of multiple ALS surveys (Table 1) and the desire to publically share these data has been the primary driver for the development of the PRF supersite. The first ALS surveys were conducted in early September 2005 using the Leica ALS40 sensor mounted in a King Air 90 aircraft flown at an altitude of 2740 m above ground level, with a ± 20 degrees field of view, and a maximum pulse repetition frequency of 32 KHz. This resulted in a cross-track point spacing of 2.8 m and along-track point spacing of 2.4 m, with an average point density of 0.5 points/m². Woods *et al.* (2008) used these data to generate area-based models for top height, average height, basal area, volume, quadratic mean diameter, and stem density for natural hardwoods, natural conifers, and plantation conifers. Thomas *et al.* (2008) subsequently used these data to model diameter size class distributions. High resolution 4-band (R, G, B, NIR) digital airborne imagery (0.4 m) was acquired concurrently using a Vexcel Ultracam and a mosaic of these data have also been made available for the supersite (Table 2).

In August 2007, transects of ALS data were collected for the PRF and two additional study areas using an Optech ALTAM 3100 mounted in a Cessna Grand Caravan aircraft flown at 1000 m AGL, with a ± 20 degrees field of view and maximum pulse repetition frequency of 100 KHz. This resulted in a cross-track spacing of 0.5 m, and along-track spacing of 0.6 m. ALS data were acquired at two different point densities: three points/m² and 10 points/m². Treitz *et al.* (2012) used the three points/m² data in a subsequent investigation of the impact of pulse density on the accuracy of area-based forest attribute models. Note that the 10 points/m² data were not used in Treitz *et al.* (2012), as the operational acquisition costs for point densities above three points/m² constrained the use of these data for forest inventory at that time.

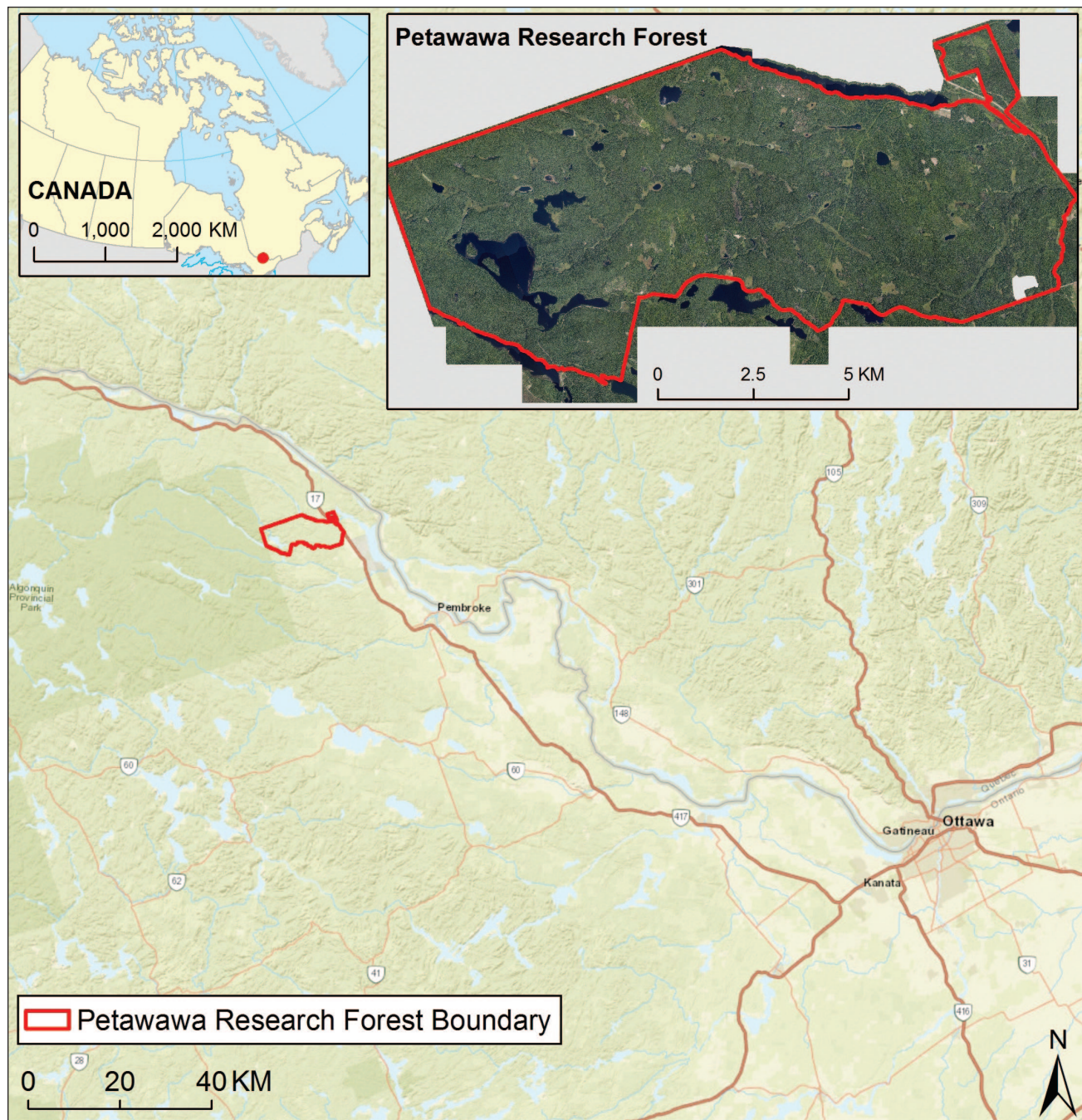


Fig. 1 Location of Petawawa Research Forest in Ontario, Canada

Wall-to-wall ALS data were acquired for the PRF in August of 2012 using a Reigl LMS-680i mounted in a Cesna 172, flown at an altitude of 750 m above ground level, and a maximum pulse repetition frequency of 150 KHz, with a ± 20 degrees field of view. This resulted in cross-track and along-track spacing of 0.6 m and an average pulse density of 10 points/m². Note that additional ALS data is available for the PRF, including an Optech Titan multi-spectral ALS acquisition from 2016, and single photon LiDAR acquisitions from 2018 and 2019. These data will be shared on the supersite in the near future.

Digital airborne imagery

Numerous analog and digital images have been acquired for the PRF over the years (Table 2). The first aerial photography campaign for the PRF was conducted in 1925, with photos used to generate a basic map of forest cover types (Place 2002). Although the historic analog air photo acquisitions for the PRF have not been digitized in a systematic fashion, many of the acquisitions are available through the National Air Photo Library², with some available to be scanned on

² https://www.eodms-sgdot.nrcan-rncan.gc.ca/index_en.jsp

Table 1. Airborne Laser Scanning (ALS) data acquired for the PRF supersite

Year(s)	Sensor	Spatial extent	Description
2012	Lidar Riegl Q680i	Wall-to-wall	ALS data were acquired for the PRF in September 2012 in support of Enhanced Forest Inventory (EFI) research and development objectives. Point density = 10 pts/m ² . Normalized to heights above ground. LAZ files (1km x 1km) tiles bundled as single .zip file. Derivatives include full PRF mosaics of a 1 m DTM and a 0.25 m CHM. Original vertical datum = CGVD28. Search terms: “PRF” and “LAS” and “2012”
2007	Optech ALTM 3100	Transects	Transects of ALS data were acquired for the PRF in August 2007 at two different point densities: 3 pts/m ² and 10 pts/m ² . Each transect is delivered as a separate .LAZ file. Original vertical datum = CGVD28. Search terms: “PRF” and “LAS” and “2007”
2005	Leica ALS40	Wall-to-wall	ALS data acquired for the PRF in September 2005. Normalized to heights above ground. Point density = 0.5 pts/m ² . LAZ files (1km x 1km tiles) bundled as a single .zip file. Note a small area to the southwest of the PRF without coverage. Original vertical datum = NAVD1988. Search terms: “PRF” and “LAS” and “2005”

Table 2. Digital airborne image data acquired for the PRF supersite

Year(s)	Sensor	Spatial extent	Description
2013	Vexcel Ultracam Lprime	Wall-to-wall	Mosaic of 4-band (R,G,B,NIR) digital imagery acquired August 18, 2013 with a 0.15 m spatial resolution. RGB and CIR (NIR,R,G) mosaics generated. Search terms: “PRF” and “optical” and “2013”
2009	Leica ADS80	Wall-to-wall	Mosaic of 4-band (R,G,B,NIR) digital imagery acquired September 6, 2009 with a 0.4 m spatial resolution. The derived SGM image point clouds (in LAZ format) are also available (search terms “PRF” and “SGM”). Search terms: “PRF” and “optical” and “2009”
2007	Vexcel Ultracam	Transects	Raw photos, orthorectified imagery, and mosaics of 3-band (NIR, R, G) digital imagery with a 0.2 m spatial resolution acquired August 1, 2007. Search terms: “PRF” and “optical” and “2007”
2005	Vexcel Ultracam	Wall-to-wall	Mosaic of 4-band (R,G,B,NIR) imagery with a 0.4 m spatial resolution acquired September 5, 2005. Concurrent to ALS acquisition in 2005 (see Table 1). Search terms: “PRF” and “optical” and “2005”

Table 3. Earth Observation data compiled for Petawawa supersite

Satellite	Year(s)	Sensors	Spatial extent	Description
Landsat	1972–2018	MSS, TMETM+OLI	Wall-to-wall	Archived Landsat data. TM, ETM+, OLI data from USGS ESPA as surface reflectance product (LEDAPS). MSS data is Landsat Collection-1, most in L1TP format. Search terms: “PRF Landsat MSS”; “PRF Landsat4 P17R28 TM”; “PRF Landsat5 P17R28 TM”; “PRF Landsat7 ETM+ P17R28”; “PRF Landsat8 OLI P17R28”
Sentinel-2A and 2B	2016–2018	MSI	Wall-to-wall	Archived Sentinel-2 data obtained from ESA’s Copernicus Open Access Hub and corrected to surface reflectance using Sen2Cor. Search terms: “PRF Sentinel2 Sen2Cor”
Harmonized Landsat and Sentinel-2	2013–2018	OLI and MSI	Wall-to-wall	Harmonized Landsat-8 OLI and Sentinel-2 MSI surface reflectance data generated by NASA/USGS (2013–2018). Data resampled to 30 m over the Sentinel-2 tiling system. Search terms: “PRF HLS”
Sentinel-1A	2016–2018	SLC	Wall-to-wall	Sentinel-1A IW SLC data acquired from the ESA was processed using ESA’s SNAP. The processing steps included calibration, multilook, speckle filter, terrain correction, and subset. The georeferenced product was coregistered to a master on 2017-09-02 and exported as 32-bit geotiff with 30-m pixel spacing. Search terms: “PRF Sentinel1”

demand. The airborne image data that has been made available through the PRF supersite is primarily recent digital acquisitions (Table 2), including three-dimensional point clouds generated from digital aerial photogrammetric (DAP) data acquired in 2009. Image-matching algorithms such as the semi-global matching algorithm or SGM (Hirschmüller 2008) are applied to digital imagery to generate a three-dimensional point cloud, similar to that produced from ALS data, but primarily representing the top of the canopy (White *et al.* 2013b). DAP data are increasingly used in forest inventory applications (Pitt *et al.* 2014; Penner *et al.* 2015; Goodbody *et al.* 2019).

Earth observation data

Optical satellite earth observation data collated for the PRF supersite include Landsat, Sentinel-2, and Harmonized Landsat-Sentinel-2 (HLS) products (Table 3). All available Landsat data for the PRF with $\leq 70\%$ cloud cover from MSS, TM, ETM+, and OLI sensors were downloaded from the USGS Earth Resources Observation and Science (EROS) Science Processing Architecture (ESPA). TM, ETM+, and OLI data were downloaded as surface reflectance data products, whereas the MSS data are Collection-1, Tier 1 products, with the majority of MSS images in Level 1 Precision and Terrain (L1TP) corrected format (USGS 2019), as digital numbers (i.e., not atmospherically corrected). In addition, a total of 142 Sentinel-2 MSI images with $\leq 70\%$ cloud cover were downloaded from the ESA Copernicus Open Access Hub as Top-of-Atmosphere (TOA) Level 1C images and corrected to surface reflectance using the Sen2Cor algorithm (version 2.5.5; Mueller-Wilm *et al.* 2018). Harmonized Landsat-8 OLI and Sentinel-2 MSI (HLS) data representing the 2013–2018 time period with $\leq 70\%$ cloud cover were downloaded from the National Aeronautics and Space Administration (NASA³; Claverie *et al.* 2018). Synthetic Aperture Radar (SAR) data were also acquired from the ESA Copernicus Open Access Hub. A total of 48 Sentinel-1 Interferometric Wide (IW) Single Look Complex (SLC) images with VV+VH polarisation were acquired from the European Space Agency (ESA) Open Access Hub and processed using ESA's Sentinel Application Platform (SNAP; for processing details see Table 3).

Data related to the 2012 Enhanced Forest Inventory

As noted above, ALS data were acquired for the PRF in 2012 to support the development of an EFI. The wall-to-wall raster surfaces generated from the ALS data and used as predictors in the development of area-based models for estimating forest inventory attributes (White *et al.* 2013a, 2017) are included for the supersite, as are the resulting wall-to-wall area-based predictions for attributes such as top height, basal area, volume (Table 4). Ground plot data are expensive and challenging to acquire in some of Canada's more remote forest regions; however, ground plots are critical to the development of enhanced forest inventories and a myriad of other applications. At present, only ground plot data acquired in 2012–2014 to support the development of an EFI at the PRF have been shared on the supersite ($n = 223$ plots). In the near future, it is anticipated that PSP data will also be made available on the supersite portal, including data from Canada's oldest PSP (Burgess and Robinson 1998).

Data processing and hosting

The overarching goal of the data processing was to generate Analysis Ready Data (ARD) products from the available data collections where possible. ARD implies that a certain minimum level of pre-preprocessing has been applied in a consistent and transparent manner. At a minimum, processing was intended to ensure common and consistent spatial referencing. Key datasets that have formed the foundation of the supersite to date include various ALS and associated ground plot data.

Projections and file formats

All data compiled for the supersite were projected to a common map projection (Table 6). A common map projection enables data integration.

Data hosting platform

Benefits that flow from the investments of public funds in the acquisition and analysis of geospatial data can often only be realized if that data are made freely and openly accessible to all (Zhu *et al.* 2019). Moreover, increasingly sophisticated data sharing capabilities have moved beyond the mere posting of data to a file transfer protocol (ftp) site, toward automated data discovery by other online data services, as well as providing data visualization and manipulation functionality to end users. Data collections for the PRF are hosted on Canada's National Forest Information System (NFIS) (<http://nfis.org> or <https://ca.nfis.org>), a distributed computing infrastructure that connects the federal, provincial, and territorial governments together to share and publish information on Canada's forests and sustainable forest management. The NFIS was established by the Canadian Council of Forests Ministers (CCFM) in 2000 and is maintained by the Canadian Forest Service (CFS), Natural Resources Canada (NRCAN). The NFIS infrastructure utilizes a variety of geospatial and mapping software and provides web tools that enable simple visualizations of data to more advanced analytical capabilities, such as Canada's NFI Biomass Calculators⁴. This functionality allows users from anywhere in the world to discover, display, and integrate data hosted on the NFIS for their own applications.

The NFIS infrastructure supports Canadian national programs and initiatives such as the Federal Geospatial Platform (FGP), Canadian Geospatial Data Infrastructure (CGDI), and Canadian Wildland Fire Information System (CWFIS), and many applications such as National Forest Inventory (NFI), Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3), System of Agents for Forest Observation Research with Advanced Hierarchies (SAFORAH) and more. The SAFORAH application is an Open Geospatial Consortium (OGC) Catalogue Service compliant data catalog system, based on GeoNetwork, an open source software for cataloging and managing spatially-referenced resources⁵. The current implementation of SAFORAH provides geospatial value-added information products acquired and/or generated by the CFS and its partners. Metadata harvested from other geospatial data systems operated by various levels of Canadian governments (federal, provincial and territorial) and academic institutions are also discoverable on

³ <https://hls.gsfc.nasa.gov/>

⁴ <https://nfi.nfis.org/en/biomass>

⁵ <https://geonetwork-opensource.org/>

Table 4. Data related to the development of an Enhanced Forest Inventory (EFI) at the PRF

Dataset	Year(s)	Spatial extent	Description
Enhanced Forest Inventory (EFI) Predictors	2012	Wall-to-wall	A broad range of point cloud metrics generated from the 2012 wall-to-wall airborne LiDAR data that were used as predictors in the area-based EFI models (height percentiles, density metrics, etcetera). Search terms: “PRF predictors”
Enhanced Forest Inventory (EFI) Predictions	2012	Wall-to-wall	Area-based estimates for a suite of forest inventory attributes including height, basal area, volume, etcetera. Search terms: “PRF inventory attributes”
Field plot data	2012–2014	Samples	Field plots established to support the development of the EFI. Plots had a 14.1 m radius (625 m ²). Details on attributes and data acquisition protocols are provided with the data. Search terms: “PRF field plots”

Table 5. Other miscellaneous data layers included in PRF supersite collection

Dataset	Year(s)	Spatial extent	Description
Base data	Various	Wall-to-wall	Base data layers include the PRF boundary, lakes, wetlands, and various digital elevation models. Search terms: “PRF” AND “vector”; “PRF” AND “DEM”
Forest Inventory	2000 and 2007	Wall-to-wall	Forest inventory data generated using air photo interpretation and ground plot data. Inventories for the PRF were completed in 2000 and 2007. Search terms: “PRF” AND “Forest Inventory”
Wet Areas Mapping	2012	Wall-to-wall	A suite of products derived from the 2012 LiDAR DTM that characterize streams, depth-to-water, etcetera. Search terms: “PRF” AND “WAM”

Table 6. Standard projection information

Property	Value
XY Coordinate System	WGS 1984 UTM Zone 18N
Linear unit	Meter (1.00000)
Angular unit	Degree (0.0174532925199433)
False Easting	500000
False Northing	0
Central Meridian	-75
Scale Factor	0.996
Latitude of Origin	0
Datum	WGS 1984
Vertical Datum (where relevant)	CGVD1928

SAFORAH. To establish the remote sensing supersite at the PRF, we utilized SAFORAH to describe and publish all available remotely sensed and ancillary datasets.

Data services

SAFORAH GeoNetwork publishes metadata following the OGC Catalog Services for the Web (CSW) protocol, which allows for the querying, updating, and ingesting of metadata records in the data catalog. A customized CSW client written in HTML/Javascript was developed at the CFS to allow for

the discovery of metadata information from compliant distributed CSW servers. Accessing metadata information collected in SAFORAH GeoNetwork can be conducted either by using the SAFORAH web client⁶ or through the OGC web application interface.⁷ The metadata editor in SAFORAH GeoNetwork supports ISO 19115/119/110 metadata standards used for geospatial data and resources. SAFORAH provides metadata linkages to the available OGC services⁸ such as the Web Map Service (WMS) and the Web Coverage Service (WCS) and other OGC services. For the PRF, geospatial data resources are managed by the CFS, and the metadata standards comply with the Harmonized ISO 19115:2003 North American Profile (NAP), introduced by the Government of Canada through the Treasury Board Secretariat in 2009. This Harmonized ISO 19115:2003 NAP not only requires federal government departments and agencies to implement internationally recognized and adopted standards (ISO 19115), but also minimizes discrepancies in interpretation and implementation of the NAP specifications.⁹

Data included in the PRF supersite are published using the open source web mapping product called MapServer¹⁰ with

⁶ <https://saforah2.nfis.org/CSWClient/>

⁷ <https://saforah2.nfis.org/geonetworkmain/srv/eng/csw?SERVICE=CSW&VERSION=2.0.2&REQUEST=GetCapabilities>

⁸ <https://geonetwork-opensource.org/>

⁹ <http://nap.geogratis.gc.ca/home.html>

¹⁰ <https://mapserver.org/>

instances of OGC WMS and WCS. Web Feature Services (WFS) are also configured for data dissemination. The OGC WMS protocol allows users to visualize the data as images on the web or through specific geographic information system software. The WCS services allow for the raw digital numbers or classifications of raster data to be disseminated for further analysis or representation. The WFS allow for the dissemination of vectorized geographic data with associated attributes. All of these WMS, WCS and WFS services allow user to access data using a variety of software packages and/or web tools. Users reading PRF metadata records hosted on the SAFORAH GeoNetwork data catalog can utilize web visualization tools to further explore the discovered PRF dataset from the catalogue interface. Data can then be download via OGC web services to the users' own environment for further analysis.

The OGC WMS, WCS, and WFS services support standardized interfaces that can be harvested by machine learning (ML) frameworks, using them to automatically discover and access the PRF supersite data. In conjunction with OGC Web Processing Service (WPS) and dynamic orchestrations of required computing and geospatial resources, processes can be developed, discovered, and executed directly on the web. Research and development of forest and scientific earth observation applications with cloud-based machine tools are continuing. In addition to OGC WCS, SAFORAH also provides http-download links through the SAFORAH CSW client, enabling users to download full datasets directly.

Establishment of a remote sensing supersite: issues and opportunities

The PRF remote sensing supersite was established as a location to share data and develop best practices, tools, and information products to address common information needs associated with forest management. The supersite concept is premised on facilitating efficient and open access to the wealth of data holdings at the PRF. As an innovation incubator, the PRF supersite maximizes investments that have been made in public data, allowing more users to directly access and use the data and thereby enabling further research and development. An example is a recent initiative of the Open Geospatial Consortium to use the PRF supersite data in its exploration of interoperable geospatial data processing functionality (Testbed-15; Meek 2019).

The availability of reference data in the form of ground plots and ALS data make the PRF an invaluable test site and benchmarking location for testing new sensors, technologies, algorithms, and approaches. Indeed benchmarking is one of the key applications of a remote sensing supersite, enabling efficiencies and reducing investment risk for stakeholders. In this context, supersites are valuable for service providers and industry stakeholders, who may need to demonstrate initial results or conduct proof-of-concept studies to garner further support for a proposed product or service. Supersites likewise can foster increased collaboration, providing an opportunity for sharing resources in the development of remote sensing applications. In a Canadian context, the supersite concept represents a particular benefit to provinces and territorial forest management agencies by providing a foci for research investment and collaboration to address common questions

and information needs. Supersites also provide useful data for both research and education purposes, enabling researchers and students alike to avail upon curated data collections to explore new and emerging research questions, without barriers associated with data acquisition costs or access.

Supersites also have other less tangible benefits. Foremost among these is the maintenance of a clear and consistent data sharing policy. Sharing data openly not only reduces the administrative burden to respond to data requests, it is also a mechanism for enabling data version control and accessibility for all interested users. Open data also allows legacy data to be leveraged in new ways, or to address new questions or issues not previously conceived of, further increasing value to society from investments in public data. However, legacy data is not always a panacea: it may be stored on media that are no longer supported by current technologies, or these data may lack sufficient metadata to make them fully useable. As a result, supersites are often dynamic, with new data added as it becomes available or as data sharing policies change.

The PRF is unique in the Canadian context in terms of the availability of data and investments in infrastructure that have been made over time. Moreover, the PRF also represents distinctive forest conditions that are characteristic of the Great Lakes–St. Lawrence forest region within which the PRF is located. Ideally, remote sensing supersites would be established in other forest environments, particularly the boreal, which represents a large component of Canada's forested ecosystems. As such the establishment of a remote sensing supersite in the PRF is an initial step, providing centralized access to a subset of data, that will hopefully benefit from an increasing trend in towards more open and transparent data sharing of public data, both in Canada and beyond.

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