Forest inventory in Canada with emphasis on map production

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Forest inventory procedures are likely to change or evolve at a more rapid rate over the next 15 years. Changes will be brought by changing forest management practices and priorities, increasing importance of environmental and multiple use issues, new technologies, increasing participation of industry, new market forces, and budgetary considerations.

Map production is a major and costly component of forest inventory and one which will be much affected by these changes. This paper focuses on the map production component of forest inventory in Canada, but places it in the context of overall management inventory production. Inventory mapping procedures from provincial inventory cycles are summarized. The costs, time, and resources expended on each component of map production (photo acquisition, interpretation, transfer and drafting, and digitizing) are outlined. They are summarized in the context of the cost and resources needed for the total inventory process including volume sampling. Recent innovations, forces causing changes and rethinking of inventory philosophies, and future trends are discussed.

Key words: forest inventory, GIS, map production, photo interpretation

Les procédés d'inventaire forestier vont probablement changer ou évoluer à un rythme plus rapide durant les quinze prochaines années. Ces changements seront dus à une évolution des priorités et des pratiques de gestion forestière, à l'importance croissante de facteurs reliés à l'environnement et à l'utilisation multiple, aux nouvelles technologies, à une participation croissante de l'industrie, à l'influence de nouveaux marchés, et à des considérations budgétaires.

La production de cartes est une composante majeure et coûteuse de l'inventaire forestier qui sera très affectée par ces changements. Cet article vise la production de cartes d'inventaire forestier au Canada, tout en la situant dans le contexte global de la production complète d'inventaires d'aménagement. Ces procédés cartographiques sont résumés pour chacun des cycles d'inventaires provinciaux. Les coûts, le temps et les ressources utilisés pour chaque composante de la production de ces cartes (l'acquisition de photos, l'interprétation, le transfert et le tracé, ainsi que la numérisation) sont esquissés. Chaque composante est aussi exprimée en termes de coûts et de ressources du processus complet d'inventaire, incluant l'échantillonnage en volume. Les innovations récentes, les forces qui causent un changement et un réexamen des philosophies d'inventaire, et les tendances futures sont discutées.

Mots clés: inventaire forestier, SIG, production de cartes, photo-interprétation

Introduction

Forest inventory is a survey of an area to determine the volume, location, extent, condition, composition, and structure of the forest resource. Forest inventories provide the essential data used to derive the information required for resource evaluation for all levels of management planning. For example, an extensive reconnaissance-level inventory may be used for exploratory purposes to provide strategic level information regarding northern non-commercial forests. Operational-level inventories, which usually include ground based timber cruises, are used before harvesting to obtain location specific estimates for harvest planning. Forest management inventories, on the other hand, provide the data used for longer term forest management planning and decision making. Forest management in Canada is a provincial responsibility and each province has evolved its own requirements and procedures for management inventory. However, the general approach is similar. Management inventories consist of complete-coverage stand mapping derived from interpretation of aerial photography, plus volume estimates derived from field sampling and stratification based on the inventory maps. They are conducted within the commercial forest regions of each province on a 10- to 20-year cycle. Provinces are divided into forest management units and inventories are often conducted in blocks of one or several management units at a time. Inventory information including maps are provided to regional and district forest offices and forest companies for use in forest management planning of the management unit. Maps are also made available to the public. Between inventory cycles, inventories are updated for major changes (e.g. burned area, harvesting, insect and disease damage, silviculture activities and forest growth) with varying methods, levels of detail and schedules.

Major new factors and trends are affecting forest management and inventory, especially map production. Increasing multiple use of the forest and assessment of environmental impacts are placing new demands on the use and gathering of forest information. With the adoption of forest management agreements in many provinces, forest industry is becoming more involved in production of the forest inventory. The consulting and service industry is also becoming more active in conducting elements of inventory under contract. In the 1980s, Canada led the way with implementation of large area forest inventories on geographic information systems (GIS). This was done primarily to facilitate analysis and decision support in forest management. However, implementation of provincial forest inventories on GISs has resulted in fundamental changes in the production of forest-type maps. In addition, inventory is likely to evolve more rapidly due to the fact that inventories are now, for the most part, in digital format and a strong technological infrastructure to use digital inventory is becoming established. New digital remote sensing technologies are being examined as primary data sources for inventory mapping.

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A clear outline of existing procedures and resource requirements is useful as baseline information to the broad community of users of forest inventories and to give the framework into which new information uses and requirements can be placed and new technologies must fit. This paper reviews the procedures, costs, time and operational considerations of producing forest inventory maps for management inventories in Canada. A companion report (Gillis and Leckie 1993) provided a scenario of how inventory is conducted in each province and described in detail the photointerpreted forest stand attributes. Seely (1957), Bickerstaff and Hirvonen (1960), Smith and Aird (1975), Smith (1976), and Bonnor (1982) have summarized past forest inventories in Canada.

The procedures, costs, human resources and operational considerations of each province are determined. These are summarized and where possible generalized for the following components of forest inventory mapping: photo acquisition, photointerpretation, transfer, drafting, digitizing, and overall map production. Because inventory mapping is only part of the whole inventory process, a summary is given of map production, its costs and requirements, in the context of the entire forest inventory. The provincial information provided is not suitable for comparison as each province has differing procedures and requirements, but the information does provide a good guideline to inventory mapping practices and resource requirements. The summary of inventory mapping practices is followed by a discussion of trends in inventory, current and potential innovations, and external forces and trends influencing forest management and inventory approaches, particularly those affecting map production.

Overview of Map Production

The information provided by management inventory forest type maps and corresponding volume estimates is the primary source of data on which forest management longterm and operational planning decisions are based. They are part of the total forest inventory process which includes design and planning, map production, volume sampling, and volume compilation. Map production consists of planning, photo acquisition in the summer, followed by photointerpretation which includes field reconnaissance, calibration, and checking. Interpretations are then transferred to a base map and either drafted and/or digitized to produce a final map. The end-to-end mapping process can take several years.

Management inventories in each province are typically conducted on a cyclical basis, typically with 10- to 20-year cycles. Within each cycle completely new forest maps are made and a new inventory compiled. Complete coverage inventory mapping with aerial photography began in the 1950s under shared cost federal-provincial agreements. Most provinces are now on a third or fourth inventory cycle. Some provinces conduct continual inventories in which a percentage of the province is mapped and inventoried each year. Over the inventory cycle, mapping of the province is completed. Others conduct discontinuous inventories with relatively short inventory campaigns to conduct the whole inventory for the province and then have a hiatus until the next inventory cycle. Table 1 describes the inventory cycle of each province, the amount surveyed each year, the length of the inventory campaign, and the dates of the last and next inventory cycle.

Table 1. Inventory cycle

Province	Inventory area (000,000 ha)	Forest inventory procedure: Type	Cycle number	Cycle period	Elapse time[1]	Annual[2] area inventoried (000,000 ha)	Inventory timing: Beginning	Completion	Next
Newfoundland	10.16[3]	Continual	3	10	10	0.50	1985	1995	1995
Nova Scotia	5.31	Continual	3	10	10	0.50[4]	1987	2001	2001
Prince Edward Island	0.58	Discontinuous	2	10	2	–	1980	1982	1990
New Brunswick	7.11[5]	Discontinuous	4	10	5	1.40	1981	1986	1993[6]
Quebec	73.08[7]	Continual	2	10	9	6.00	1981	1989	1990
Ontario	59.26	Continual	3	20	20	4.00	1977	2007	2008
Manitoba	40.56	Continual	3	10–25	20	1.50	1986	2006	2007
Saskatchewan	15.88	Continual	4	15	15[8]	0.75	1984	1999	2000
Alberta (Phase 3)	33.60[9]	Discontinuous	3	14	8	5.00[10]	1976	1986	1988
Alberta (AVI)	5.08	Pilot	1[11]	–	2	2.50	1988	1990	–
British Columbia	93.43	Continual	3	10–20	10–15	8.00	1988	1998	1999

[1]Time to complete inventory within a cycle.
[2]Typical annual area. Average annual area can be calculated from total area and elapse time or alternatively cycle period.
[3]7.96 million ha on the island, 2.2 million ha in Labrador.
[4]Currently 1 million ha/year under an accelerated inventory program.
[5]Without federal lands.
[6]Tentative plans are for a 5 or 10 year cycle of a continual type.
[7]Total inventoried area. The second inventory cycle is for the southern zone which is 36.5 million ha. The first inventory included the whole inventory area of 73.08 million ha.
[8]The 3rd cycle, 1974 to 1983 was a 10-year cycle.
[9]An additional 6 million ha based on the Broad Inventory was converted to Phase 3 equivalent.
[10]There was less done in several start up years. The amount given is that done over 5 or 6 peak production years.
[11]The pilot area is in the fringe forest zone and is the first management inventory forest type mapping of the area.

The characteristics of the forest type maps of each province were compiled (Table 2). Scales range from 1:10,000 to 1:20,000. Map sheets in Alberta and Manitoba are based on township grids and Saskatchewan and Ontario have recently changed from largely a township base to systems based on Universal Transverse Mercator (UTM) grids. Other provinces are based on varying grid systems. The number of map sheets for the larger provinces is impressive, some handling 7,000 to 10,000 maps. The number of stands per map sheet typically ranges from 400 to 800. The number of polygons on the map is larger (commonly 1.3 times as large) due to lakes, wetlands, and other non-forest features. The typical size of stands varies with inventory specifications, mapping scale, and forest complexity, but they range from 5 to 25 ha. Each province has a minimum stand size for mapping (typically near 2 ha) but the minimum area for non-forested land (e.g. non-forest within a stand) is often less. Prince Edward Island forest inventory maps contain unique detail, with hedgerows being designated as stands.

Photo Acquisition

Aerial photography is acquired with 23 × 23 cm format film at scales of 1:10,000 to 1:20,000 (Table 3). Black and white (B&W) panchromatic, normal colour, black and white infrared, and colour infrared film is used. In the past, the trend was towards use of larger scale higher resolution photography and from B&W panchromatic to normal colour film. More recently, there has been some movement towards smaller scales. Ontario has recently changed from 1:15,840 to 1:20,000 scale photography, although they use 1:10,000 in southern regions. They have also tested various films. Ontario used Agfa 200 from 1987 to 1989, but has returned to Kodak 2405 B&W film. They have conducted some experimentation with colour infrared film with negative processing (Klimes *et al.* 1987). Alberta conducted trials of a new inventory cycle with 1:20,000 scale photographs with Agfa 200 B&W near-infrared film that led to its adoption. B&W infrared (Kodak 2424) 1:15,000 photography was acquired for the previous inventory cycle. Prince Edward Island acquired simultaneous 1:10,000 B&W and colour infrared photography during its 1980 inventory but the colour infrared photographs were not used extensively because they were in transparency format and difficult to use. After various tests, 1:17,500 colour infrared prints with negative processing were selected and used for the 1990 inventory. Quebec uses colour infrared in regions predominated by hardwoods and mixedwoods, and where there is significant spruce budworm damage. Saskatchewan normally uses B&W infrared photographs but will use B&W panchromatic film if flying is delayed to the early fall, after fall colouration has begun. In this case, the near-infrared reflectance of the hardwoods does not permit as good a contrast as the panchromatic film for identifying hardwood species.

Photography is generally acquired to Interdepartmental Committee on Air Surveys (ICAS) specifications (ICAS 1973, 1982) with 150 mm lens class A 23 × 23 cm format cameras. Common cameras are the Wild RC-8 and RC-10 models, and the Zeiss RMK-A, 15/23, and MRB models. Ontario and Saskatchewan have used the Wild RC-20 with motion compensation. An overlap of 60 % is specified for stereo viewing, with a sidelap of 30% to ensure complete coverage. With this, only 28% of the area covered by each photograph contributes new coverage of the area to be mapped. Most contracts specify solar altitudes between 30 and 60 degrees, which generally makes available for photo acquisition 6 to 8 hours between 0730 h and 1630 h with up to a 3-hour break around solar noon in southern latitudes due to high solar altitudes. The number of prints produced as part of the inventory ranges from one to four depending on the province. Many keep one copy in the central inventory office and one in district offices. Some produce a copy for a provincial photo library. Manitoba makes two photomosaics, one for the central office and one for the relevant district forestry offices.

Table 2. Forest inventory map characteristics

	Map characteristics					Stand characteristics		
Province	Scale	Size (km)	Area (ha)	Total number	Typical stands per mapsheet	Total number (000,000)	Typical size range (ha)	Typical size (ha)
Newfoundland	1:12,500	9.0 × 7.0	6,300	1,894[1]	250	0.18	0.5–40	10
Nova Scotia	1:10,000	8.0 × 5.6	4,480	515	1,200	1.60	1–150	5
		6.4 × 4.6	2,944	1,792	800			
Prince Edward Island	1.10,000	7.7 × 5.6	4,300	212[2]	1,250[3]	0.17	0.1–55	2
New Brunswick	1:12,500	7.7 × 5.6	4,300	1,889	450	0.90	3–100	12
Quebec	1:20,000	13.9 × 18.3	26,000	3,300	2,500	1.50	5–100	10
Ontario	1:20,000[4]	10.0 × 10.0	10,000	5,185	330	2.30	2–3,000	27
	1:10,000	5.0 × 5.0	2,500	5,380	125[5]			
Manitoba	1:15,840	9.7 × 9.7	9,500	4,300	400	1.70	2–1,000	20
Saskatchewan	1:12,500	10.0 × 10.0	10,000	1,696	800	1.40	1–100	8
Alberta (Phase 3)	1:15,000	9.7 × 9.7	9,324	3,600	500	1.50	2–20	17
Alberta (AVI)	1:20,000	9.7 × 9.7	9,324	545[6]	600	0.30	2–300	15
British Columbia	1:20,000	14.0 × 11.0	15,400	7,000	500	2.80	5–1,000	25

[1]1460 maps on the island, 434 in Labrador.
[2]For the 1980 inventory there were 196 maps; maps with small areas of land (i.e. which are mostly ocean) were incorporated into adjacent map sheets.
[3]Typical for a full map sheet (i.e. no ocean); overall the typical number of stands per mapsheet is 900.
[4]Forest districts in the south are mapped at 1:10,000 which accounts for approximately 20% of the area inventoried.
[5]Is highly variable depending on the amount and complexity of forest land.
[6]545 maps were produced for the Alberta Vegetation Inventory pilot study; inventory is continuing with similar procedures.

Table 3. Aerial photography characteristics

Province	Photo scales	Film type[1]	Film name	Number of photos	Date window for photo acquisition
Newfoundland	1:12,500	NC	Kodak Aerocolour Negative 2445	62,625[2]	July 1–Aug. 25
Nova Scotia	1:10,000	NC	Kodak Aerocolour Negative 2445	44,000	May 1–Sept. 30
PEI (1980)	1:10,000	BW	Kodak Double × Aerographic 2405	4,720	June 15–Sept. 15
		CIR	Kodak Aerochrome 2443	4,720	
PEI (1990)	1:17,500	CIR[3]	Kodak Aerochrome 2443	2,300	June 15–Sept. 15
New Brunswick	1:12,500	NC	Kodak Aerocolour Negative 2445	36,760	May 18–June 15
Quebec	1:15,000	BW[4]	Kodak Double × Aerographic 2405	220,000	June 15–Sept. 15
		CIR	Kodak Aerochrome 2443		
Ontario	1:20,000[5]	BW	Kodak Double × Aerographic 2405[6]	90,000	June 1–Sept. 15
	1:10,000	BW	Kodak Double × Aerographic 2405[6]	93,000	
Manitoba	1:15,840	BW	Kodak Double × Aerographic 2405	100,000	June 15–Sept. 15
Saskatchewan	1:12,500	BWIR	Infrared Aerographic 2424	60,000	June 1–Aug. 31
Alberta (Phase 3)	1:15,000	BWIR[7]	Infrared Aerographic 2424	130,000	May 15–Sept. 15[8]
Alberta (AVI)	1:20,000	BWIR	Agfa 200	9,000	
British Columbia	1:15,000	BW	Kodak Double × Aerographic 2405[9]	285,000	May – Sept.

[1]BW = black and white panchromatic, BWIR = black and white infrared, CIR = colour infrared, and NC = normal colour.
[2]52,000 for the island, 10,625 for Labrador.
[3]Colour negative processing is used to produce both colour and black and white prints.
[4]60% is black and white and 40% colour infrared.
[5]Starting in 1987, 1:20,000 photography was used, 1:10,000 is used in the south of the province where mapping scales are 1:10,000. Previous to 1987, 1:15,840 scale photography was flown for all parts of the province.
[6]Between 1987 and 1989 Agfa 200 black and white infrared was used, but in 1989 Kodak 2405 was used again in the south. After 1990 it is being used for the whole province.
[7]Thirty percent of the photography was done with black and white (Kodak Double × Aerographic 2405) early in the inventory cycle.
[8]June 1–Aug. 31 in northern Alberta.
[9]Normal colour (Aerocolour Negative 2445) is sometimes used in areas of mountain pine beetle attack.

Most surveys are conducted for blocks of photography which often represent forest management units. These can have boundaries varying from rectangular to irregular, for example following watershed boundaries or other physical features. The typical area flown each year while inventories are being constructed was summarized (Table 1). Seven of the 10 provinces conduct continual inventories, with usually one block of the province flown every year. The other provinces undertake the inventory and its photography during short inventory campaigns of two to eight years depending on the size of each province's forests (Table 1). All photography is acquired under contract by private companies. One contractor is generally hired to do the photography for each year. The number of contractors available to do the photography depends on the size of the aerial survey industry near each province, and ranges from four to thirteen. Some of the larger provinces, for example British Columbia, Alberta and Quebec, tend to use contractors from within the province, whereas the Maritime provinces, Manitoba, and Saskatchewan use contractors from their region or adjacent regions. The aircraft used are twin engined planes such as the Piper Aztec or Navajo, Cessna models 310, 440 and Conquest, and the Rockwell Aero Commander. Although undesirable, most surveys require several deployments of the aircraft from its home base to complete the acquisition. New Brunswick required the aircraft to be based in New Brunswick until all photography was completed. The time window in which photography is acquired varies with province (Table 3). Most specify a 6 to 12 week period between June and mid-September. Therefore, some photography may occur before full foliage development or during the period after leaf flushing in which the new foliage is highly reflective. Some may also be acquired when senescence and fall colouration is present. New Brunswick specifies a period in spring when hardwoods are in partial to full foliage. This early date is considered to have several advantages: leaf flush provides better species discrimination, cumulus cloud cover is less common, sun angles are higher than late in the summer, and photography is received earlier so that interpretation can proceed sooner.

Costs of aerial photography for provincial forest inventories include charges for flying, film, film processing, and the production of both one print and the number of prints normally ordered (Table 4). As they represent different scales, film types and time periods, the costs cannot be compared. However, they do give the true costs of the photography acquired for management inventories.

Photointerpretation

Attribute Interpretation

Stereo prints are interpreted and forest stands defined and delineated in most cases on the basis of homogeneous species, density, height and age characteristics. A site quality parameter is also an attribute usually ascribed to each stand. Gillis and Leckie (1993) described these in detail.

Species composition is often given by the three most prevalent species, each estimated to the nearest 10 percent. Species groupings, such as intolerant hardwood, tolerant hardwood, or spruce-fir are sometimes used instead of the individual species. Species composition is estimated on the basis of percent crown cover, percent of the stand volume (e.g. gross merchantable volume) or, as in Manitoba, percent basal area by species.

Table 4. Summary of resource expenditures[1]

	Photo costs				Interpretation costs		Interpretation rates		Base[4] map	Transfer and drafting			Digitizing costs		Digitizing rates		Attribute	Total mapping		Volume			Total Mapping
											Rates												
Province	1 print $\$ ha^{-1}$	No. of prints ordered	No. of prints[2] $\$ ha^{-1}$	Interpretation[3]	Interpretation $\$ ha^{-1}$	Field work $\$ ha^{-1}$	Photos day^{-1}	ha h^{-1}	$\$ ha^{-1}$	Cost $\$ ha^{-1}$	hr map^{-1}	ha h^{-1}	Labour $\$ ha^{-1}$	Equipment $\$ ha^{-1}$	h map^{-1}	ha h^{-1}	keypunching $\$ ha^{-1}$	w/o base map	w/base map	Sampling[5] $\$ ha^{-1}$	Compilation[6] $\$ ha^{-1}$	Total $\$ ha^{-1}$	and volume[7]
Nfld.	0.076	2	0.093	I[8]	0.065	0.068	6	180	0.012	0.037	20	315	0.075	0.465	37	170	0.005	0.808	0.820	0.267	0.005	0.272	1.092
NS	0.229	4	0.317	I	0.460	0.260	3	59	0.050[9]	0.038[10]	7	–	0.340[11]	0.082[12]	55	54	0.003	1.500	1.550	0.600	0.029	0.629	2.179
PEI (1980)	0.168	1	0.233[13]	C	0.100	0.050	15	294	0.112[14]	0.134	56	71	–	–	–	–	0.005	0.522	0.634	0.150	0.068	0.218	0.852
PEI (1990)	0.120	2[15]	0.130	C	0.258	0.058	33[16]	100[16]	0.053	0.045	10	271	0.218	0.204	28	151	0.019	0.932	0.985	0.190	0.000	0.190	1.176
NB	0.115	4	0.165	C	0.090	0.280[17]	8	230	0.010	0.070	8	538	0.038	0.180	14	300	0.005	0.828	0.838	0.355	0.011	0.366	1.204
Que.	0.110[18]	3	0.120[18]	C	0.085	0.044	12	528	0.004	0.100	56	465	–	–	–	–	0.005	0.354	0.358	0.330	0.031	0.361	0.719
Ont.	0.030[19]	3	0.040	I	0.058	0.120	7	582	Nil	0.021	11	910	0.023[20]	0.097[20]	14[20]	714[20]	0.013	0.372	0.372	Nil	0.000	0.000	0.372
Man.	0.020	4	0.039	I	0.027	0.006	16	825	Nil[21]	0.017	12	790	0.042	0.054	32	300	0.010	–	0.195	0.008[22]	0.003[22]	0.011	0.206
Sask.	0.066	1	0.066	I	0.110	0.040	5	155	0.043	0.080	38	227	0.074	0.250	55	180	0.010	0.630	0.673	0.100[23]	0.004[23]	0.104[23]	0.777
Alta. (Phase 3)[24]	0.052	1	0.052	I	0.082	0.090	5	235	0.048[25]	0.232[26]	18	518	–	–	–	–	0.012	0.468	0.516	0.055	0.056	0.111	0.627
Alta. (AVI)[27]	0.030	1	0.030	C	0.129	0.027	4	260	0.040[25]	0.057	16	585	0.110	0.156	24	395	0.016	0.525	0.565	0.110	0.015	0.125	0.690
BC	0.120	3	0.140	C	0.200	0.090	6	266	0.015[28]	0.040	27	550	0.090[29]		19	830	0.015	0.575	0.590	Nil	0.000	0.000	0.590

[1]Circa 1989–1992. For PEI, New Brunswick and Alberta, costs are dollar values for the period of the inventory.
[2]Cost for the number of prints normally ordered as part of the inventory.
[3]I = in-house; C = by contract.
[4]Cost of base map or control purchased by forest mapping agency (e.g. orthophotos). Where base map is supplied at no charge cost is nil.
[5]The cost of planning the volume sampling program (e.g. sample plot layout and preparation for field work) is typically < $\$0.005\ ha^{-1}$ and is included in the cost of sampling.
[6]Includes volume sample keypunching, running compilation programs, and where appropriate, stand area determination.
[7]With base maps.
[8]Recently have done one management unit on contract.
[9]Cost of new digital base map. Previous cost using only orthophotos was nil.
[10]Cost and time to obtain control (i.e. control points on air photo and orthophotos or digital base map) for transfer of digitized information from the air photos to base map coordinates. This could be considered part of digitizing.
[11]Includes $\$0.26\ ha^{-1}$ for digitizing stand boundaries on contract and this portion therefore, includes labour, equipment and profit.
[12]Part of the equipment for stand boundary delineation is in the labour portion of digitizing.
[13]Includes cost of colour infrared film and processing. The one print cost is the cost of flying and one B&W print.
[14]Converting existing base map to 1:10,000 scale.
[15]1 colour, 1 B&W print.
[16]Interpretation rate varied greatly because of different amounts of agriculture versus forest land. Photos/day is the average over all photos, but the ha/h is the hectares of forest land per hour. Total ha h^{-1} = 213.
[17]Includes an extensive quality check field program which cost $\$0.21\ ha^{-1}$.
[18]For B&W photographs. For colour infrared it is $\$0.13\ ha^{-1}$ for one print and $\$0.20\ ha^{-1}$ for three prints.
[19]For 1:20,000 scale photographs.
[20]Ontario digitizes forest stand boundaries by automatic scanning; costs and digitizing rates are for the whole digitizing process including automatic scanning of stand boundaries. Previously stand boundaries were digitized manually. Labour costs and times with this procedure were $\$0.032\ ha^{-1}$ and 21 hours map^{-1}, equipment costs were $\$0.095\ ha^{-1}$, and total mapping costs $\$0.0379\ ha^{-1}$.
[21]Base mapping operations are part of transfer and drafting, as base maps are produced as part of forest mapping.
[22]Until recently, an extensive field sampling program was in place with 6–8,000 plots/year. Costs were $\$0.100\ ha^{-1}$ and compilation $\$0.007\ ha^{-1}$.
[23]Currently there is no volume sampling program and therefore costs are insignificant.
[24]Labour costs include benefits.
[25]For orthophotos.
[26]Includes $\$0.087\ ha^{-1}$ for transfer and drafting the base map. Material cost an additional $\$0.023\ ha^{-1}$.
[27]Costs are for a pilot study in the forest fringe zone. Costs for the forest zone ("green zone") are expected to be 20% more for most components.
[28]Cost for new TRIM base maps. Previously using other base maps cost was nil.
[29]Digitizing done on contract. Includes labour, equipment and profit. Doesn't include equipment of BC Ministry of Forests GIS system.

There are typically four density classes related to the proportion of area covered by tree crowns. Ontario uses a stocking factor concept in which actual basal area is related to a normal basal area (the basal area that will produce maximum merchantable timber yield at rotation). In practice, the stocking factor is photointerpreted directly using stands of known stocking factor to calibrate the interpretation.

Height is typically given in 3 to 6 m height classes. Some provinces such as Nova Scotia, Ontario and British Columbia do not use height classes but estimate actual height to the nearest meter while others, such as New Brunswick and Manitoba, do not have height as a distinct attribute.

Age is dealt with in a variety of ways, but most provinces have 10- to 20-year age class intervals or seven maturity classes. These are generally photointerpreted on the basis of height, site and contextual information. Saskatchewan undertook a separate age survey between 1977 and 1983. It included extensive field sampling (averaging one sample per 600 ha). This information was used to calibrate the photointerpretation of age. New Brunswick has maturity classes which combine interpreted height, age and volume information. Manitoba does not have age classes *per se*, but incorporates age information in a cutting class estimate related to rotation age. Age, height and site interpretations are the key inputs in determining cutting class.

Each province has a different method to classify site. Some do not have site class, but describe some of the parameters influencing site type directly, for example soil texture or drainage. Site is most often estimated using predefined relationships among height, species and age. In other cases, it is interpreted from the height and age as well as other interpreted site indicators such as slope, soil and moisture conditions. There is obvious interdependence between the classes of site and age as neither is a physical parameter that can be interpreted directly and both are estimated using similar photo parameters.

Organization

Interpretation is done either in-house by interpreters employed by a central provincial inventory branch or by contractors (Table 4). The provinces with in-house interpretation units all conduct continual inventories, whereas provinces with discontinuous inventory programs generally use contractors. Quebec conducts a continual survey with contractors. Several provinces (e.g. Newfoundland and Nova Scotia) not previously doing interpretation under contract, have recently used contractors on a limited basis. The size of the in-house interpretation units ranges from three to eight interpreters. Alberta, during peak production of its Phase 3 inventory, had 21 interpreters. The interpreters are generally dedicated to tasks related to interpretation. They spend 40% to 80% (most 70 to 80%) of their time actually interpreting (office and field work) and the rest planning and participating in field programs. The proportion of time spent in the office interpreting versus field work to calibrate the interpretation is typically 75% to 85%. In Newfoundland and Manitoba interpreters are also involved with volume or other field sampling programs that are unrelated to interpretation.

Procedures

Photointerpretation can be divided into a number of components: calibration (e.g. collection of historical data, aerial or ground reconnaissance or plots, experience), interpretation (sometimes including field visits during interpretation), interpretation checking (verification) (e.g. by senior interpreters, spot field checks, systematic ground plot systems), and sometimes revision of the interpretation based on the interpretation checks. Each province has its own unique interpretation procedure and schedule within this framework. A generalized schedule follows. Photography is acquired the first summer and delivered in the fall. Field work for calibrating the interpretation is sometimes conducted prior to interpretation. Photo-interpretation is then conducted over the winter. Some provinces wait for field programs within the second summer and then begin interpretation in the second summer or fall. Quality assessment programs of varying nature are conducted. Some provinces use information from the quality assessment program to revise the interpretations and map, while others do not. Although the products and process of interpretation are very similar among provinces, the approaches to calibration and quality checking are often dramatically different depending on the inventory philosophy and operational circumstances (e.g. contracting, personnel, budget).

Information is needed to help calibrate the interpretation. Most provinces collect historical information on subjects such as old inventory maps, plot data, silviculture records and fire incidence maps. For example, information from existing volume sampling is often placed on the photos to improve calibration. About half the provinces have a preliminary (calibration) field program prior to commencement of interpretation, to provide information that acquaints interpreters with forest types and helps calibrate their interpretation. For several provinces, these consist of aerial reconnaissance, generally by helicopter, plus ground visits or a field plot system. Provinces with contract interpreters generally require preliminary calibration work by the contractors. Others with permanent interpretation staff often feel that interpreters do not require this preliminary calibration. For example, Manitoba employs three interpreters, each with long experience interpreting in the province. Saskatchewan and Ontario, on the other hand, conduct extensive field programs for calibration. Saskatchewan interpreters conduct field visits in which they try to acquire one plot for every kilometer of access. Ontario's program consists of collecting plot information (on average one every 500 ha of productive forest land) on contract. The Ontario Ministry of Natural Resources in turn conducts a minimum 5% sample check on these field cruises (until recently this had been a 10% check). The interpreters are active in this sample check program.

During the interpretation process, field checks are generally conducted by the interpreters for verification of their interpretation and additional calibration. These typically concentrate on problem stands and stand types. Nova Scotia interpreters, for example, spend approximately one day a week in the field while interpreting.

After interpretation, most provinces also have a field program to check the interpretation for accuracy and revise the interpretation if necessary. For example, Newfoundland uses volume sample information gathered the summer after interpretation to revise interpretations. Nova Scotia conducts a ground plot survey to check and revise the interpretation. This survey averages one plot for every 500 ha. Alberta Phase 3 deliberately involved district forestry personnel in checking the interpretation in order to use their local knowledge and give them confidence in the final product. The information gathered was used to revise the interpretation. Other provinces which conduct interpretation in-house do not have formal quality control programs; the interpretation is, however, often checked by senior interpreters or supervisors. The provinces conducting interpretation under contract generally have more rigorous quality control programs. These consist of inventory branch interpreters checking a percentage of the photographs (often 5%) or scanning all photographs and interpretations plus, in some cases, spot field checks. Under this procedure the check interpreters become familiar with common errors and difficulties of individual contract interpreters. This knowledge, in turn, guides the checking and governs the amount of checking needed. Alternately, New Brunswick developed an extensive network of 5700 measured plots and 17,000 ground plots visually inspected to check the interpretation of the contractors. Interpretation checking is generally inexpensive, often at \$0.01 ha^{-1} to \$0.02 ha^{-1}, but where field sampling programs are involved, costs can be large (e.g. \$0.15 ha^{-1} to \$0.21 ha^{-1}).

British Columbia's interpretation procedure is different in that it conducts the interpretation in phases. Before any field work is conducted, stand boundaries are delineated on the photographs but no attributes ascribed to the stand. A field program of aerial and ground observations and ground plots is then conducted for calibration. Interpretation of stand attributes follows. The 1990 Prince Edward Island inventory also delineated stand boundaries in a separate phase. The boundaries were digitized and then returned to the interpreters along with a map of various plot and silviculture records for attribute interpretation.

Time and Cost Summary

The cost and rate of interpretation for each province (Table 4) represent a significant portion of total map production costs. The different scales of photography and attributes interpreted for the provinces must be kept in mind. As well, for some provinces, base map information such as roads, lakes, and streams is also delineated as part of interpretation. Interpreters were able to interpret between 3 and 16 photos day^{-1} which represented 60 to 825 ha $hour^{-1}$. Interpretation of smaller scale photographs did require less time. Costs for photointerpretation without the field work component range from \$0.03 to \$0.46 ha^{-1}, with most being between \$0.06 and \$0.12 ha^{-1}. The costs of the interpretation field programs are variable but can be large. New Brunswick's program of field checking of the interpretation, for example, cost \$0.21 ha^{-1}, a significant proportion of the whole mapping program.

Accuracy

The accuracy of interpretation is difficult to determine rigorously and is often assessed and expressed in different ways. Desired or specified accuracy of species composition is often 80% to 85% for the correct order of dominant species or species groups. Achieved accuracy depends greatly on the species mix. High accuracy is obtainable where there are few species and pure stands but very difficult to achieve in areas of mixtures of many species. A best estimate of species accuracy is that 70% to 85% of the time the species composition is interpreted in the correct order or to within ± 25% of the true species proportion in a stand. The authors estimated that both height and age class were commonly interpreted within ± one class (and more often than not the correct class) 80 to 85% of the time. Crown closure estimates were commonly more accurate, being estimated to the correct class 95% of the time. However, when considering the complete stand attribute description (e.g. species, height, age, crown closure), the probability of the description being completely correct can be low.

Transfer, Drafting and Digitizing

Transfer and Drafting

Interpreted information must be transferred to a base map and a final forest inventory map produced. Although not having much impact on the method of transfer, geographic information systems have had a tremendous impact on drafting and final map production procedures. Currently, nine provinces are using GIS for the production of new inventory maps. Quebec is examining and setting up systems in order to start operational production. Prince Edward Island conducted its recent 1990 inventory with a GIS. For comparison purposes, however, it is interesting to describe the map production procedures for recent operational systems not using GIS as well as those current systems using GIS.

Transfer of interpreted stand boundaries requires a base map. Some provinces use base maps created independently of the forest inventory survey, while others produce the base map along with the forest cover map. Still others use existing base maps for cartographic control but add the road, streams and other base map features from the new inventory photography to create a new base map on the old cartographic base. The transfer, drafting and digitizing procedures used by each province were described previously (Gillis and Leckie 1993). New Brunswick used a new provincial base map series. Nova Scotia and Prince Edward Island (1990 inventory) are using digital base maps. Alberta, Ontario, and British Columbia are in process of producing new provincial base maps. These base map series cost in the order of \$0.70–\$1.25 ha^{-1}. They are available in digital format. For base maps produced recently by forestry agencies the costs of control (e.g. purchase of orthophotos or generating control from other sources) were \$0.04–\$0.05 ha^{-1}.

Interpretations are marked on the photos and transferred either in ink or pencil, to a transparent mylar or chronoflex generally via optical transfer using vertical sketch-masters, Kargl reflecting projectors, or zoom transfer scopes. Cartographic control is achieved by aligning the base map features such as roads, streams and lakes with the corresponding feature on the aerial photographs. Sometimes (e.g. Manitoba) the centre points and other control points from photography used for base mapping are transferred to the inventory photos. These points have previously been marked on the base maps. The points on the inventory photographs are then aligned with the same points on the base map. Saskatchewan uses a similar principle but transfers the centre points of the inventory photography to the photography used to produce the National Topographic System (NTS) map series and calculates the position of these points on the base map through the block adjustment used for NTS mapping. Alberta's new Alberta Vegetation Inventory uses a pseudo-stereo transfer technique. They obtain orthophotos produced at a scale of 1:20,000 (the scale of their mapping and photography) from the 1:60,000 scale photographs used for producing the Alberta base map series. This orthophoto is viewed stereoscopically with the interpreted inventory aerial photograph through a mirror stereoscope. The interpreted lines are then transferred directly to the orthophoto, which is then digitized and registered to cartographic coordinates directly. Nova Scotia uses an innovative technique that bypasses the transfer step and digitizes the interpretations on the photos directly. The polygons are subsequently registered to the proper cartographic base by applying rubber sheeting software to control points established on both the inventory photos and existing orthophotos. Newfoundland is using a similar approach for some of its mapping.

Transfer of information to a map is sometimes done by the interpreters as in the case of the Alberta Vegetation Inventory, but it is generally done by a separate drafting group attached to a central inventory branch. In cases where interpretation is done on contract, transfer and drafting of maps is also done on contract either as part of the interpretation contract or as a separate contract. Provincial inventory drafting units range in size from three to seven people, but these persons are not always fully dedicated to drafting of inventory maps. Other tasks include map duplication to fill requests, inventory update, miscellaneous drafting and, in a few organizations, field work. In some cases the drafting and digitizing personnel are combined into one group.

The cost and time for transfer and drafting (Table 4) range from \$0.02 to \$0.13 ha^{-1}; \$0.02–\$0.08 for those with digitizing. Typical rates were between 8 and 40 hours map^{-1} and 500 ha $hour^{-1}$ (typically ranging from 230 to 700 ha $hour^{-1}$). Note, procedures for each province vary. Some require additional resources because either an entire new base map is created or the base map features are transferred and drafted.

Although there are cost savings by using existing base maps, these maps, as noted above, are very expensive to produce. Use of digital base maps should also result in potential cost savings, but many factors are involved. For example, in Alberta the interpretation is transferred to orthophotos and then digitized from the orthophotos. Base map information is not collected. As digital base maps become available for the areas mapped, the forest stand delineations will be merged with the base map information. For new areas being mapped, the need for an orthophoto is eliminated (saving approximately \$0.04 ha^{-1}) as the interpretations will be transferred to the base map. However, since orthophotos are also used to give the interpreters an overview of their interpretation on a large area, thus improving results, the current procedure with orthophotos may still be used. If so, there may be a small additional cost to ensure registration of features such as lake boundaries mapped on both the forest and base maps. Nova Scotia does not expect significant savings using digitial base maps because of the need to update these maps with new information. Regardless, the trend is towards production of new base map series which are in digital format and also have digital terrain models. These are produced independently of forest maps by provincial survey and mapping agencies and are being adopted by the province as the standards for all provincial mapping. Integration of these maps and inventory maps is important for both map production and forest management decision making. A common base map for data will be increasingly important in future.

A consequence of digitizing maps and relying on plots of the digitized forest map as a final paper output product is that the transfer and drafting process is less onerous. Pencil copies of the transferred map are used for digitizing. Previously a copy of the transferred pencil version had to be carefully inked. As well, cadastral information, labels and legends had to be drafted. This took 15 to 30 hours per map sheet and cost \$0.02–\$0.05 ha^{-1} or sometimes more; some provinces, however, indicated that there was no time savings in transfer and drafting by not having to ink the final map.

The accuracy of the location of forest stand boundaries is difficult to determine precisely. There are two issues in this context. First is the accuracy of transfer to a base map and second is the precise placement on the earth's reference ellipsoid. The base maps used for forest inventory are of varying accuracy. The newer provincial base map series of the Maritimes, Alberta, Ontario, and British Columbia have specified accuracies of approximately ± 3–5 m in x, y and 2.5 m in z (the vertical) for maps at 1:10,000 and 10 m x, y and 5 m z for 1:20,000 base maps. The need for accurate placement of forest stand boundaries is uncertain, especially because the choice of stand boundaries is essentially subjective, varying from interpreter to interpreter, and the fact that stand boundaries are often gradational. The impact of imprecise placement on forest management planning and operations will vary. Correct area estimates are perhaps more important than precise positioning. The consensus among inventory and forest management specialists was that stand boundaries should be placed within 20 m of their true location. The more important factor was that the boundaries should be referenced within this tolerance of recognizable features on the ground (e.g. roads and streams) for proper location of the boundaries by workers on the ground. The accuracy of most forest inventory maps were considered to be in the 10 to 25 m range. The requirement for precise location of forest information on the earth's reference ellipsoid will become increasingly important as information from other sources is integrated with forest information within a GIS in order to assist in resource and land management decision making. These different information sources must overlay correctly. As well, accurate stand placement facilitates incorporation of inventory update information (e.g. cut areas) and additional forest information such as sample plot data, which perhaps could be located with respect to cartographic coordinates using a Global Positioning System.

Digitizing

Digitizing is done manually, generally from a pencil or inked mylar chronoflex produced in the transfer and drafting stage. There was, however, a case in New Brunswick where the portion of the inventory conducted by a forest company (in the early 1980s) was digitized by automatic scanning of an inked forest stand overlay. Automatic scanning has been, in general, more expensive than manual digitizing. Recently, Alberta has been experimenting with automated scanning of its old inventory (Phase 3) maps and interpretations transferred to orthophotos with red lines for its new inventory. Costs are somewhat higher than manual digitizing. Ontario, however, has recently adopted automated scanning as the principle method of digitizing. Stand boundaries only are transferred and drafted onto a chronoflex and then scanned. Base map information resides in digital format as part of a provincial base mapping program. This procedure has eliminated approximately one person day over manual digitizing.

The manual digitizing process can be separated into several steps:

- digitizing forest stand boundaries which generally also includes lake and swamp polygons,

- digitizing base map features such as roads, rivers, and power lines,
- loading and digitizing geo-administrative boundaries (e.g. ownership, forest management unit boundaries),
- edgematching at the boundaries of map sheets,
- editing and cleaning,
- label placement,
- quality control,
- final map output.

The density level of manual digitizing (i.e. points cm^{-1}) is high so that the smoothness of the original stand boundaries are generally maintained. As well as stand boundaries, there are several other layers of information that must be loaded as a coverage in the GIS. Base map information and geo-administrative boundaries may already reside on a GIS, as in the case of digital base maps, and only require loading and not digitizing. Stand attributes must also be loaded in the database. For the purposes of this discussion, attribute keypunching and loading will be considered as part of compilation for map production and is discussed later. Label placement is often assisted by the GIS software, but human intervention is needed in most cases and can be very time consuming. Automated label positioning programs are improving and this step may become almost fully automated in the near future.

Until recently almost all digitizing was done by provincial inventory staff in central digitizing units. An exception was some holdings of large companies in New Brunswick. British Columbia has done its digitizing under contract since 1988, Nova Scotia now contracts digitizing of stand boundaries, and several other provinces sometimes use contractors. The central digitizing units of the provinces range in size from four to 12 people. There is generally a central computer on which the GIS software and database reside plus four to 11 digitizing tables (Table 5). Workstations or workstation networks are becoming common and replacing central systems. The digitizing tables are often used in two shifts day^{-1} and in BC in peak periods when digitizing was done in-house, sometimes three shifts day^{-1}. This provides needed throughput and better utilizes expensive equipment. The ESRI ARC/INFO GIS is used by almost all provinces. Prince Edward Island uses CARIS. The British Columbia Inventory Branch uses Intergraph as its main GIS but also uses others. Data and filing systems are becoming more compatible and transferable and, while maintaining the inventory centrally on a main system, other GIS systems are coming into use for input and analysis. Alberta has developed an innovative mix, using Intergraph software for polygon input (digitizing), polygon storage, and final map output and ARC/INFO for building topologies (polygons), label placement, and the attribute database and its management.

Most provinces are only digitizing new maps as they are produced, although some digitize existing maps as time permits or for special interest areas. British Columbia was the first province to implement its forest inventory on a GIS, starting its program in 1978. In March 1992, it completed a digitizing program of 6648 maps involving digitizing primarily existing maps. New Brunswick conducted a complete new inventory between 1981 and 1986, inputing all maps into a GIS as they were produced and was the first province with its entire inventory digitized. With Prince Edward Island's 1990 inventory completed, there are now three provinces with complete digital inventories. It will, however, be 7 to 10 years or more before all provinces have complete digital map coverage (Table 5).

Labour costs of digitizing commonly range from \$0.03 to \$0.08 ha^{-1}; each map sheet generally taking between 15 and 55 hours to produce (Table 4). Rates typically range between

Table 5. The status of digitizing

Province	Digitizing stations	Number of digitizers[1]	Number of shifts	Number maps digitized[2]	Total maps to be digitized	% of total[3]	Start date	Expected completion date
Newfoundland	5	6[4]	1[4]	1420	1894[5]	75	1986	1995
Nova Scotia	4	4	1	450	2000	23	1987	2000
Prince Edward Island[6]	4	4	1	212	212	100	1990	1991
New Brunswick	4	10[7]	2	1880[8]	1880	100	1981	1989
Quebec	–	–	–	–	–	–	–	–
Ontario	11	11	1	1560	10600	15	1987	2007[9]
Manitoba	5	6	1[10]	2750	4300	64	1985	2000[11]
Saskatchewan	4	4	1	515	1696	30	1980	2000
Alberta (AVI)	9	12	1	730	4300	17	1988	–
British Columbia	Contract	–	–	6648	6648	100	1981	1992

[1]Includes supervisors.
[2]As of May 1993.
[3]Percent of total maps to be digitized that have been completed.
[4]Before April 1992 there were 12 digitizers and 2 shifts.
[5]1460 (986 completed) for the island, 434 (434 completed) for Labrador.
[6]For 1990 inventory.
[7]At the peak of inventory production. Currently there are four for updating purposes.
[8]Out of a total of 1889 were digitized, maps encompassing Fundy and Konchilongnac National Parks have been excluded from the system.
[9]Based on current production levels.
[10]Sometimes two shifts.
[11]Depends on funding (may be complete earlier).

170 and 400 ha h^{-1}. Costs and rates again depend on the procedures used, the size of the map sheet, the number of stands, and whether base map and geo-administrative information is digitized as part of the inventory mapping process or whether it already exists. Equipment and personnel are also important especially as many organizations are at the early stages of implementing digitizing programs. Gillis and Leckie (1993) provided examples of the times for each of the digitizing functions. A typical breakdown of times might be: 42% of the time spent for digitizing stand boundaries, 7% for base map features, 10% for geo-administrative boundaries, 7% for edgematching, 10% for editing and cleaning, 10% for label placement, 10% for quality control, and 4% for final map output.

Of course, there is also a large cost component in the capital cost and maintenance of computer and digitizing hardware and software. It is difficult to cost these precisely.[1] As can be seen (Table 4), equipment costs can account for a considerable portion of the overall map production costs. There are some additional costs such as system management and sometimes building modifications for computer installations not included in the digitizing costs. Equipment costs are decreasing as cheaper workstations are replacing larger central minicomputers. An alternate way of assessing equipment costs is that the GIS software and computer systems, except the digitizing tables and attached display systems, are needed to store, manipulate, and utilize the map information and should perhaps not be costed as part of map production. This would decrease the equipment cost considerably.

Inventory Map Data Compilation

Several functions associated with inventory mapping can be considered part of map production or equally as part of inventory volume compilation. The attributes of each stand are generally put on the interpreted photograph and/or a separate listing. Some procedures require transfer of these to the mylar or pencil map to be digitized. If the map is not digitized, the labelling is part of the drafting stage. Regardless, the stand attributes must be input into a database for volume compilation. For digitized maps, the stand attributes are keypunched and put into the GIS database as polygon attributes which are then used for map labelling as well. Keypunching of attributes on average takes 3.5 hours map^{-1} at a small cost of typically \$0.005 to \$0.010 ha^{-1}.

The area of each stand is often included in the stand description label on the map and is also required for volume compilation. For digitized maps, this is fully automated and involves no extra cost. For hand drafted maps, the area must be determined by planimetry, dot counting or, in the case of Saskatchewan (before it began digitizing maps), by computer assisted dot counting using a digitizing tablet and special software. This represented a significant cost, usually taking 2 to 4 days map^{-1} and costing from \$0.01 to \$0.04 ha^{-1}.

[1]Several assumptions are made to derive the cost figures for digitizing equipment: 1. The entire computer system and hardware is used for map production. This is close to true for many units or the system is utilized so fully that the proportion used for mapping would require a full system under normal usages. 2. The equipment is depreciated fully over a 5-year period. 3. Maintenance costs were true costs and when not available are those typical for similar software and hardware.

Overall Inventory Production

Map production is only a part of the whole inventory process. This section describes the timing of the various inventory steps, including the map production components, summarizes volume compilation procedures, and puts map production costs in perspective with the costs of the entire inventory.

Typically, the elapse time for map production is 1.5 to 3 years from the time of photo acquisition to finished map. Photographs are received three to five months after acquisition. Interpretation and associated field work generally commences after the photographs are received and checked for quality, and, therefore, often occurs over the first fall and winter. In some provinces there is an hiatus in activity over the fall and winter, with field work in the following summer and interpretation in the second fall and winter. Elapse time for interpretation is commonly six to 12 months, although it is shorter in several provinces. Elapse time for transfer, drafting, and digitizing is typically several weeks or months. In provinces with contracted interpretation and map production elapse times are often short. For example, Quebec receives its photographs in the fall and contractors have maps ready for final drafting by March. New Brunswick acquired photographs in late spring and received them within a month. Contractors conducted the interpretation, did the interpretation field work, and provided final maps ready for digitizing by March.

Volume sampling is an equally important component to the inventory as mapping. Gillis and Edwards (1988) outlined the volume sampling and compilation procedures of each province. Field plots are established in stands of selected characteristics according to a specific sampling system. From measurements in the plots, volume is characterized for groupings of stand types (strata); these are later compiled into inventory volume estimates by using the area and stand types from the inventory map. The field work is typically done the summer after the inventory photography is acquired, although some provinces conduct the survey the following (third) summer. A problem arises because to set up an optimum sampling design, the area, location and quantities of different stand types should be known (i.e. the final inventory maps of the entire area being inventoried should be completed). As this would result in unacceptable delay in completing the inventory and present logistical difficulties, many provinces do their sampling before map completion. Modifications of the sample strata are often required after the final map is available. Volume is compiled after map production and therefore the elapse time for the entire inventory of a block is often two to four years.

Volume field plots sample a single stand and generally consist of several variable radius prism points (e.g. BAF 2M) with some using fixed area plots (e.g. 0.02 to 0.04 ha). A two-man crew typically does three to seven plots day^{-1}. Costs typically range from \$75 to \$350 $plot^{-1}$. The number of samples $year^{-1}$ ranges from 500 to 8000. When averaged over the area inventoried this gives a typical range of one plot for every 400 to 1500 ha mapped. Provinces, therefore, have thousands or tens of thousands of volume plots. Volume sampling and compilation altogether commonly costs \$0.10 to \$0.40 ha^{-1}; the design and planning component of this is generally small (< \$0.005 ha^{-1}). Ontario is an exception. It was using previously determined stand type volume relationships (yield tables) and does no volume sampling. Manitoba is decreasing significantly the number of volume samples associated with its inventory as they begin to reinventory areas and use plots from the previous inventory cycle. They are also concentrating their sampling efforts on increased permanent sample plots for volume change information. British Columbia was using previous volume sample data and conducting limited new sampling with the goal of augmenting data for undersampled strata. They currently collect no volume samples due to budgetary restrictions. Saskatchewan no longer undertakes volume sampling due to budgetary constraints and because they are reinventorying areas and using previous plot data.

An additional aspect of volume sampling is inputting the field data into a computer database. Keypunching is often done by clerical staff and generally takes two to three person months year^{-1}. Costs are typically \$0.002 to \$0.004 ha^{-1}. Manitoba, Quebec, Newfoundland, Prince Edward Island and Nova Scotia use data recorders and thus eliminate the keypunching step. Previously, Manitoba spent \$5000 to \$6000 year^{-1} keypunching. Data recorders bring greater efficiency and error reduction, but when capital costs are considered, cost savings may be small. Compilation of volume is the final component of inventory. This procedure is well automated, mainly involves computer runs, and costs are generally small or insignificant.

Total costs for producing an inventory include those for design and planning, map production, and volume compilation. There are equipment and maintenance costs associated with map production and volume compilation. There is also the cost of management and overhead such as building space and building operating costs. This survey includes the costs of supervision but not overall management and overhead. Management is often 15% to 20% of total staff salaries. Overhead is commonly 10% to 15%. Salaries used for labour do not include benefits, which can be in the order of 15%. In costs for contractors, all factors including a profit are included. Total map production costs (without base map costs) are approximately \$0.64 ha^{-1} averaged over all provinces. Photo acquisition is 19% of the total cost at \$0.12 ha^{-1}. Interpretation is 36% of the total at \$0.23 ha^{-1}, with variable proportions of this for field work (on average 1/3 the cost), 44% (\$0.28 ha^{-1}) is for transfer, drafting, and digitizing, and a small amount is for keypunching stand attribute data. For those inventories not on a GIS, transfer and drafting accounted for, on average, 1/3 of the mapping costs (without base maps). Generally for those with digitizing and input into a GIS, transfer is 7% of total costs, digitizing labour represents 15%, and equipment costs are greater than labour costs at \$0.18 ha^{-1} or 25%. Planning and design costs are low for continual inventories, whereas discontinuous inventories have a short intensive design and planning period. Overall, planning and design costs are low to insignificant. With the base map costs associated with forest mapping, the total mapping costs averaged \$0.67 ha^{-1}. Volume sampling and compilation is also a significant portion of the inventory program. For provinces using new field samples from the area inventoried, volume sampling costs were \$0.24 ha^{-1} on average, including planning and design which is small (usually < \$0.005 ha^{-1}). The compilation component of volume estimation was small for those inventories on a GIS (on average \$0.01) and larger (approximately \$0.05 ha^{-1}) for those without a GIS, mainly due to the necessity to determine stand areas manually. In total, for those with new volume sampling programs and GIS, total volume sampling (planning and design, field sampling, and compilation) was 22% of total mapping and volume sampling costs. Costs were variable but averaged 31% of the total for those inventories not using GIS.

Discussion

Procedures for forest inventory are well established and have been similar for the last 40 years. However, there is continual evolution, innovation, and change prompted by technology changes, budgetary considerations, rethinking of inventory philosophy and procedures and, of course, pressures due to changing forest management practices and priorities. The following discussion outlines some recent and potential future changes and trends in each component of the inventory (i.e. data acquisition, interpretation, base mapping, transfer, drafting and digitizing, overall mapping, and volume sampling) as well as the impact of several important developments and trends in forestry (e.g. new technologies, greater involvement of industry in forest stewardship and inventory, and environmental and multiple use issues).

Developments and Trends in the Components of Inventory

Data Acquisition. Use of larger scale photography (e.g. 1:10,000 and 1:12,500) and normal colour film is continuing, although there is some reversal of this trend with the use of smaller scale photography by some provinces. New films are examined as they become available. Other ideas are tested from time to time. For example, high resolution airborne multispectral imagers are seen by some as a potential alternative to aerial photography.

Interpretation. Interpretation remains the most important element of map production. The importance of experienced photointerpreters cannot be overestimated; they provide faster, more accurate and consistent mapping. Experienced interpreters also need less field work for calibration and resolving problem areas and conditions. As well, less quality control and revision of the interpretation is required. Quality checks can be expensive. They are often more rigorous for contract interpretation than for in-house interpretation. For in-house interpretation quality control is generally done via checks by senior interpreters. With experience, confidence is built in the interpretation and quality control efforts and costs are often minimal. Contract interpretation undergoes varying degrees of quality control ranging from a 5% check by provincial agency interpreters (approximately \$0.01 ha^{-1}) to extensive and costly field programs (e.g. \$0.21 ha^{-1} for New Brunswick). Acquiring and training good interpreters is a major problem for forestry agencies whether interpretation is done in-house or on contract.

Base Mapping. The survey and mapping branches of most provinces have undertaken or plan new base mapping programs. These result in base maps of improved quality and in digitial format, including digital elevation models. Such maps are being implemented as the base for forest inventory mapping as they become available. More integrated systems to take advantage of the digital nature of the base maps are evolving but significant cost savings are not expected from the decreased necessity to digitize base map information. The important advantage will be in better quality base maps and in integration with a common digital base, which will also include digital elevation data and themes such as soil. This, in turn, permits powerful analytical tools using georeferenced data sets to be developed for forest and other resource management planning and decision making.

Transfer, Drafting and Digitizing. The implementation of forest inventories on GIS has had enormous impact on forest inventory map production procedures and operations for several years, whereas its effect on forest management planning and operation is just beginning to be felt. The key benefits of GIS will come from its use for forest management (e.g. improved ability for modelling, better data manipulation and display for forest management planning and operations, and providing an infrastructure for decision support systems such as those for testing management strategies). Geographic information systems also permit efficient updating of inventory maps. The cost of inventory mapping using a GIS is not less expensive. Indeed, the cost and procedures of transfer are similar and the labour costs of digitizing approximately equivalent to final inking of paper maps and often more. Digitizing does, however, eliminate the tedious task of area determination which typically took 2 to 4 days map^{-1} and cost \$0.01 to \$0.04 ha^{-1}. The equipment capital and maintenance costs for digitizing are large, although these are decreasing with microcomputer-based GIS and digitizing stations. There are dramatic improvements in digitizing efficiencies in the initial stages of implementing GIS as the digitizers become experienced and operational procedures streamlined. The costs and times of digitizing (Table 4) generally represent the costs of experienced operational digitizing groups. A potential efficiency is in digitizing interpreted delineations directly from photographs, as opposed to transfer onto paper maps and then digitizing as most operations do now. This transfer step accounts for approximately \$0.02 to \$0.08 ha^{-1} or 8% of map production costs. Nova Scotia is digitizing directly from photographs and Newfoundland has done some direct digitizing as well. Several procedures are possible and should be investigated. In general, the use of GIS in map production is not cost effective when viewed strictly in terms of inventory mapping. It is however, in its early stages and innovative transfer techniques or perhaps totally digital systems using imagery in digital format are needed to improve its efficiency. The investment in digital technology (GIS) has been primarily for improved data storage, manipulation and analysis. In order to obtain the full benefits to mapping, integration of interpretation, transfer and digitizing into one step within a fully digital environment must evolve. Inventory practitioners are desparate to develop new methods to improve, eliminate, or avoid the costly, time consuming, labour intensive process of transfer and hand digitizing.

All provinces have conducted digitizing in-house and while most digitizing is still being conducted by provincial inventory agencies, there is a trend towards digitizing on contract. British Columbia, which digitized in-house from 1978 to 1987, has digitized on contract since. Nova Scotia now does stand boundary digitizing on contract. Newfoundland and Ontario have contracted some digitizing. Alberta, New Brunswick, and Quebec plan to digitize on contract. This appears to be a definite trend, the technology being initiated in-house and then contracted out as a private sector develops locally and in-house experience has been gained to understand and quality control the process. This coincides with greater emphasis on the use of GIS information rather than the process of inputting data. There is a general feeling among groups responsible for inventory that innovations such as GIS are easier and best done first in-house and then contracted once they are proven.

Overall Inventory. Coordination of the various components of inventory production is important to overall map production, but there is not a high priority for short elapse time for the whole mapping and volume compilation process. Interpretation for most provinces takes place over the first fall and winter, including any field checking during interpretation. Several provinces (Ontario, Saskatchewan and BC), however, require an interpretation field sampling program before interpretation takes place. This is done the summer following photo acquisition: therefore, interpretation on that area does not begin until the second fall or winter. In addition, as mentioned above, a serious logistical problem can occur in the timing of the volume sampling field program due to the final map not being ready in time to plan the volume sampling. Faster mapping would help, but in some provinces volume sampling is used to revise the interpretation.

Most provinces conduct continual inventories, mapping a portion of the province each year with no hiatus between cycles. Prince Edward Island, New Brunswick and Alberta have discontinuous inventory cycles. Discontinuous inventories provide a formal period between inventory campaigns in which to reassess inventory criteria and procedures and experiment with new methods. Disadvantages are uneven workloads and changing personnel requirements. An additional problem is in obtaining financing for a new inventory cycle. A constant expenditure from year-to-year is easier for governments to handle than large requirements for money over short periods as is required for discontinuous inventory cycles. There is a tendency to delay or not make decisions to make the necessary expenditures to implement a new inventory cycle. New Brunswick is considering changing to a continual inventory on a 10-year cycle. Inventories on one of five areas would be conducted every two years. The inventory schedule may be tied to the 5-year management planning process so that a new inventory is available for creating every second management plan.

There are several innovative ideas, related to use of existing inventory data for generating new inventories, that are earning widespread consideration. Greater use is being made of old inventory data and possibly making more use of the old forest type maps for producing a new inventory. For example, Manitoba experimented with the concept of using old stand boundaries in areas being reinventoried. The old stands would be given updated attributes when there was not a change which required new boundaries. This concept seems sound in principle for inventories conducted on a 10- to 20-year cycle. It was found in practice, however, that for the area tested, it was not practical. There were too many changes. It was considered faster, easier and less confusing to remap the whole area and the concept was abandoned. Ontario, on the other hand, recently adopted a similar procedure for areas in which the local forestry office agrees that little change has occurred. New Brunswick, with its current inventory in a GIS, is also considering such an approach for its next inventory cycle. With the infrastructure and expense of digitizing new stand boundaries and the availability of existing boundaries in digital format, the concept of retaining the existing boundaries is attractive.

From time to time serious consideration is given to abandoning the strict inventory cycle altogether. Instead, efforts would be place on updating maps every one or two years and growing the stand attributes and volume within the database. In this way reinventory would not be needed. Inventory would only be done in special interest areas such as those planned for large harvesting operations. This would, of course, fundamentally change inventory procedures and costs. The concept is sound, but has not yet been adopted. Most provinces are on their third or fourth cycle and there are more stringent requirements in place to collect update information. As well, the availability of GIS, computer models, and remote sensing technology to assist update and the large cost of new inventories makes this scenario more appealing. There is large potential for sophisticated remote sensing techniques based on examining the characteristics of already existing stand polygons and using these to monitor changes or normal expected stand development. There are, however, concerns with this concept, especially regarding the ability to grow stands beyond 20 or 25 years, unpredictable changes in stand make-up, and the practicality of predicting and acquiring new inventory data of the special interest areas in a timely fashion. Regardless of the future methods used, the dynamic nature of the inventory must be recognized by some modelling of stand dynamics and growth predictions and good inventory update procedures.

Volume sampling is an expensive component of the inventory and as inventory is conducted over the same area for the third or fourth cycle, some provinces have ceased their sampling program and use plot data and stand volume relationships from previous inventories. Ontario has always used stand volume relations determined by a special survey. This concept would appear to be appropriate and cost-effective where a good sample base exists and a network of permanent sample plots is maintained to monitor growth trends over time.

General Developments and Trends

New Technologies. Technology has had a large impact on map production in recent years. The introduction of GIS has altered the drafting and digitizing procedures. Use of GIS in forest mapping has not resulted in less expensive map production. The benefit is in better information access, manipulation, and use for forest management decision-making. As well, GIS provides an infrastructure suitable for new survey technologies. High resolution (< 1 m) digital data from airborne multispectral imagers, although unproven, may be one such technology (Leckie 1990; Leckie and Gillis 1993). This technology is compatable with the digital nature of the database and may provide large efficiencies in the transfer, drafting and digitizing component of map production which now requires considerable labour. This labour accounts for 23% of total map production costs. Map production will also be affected by decreasing cost and improving performance of computer hardware. Therefore, increasingly sophisticated technology can be implemented. As well, costs of equipment to meet existing requirements is decreasing. For example, equipment costs are a large expenditure in GIS technology, but this is decreasing rapidly with the introduction of less expensive but powerful workstations and inexpensive mass storage devices and media. Cheap storage has led to policies of maintaining a full database online. Field data recorders have brought greater efficiency to volume sampling and use of Global Positioning Systems may provide better location of sample plots. Technology will play an increasing role in accelerating the rate of innovation in forest inventory.

Implementation of technologies can have secondary, less direct, effects that have equally important implications. Geographic information systems, increased computer power, and advances in decision support systems have led to a greater ability to use inventory information. With this greater ability there is increasing demand for more accurate, detailed and up-to-date data. For example, there is increased capability to store and manipulate stand attribute data and to generate and use finer aggregations of the data. For example, there is increased capability to store and manipulate stand attribute data and to generate and use finer aggregations of the data. Thus there is a trend towards interpreting and assigning continuous values for stand attributes (e.g. height to the nearest meter) as opposed to categorized attributes (e.g. 5 m height classes). In addition, incorporation of data on silviculture and other treatments is becoming more desirable, as is integration of inventories with forest ecosystem classifications and their procedures. Also, with these new tools plus the high cost of operational cruise surveys, there is a growing tendency to use management inventory data for operational planning. There will be a greater demand to make the inventory more operationally useful and include greater varieties of data (e.g. information relevant to logging costs or road construction).

New market forces and utilization changes can drastically change the priorities on the information that is required from an inventory. For example, environmental issues may alter the acceptability of a product or the source country or region of a product. New technologies can change the importance of species within the inventory. For example, a new hardwood pulping process has necessitated more attention to inventory of hardwood species and sometimes more intensive surveys in hardwood dominated regions. The development of oriented strand board plants in Alberta has created an inventory problem to differentiate balsam poplar (*Populus balsamifera* L.) from aspen (*Populus tremuloides* Michx.) in the inventory. These were not previously distinguished and much work has gone into trying to develop a method to do so.

Greater Industry Involvement. The forest survey and mapping industry are playing an increasing role in the production of forest inventory. There is a trend towards more contracting of components of the inventory and of the whole map production process. This is in part a response to the general trend recently of governments to contract out services. In the past, except for Quebec and Alberta, provinces with continual inventories conducted mapping, whereas those with discontinous inventories contracted components of their mapping. Recently, however, British Columbia is obtaining interpretation, transfer and digitizing under contract. British Columbia has an interesting approach. Contract payment in most provinces is based on a cost for mapping a given area (e.g. per map). British Columbia's contracts for interpretation and digitizing, on the other hand, are on the basis of cost polygon–1. The Alberta Vegetation Inventory (a trial of a new inventory procedure) conducted interpretation transfer and volume sampling by contract but undertook digitizing in-house. Newfoundland is experimenting with contract interpretation, transfer, digitizing and volume sampling. The merits and disadvantages of contracting will not be discussed here, but a few points will be highlighted. For interpretation, the key element is experienced interpreters. The larger provinces may be able to maintain a contingent of experienced interpreters among contractors. Provinces with discontinuous inventories will have difficulty maintaining expertise in-house and may have to contract from outside the province. Smaller provinces with continual inventories can likely maintain a small interpretation unit but may have difficulty contracting experienced interpreters. Secondly, for all cases contracted work a significant quality control program has been created. Depending on its rigour it can be an important cost and, along with contract supervision and administration, can result in a large effort and cost to the forest agency.

Another important change in forest inventory in the past 10 years is the apportionment of large areas of forest land to the management of forest companies under what is commonly referred to as forest management agreements. In total, these can cover significant portions of forest land in a province (e.g. 48% in New Brunswick, 69% in Ontario, 38% in Manitoba, 40% in Alberta[2], and 6% in BC). Arrangements for their inventory varies among provinces and depends on each agreement. They vary from Saskatchewan, where the province is responsible for providing inventory information, to British Columbia and Alberta where the companies are responsible for the entire inventory. In most cases, the inventory data is required to be passed on to the province. Alberta, however, does not require the companies to provide the data to the province, but it is expected that data will be provided voluntarily in lieu of mandatory surveys. The British Columbia Ministry of Forests has been receiving only summary data from the companies, but there is a trend towards providing more complete polygon-specific data. In cases where companies are responsible for inventory, they are required to conduct inventories to provincial specifications. Companies have a large interest in the inventories of their lands and many gather additional data beyond the specifications. In Ontario there is joint gathering of inventory data with each agreement being different. The companies generally provide field data for the interpretation and some do the interpretation. As GIS gets implemented within these companies, some may conduct their own digitizing; indeed, some have digitized existing maps in order to take advantage of GIS technology for forest management decision-making. Companies generally have much of their inventory work done on contract. In several provinces the impact of these agreements will have a large affect on their inventory mapping program. They are no longer directly responsible for producing the inventory on large percentages of the province.

Environmental and Multiple Use Issues. A third major factor that will assert increasing influence on forest inventory is concern over the environment. The importance of environmental issues and non-timber uses of the forest has several implications.

A wide variety of people are using the data. Many people using the data are not familiar with how the inventory is derived and its limitations, accuracy and reliability. As well, it is being used, often by necessity (since it is the only data available), for purposes for which it was not designed and is not appropriate. In addition, as part of environmental assessment processes, the data and its interpretation often gets into the legal realm and of course into the emotional realm. In both realms, the same data often mean different things to different people and the data themselves may be brought into question if they don't support a particular position.

The data are coming under increasing scrutiny which creates increased need for assessments of accuracy and reliability, and currency. Traditionally the accuracy, reliability considerations of an inventory have been based on producing good volume estimates (e.g. timber volume for a management unit within ± 10% gross merchantable volume at the 0.75 or 0.67 probability level). The accuracy of the components of the inventory (e.g. species composition, density, site quality) is becoming more important due to the expanded use of the inventory information for forestry, multiple-use and environmental uses. More effort is beginning to be applied to formal assessment of these accuracies.

With the importance of environmental issues, recreation, aesthetics, conservation, other uses of the forest, and ecosystem management concepts, there is a great need for different kinds of data (e.g. minor species, ground vegetation, deadfall and standing dead trees for habitat, environmentally sensitive areas). In terms of wildlife, for instance, data needs are governed by conservation, hunting and, increasingly important, watchable wildlife. Biodiversity and sustainable development are two emerging and important issues. There is a growing interest in developing indices from forest inventories or, alternately, developing new inventory procedures and attributes to provide information on diversity and sustainability. If such factors along with other multiple use and environmental parameters become part of inventories, they will have a tremendous impact on procedures, cost, and data volume.

Although far from a new concept, integrated resource surveys are being investigated to provide the increasing amount and variety of information required in managing forest areas. Indeed several provinces have implemented aspects of these types of surveys. PEI conducts a biomass inventory, Nova Scotia collects wildlife management information in their volume sampling program, Alberta has piloted and is proceeding with a new vegetation inventory which incorporates vegetation information suitable for wildlife management, and currently British Columbia generates several map layers in its GIS associated with environmental, wildlife and operational logging considerations. British Columbia is closely examining these issues and is currently in the process of defining a new vegetation-based inventory. Many environmental parameters, however, cannot be readily interpreted from aerial photographs and will require augmented and additional field sampling programs. The costs to inventories will be large. It will be helpful to find surrogates for these parameters that can be interpreted or mapped by remote sensing techniques. Integrated approaches are required. It will not be possible to conduct separate surveys and hold individual inventories for the myriad of information types needed for forest resource management.

The need for innovation and evolution of forest inventory and mapping is increasing. The pace will depend on the pressures for change, available budgets to implement the changes, technological innovations and infrastructure development, and the creativity and enterprise of inventory practitioners.

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[2]Forest management agreements comprise approximately 40% of the Green Zone forest. The Green Zone is the main commercial forest areas of crown land, which excludes the southern transition forest to the grasslands and transition zone to the northern forest.

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