Chapter 12
Canada

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12.1 Canada's National Forest Inventory

12.1.1 History and Objectives

Canada's National Forest Inventory (NFI) is undertaken as a collaborative program involving ten provinces, two territories and the federal government. Most of Canada's forests are on publicly owned land. Provinces and territories have constitutional responsibility for the management of forests on most publicly owned land, and develop legislation, regulations, policies, and practices to support their forest stewardship. They also maintain forest inventory programs. The NFI program complements these programs by providing strategic-level data and information

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products that are consistent across all jurisdictions and forest types in Canada (Gillis et al. 2010).

Forest inventory data from across Canada were first summarised into a computerised national dataset in 1981 (Bonnor 1982). This dataset, referred to as "Canada's Forest Inventory" (CanFI), was updated periodically, with the last update published in 2006 (Forestry Canada 1988; Lowe et al. 1994; Power and Gillis 2006). The need for a new, design-based NFI was recognised in the 1990s (Barker et al. 1996). The variety of standards and protocols used by provincial and territorial inventory programs and inconsistency over time made it impossible to generate consistent national information or assess forest change at the national scale. Consensus on the NFI design was reached in 1997 and plot establishment was completed during 2000–2006. The target population is Canada's entire non-Arctic land base, stratified for reporting purposes into 12 terrestrial ecozones (Ecological Stratification Working Group 1996; Fig. 12.1). The data are used for national and international reporting, for supporting forest research and policy development, and for responding to national and international enquiries about Canada's forests. The NFI program is currently completing its first ten-year re-measurement cycle (2008–2017).

Fig. 12.1 The terrestrial ecozones of Canada (Ecological Stratification Working Group 1996)

12.1.2 Sampling Procedures

Canada's NFI includes a field survey component and a remote sensing survey component (Gillis et al. 2010). The remote sensing survey consists of square (2 × 2 km; 400 ha) sample units located on a systematic national sampling grid (every 20 km). The current survey has been reduced to units spaced every 40 km in some ecozones (Fig. 12.2). In total, there are 13,158 sample units included in the current (first re-measurement) survey. Permanent field survey units (ground plots) are maintained in a subset of the forested remote sensing survey sample units.

12.1.2.1 Remote Sensing Survey

Stereo photography flown at scales ranging from 1:10,000 to 1:20,000 are the preferred imagery data for the NFI remote sensing survey due to their high degree of spatial detail and the opportunity they present to interpret and measure land cover and forest attributes stereoscopically (Gillis and Leckie 1993). NFI remote sensing survey plots are therefore commonly referred to as 'photo-plots', even though some of the image data are acquired by sensors mounted on orbiting satellites (Falkowski et al. 2009). During NFI establishment, northern portions of the survey that could not be completed in time were done using a medium resolution remote sensing land cover product (Wulder et al. 2008).

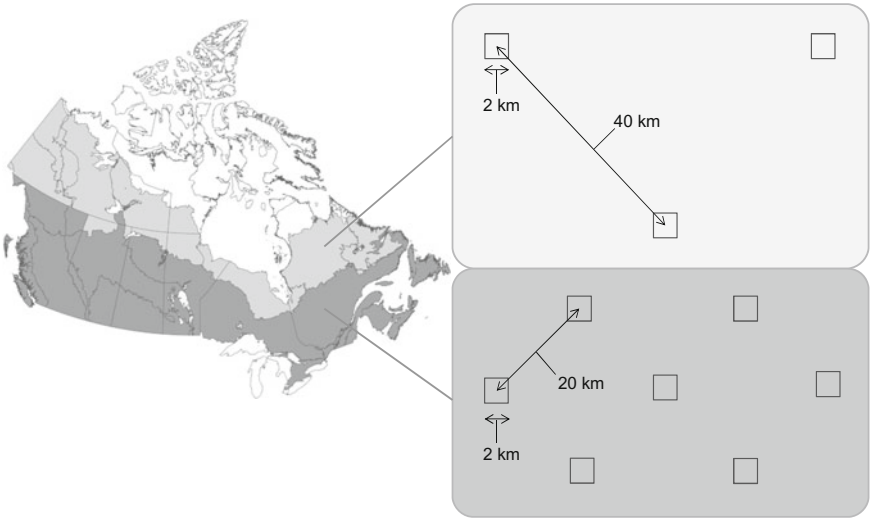

Fig. 12.2 NFI remote sensing survey sampling densities for first re-measurement (T1: 2008–2017). In southern Canada (*dark grey*), 2 × 2 km photo-plots are located on a 20 × 20 km grid and in the north (*light grey*) on a 40 × 40 km grid

At the outset of the first re-measurement cycle (T1: 2008–2017), NFI photo-plots were divided into two 'panels'. Each panel included one half of the survey plots distributed evenly across the sampling frame. The first panel (P1) was to be surveyed during the first five years of the ten-year re-measurement period, and the second panel (P2) was to be surveyed during the second five years. In this way, the sub-sample available at the T1 mid-point could be used to produce mid-cycle statistical reports without geographic bias. When it became evident that the P1 and P2 surveys would not be completed as planned because of poor alignment with provincial and territorial inventory program activities, the survey was adjusted to align better with provincial and territorial inventory activities by relaxing the two-panel approach and focussing instead on completing the photo-plot survey over the ten year period.

12.1.2.2 Field Survey

The NFI field survey program maintains 1116 ground plots across Canada (Fig. 12.3). These plots are measured over ten years with, on average, one tenth of the plots measured each year. The plot design consists of two transects for assessing woody debris and surface substrate; four microplots for destructive sampling of

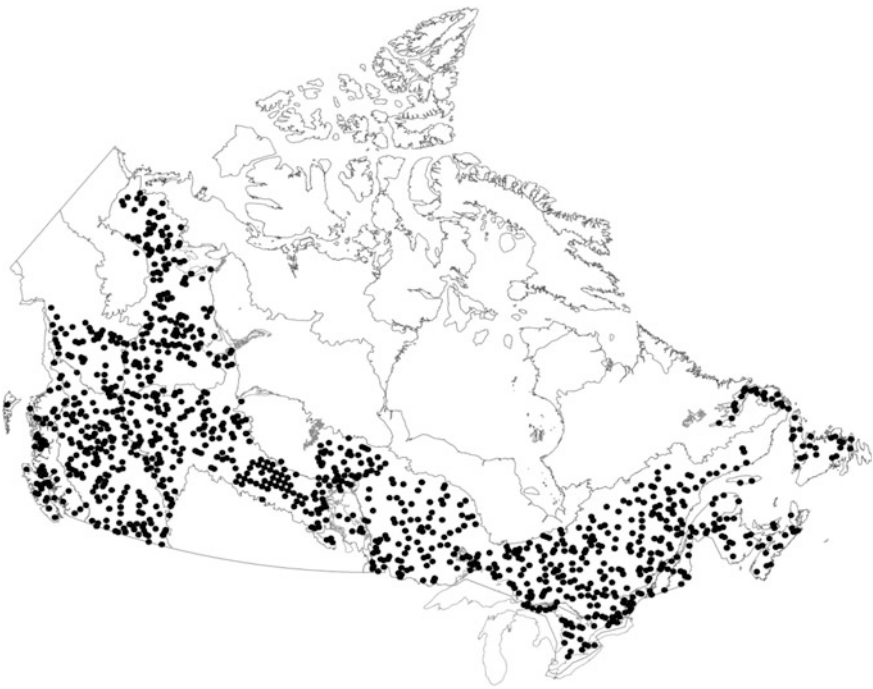

Fig. 12.3 NFI ground-plots (field plots)

understory vegetation, forest floor organic material and soils; two ecological plots for assessing biodiversity; a soil pit; a large tree plot; and a small tree, shrub and stump plot (NFI Task Force 2008; Gillis et al. 2010). While 1116 is a small number of ground plots for a country the size of Canada, the high per unit costs associated with field sampling make it challenging to maintain even this number. Many plots are remote and crews must be flown in over long distances by helicopter or float plane.

The plots are used to support the photo-plot sampling program and provide data for research (e.g. Shaw et al. 2013; Neigh et al. 2013; Zhang et al. 2014; Mansuy et al. 2014; Girardin et al. 2015). These plots provide an important complement to the much larger networks of permanent and temporary sample plots (PSP and TSP) that are established and maintained annually by the provinces and territories for their respective inventories. It has been a long-standing goal for the NFI team to exploit these data in connection with remotely sensed imagery. Issues surrounding geo-location accuracy of these plots and harmonization of data are the greatest obstacles to progress.

12.1.2.3 Data Collection

Photo interpreted attributes constitute the core data in the NFI. Four data-layers of information are sought for each photo-plot: (i) land cover, (ii) land use, (iii) ownership, and (iv) protection status (Gillis et al. 2010). Attributes and classification are described in detail in the NFI Photo Plot Data Dictionary (available online at: nfi.nfis.org).

Data collection at NFI ground-plots is described in Canada's National Forest Inventory Ground Sampling Guidelines (also available online at: nfi.nfis.org).

12.1.2.4 Data Processing, Reporting and Use of Information Products

During NFI establishment, collaborating government agencies developed reporting strategies and designed a suite of standard statistical estimators and indicators to meet the information needs of the Montreal Process and the Canadian Council of Forest Ministers Criteria and Indicators (CCFM 2003; Montreal Process 2009). Baseline reports, based on NFI establishment data (collected during 2000–2006), were published on the NFI website in 2009 (accessible at: nfi.nfis.org). The baseline reports have since been updated in response to changes in data compilation routines and statistical estimation procedures.

The standard strata for statistical estimation are the 'NFI Units', which are derived from the geographic intersection of provincial and territorial borders with the Terrestrial Ecozones of Canada mapped at a 1:1,000,000 scale (Ecological Stratification Working Group 1996). The NFI sampling density does not provide sufficient accuracy to support reporting for all NFI Units because some are quite small. Estimates produced for NFI Units are summed up to provide reporting for 12

Terrestrial Ecozones. National reports are produced by summing across all NFI Units. The NFI also produces separate reports for the Boreal Zone (Brandt 2009) and will produce reports for FAO ecological zones (CEC 2011).

Estimators of NFI attributes are computed on a per stratum basis and combined to a national or ecozone estimate assuming stratified random sampling and known strata areas and hence strata weights. There are two basic types of estimators: those that relate to areas with a certain attribute (e.g. cover type coniferous); and those that relate to per unit area values (e.g. volume per ha).

Area defined attributes are estimated by first estimating the mean area-proportion of the attribute in the NFI sample of photo-plots. The total area is then obtained by multiplying this proportion with a known total area obtained from an official statistic. The standard error of an area estimate is obtained as for stratified random sampling of a proportion and multiplied by the total known area.

Two different types of estimators are provided in our inventory results. The first type has the entire landbase as the population of interest. Here traditional design-based estimators of means and variances for simple random sampling within a stratum, region, or inventory unit are used (Cochran 1977, Chap. 2). Weighted estimators are used whereby weights are proportional to the area of a photo-plot that resides within the population of interest.

The second type of estimator is a ratio estimator for single stage sampling with clusters of unequal sizes. Here the sample frame is the land in a specified condition class (e.g. treed and coniferous). For each 400 ha photo plot we obtain the total of an attribute value (e.g. total volume) and the total area in the specified condition class (coniferous). Means and approximate variances are computed as for ratio estimators (Cochran 1977, Chap. 6). Volume is a derived attribute from photo-interpretation of one or more of the following: species composition, height of leading species, basal area or stocking or crown closure (by species), and age. To the extent possible, the photo-interpretation is by visible stand layers. Local and regional look-up tables, volume equations, and yield tables are also used where deemed appropriate by the provincial or territorial forest inventory agency supplying the volume data to the NFI. Volumes are calculated for the main stem (without bark), including stump and top as well as dead and decayed wood for all trees greater than 1.3 m tall. The NFI will produce its first estimates of volume changes and increments when enough re-measurement data have been processed, loaded into the central NFI database, and made available to the estimation routines.

Map products have been produced from NFI data by Beaudoin et al. (2014) using the k nearest neighbours (kNN) method with 26 geospatial data layers including MODIS spectral data and climatic and topographic variables. Progress is also being made toward the production of more advanced products at substantially higher spatial resolution (e.g. White et al. 2014; Hermosilla et al. 2015). This progress is welcome because more and more research applications require spatially-explicit inputs about forest ecosystems, and visually engaging maps communicate information to some audiences in a way that statistical reports cannot.

12.2 Land Use and Forest Resources

12.2.1 General Classification of Land and Forests

Canada uses a hierarchical land cover classification system. At the highest level, the land base is classified as vegetated or non-vegetated; at the second level, vegetated land is classified as treed or non-treed. The land cover is considered to be treed if at least 10 % of the area, by crown cover, consists of tree species of any size. In total, five levels of classification are specified: (i) land base, (ii) land cover type, (iii) landscape position, (iv) vegetation type, and (v) density class (refer to the NFI Photo Plot Data Dictionary for details; available online at: nfi.nfis.org). Table 12.1 reports the estimated area in each of the first- and second-level land classes for the surveyed portion of Canada (the three Arctic ecozones and very small areas in the Taiga Plains and Hudson Plains ecozones that are in Nunavut are not surveyed by the NFI).

'Forest' is not a land cover class because the area of forest cannot be inferred from the current land cover alone. Some treed lands are not forest (e.g. lands predominantly under agricultural or urban land use) and some forest lands are not treed (e.g. lands that are temporarily non-stocked). It is important to distinguish between the 'forest area' and the 'treed area' (often referred to as the area of 'forest cover') to avoid interpreting treed area gains and losses as forest area gains and losses. In Canada, treed area gains and losses occur far more frequently, are far less enduring than forest area gains or losses, and have substantially different impacts on forest resource availability and ecosystem services.

Canada has an estimated forest area of 347.6 million hectares, where 'forest' is defined following the FAO (2012) definition:

> Land with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

This definition of forest creates some uncertainty when applied in Canada. The area of greatest concern is where land cover does not currently meet the 5 m tree

Table 12.1 Area by land cover class

Level 1 (land base)	Level 2 (land cover type)	Area (million ha)
Vegetated	Treed	362.1
	Non-treed	227.7
	Sub-total	589.8
Non-vegetated	Land	58.6
	Water	87.4
	Sub-total	146.0
Total*		735.8

*Note that the total area of Canada includes both the total reported here plus the total area not surveyed by the NFI, which includes the Arctic ecozones and small portions of the Taiga Plains and Hudson Plains ecozones that are in Nunavut

height threshold and the available land cover attributes fail to provide a clear indication about the capacity of the in situ vegetation to attain or exceed this threshold. Distinguishing between young, post-disturbance tree cover and shrub cover that will never attain 5 m can be difficult when relying solely on photo-interpreted forest attributes, especially those derived from satellite imagery. This is a particularly acute challenge in unmanaged forests where records of natural disturbances and site quality indicators are often lacking. Forest area is therefore estimated with more certainty in the managed forest and with less certainty in the unmanaged forest. These uncertainties will lessen when multiple successive inventory cycles provide a greater temporal scope affording improved consistency across time.

Estimation of forest area change between successive inventory cycles is not yet possible because the NFI is currently in the midst of its second cycle (first re-measurement). A special-purpose national system outside of the NFI is used to monitor and report on the area of deforestation (Dyk et al. 2015). The NFI survey (13,158 plots; 400 ha each) does not afford a sufficiently precise estimation of the area of deforestation in Canada, which is very small relative to the area of Canada's forest. The most current estimated rate of deforestation is 46 thousand ha per year, or 0.01 % of Canada's forest area per year (NRCan 2014). The area of afforestation in the recent past has been even smaller (<10,000 ha per year; White and Kurz 2005), and no special-purpose system is currently monitoring afforestation in Canada. Canada has therefore reported a small net forest area loss in the 2015 Global Forest Resource Assessment (FRA; FAO 2015) and in reports to the UNFCCC (e.g. Environment Canada 2015).

12.2.2 Classification by Ownership Categories

Most of Canada's forests are on publicly-owned, 'crown' land. Public ownership in Canada can be broken down into several sub-categories (Table 12.2), including provincial, territorial, federal and municipal. A relatively small area of forest is under the jurisdiction of municipal governments. Federally reserved lands include national parks, national defense establishments, and other reserves.

Crown forests under provincial and territorial jurisdiction are managed according to the legislation and regulations established by provincial and territorial governments. Various agreements have been made by provincial and territorial governments to allow sustainable private extraction of forest timber resources on crown lands. These agreements are referred to as 'tenures' (CCFM 2006). Management plans are in place for 206 million ha, and large areas are certified under one or another independently verified forest certification scheme (54 million ha under FSC; 58 million ha under the *Programme for the Endorsement of Forest Certification* (PEFC); and 44 million ha under Canadian Standards Association (CSA) as of 2012). Some of Canada's forests have no tenures and no formal management plans; no commercial timber extraction occurs in these forests.

Table 12.2 Forest area by ownership

Ownership category	Forest area (million ha)	Area (%)
Public (sub-total)	324.5	93.3
Federal	5.4	1.6
Provincial or territorial	311.3	89.6
Municipal	0.9	0.3
Aboriginal	6.8	2.0
Private	21.7	6.2
Other*	1.5	0.4
Total	347.6	

*Ownership information is missing or not available

Information about tenures, forest management plans and third party certification is maintained outside of the NFI.

12.2.3 Wood Resources and Their Use

The total volume in Canada's forest is estimated to be 47 billion cubic meters. Spruce (*Picea* spp.) is the predominant species group in Canada; black spruce (*P. mariana*) is found across most of Canada (Farrar 1995) and is, by far, this country's most common tree species. Other important species groups are Poplar (*Populus* spp.), Pine (*Pinus* spp.), Fir (*Abies* spp.), Hemlock (*Tsuga* spp.), Douglas-fir (*Pseudotsuga menziesii*), Birch (*Betula* spp.) and Maple (*Acer* spp.) (Table 12.3).

Table 12.3 Total tree volume by species group

Species group	Total tree volume (million m^3)	Volume (%)
Spruce (*Picea* spp.)	22,383	47.3
Pine (*Pinus* spp.)	5611	11.9
Fir (*Abies* spp.)	3499	7.4
Hemlock (*Tsuga* spp.)	2741	5.8
Douglas-fir (*Pseudotsuga menziesii*)	1653	3.5
Larch (*Larix* spp.)	298	0.6
Cedar and other conifers	1267	2.7
Unspecified conifers	344	0.7
Poplar (*Populus* spp.)	6176	13.1
Birch (*Betula* spp.)	1575	3.3
Maple (*Acer* spp.)	1403	3.0
Other hardwoods	223	0.5
Unspecified hardwoods	101	0.2
Unclassified	46	0.1
Grand total	47,320	

Mean volume densities vary regionally. Most of Canada's forests are located in boreal and taiga ecozones (Fig. 12.4). Mean volume densities are generally higher in western Canada compared to eastern Canada. The highest volume densities are found in the Pacific Maritime ecozone, where temperate climate and infrequent natural disturbances allow long-lived species such as Douglas-fir, Sitka Spruce (*Picea sitchensis*), Western Redcedar (*Thuja plicata*) and others to attain very large sizes.

A variety of silvicultural practices and harvesting systems are used in Canada, tailored to the different operational and ecological circumstances across the country. Ecosystem-based management systems are used to minimise the differences between natural forests and those contributing to timber supply (Gauthier et al. 2009). Current scientific understanding of natural disturbance regimes and stand dynamics is used to design silvicultural systems, harvesting methods and landscape management strategies that will sustain productivity and biodiversity in managed areas by preserving key forest processes and attributes at multiple temporal and spatial scales.

12.3 Assessment of Wood Resources

12.3.1 Forest Available for Wood Supply

The forest area available for wood (timber) supply is sometimes reported by Canadian provinces and territories, but it is not reported at the national level. Canadian ecosystem-based management systems take both the available and restricted forest areas into consideration when evaluating progress toward timber and non-timber management goals. Classification of land into different categories of restriction and availability for one type of management or another is done during the planning process, but the emphasis is on assessing the sustainable supply of timber and the flow of other benefits from the managed land base as a whole.

Detailed timber supply analyses are conducted by provincial and territorial governments for each crown forest management unit to support the determination of allowable annual cut (AAC) levels. These AAC levels are reported to the public. The restrictions placed on harvesting in crown forests differ between jurisdictions (provinces and territories) because each has its own legislation and regulations. Restrictions are made to protect environmentally sensitive areas, riparian management areas, wildlife management areas and sensitive terrain areas. Inoperable areas and low productivity timber areas are also accounted for when determining AAC levels, and these levels may be adjusted to shift the balance between pursuit of timber and non-timber objectives for a management unit without identifying specifically parcels of reserved land.

The current harvest level in Canada (148 million m^3 in 2012) is well below the estimated sustainable wood supply (227 million m^3 in 2012) (NRCan 2014). The

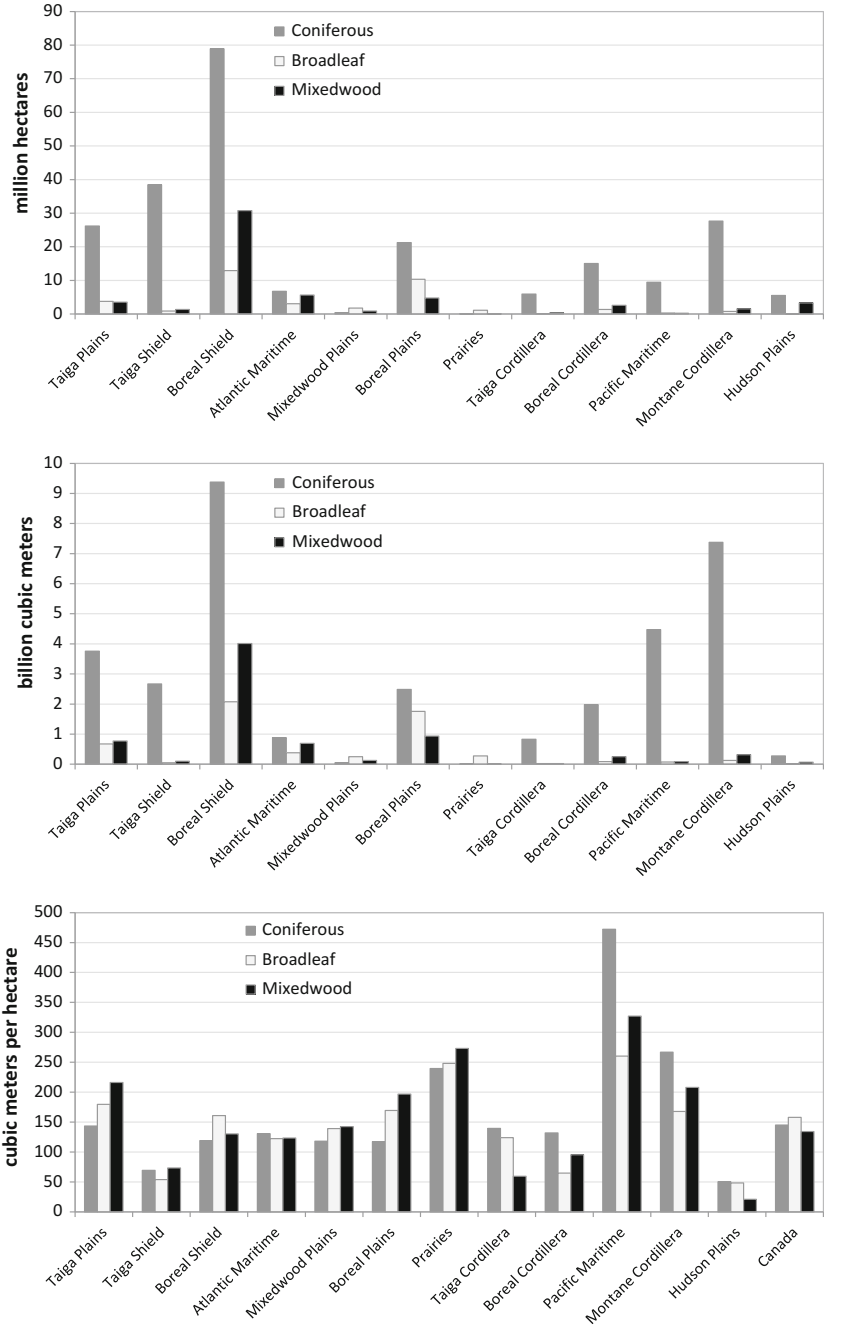

Fig. 12.4 Forest area, total volume and mean volume density by ecozone and forest type

gap between wood supply and wood harvest is expected to narrow as harvest levels increase slowly in response to the recovery of North American demand for wood products and the available wood supply declines as a result of natural disturbance impacts.

12.3.2 Assessment of Change

The NFI is not yet in a position to report statistical estimates of increment, harvest, disturbance depletions or other changes because the first re-measurement cycle is still in the process of being completed. Harvest and disturbance data are, however, compiled from provincial and territorial sources in the National Forestry Database (NFD; accessible online at nfdp.ccfm.org). The NFI and NFD are complemented by national science programs that monitor forest change (e.g. Guindon et al. 2014; Hermosilla et al. 2016). The federal government's *Forest Change* science program brings together several such initiatives into a national tracking system (Ste-Marie et al. 2015). Integration of programs such as these with the NFI and NFD, and completion of the first NFI re-measurement, will soon make it possible to assess forest change at the national level, including assessment of remote wilderness forests for which we historically had very little information.

12.3.3 Other Wooded Land and Trees Outside the Forest

Canada's NFI uses the FAO definition of forests (as described in Sect. 12.2), but most foresters in Canada would not consider lands having <25 % crown cover at maturity to be 'forests'. Estimates of national forest and other wooded land areas prior to establishment of the NFI have therefore varied over the years, depending on definitions and assessment techniques used. National estimates are most sensitive to monitoring and assessment of boreal- and taiga-tundra ecotones, which are very large. Canada relies on remote sensing to monitor these systems, and it can be very difficult to definitively classify lands as 'forest' or 'other wooded land' using the FAO definition. It would be beneficial to have an operational definition of forest that can be applied in the field and directly in remote sensing image interpretation, rather than inferring what is or is not 'forest' using measured forest inventory attributes and assumptions about future stand development where mature tree cover is expected but not currently present.

Other wooded lands and trees outside of forests also occur in southern Canada, and these provide important environmental services. Shelterbelts are planted and maintained on agricultural lands to mitigate the effects of wind erosion (Wiseman et al. 2009) and to provide habitat for wildlife. Farmers often allow woody vegetation to grow on previously cleared agricultural lands when economic conditions do not favour continued cultivation. In some regions, anecdotal evidence suggests that the area of wooded agricultural land has increased significantly since the

mid-twentieth century, but no estimates of this increase have been produced yet. In other areas, the conversion of wooded lands to agricultural land uses continues.

Municipalities in Canada maintain urban 'forests' that provide a multitude of benefits to Canada's increasingly urbanised population. Detailed inventories and assessments have been done at the municipal level. Highly successful urban and rural tree planting programs have been implemented, and considerable efforts have been made to manage urban and rural tree health problems caused by alien invasive insects and diseases, such as emerald ash borer (*Agrilus planipennis* Fairmaire) and Dutch elm disease.

12.4 Conclusion

Canada's NFI is a key element of this country's national forest data and information infrastructure. The computing infrastructure for NFI data management and information dissemination is provided by the National Forest Information System (NFIS; accessible at: nfis.org), which also provides the computing and online data delivery infrastructure for NFD. The NFI and NFD are used in combination, together with data from other federal, provincial and territorial government sources, to produce the information needed for annual state of the forest reporting (e.g. NRCan 2014), for FRA, and to meet other international reporting obligations and domestic data demands.

An important challenge facing Canada's NFI is the development of new inventory technologies. Computer science and software engineering advances have enabled the development of more robust data loading and validation tools, and new remote sensing technologies create opportunities to collect new types of data (e.g. White et al. 2013, 2014). Canada's NFI is perhaps more susceptible to technological change than most NFI programs because of its reliance on contemporary remote sensing technology. Canada's size and lack of a clearly legislated mandate for NFI make it necessary to align the NFI program delivery with provincial and territorial inventory programs, which means that as these programs adopt new remote sensing technologies, so must the NFI. From a NFI perspective, however, any change to established protocols must be approached carefully to ensure that temporal consistency in the data is not compromised.

Meeting all demands for information about national forest resources and their availability is challenging, particularly as new demands for information emerge. NFI programs must evolve to meet emerging demands for forest information, but NFI programs have considerable intrinsic inertia and cannot change direction quickly or easily. NFI programs must also collaborate in order to achieve the level of harmonisation that is needed internationally (Tomppo et al. 2010).

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