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INTEGRATING FORESTRY IN LAND USE PLANNING (P BETTINGER, SECTION EDITOR)

Current Perspectives on Sustainable Forest Management: North America

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Abstract

Purpose of Review Increased availability of current forest resource information provides an opportunity to evaluate the continued concerns about forest sustainability in North America. The purpose of this study is to assess and discuss the current state and trends of North American forest resources, sustainable forest management, and their implications for forest sustainability.

Recent Findings Recent information indicates that forest sustainability in North America is not under threat. Forest area, inventory, and carbon stocks have been increasing while wood harvest has been declining. Large expanses of forest resources are covered by management plans, and many forests are certified. The areas of concern include forest fires and bark beetle infestations in primarily public forests in the western USA and Canada, and continued loss of forest cover in Mexico.

Summary Despite progress made in gathering information on forest resources, evaluating forest sustainability remains challenging. Practicing sustainable forest management is made difficult by unfavorable market conditions and the ensuing lack of funding, challenges in developing and implementing forest management plans, and uncertainties including potential impacts of climate change, population growth, and changing markets.

Keywords Forest sustainability · United States of America · Canada · Mexico

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Background: Forest Sustainability and Sustainable Forest Management

Calls for a more sustainable path to development first rose to global attention following the Second World War, when rising populations and ensuing environmental degradation in many regions of the world raised concerns about threats to human civilization. Echoing concerns posed by Garrett Hardin [1], in his famous paper "The Tragedy of the Commons", the Club of Rome expressed concerns for the pace and impact of unrestrained development in the report "Limits to Growth", published in 1972, which advocated for a world system that was sustainable and equitable for all people without a threat of a sudden and uncontrollable collapse [2]. These concerns continued to evolve in the years that followed. In 1987, the report "Our Common Future" from the United Nations World Commission on Environment and Development defined sustainable development as: "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3].

Defining Sustainable Forest Management

Concurrently, concerns about forest sustainability mounted with unchecked destruction and degradation of forest resources in many world regions, particularly in the tropics. These concerns were first addressed at the global level during the 1992 United Nations Conference on Environment and Development (UNCED), which produced an agenda for sustainable development for the twenty-first century including a chapter on forests. It also produced a non-binding "Statement of Forest Principles" encompassing guidelines and means for protecting the world's forests, at the time representing a global consensus on sustainable forest management [4].

Sustainable forest management (SFM) encompasses environmental, economic, and social dimensions of forests and their uses. Definitions of SFM have evolved over time. The Helsinki resolution H1 defined SFM as: "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems…" [5]. Today, the General Assembly of the United Nations defines SFM "…as a dynamic and evolving concept that aims to maintain and enhance the economic, social, and environmental value of all types of forests, for the benefit of present and future generations." Similarly, the Food and Agriculture Organization (FAO) of the United Nations defines SFM as: "the sustainable use and conservation of forests with the aim of maintaining and enhancing multiple forest values through human interventions. People are at the centre of SFM because it aims to contribute to society's diverse needs in perpetuity." [6].

Criteria and Indicators of Sustainable Forest Management

While definitions of SFM are necessarily quite general, criteria (objectives) and indicators (measures of progress towards objectives) are a means for defining SFM in a way that is well suited to a relevant context (tropics, temperate, community forests) or scale (international, regional, national, local). Following agreements made at UNCED and guided by its Forest Principles, criteria and indicators (C&I) for measuring, monitoring, and reporting on progress towards SFM were developed for multiple contexts and at multiple scales.

C&I for forests are used to gather information, facilitate decision- and policy-making, assess sustainability, and develop SFM programs' certification objectives and indicators [6]. At the global level, C&I have informed various global initiatives and serve as a reference framework for Global Forest Resource Assessments (FRA) coordinated by FAO, including the most recent 2015 FRA. Regional C&I initiatives provide a platform for collecting and communicating information about forests across similar forest types or regions. Some of the most active regional C&I initiatives to date include the International Tropical Timber Organization C&I for sustainable tropical forest management, the Montréal Process C&I for Temperate and Boreal Forests, and Forest Europe (a.k.a. the Pan-European Process C&I for SFM and previously known as the Helsinki Process). National-level C&I are used to structure policy debates and inform the public, while at the local level, C&I can be used to guide corporate social responsibility initiatives, forest certification schemes, trade in forest products, forest governance, or forest law enforcement.

The Montréal Process, with signatories that encompass the largest C&I area, is relied on in this review of SFM in North America. Following up on agreements made at UNCED, an International Seminar of Experts on the Sustainable Development of Boreal and Temperate Forests was held in Montréal, Canada in 1993 [7]. This and subsequent meetings, collectively referred to as the Montréal Process (MP, full name: Montréal Process Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests), focused on the development of guidelines for measuring and tracking progress towards forest sustainability at the national level in non-European countries with temperate and boreal forests. In 1995, MP participating countries signed the Santiago Declaration, agreeing on a comprehensive C&I framework for assessing and reporting on the conservation and sustainable management of temperate and boreal forests.

The Montréal Process Framework of C&I (MPC&I) includes seven broad criteria: (1) conservation of biological diversity; (2) maintenance of productive capacity of forest ecosystems; (3) maintenance of ecosystem health and vitality; (4) conservation and maintenance of soil and water resources; (5) maintenance of forest contribution to global carbon cycles; (6) maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies; and (7) legal, institutional, and economic framework for forest conservation and sustainable management. These criteria are associated with a total of 54 specific indicators. Together, these C&I can be used to measure forest status and trends at the national and sub-national levels, but not at the stand level.

Today, 12 countries participate voluntarily in the Montréal Process: Argentina, Australia, Canada, Chile, China, Japan, the Republic of Korea, Mexico, New Zealand, Russia, Uruguay, and the USA. Together, they account for 45% of world trade in wood and wood products, about half the world's population, and about 60% of the world's forest area [7]. Most member countries have used the MPC&I at least twice to assess the status of and trends in their forests, with varying levels of detail and efficacy. Ultimately, assessments based on the MPC&I provide information that may lead to changes in forest management and conservation, but are not directly linked to nor trigger mandatory changes in policy or practice.

Forest Science Context

The concept of SFM in the forest science context can be traced to Hans Carl von Carlowitz, the administrator of mining at the court of the Electorate of Saxony. In 1713, von Carlowitz published the treatise *Silvicultura oeconomica* ("Economics of silviculture") in which he introduced the concept of *Nachhaltigkeit* ("sustainability") to advocate for a continued, stable and sustained use (*nachhaltige Nutzung*) of forests [8]. Subsequently, the idea of sustained use of renewable natural resources was incorporated and developed in forest science, and has since been applied in forest management planning and operations. The resulting concepts of the maximum sustained yield (MSY), normal forest (fully regulated forest) and regulated forest models, and subsequent area and volume control methods (extended to contemporary harvest scheduling approaches) are still the cornerstones of management planning and are often relied on in present day forest operations in North America and beyond [9].

In forest science deliberations, forest sustainability and, by extension, SFM were framed initially in terms of wood volume. The goal often has been to maximize wood volume growth (and therefore harvest) and to sustain it in perpetuity. Today, a multitude of forest products, uses, and functions are recognized and valued such that forest sustainability concepts have continued to evolve and incorporate these new dimensions. Indeed, modern forest planning methods allow for the incorporation of a multitude of desired forest outputs through formulating appropriate management objectives and constraints in developing forest plans. This multidimensionality certainly makes forest management planning and operations increasingly complex endeavors, and ideally more successful ones as well.

Materials and Methods

In assessing and discussing the current state and trends of North American forest resources and sustainable forest management, this review relies on a number of sources, including reports developed by the Food and Agriculture Organization such as the Global Forest Resources Assessment (FRA) 2015 [10••] and supporting country reports, the Montréal Process country reports and documents, national forest statistics, remotely sensed data, forest certification program reports and information gathered from literature review, including current examples of forest management plans in North America [11•]. The FRA provides information about the evolution of forest resources over the past 25 years (1990–2015). The assessment of forest resources sustainability relies largely on information pertaining to the following FRA 2015 sustainability indicators for forests: (1) the extent of forest resources, (2) sustainable forest management, (3) maintaining ecological integrity and biodiversity, and (4) economic and social benefits [10••]. For purposes of this review, we first discuss North American forest resources status and trends, including the extent and composition of forest resources and forest production, management, protection, tenure, and legal environment. We then address the implications of these findings for sustainable forest management with particular focus on the role of plantation forests, management plans, forest management certification, and forest ownership and governance.

Results

North American Forest Resources and Harvests: Status and Trends

The extent of forest resources is considered an important SFM indicator as it allows one to assess changes in the availability of forest resources and helps ensure that adequate resources are available to meet social, economic, and environmental forest functions. Further, FRA 2015 also reports on forests that are designated for permanent forest land use. While this information is of interest, it is perhaps more telling in the context of public ownership in which governments may declare the desired area of a permanent forest estate and allocate adequate resources to achieving such goals. In areas where private ownership dominates and where there is no requirement to keep forest land in forested uses (as may be the case in the southern USA), it could be perhaps somewhat less useful. A closely related indicator focuses on *the area of forests designated for the protection of soil*, *water*, *and other ecological values*, which oftentimes is an objective of forest protection and conservation. *The forest area under management plans* is also considered an important sustainable forest management indicator as it signals that forests have been inventoried and decisions regarding their use have been made. Lastly, *independent forest certification* programs may be considered as an important SFM indicator as it signifies formal commitments evaluated by independent verifiers.

As of 2015, North American forests covered 723 million ha, which represents a nearly 3 million ha increase from 1990 (Table 1). The USA experienced an increase of nearly 8 million ha from 1990 to 2015, while both Canada and Mexico experienced forest land losses. The loss of forest area has been particularly pronounced in Mexico, where it amounted to

Table 1 North American forest statistics

Category/country	Canada	USA	Mexico
Forest area			
Forest cover 2015 (% total land area)	38.2	33.8	34.0
Forest area 2015 (1000 ha)	347,069	310,095	66,040
Forest area 1990 (1000 ha)	348,273	302,450	69,760
Forest area change 1990–2015 (1000 ha)	− 1204	7645	− 3720
Forest characteristics 2015 (% forest area)			
Primary forest	59.3	24.3	50.1
Other naturally regenerated forest	36.1	67.2	49.8
Planted forest	4.5	8.5	0.1
Carbon stock in living forest biomass (million tonnes)			
Carbon stock in living forest biomass 2015 (Canada 2010)	13,992	17,730	1993
Carbon stock in living forest biomass 1990	14,427	14,448	2089
Carbon stock in living forest biomass change 1990–2015	− 435	3282	− 96
Wood production (million m^3 u.b.)			
Total wood removals 2011	149.86	324.43	5.5
Total wood removals 1990	162.57	509.32	8.16
Total wood removals change 1990–2011	− 12.71	− 184.89	− 2.66
Forest protection			
Protected forest area 2015 (% forest area)	6.9	10.6	13.3
Disturbance (1000 ha)			
Average forest area burned 2003–2012 (USA 2003–2010)	2202	2500	37
Sustainable Forest Management 2010			
Forest area with management plan 2010 (% of forest area)	59.3	65.5	26.7
Forest certification 2014 (% forest area)			
Forest Stewardship Council (FSC)	15.8	4.4	1.4
Programme for the Endorsement of Forest Certification (PEFC)	33.7	10.8	0
Domestic forest management certification	0	0	0.3
Forest ownership 2010 (% forest area)			
Public	91.4	42.1	1.3
Private	8.2	57.9	51.2
Unknown	0.4	0.0	47.5

Sources [10••, 12, 13]

nearly 4 million ha over a quarter of a century. North American forest resources are globally important with Canada and the USA listed among the world's 10 most forested countries, and the USA is listed among the top 10 countries with the greatest annual forest area net gain over 2010–2015 [10••].

Forest cover in the region ranges from 34% to more than 38% (Table 1). In both Mexico and Canada, the extent of primary forest exceeds 50% of the forest area. The share of primary forest is considerably lower in the USA, accounting for about 24% of forest area. In total, however, natural forests (primary forest and other naturally regenerated forests) represent the vast majority of forest area in the region. Planted forests are relatively more abundant in the USA and Canada, accounting for 8.5 and 4.5% of forest area, respectively, but quite scarce in Mexico, at 0.1%.

Total wood removals in the three countries amounted to nearly 480 million cubic meters in 2011, or nearly a third of the global output. The USA was by far the largest wood producer with more than 324 million m^3 output, and Mexico had only 6 million m^3 of timber removals. Between 1990 and 2011, wood removals declined by 200 million m^3 or nearly 30%. This change to a large extent results from market changes and wood demand contraction following the 2007/2008 global financial crisis. The majority of wood production decrease occurred in the USA where wood harvest declined by nearly 185 million m^3.

Extensive forest areas in the region are set aside for forest protection purposes as wilderness areas, parks, or reserves. Mexico has about 13% of its forest set aside to fulfill environmental protection functions, followed by the USA (11%), and Canada (7%).

Non-timber Forest Products and Payments for Environmental Services

Forests also provide non-timber forest products and economic contributions. These include hunting and fishing of game, viewing of wildlife, and watching of local and migratory birds. Tourism and recreation such as canoeing, eco/tourism, and beach recreation generate large incomes. Educational forest uses also generate forest-based expenditures. In addition, payments for environmental services occur when government regulation creates markets (carbon emission offsets, mitigation banks), or if voluntary corporate efforts occur to promote environmental protection, such as for water quality, wetlands, and endangered species.

The National Report on Sustainable Forests [14•, 15] provides national estimates of the value of non-timber forest products produced or collected in the USA and for revenue from forest-based environmental services in the USA (Table 2), which we updated based on data from Chamberlin [16] and the Draft National Report on Sustainable Forests [15]. The data on non-timber products represents only data from USDA Forest Service and USDI Bureau of Land Management direct sales, and the value of those sales at the point of first sale—not as the stumpage (standing timber) equivalent in the woods. These estimates do not include any potentially large but still unknown non-market values. The total value of the US non-timber forest products on the federal lands was $361 million in 2007. The total revenue of the US forest-based environmental services was $2.152 billion.

We calculated the total value of wood products as well, based on the 2011 national timber removals of 324 million m^3 (11.3 billion ft^3). Timber values were calculated as the mix of 50% sawtimber and 50% pulpwood, at a blended price of \$0.60 per ft^3 (\$21 per m^3) for stumpage for both softwood and hardwood species groups [17]. The value of the annual timber harvest in the USA was calculated as $6.8 billion. This could be compared with the 2011 non-timber forest products prices for the US federal lands of $361 million, and environmental service payments of $2.2 billion. Thus, combined for the entire USA, non-timber products and environmental service payments of $2.5 billion were reasonably large compared to timber stumpage prices of $6.8 billion, at about one-third of the total national timber stumpage values, or about one-quarter of all receipts from timber stumpage and non-timber products. This non-timber receipts share was based on the relatively low US harvest levels in 2011, and probably would have decreased based on higher timber harvests in 2017. On the other hand, non-timber products from private lands would increase their share considerably as well.

It is difficult to calculate similar non-timber and environmental service payments for Canada and Mexico, although one can surmise that per unit values in Canada would be somewhat similar to the US values. The annual value of maple products is about $354 million, wild blueberries $207 million, and Christmas trees $39 million, totaling $600 million for these products [18]. Regarding Mexico, Cubbage et al. [19•] found that for a relatively large sample of 30 *ejidos* (a type of community forest ownership), average returns for all products and services were about $250 per ha per year, comprised of 89.9% timber revenues, 6.6% non-timber forest products revenues, and 3.5% payments for environmental service revenues—indicating less developed markets for non-timber and environmental incomes than in the USA.

Sustainable Forest Management and Certification

As noted above, North America contains a large share of the world's forests (18%) and produces a large share of global industrial roundwood (33%) and total (industrial roundwood and fuelwood) harvests (16%). The USA and Canada have 8.5 and 4.5% of their forest area in planted stands, which provide a much greater share of the total industrial wood harvests in each country.

Table 2 Value of non-timber forest products produced or collected and of payments for environmental services in the USA

Non-timber forest products federal receipts	Value, 2012 ($ million)	Payments for environmental services	Value, 2012 ($ million)
Landscaping	3	Total government	588
Crafts/flora	52	Non-government	
Seeds/cones	2	Wetland mitigation banks	446
Edible fruits, nuts, sap	25	Hunting leases and entrance fees	789
Grass, forage	9	Conservation easements	199
Herbs/medicinals	2	Conservation banks	52
Fuelwood	207	Wildlife viewing	71
Posts and poles	11	Carbon offsets	7
Christmas trees	50	Total non-government	1564
Total	361	Total	2152

Sources [14•, 15, 16]

In terms of forest management planning (Table 1), nearly 66% of forest area in the USA had management plans as of 2010. This would essentially include all of the public lands (42% of the US area); all of the private, corporate/industrial (10%); and about one-quarter of the private, non-corporate (14% of the area with plans, out of 48% of US forests) [20, 21]. Canada had nearly 60% of its forest covered by forest plans and Mexico 27%.

Forest certification develops sets of standards and uses third-party auditors who evaluate companies and public organizations who volunteer for such programs assessing their compliance with those standards, and arguably represents the highest standard for forest management, going beyond mere management plans that comply with laws. Certification schemes develop numerous ecological, economic, and social criteria and indicators to measure on-the-ground field and management performance. In contrast to the MPC&I, forest certification evaluations are intended to be formative, leading to better forest management at the stand level.

With the exception of about 1 million ha in Mexico that are certified under the Mexican Forest Certification System (MFCS), forest management certification mostly falls under one of the two umbrella certification schemes—the Forest Stewardship Council [13] or the Programme for the Endorsement of Forest Certification [12]. Canada has more than half of its forests certified (53.5%). In the USA, about 15% of forests are certified, followed by Mexico with less than 2%.

Forest certification does, however, affect a greater share of the timber-producing forests (timber land), since forest reserves or non-productive lands are not subject to a certification of forest management practices, and it affects an even greater share of private and non-federal forest lands, which harvest comparatively little in the USA and are not certified. For example, private industry, family forest, and non-federal public owners in the USA held 166 million ha of timber land in 2012 [22]; the 47 million ha certified in 2017 would represent 28% of those productive timber lands.

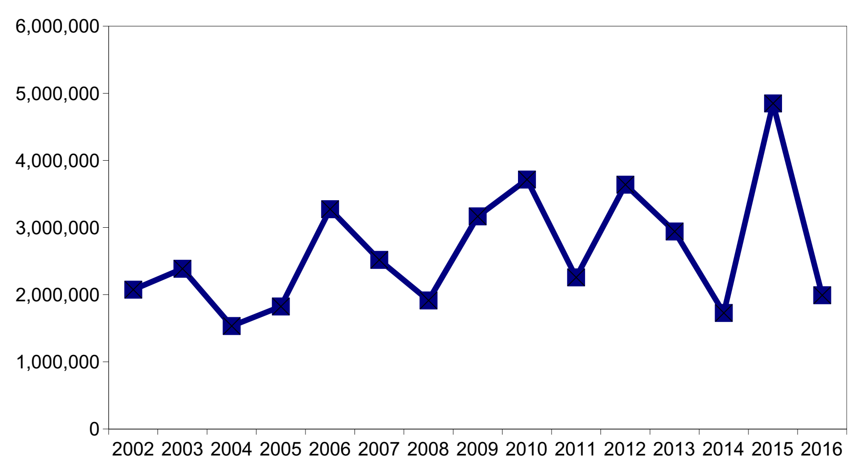
Insects and Diseases

Insects and diseases cause changes in forest structure and function, species succession, and biodiversity, which may be considered negative or positive depending on management objectives [23]. An important task for forest managers, pathologists, and entomologists is recognizing and distinguishing between natural and excessive mortality, a task that relates to ecologically based or commodity-based management objectives. The impacts of insects and diseases on forests vary from natural thinning to extraordinary levels of tree mortality, but insects and diseases are not necessarily enemies of the forest because they kill trees [24]. If disturbances, including insects and diseases, are viewed in their full ecological context, then some amount can be considered "healthy" to sustain the structure of the forest [25] by causing tree mortality that culls weak competitors and releases resources that are needed to support the growth of surviving trees [24]. On the other hand, many more utilitarian forest landowners and professionals view loss of wood fiber as an unnecessary economic loss and perhaps a destructive ecological disruption.

Forest Health Protection (FHP) National Insect and Disease Survey (IDS) data (26) of the USDA Forest Service were used based on aerial survey data to identify forest landscape-scale patterns associated with forest insect and disease activity in the USA [26, 27]. These data measured tree defoliation (Fig. 1) and tree mortality (Fig. 2) on an annual basis for each of these years (Table 3). The annual survey efforts identify areas of mortality and defoliation caused by insect and disease activity, although some important forest insects (such as emerald ash borer and hemlock woolly adelgid), diseases (such as laurel wilt, Dutch elm disease, white pine blister rust, and thousand cankers disease), and mortality complexes (such as oak decline) are not easily detected or thoroughly quantified through aerial detection surveys.

Based on prevailing popular opinions, one might expect these empirical trends to reveal considerable forest health problems, but the data are less conclusive and show large

Fig. 1 Tree defoliation in conterminous USA, 2002–2016 (hectares)



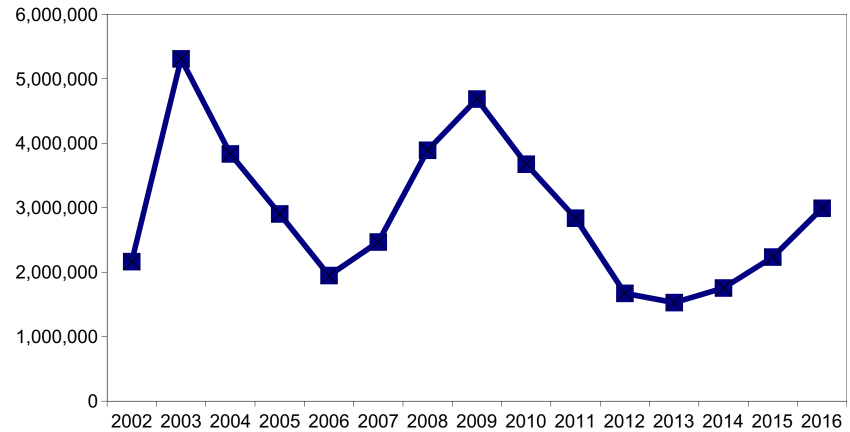


Fig. 2 Tree mortality in conterminous USA, 2002–2016 (hectares)

variation from year to year. At least some of this variation may result from differences in annual sampling intensities and survey locations. On average for 5-year periods, forest defoliation seemed to be increasing from 2003 to 2016, with 2.3 million ha per year defoliated in the USA in 2011 to 2016 period, and 3.3 million ha per year defoliated in the 2012–2016 period. However, the tree mortality measured during this period was mostly the reverse. It increased from an average of 3.2 million ha per year during the 2012 to 2016 period, went up to 3.6 million ha per year on average from 2007 to 2011, and decreased to 2.1 million ha per year in the 2012 to 2016 period. The highest amount of defoliation in the conterminous USA did occur in 2015, at 5.0 million ha, but the greatest amount of mortality occurred in 2003 and 2009, at 5.3 and 4.7 million ha, respectively. As of 2015, insect diseases affected nearly 18 million ha of forests in Canada [29]. The spruce budworm infestation continued to spread affecting nearly 7 million ha. On the other hand, the area affected by pine beetles in British Columbia decreased from about 10 million ha in 2007 to less than 2 million ha in 2015. Mexico had about 165 thousand ha affected by insects in 2012, with bark beetles accounting for 77% of the area [30].

Wildfire

Wildland fire is a key abiotic factor affecting forest health both positively and negatively. Wildland fire regulates forest health processes, shapes the distributions of species, maintains the structure and function of fire-prone communities, and acts as a significant evolutionary force [31]. At the same time, wildland fires have created forest health problems in some ecosystems [23], where fire outside the historic range of frequency and intensity can impose extensive ecological and socioeconomic impacts. Current fire regimes on more than half of the forested area in the conterminous USA have been moderately or significantly altered from historical regimes, potentially altering key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings. As a result of intense suppression efforts during most of the twentieth century, the forest area burned annually decreased from approximately 16 to 20 million ha in the early 1930s to about 2 million ha in the 1970s [32].

Annual monitoring and reporting of active wildland fire events using the Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the US database [33] allows analysts to spatially display and summarize forest fire occurrences across broad geographic regions [34•]. It is important to underscore that estimates of burned area and calculations of MODIS-detected forest fire occurrences are two different metrics for quantifying fire activity within a given year. Analyses of the MODIS-detected fire occurrences measure the total number of daily 1 km^2 pixels with fire during a year, as opposed to quantifying only the area on which fire occurred at some point during the course of the year. A fire detected on a single pixel on every day of the year would be equivalent to 365 fire occurrences.

Table 4 and Fig. 3 summarize the MODIS fire occurrence data from 2001 to 2017 after their intersection with forest

Table 3 Tree defoliation and mortality for selected years in the conterminous USA, 2002–2016 (thousand hectares affected)

Year	2002	2004	2006	2008	2010	2012	2014	2016
Defoliation	2074	1534	3273	1915	3715	3639	1728	1991
Mortality	2164	3833	1948	3890	3675	1670	1754	2991

Source [28]

Table 4 MODIS fire occurrences for selected years in Canada, Mexico, and the USA, 2001–2017 (thousand of occurrences)

Country/year	2001	2003	2005	2007	2009	2011	2013	2015	2017
Canada	1.8	14.0	8.7	9.4	22.2	25.9	87.0	53.2	57.7
Mexico	8.0	24.2	28.8	17.3	27.8	39.3	36.4	14.9	30.9
USA	9.3	29.3	27.0	33.5	54.3	51.8	80.2	80.0	74.8

Sources [33, 35]

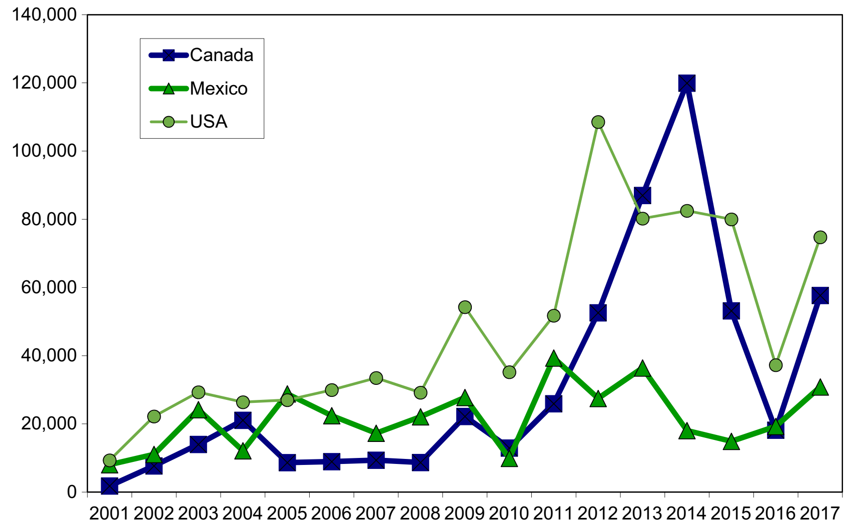


Fig. 3 MODIS fire occurrences for selected years in Canada, Mexico, and the USA, 2001–2017 (thousand of occurrences)

cover based on 30-m Landsat imagery [35] resampled at 1 km. In this case, the data confirm the perception that forest wildfires are increasing in the USA and Canada over the last 17 years, while they remain mostly level in Mexico. While there is considerable variability, the trend is undoubtedly increasing by a substantial amount in the number of occurrences from 2001 to 2017 in the two more northerly nations.

Forest Ownership and Tenure

Forest ownership indicates enforceable legal rights, usually including exclusive and permanent rights to the land and its resources, and is one type of tenure. Land tenure is a broader concept encompassing ownership, as well as tenancy, use rights, and other arrangements to manage and use forest land and resources [36]. North American forest ownership ranges from mostly public forests in Canada, through a mix of public and private forests in the USA, to predominantly communal forests in Mexico. Broader bundles of forest tenure rights, ranging from access, to management, through exclusion, and alienation vary across these ownership categories.

In Canada, the vast majority of forests (91%) are in public ownership, managed by provincial, territorial, and federal governments (Table 1). Provinces and territories control the bulk of public forests [29]. The federal government controls a comparatively small percent of Canada's forested lands (4%), including those held in reserve for, or otherwise controlled by, Aboriginal Peoples (2%) [29].

The USA has a mixture of public (42%) and private (58%) ownership. The eastern part of the country contains most private forests, while public ownership is more common in the western part. Of the 310 million ha of forest in the USA, 58% (180 million ha) is privately owned. Specifically, individuals, families, Native American tribes, and other non-corporate private entities own about 121 million ha of forest in the USA (39%), while private corporate owners own about 59 million ha (19%) of forest lands [37]. Forty-two percent (130 million ha) of forest lands are publicly held by federal (32%), state (9%), and local (e.g., municipal, county) (1%) governments (idem).

According to FRA 2015, in Mexico, less than 2% of forests are publicly owned, but this is somewhat misleading considering that only about 51% of forests are classified as private—consisting of individual owners or community land members—and the remainder (nearly 48%) are classified as unknown—including forests which do not have a clearly ascertained ownership category. In practice, local agrarian communities own about 80% of Mexico's forests and have relative autonomy to manage them [38]. These include *comunidades*, which are indigenous people's communities that received formal ownership of their traditional or customary lands, and *ejidos*, which are groups of previously landless rural people that received title to land that was expropriated by the state [19].

Discussion

Forest Sustainability in North America

Available information on forest resources in North America indicates that forest sustainability is not under threat when measured through key criteria such as forest area and production at broad scales, although some indicators at finer scales suggest cause for concern. Forest area increased in the region, particularly in the USA. The vast majority of forests are classified as primary or naturally regenerated forests. Biomass and carbon stocks in living biomass have been increasing. Large expanses of forests are set aside for forest protection purposes. SFM indicators imply that a large share of forest resources is covered by management plans, and many forests are certified. Wood harvest has declined as a result of the financial crisis, plentiful inventories exist, and timber prices have declined substantially in the last decade, reflecting these supply and demand trends.

The areas of concern include forest fires, primarily in public forests in the USA and Canada, the bark beetle outbreaks in western North America, and continued loss of forest cover in Mexico. There is also a considerable degree of uncertainty related to global climate change and how it may affect forests. Losses from wildfires and insects and diseases may be viewed as natural, but fires in particular have exceeded trends in the last few decades. These losses at least are expensive to combat, diverting funds away from land management, and represent considerable damage to land, water, wood, wildlife, homes and other structures, and human life and health.

Given a range of forest tenure arrangements and management outcomes across North America, it may be tempting to draw conclusions about how ownership and management affect the sustainability of forest resources, but this task is fraught with difficulties. Throughout the region, public and private forests demonstrate advances towards as well as struggles with achieving sustainability. Concerns with and conflicts over public forests, associated decision-making processes, and ultimately, forest sustainability persist throughout North America. Private forests experience similar challenges. While the USA and Canada struggle with forest fires and diseases, Mexico continues to experience substantial deforestation. Notably, although illegal logging in Mexico affects both communal forests and protected natural areas (public forests), forests managed by communities have experienced comparatively less deforestation [38]. Ultimately, forest ownership or broader tenure arrangements do not alone predict forest sustainability, particularly since broader forest governance arrangements (norms, processes, instruments, organizations, people) affect how forests are managed and protected [39].

Forest Management Planning and Implementation Challenges

Examples of North American forest plans indicate that sustainability is of primary importance to forest owners and managers [11•]. Many forest owners apply stringent rules to ensure sustainable management of their forests including, among others, that volumes harvested do not exceed forest growth or that harvested parcels need to be regenerated before adjacent areas can be harvested. Some of these requirements exceed what is required by applicable laws and even forest certification requirements.

Nevertheless, many plan implementation challenges persist [11•]. Without exception and regardless of ownership, the loss of markets is the biggest concern as it has harmed the ability of owners and managers to achieve management goals for their forests [40•]. Tree harvesting is the main tool that foresters have at their disposal to influence the structure and composition of forests. These operations, however, are expensive and budget constraints are common. Without the ability to market harvested trees and offset the cost of management operations, they may be delayed or even abandoned. This implies that well-functioning wood markets are important for practicing forest management and achieving sustainability. Other concerns are related to the ability to secure a qualified workforce or to insufficient logging capacity. On the other hand, the emergence of markets for ecosystem services such as wildlife habitat conservation or carbon storage (as exemplified in Table 2) provided some hope for additional revenue to support forest operations.

In the case of large public forests in the USA and Canada, challenges specific to forest plan development have also been noted. Large forest areas, multiple objectives and constraints, and an array of stakeholders make the development of forest plans a lengthy, difficult, and rather expensive endeavor [41]. Occasionally, when multiple public agencies, each with their own regulations, have a say in how forests are to be managed, the outcome may be no forest plan at all [36]. And that is even before a plan is completed and published, potentially litigated, or affected by fire and pests that would require substantial revisions.

Measurement Challenges

Evaluating forest sustainability and judging progress towards sustainable forest management remains challenging despite the recent progress in developing information sources. The seven criteria and 54 indicators of the Montréal Process present numerous challenges related to their interpretation and integration for the evaluation of forest sustainability.

Part of the challenge rests in how to translate currently available information (as exemplified by FRA 2015) about forest area and characteristics, standing wood volume, carbon stocks in living forest biomass, wood production, forest protection, disturbances, sustainable forest management and ownership into the MCP&I, and subsequently into some measure of forest sustainability. For example, the measure of protective functions of forest resources relies on an estimate of the area of forests protected by legal statute, which has several limitations. Here and elsewhere, out of necessity, we rely on proxy information in trying to evaluate complex phenomena.

The implications of various events on forest sustainability could be difficult to interpret as well. For instance, when are forest fires and pests part of natural processes occurring over centuries, and when are they destructive forces threatening their very existence? The effects of significantly declining wood harvest in the USA are also subject to interpretation. Typically, many would consider declining harvest beneficial, but if wood harvest has been sustainable, market impacts occur mostly on private land, and reduce land owners' returns and investments from the use of management practices. Thus, even presumed benefits of a wood surplus are harder to interpret.

The choice of appropriate spatial and temporal scales presents a challenge as well. Consider, for example, the massive forest fires experienced in California, Washington, and British Columbia in 2017. These can represent major setbacks to forest sustainability on state and provincial scales, but in the North American context, their impact is still relatively small given the large extent of forest resources. Given time, most of the land burned will recover, and in due time should be covered by a forest even if a different one. Furthermore, forest fires in the USA were much more widespread in the 1930s compared to today, which could be interpreted as an improvement in forest sustainability. This leads to the questions of whether there is a need for benchmarks and what they should be and whether they should be common across all dimensions of forest sustainability.

The present definitions and understanding of forest sustainability and SFM acknowledge the dynamic nature of these concepts, but is the current system capable of reflecting them in sustainability assessments? Do we have measures and tools suitable to this task of reflecting rapid changes in decadal assessments? Market changes are just one example of rapidly changing conditions. Forest fires and the pine beetle infestations in western Canada and the USA are another example.

Once the C&I are developed, the challenge is how to integrate and use the information they contain. Some information may point to improving forest sustainability in North America (for example, the growing extent of forest resources) while other data may point to worsening forest sustainability (for example, the extensive damage caused at times by fires and pests). So we have to consider these opposing trends in developing an overall understanding of forest sustainability.

Conclusions

In practice, all public forests and many private forests in North America have management plans developed in accordance with SFM principles. Many large private forests, some state and county lands in the USA, most provincial lands in Canada, and some *ejidos* in Mexico managed for timber production are all certified under one of major forest certification schemes. However, small private forests in the USA and Canada and Mexico are much less likely to have management plans, let alone forest certification. And even public lands that have plans and are certified may lack funding for forest management, and surely are subject to considerable challenges with public processes, input, collaboration, and management implementation. Regardless of ownership, management challenges persist for sustaining healthy forests due to limited incomes generated by forests, competing objectives, poor markets for timber and non-timber commodities, and even weaker markets for payments for environmental services.

Overall, determining whether North American, or even global, forests are sustainable has become more difficult with increasing knowledge and broader values that dictate what we seek from forests. Forests provide limited stocks and flows of commodity and ecosystem services, with many competing demands. Our old traditions of sustained yield of timber and game have become much broader to incorporate ecosystem and social services.

Some biocentric groups feel that forests are better protected in a relatively natural state rather than being actively managed, including letting fire, insects, and diseases run their course. However, the anthropocentric, utilitarian viewpoint surely still dominates, and indeed with human-induced impacts from urbanization to invasive species to climate change, management interventions are almost surely required to even maintain existing or prior historical states of forests.

On balance, we will continue to protect a substantial amount of mostly public forest lands in a natural state, albeit with some management, and manage the remaining public lands and most private lands relying on a mix of markets and government policies. The relatively stable area of forest and increasing wood and biomass inventories in North America in recent decades suggest that our forests have been sustained to a large extent, but major increases in population and perturbations in climate do suggest that this success will be more difficult to maintain in the future.

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