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SPECIAL ISSUE

Global changes in terrestrial ecosystems

Bruce A. Roberts · Neal P. P. Simon
Keith W. Deering

The forests and woodlands of Labrador, Canada: ecology, distribution and future management

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Abstract Labrador, Canada is the last relatively undeveloped landmass of Boreal and subarctic Canada. Its land area is over 288,000 km^2, with less than 1% developed, and a human population of below 30,000. Labrador is greater than 60% forest- and woodland-covered and over 30% tundra, soil and rock barrens. We review the ecology and distribution of forests, woodlands, and related vegetation of Labrador within the context of climate, forest site index, landform, soils, and disturbance. Recent ecosystem management through a public planning process with emphasis on past and future comanagement and development with traditional and western scientific principles is currently underway. Plant–animal interactions, traditional uses by aboriginal groups, and early history are also reviewed.

Keywords Ecology · Forests · Forest ecosystem management · Labrador · Review · Woodlands

Introduction

Labrador has a large triangular landmass of some 288,000 km^2 (Meades and Roberts 1992) and is one of the last Boreal regions of Canada without significant development, especially in the interior. Major developments include an air base in central Labrador following the Second World War, iron ore and hydroelectric developments in western Labrador, and a recent nickel mine in northern Labrador. Current exploration and mining development, untapped hydroelectric potential, forest products, tourism and new road access are being examined for future development.

Approximately 60% of Labrador is forested (30% of which has commercial potential and 25% is lichen woodland), while 5.3% is recently burned forest (Drieman 1993; Tanner 1944; Hustich 1949a, b). The non-forest portion includes 3.5% peatlands, 30% tundra and rock barren. Only 0.14% of the land is developed and its current population is < 30,000 people. From Cartwright's first western settlement in 1770–1786 to the fatal Hubbard expedition from North West River to Ungava Bay, 1905 (Wallace 1905) and the recent Mina Hubbard expedition (Hubbard et al. 2005), the vastness (Stewart 1978) and wild land ecology of Labrador has attracted worldwide attention and exploration (Goudie 1980). Recent books on early travel journals and photographs of the legendary medical doctor Grenfell (Rompkey 1996) as well as many of the stories and lore of its people and places (Rompkey 2003) are accounts of its vivid history.

Our objective is to review the biophysical components of climate, geology, geomorphology, soils, and the related vegetation of Labrador. We include accounts of past activities and outline future sustainable ecosystem management objectives that incorporate aspects of traditional and western science as new approaches in a sustainable management framework. Plant names follow Fernald (1950), Brassard (1972), Ryan (1978) and Ahiti (1983).

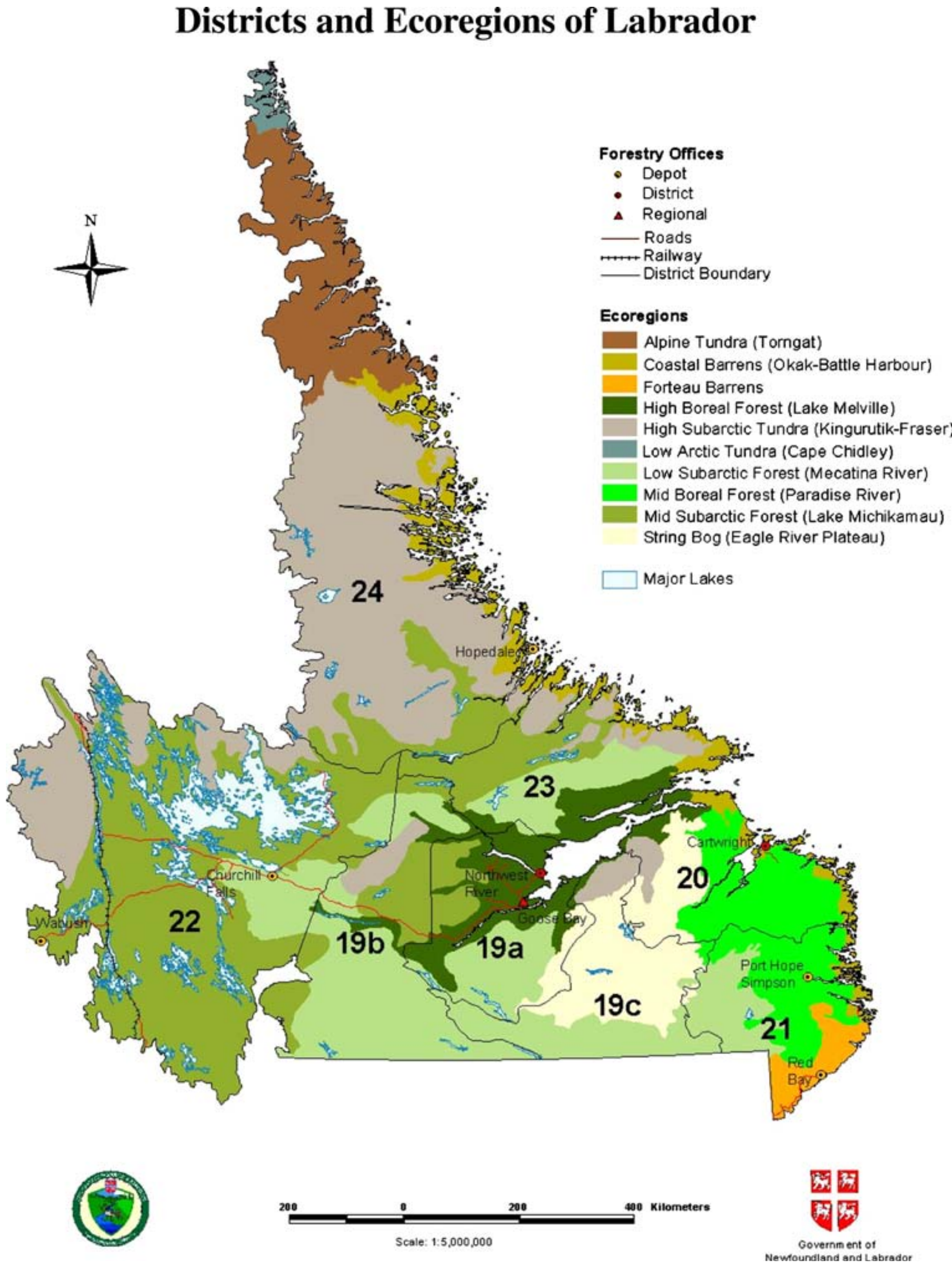
Location, extent, political and social history

Labrador is approximately 288,000 km^2 in area and extends from the northeastern coast of North America from the Straight of Belle Isle (latitude ~52°) to Cape Chidley (latitude ~60°) (Fig. 1). The name "Labrador" is thought to have originated from "lavrador," which means landowner in Portuguese; this term may have been due to Joao Fernandez, who charted the coast from Greenland to Newfoundland with John Cabot in 1498.

B. A. Roberts (✉)
Atlantic Forestry Centre, Natural Resources Canada,
Canadian Forest Service, Corner Brook, P.O. Box 960,
Newfoundland and Labrador, Canada A2H 6J3
E-mail: bar@nl.rogers.com

N. P. P. Simon · K. W. Deering
Newfoundland and Labrador, Department of Natural Resources,
Station B, P.O. Box 3014, Happy Valley–Goose Bay, NL,
Canada A0P 1E0

Fig. 1 Districts and ecoregions of Labrador, Canada



The early Norse and Basque whalers were active in southern Labrador, the latter in the fifteenth and sixteenth centuries. The Labrador territory which fell under the sovereignty of Newfoundland before 1949 referred to the coast and land extending inland to the height of the land (or all of those lands drained by rivers emptying into the Atlantic). The territory and boundary was described (from Blanc Sablon to the Romaine River northward to Cape Chidley) in early documents leading up to the Judicial Committee of the Privy Council of Great Britain. In 1927, the Council awarded Labrador to Newfoundland and not Quebec, Canada, who had argued for much of the same territory. In a referendum in 1948, approximately 75% of the residents of Labrador supported confederation with Canada, and in 1949 the island of Newfoundland and its mainland region, Labrador, became Canada's tenth province (Smallwood et al. 1991, Labrador, p 203–235).

In 2001, Labrador had a population of 27,864, with the iron-mining district in western Labrador accounting for about 40% of the population. Other population centers occur along the southern coast and in the Happy Valley–Goose Bay region. In 2001, 2.9% of the inhabitants were indigenous peoples, including Inuit and Innu (see the Government of Newfoundland and Labrador website at http://www.gov.nl.ca).

The former Labrador Inuit Association (LIA) ratified an agreement with the province in 2004, and was officially awarded the Nunatsiavut ("our beautiful land") regional government in 2005. Nunatsiavut includes five principal Inuit communities (Nain, Hopedale, Makkovik, Postville, Rigolet), about 5300 Labrador Inuit, and approximately 15,800 km^2 of land. The current settlements of Makkovik, Hopedale, Nain as well as the abandoned settlements of Okak, Hebron and Killinek owe their formal existence to the Moravian Church, which set out to evangelize the Inuit people in 1752 but did not succeed until 1771 (Smallwood et al. 1991).

The Innu are two tribes of the eastern subgroup of the Cree people formally known as the Naskapi (northern branch) and the Montagnais (southern branch). The Innu Nation (which includes two settlements of Sheshatshiu and Natuashish) are also seeking land claim settlements and refer to Labrador as Nitassinan ("our homeland") (Tanner 1998; Smallwood et al. 1991; Government of Newfoundland and Labrador website http://www.gov.nl.ca).

Climate, topography, and water resources

The main feature of Labrador's climate is the influence of the Labrador Current, which is the flow of cold water from the Baffin Land Current and the Hudson Straight Outflow. This follows the edge of the Labrador–Newfoundland continental shelf, where it combines with the much warmer Gulf Stream at the southeastern Grand Bank. Banfield (1981) lists four major climatic zones for Labrador: (1) Interior Labrador, continental regime, 900–1,100 mm annual precipitation, long severe winters with heavy snow accumulation, although a subzone of Inner Lake Melville has warmer summers and shorter winters; (2) Southeastern Labrador interior, upland, less continental, greater precipitation in winter, 1,000–1,200 mm total precipitation; (3) Coastal Labrador, less continental than interior with annual precipitation 100–1,300 mm, cold in onshore circulations; (4) Northern Labrador, tundra climate with insufficient summer warmth to support full tree growth. The total mean annual precipitation and temperature varies from 500 mm and −50 °C in the north to 1,300 mm and 0 °C in the south (Banfield 1981; Peach 1984) Annual mean snowfall is 200 cm on the extreme north coast, 300–400 cm in the central region and 400–500 cm south of Cartwright (Peach 1984; Bajzak and Roberts 1996a, b, 1999a, b).

Topography and elevation

Labrador's elevation ranges from sea level to 1738 m at Mount Caubvick—the highest point east of the Rockies in Canada. Bostock (1970) divided Labrador into ten physiographic subdivisions, which follow a north/south alignment: (1) The Labrador Highlands from the lands north of Nain; (2) The George Plateau from Kaipokok Bay Makkovik to just north of Nain; (3) The Benedict Mountain area; (4) The Hamiliton Uplands; (5) The Hamilton Plateau–Melville Plain; (6) The Mealy Mountains; (7) The Mecatina plateau and West Labrador; (8) The Lake Plateau–Michikamau; (9) The Kaniaapiskau Plateau–Labrador City; (10) Labrador Hills–Knob Lake.

Twenty-eight major drainage basins exist, with a mean annual runoff in Labrador of some 600–700mm, with 190 billion m^3 of water discharged into the Atlantic Ocean (Water Resources Division 1992). Hydroelectricity development includes the 18.7-MW Menihek Power Plant constructed in 1954 and the Twin Falls 225-MW Power Plant used for iron ore mining and processing in Labrador City and Wabush (Drake 1983). Twin Falls was mothballed in 1971 when the Churchill Falls 5428-MW Power Plant was completed. The construction of the Churchill Hydroelectric Project and the flooding impacts of Michikamau Lake, now the Smallwood Reservoir, have been outlined (Bajzak D, 1971, unpublished report: *Vegetation classification and mapping of the Smallwood Reservoir Area*, Labrador, Memorial University of Newfoundland, St. John's, Canada) and reviewed (Duthie and Ostrofsky 1974, 1975; Bajzak and Bruneau 1987), while its impacts on snow and runoff are reviewed in Bajzak and Roberts (1996a, b) and Bajzak et al. (1998). Proposed developments at Gull Island and Muskrat Falls on the lower Churchill River could potentially produce 2,000 MW and 825 MW respectively (Water Resources Division 1992).

Geology and geomorphology

Labrador contains the eastern portion of the Precambrian shield (Green 1974). The bedrock geology of Labrador is mostly igneous and metamorphic rocks that are Precambrian, > 570 million years old, but some of the metamorphic rocks of the northern section exceed 3,700 million years in age and are some of the oldest rocks on earth (Batterson and Liverman 1995; Government of Newfoundland and Labrador 1997). The Precambrian shield of Labrador is subdivided into five structural provinces: (1) the Grenville (Lake Melville and South Labrador, the largest); (2) Makkovic (just to the northeast of Grenville); (3) Nain (province covering most of the northeast coast above Makkovik); (4) Churchill (the northern interior); (5) Superior province (the smallest, on the extreme western Labrador border) (Green 1974). These provinces were brought together during several episodes of mountain building (Roberts 1980) over 1,000 million years ago.

The geology of Labrador has been responsible for the development of the extreme western interior of Labrador. Iron ore deposits mined at Labrador City and Wabush have produced over 1 billion tons of product. Development of the Voisey's Bay (South of Nain) nickel and base metals project is nearing competition. Uranium exploration and development of mineral sands of iron, titanium, zircon, and garnet are ongoing.

Most of Labrador was covered by the Laurentide Ice Sheet, the exceptions being the highest peaks of the northern Torngat Mountains and the Mealy Mountains, south of Lake Melville (Batterson and Liverman 1995). Glaciers and glacial melt-water reached the coast through the major valleys with the ice margin, moraines, eskers and kames at ice contacts. Druminloid, hummocky and veneer moraines have also been eroded and mixed with marine terrace features of the coastline to form some of the most spectacular examples of glacial and coastal geology. Studies of glaciers in northern Labrador (Ives et al. 1976; Ives 1977, 1978) and geologic studies of Labrador reviewed by Rogerson (1981) have elucidated the direction of ice flows, major moraines, and other glacial features of the late Wisconsin Glaciation.

Ecoregions and vegetation ecology

Most of Labrador's forested land is within Boreal Forest Sections (B13a and B31) (Rowe 1972), which correspond to Ecoregions 5, 8 and 9 (see the Parks & Natural Areas Division website at http://www.env.gov.nl.ca/parks/apa/panl/nl.html), although there are smaller areas in Forest Sections B12 (Ecoregions 6 and 7; Fig. 1; Table 1). The northern tree limit on the Labrador coast, as defined by boundary-separating arboreal and nonarboreal vegetation, is at Napaktok Bay (Elliott and Susan 1979). Payette (1983) also defined the tree line as a more northerly position in the Saglek fiord where four balsam poplar groves exist. Hare (1951, 1976) suggested that the northern forests of Labrador have reached their environmental limit, as opposed to climatic limit, as the valley landscape of Labrador has blocked any further movement north.

Wilton (1965) used Hustich's (1949b) classification to subdivide Labrador's forests into productivity classes using understory species to infer a soil moisture series. Linteau (1955) developed a similar classification for southern Labrador. The biophysical land classification system (Lacate 1969), now called Ecological Land Classification (ELC), has become the framework for environmental impact and land use planning analysis, and is now accepted as the basis for ecosystem management (Kimmins 1996; 1997, 2003). Early ELCs of Labrador were numerous but limited in spatial extent and reviewed the forests, costal dunes, salt marshes and the occurrence of permafrost features in the Lake Melville region (Bajzak 1973; Bajzak and Roberts 1984, Roberts and Robertson 1981, 1983, 1986). In southeastern Labrador, Foster (1983, 1984, 1985) and Foster and King (1986) evaluated the fire history and the phytosociology of the forest vegetation of fire-origin black spruce stands and adjacent vegetation. Efforts to incorporate these earlier as well as more recent studies into a comprehensive ELC for all of Labrador are currently ongoing.

Autecology of major trees and shrubs

Black spruce (*Picea mariana*, Mill. B.S.P.) is the most common tree species and is found at latitudes of up to 57°N (Ryan 1978). Other softwoods include balsam fir (*Abies balsamea*, L. Mill.), found at latitudes of up to 54°N (Ryan 1978), white spruce (*Picea glauca* (Moench) Voss), found at latitudes of up to 60°N, and Eastern larch (*Larix laricina* (DuRoi) K. Koch) (Ryan 1978). Jack pine (*Pinus banksiana*) is native to just one small area of western Labrador (Roberts BA, 2005, unpublished: *The jack pine of Ashuanipi Lake area, western Labrador*, supplied to Parks & Natural Areas Division website at http://www.env.gov.nl.ca/parks/apa/panl/nl.html), but limited planting has occurred outside of this area. White birch (*Betula papyrifera* Marsh), trembling aspen (*Populus tremuloides* Michx), balsam poplar (*Populus balsamifera* L.), and showy mountain ash (*Sorbus decora* (Sarg.) Schneid) are the main hardwoods, along with 23 species of willow (*Salix* spp.), giving a total of about 150 species of shrubs and trees (Ryan 1978).

Soils

General accounts of Labrador's soil can be found in Wilton (1959, 1961, 1965), Bajzak (1973), Loupoukhine et al. (1978), Roberts (1983), Roberts and Robertson (1983, 1986), Bajzak and Roberts (1984), Wells (1996),

Table 1 Ecoregions of Labrador (parks and natural areas: Rowe 1972; forest regions: ESWG 1995) and approximate area

Ecoregion	Rowe (1972)	ESWG (1995)	Area (%)
Low Arctic Tundra–Cape Chidley	32	7	0.5
Alpine Tundra–Torngat	32	7, 77	5.8
High Subarctic Tundra–Kingurutik–Fraser	32	77	22.4
Coastal Barrens	13a	79	4.5
Mid Subarctic Forest–Michikamau (the biggest)	12	78	29.3
High Boreal Forest–Lake Melville	12	105, 81	5.8
Mid Boreal Forest–Paradise River	12	104	6.9
Low Subarctic Forest–Mecatina River	13a	31, 86, 80, 83–85	17.6
String Bog–Eagle River Plateau	31	82	6.2
Forteau Barrens	32	103	1.0

Woodrow (1995) and van Kesteren (2000). Soil fertility, moisture and drainage are the main factors involved in vegetation and habitat diversity, and the soil type (humus type, texture moisture, fertility and drainage) is the main factor that differentiates between black spruce vegetation forest types, many of which contain the same species of understory plants (Table 2). Soil texture, the presence of iron, ortstein and duric hardpans (caused by initial rapid drainage on sandy deposits), soil seepage, clay and fragipans are important soil properties that greatly influence forest type and growth properties.

Global change and human impact on vegetation

Sand dunes

Coastal and inland sand dunes are common in Labrador, especially in the Lake Melville Ecoregion (Roberts and Robertson 1981). Natural stabilization has taken place in many areas, but active blowouts occur and can be initiated through land disturbances (e.g., road building, all terrain vehicle use). *Cladonia* and *Cladina* lichens and dwarf shrubs (mainly *Vaccinium* spp. and *Rhododendron* spp.) form the understory and black spruce is the main tree species. The mainly podzolic soils often have iron, ortstein or duric hardpans, which actually increases the trafficability. Coarse woody debris provide protection from erosion and add organic matter and nutrients, which maintains sustainability.

Palsa bogs

Palsa denotes peat with an ice–peat core found in regions of sporadic permafrost (Railton and Sparling 1973). Palsas from Labrador (Roberts and Hirvonen 1980) appear to have a cyclic development, from youthful ice core hummocks to intermediate ridge palsas to mature palsa mounds. The over-mature stage of eroded or degenerating palsas, worn by erosion to different stages including complete collapse of unvegetated peat to open pools, is another feature of palsa, and all stages can occur within a complex (Zolati 1971; Roberts and Hirvonen 1980). Similar vegetation is associated with all four palsa stages; this vegetation has extremely low trafficability tolerance, and any road construction will disturb the insulating lichen layer, causing melting and collapse.

Table 2 Landscape features and forest site classification

Landscape features
1. Regional climate
2. Topography or relief
3. Landform parent material and depth
Repeating patterns—land system or ecosection with toposequence made up of land types or ecosites
Vegetation
1. Floristic composition
2. Differential species
3. Forest floor composition
4. Stand structure
Vegetation types
Soils
1. Taxonomy
2. Moisture regime, drainage
3. Texture
4. Humus type, depth
Soil type + vegetation type = forest type, e.g., Cladonia–black spruce forest, i.e., Lichen forest on well drained Orthic Humo–Ferric Podzol., Capability class 7md

Salt marshes

The headlands are mostly rugged and rocky shorelines, but there are several salt marshes in Groswater Bay between Cartwright and Makkovik of global significance (Roberts and Robertson 1983, 1986; Adam 1993). The Labrador salt marshes are grazed by migratory waterfowl and are important feeding, mating and staging areas for some 75 migratory bird species, even though their total area is probably <200 km^2. Birds and ice scouring are factors in the salt marsh structure in Panne and Sward communities, as well as intertidal mud flats and shorelines (Roberts and Robertson 1986; Adam 1993).

Forest site ecology

Prout (1977), using Landsat imagery, delineated 27 land regions containing 163 land districts under the biophysical land classification method (Lacate 1969; Bajzak 1973). The ecodistricts and ground truthing formed the basis of a descriptive report and map (Loupoukhine et al. 1978). Drieman (1993) repeated the forest zone mapping using similar techniques in order to compare with Wilton's (1965) five forest zones, and got comparable results.

Wildfires in dry black spruce forests usually ensure black spruce regeneration (Richardson 1974), but this can be greatly affected by both physical and alleopathic factors (Mallik 1987, 2003), with an Ericaceous understory depending on fire interval and intensity. *Rhododendron groenlandicum* (Oeder) Kron and Judd is usually the dominant Ericaceous shrub in dry, moist and wet black spruce types (Simon 2006). Burning temperature favors black spruce opening current and residual cones and removing the thick Ericaceous duff and understory (Mallik and Roberts 2003). However, studies in Labrador (Richardson 1974; Foster 1985; Simon and Schwab 2005a, b) speculate that charred duff that is incompletely removed by fire contributes to slow regeneration on some burned sites. Initial and dramatic improvements in root growth and more favorable pH conditions with the ashing of acidic humus to more basic conditions with burning temperature (Mallik and Roberts 1994) have been reported for burning temperatures >200 °C, with 400–600 °C found to give optimum seed bed conditions.

In forests dominated by *Cladonia* and *Cladina* lichens, five phases oflichen succession can be related to five different age fire intervals (Roberts and Mallik 1994). These lichens are associated with dry conditions and form poor seedbeds (Richardson 1974).

In many areas of Canada, black spruce forests that are clearcut often fail to regenerate adequately, so strip clearcutting (van Nostrand 1971) is widely used to promote black spruce regeneration. However, early results from Labrador report good black spruce regeneration after clearcuts (Simon and Schwab 2005b). Further, Elson and Simon (2006) report higher black spruce abundance after clearcuts and more balsam fir after strip clearcuts, although these differences largely disappeared thirty years after harvesting.

Timber productivity and forest capability

Wilton (1965), shows three major site classes, with the best site (class I) averaging a mean annual increment (MAI) of 2.52 m^3/ha/year. Class II and III sites have MAI's of 1.05 and 0.35 m^3/ha/year, respectively. Each site class occurred in five different zones: I, Excellent Forest Zone; II, Good Forest Zone; III, Fair to Marginal Forest Zone; IV, the Scrub and Unmerchantable Forest Zone; V, Arctic and Coastal Tundra. Five to eight ecological types have been described for zone I (Table 3), and were encountered in other zones, often in a lesser site class due to exposure and soil conditions. The site index (modified from Wilton 1965) for zones I–III is given in Table 3. The majority of the Excellent Forest and Good Growth Forest zones (Wilton 1965) fall into capability classes 4 and 5 (and very occasionally 3, see Tables 3, 4), with a forest capability class of 6 associated with most of the drier black spruce feather moss and fairly closed lichen forest types (fair zones of Wilton 1965). Little increase in merchantable volume occurs beyond 120 years of age (Wilton 1965; Bajzak 1973). South-facing slopes usually show a higher capability than north-facing slopes of the same landform and drainage due to more sunlight input. However, sufficient moisture availability is the key to tree growth, which appears to vary with elevation, slope, aspect, and drainage (Simon 2006).

Species richness

Gillet (1963) reviewed early botanical expeditions and lists more than 390 vascular plants from the Goose Bay Region. He notes 62 vascular species from the Mealy Mountains area (Gillet 1954) and 156 vascular plants near northern Labrador's Merewether crater (Gillet 1958). Brassard and Williams (1975) report 79 species of liverworts, while Brassard (1972), Brassard and Hancock (1975) and Brassard and Weber (1978) list 348 species of mosses. The first list of lichens from Newfoundland and Labrador (Eckfeldt 1895) enumerates 346 species and 610 species are known for Newfoundland and Labrador (Ahiti 1983). In southern Labrador, Foster (1984) reports some 77 species in white birch-, balsam fir- and black spruce-dominated forests. The history of fire-origin white birch forests (Foster and King 1986) showed regeneration from softwood to white birch on higher quality stands but depended on seed source, much like central Newfoundland (Wells and Roberts 1973; Roberts et al. 1998a). The vegetation history of southeastern Labrador based on pollen stratigraphy is reported by Lamb (1984), Engstrom and Hansen (1985), and is reviewed by Macpherson (1995).

The most comprehensive published account of Labrador's birds is that by Todd (1963), who lists 384 bird species (14% are listed as accidental) from the Carnegie Museum Expeditions which took place in Labrador between 1901 and 1954. The most accurate up-to-date estimate of terrestrial bird species in Labrador was provided by the Province's Wildlife Division, which includes published accounts and records from amateur and professional naturalists. Currently 152 terrestrial bird species occur in Labrador, and the presence of the mammals wolf, wolverine, porcupine and groundhog are examples of mainland populations that did not reach insular Newfoundland. Moose populations are not sufficient to alter forest succession as reported (Roberts and McLaren 2002; McLaren et al. 2004) in fir forest of insular Newfoundland.

Table 3 Forests of the Ashuanipi lake area, western Labrador (Wilton 1961) and site index (i.e., total heights at 50 years breast height age), for the three site classes I, II, III (Wilton 1965) in meters (m)

Forest type	Moisture regime	Site class	Site index (m)			
			Mean	Min	Max	SE
Black spruce/lichen, fire type	Very dry	III	6.4	5.2	7.9	0.37
Black spruce/feathermoss, fire type	Dry	II	9.1	7.0	11.6	0.18
Black spruce/feathermoss, fire type	Dry	II	9.1	7.0	11.6	0.18
Fir–spruce–birch/rich herb type, undisturbed type	Moist	I	12.5	9.2	14.9	0.49
Black spruce–white birch/bunchberry, fire type	Moist	I	12.5	9.2	14.9	0.49
White birch–bunchberry, fire type	Moist	I	12.5	9.2	14.9	0.49
Black spruce–balsam fir/sphagnum, undisturbed type	Wet	II	9.1	7.0	11.6	0.18
Black spruce–rhododendron, undisturbed type	Very wet	III	6.4	5.2	7.9	0.37

Table 4 The common forest types of the Goose Bay area (Roberts et al., in preparation)

Region	Landform	Drainage	Soils	Vegetation	Forest capability
A1	Lower terraces fine textured	Moderate (3)	Degraded Dystric Brunisol, Orthic Humo–Ferric Podzol	Hylocomium-bF and uncommon Dryopteris-bF & serel, w. Birch	3f
A2	Middle terraces medium textured	Good (2)	Orthic Humo–Ferric Podzol, incipient ortstein	Pleurozium-bS	5mf
A3	Middle terraces coarse textured	Good (2)	Orthic Humo–Ferric Podzol with continuous ortstein	Ledum-bS	6md
A4	Upper terrace	Rapid (1)	Minimal (Juvenile) Podzol on sand (aeolionized veneer)	Clad- Kal/Led -bS	7mf
A5	Dissected marine	Moderate (3)	Degraded Dystric Brunisol	Hylocominum-bS clays	3e
B1	Long slopes with medium textured till and colluvium	Good (2) to moderate (3) with seepage	Orthic Humo–Ferric Podzol with seepage	Clintonia-Bf	4hm
B2	Long slopes with medium textured till and colluvium	Imperfect (4) with seepage	Gleyed Humic Podzol with seepage	Sphagnum-bF	5hf
C1	Drumlinoid moraine	Good (2)	Orthic Ferro–Humic Podzol with discontinuous ortstein and fragipan	Pleurozium-bS	6md
C2	Dissected moraine	Rapid (1)	Orthic Humo Ferric Podzol with ortstein (classic iron Podzol)	Cladonia-bS	7md
C3	Drumlinoid moraine	Imperfect (4)	Gleyed Humic Podzol	Sphagnum-bS	7fw
D	Transition region: contains elements of regions C and E				
E	Exposed bedrock, solifluction slopes and peatlands, unforested	7c			

Plant–animal interactions

Schwab et al. (2001) found that three species (dark-eyed junco, white-throated sparrow and ruby-crowned kinglet) accounted for 50% of all individuals across fire-induced successional stages ranging from 2 to 35 years. In fire-disturbed systems, total bird densities and species richness follows a bimodal distribution with forest age, peaking at early and late seres. Most species are not unique to particular forest ages, but young and mature coniferous forests tend to be dominated by ruby-crowned kinglets (*Regulus calendula*), yellow-rumped warblers (*Dendroica coronata*) and boreal chickadees (*Poecile hudsonicus*). Hence, these species are associated with conifers >10 m tall for nesting and foraging substrate. Yellow-bellied flycatchers (*Empidonax flaviventris*) are most prominent in hardwood-dominated forests which are relatively rare in Labrador (Schwab et al. 2001; Simon et al. 2000, 2002a).

Early-burned forests (<40 years old) tend to be dominated by fox sparrows (*Passerella iliaca*), white-throated sparrows (*Zonotrichia leucophyrs*), white-crowned sparrows (*Zonotrichia albicollis*) and hermit thrushes (*Catharus guttatus*) (Schwab et al. 2001; Simon et al. 2003). The former three species are most associated with broad-leaved trees <2 m tall, while the latter is most associated with snags (Schwab et al. 2001, 2006; Simon et al. 2002a).

By completely removing overstory canopy, clearcutting reduces the densities of mature forest birds, e.g., yellow-rumped warblers, boreal chickadees and ruby-crowned kinglets. Yellow-rumped warbler and boreal chickadee numbers are still reduced, even when 40% of the forest canopy is retained (Simon et al. 2000). However, the increased amount of low-growing, broad-leaved trees and shrubs associated with clearcutting will increase the abundance of some species associated with young natural forest, e.g., fox sparrows, white-throated sparrows, white-crowned sparrows, Tennessee warblers (*Vermivora peregrina*) and Wilson's warblers (*Wilsonia pusilla*) (Simon et al. 2000, 2002a). While clearcuts can mimic the structure required by some birds in early-burned forests, other species (i.e., hermit thrushes and black-backed woodpeckers (*Picoides arcticus*) are absent from early clearcuts (Simon et al. 2002a). Both of these species are associated with snags and attain their highest densities in burned forests <10 years old when snag densities are highest (Schwab et al. 2001, 2006; LeCoure et al. 2000; Simon et al. 2002a). Thus, forest activity that reduces the amount of early successional forests with snags (e.g., fire suppression, commercial salvage logging, firewood harvest) will reduce the densities of these species. Dark-eyed junco (*Junco hyemalis*) is the most ubiquitous songbird species in Labrador, and with the exception of scarification, has similar densities across most fire- and logging-induced successional stages (Simon et al. 2000; Schwab et al. 2001, 2006; LeCoure et al. 2000; Simon et al. 2002a).

The boreal red-backed vole (*Clethrionomys gapperi*) and meadow vole (*Microtus pennsylvanicus*) are perhaps the most common microtines in Labrador's forested areas (Simon et al. 1998, 2002b) and have implications for marten populations, as does trapper access (Simon et al. 1999). Red-backed voles dominate later successional stages (≥30 years old), but they are most abundant in mature forests (> 130 years old) with relatively open canopies, abundant coarse woody debris and low-growing shrubs (Simon et al. 1998). Meadow voles are most common in fens, but are also present in early-burned forests (< 20 years old) along with heather voles (*Phenacomys intermedius*). Meadow voles are most associated with grasses and sedges, while heather voles are associated with coarse woody debris (Simon et al. 1998, 2002b). The increased relative abundance of trees, shrubs and coarse woody debris on young clearcut sites relative to young burned sites generally increases small mammal abundances on clearcuts (Simon et al. 2002b). While nearly absent on young burns, red-backed vole numbers are high on young clearcuts (~5 years old), then decline as coarse wood debris declines (~14 years old), but begin to increase when coniferous tree abundances increase (~30 years old) (Simon et al. 1998, 2002b). Meadow voles are also more abundant on young clearcuts than burns but only begin to decline when coniferous tree abundances increase (Simon et al. 1998, 2002b).

In a successional series consisting of clearcuts and mature forests, Newbury and Simon (2005) found that snowshoe hare (*Lepus americana*) abundances followed a unimodal relationship with forest age. They found snowshoe hare pellet abundance was 5 and 37 times greater (new and old pellets respectively) in clearcut stands 30 years old than in the next highest, 20-year-old cuts. There were few hare pellets in the remaining stand ages. They attributed this to the white birch abundance on these sites, which was the most proportionately used browse species and likely provided cover for predator avoidance and thermal protection.

Caribou (*Rangifer tarandus caribou*) is perhaps the most important wildlife species to Labrador residents. They were a primary source of clothing and continue to be a cultural symbol for aboriginals (Schmelzer et al. 2004). Caribou are currently an important source of food for most residents (Schmelzer et al. 2004) and provide income through tourism and outfitting. Both migratory and sedentary ecotypes occur within Labrador; the three recognized sedentary herds, (Lac Joseph herd, Red Wine Mountains herd and the Mealy Mountain herd) form a continuum across southern Labrador and are bounded to the north by the migratory George River herd (Schmelzer et al. 2004). Winter migration of the George River herd often overlaps with the sedentary herds, resulting in intermingling, but they habitually segregate prior to summer calving (Schmelzer et al. 2004). The migratory ecotype (George River herd), numbering 440,000 individuals (Otto and Couturier 2002), is currently the herd most used by Labradorians. The three sedentary herds have experienced significant population declines (Schaefer et al. 1999; Schmelzer et al. 2004), similar to most sedentary ecotypes across Canada (Bergerud 1988; Schaefer 2003), and are designated as being threatened by COSEWIC (2002). The reasons for the decline in Labrador sedentary caribou are uncertain. Overharvesting is believed to have contributed significantly to the decline of all three herds. Despite the ban on hunting these herds, incidental mortality occurs during legal hunting for George River caribou, where intermingling occurs, and illegal harvest remains a significant impediment to population recovery today (Schmelzer et al. 2004). Flooding for hydroelectric developments has been implicated in the decline of the Lac Joseph herd, while increased wolf numbers in response to increased moose has been implicated in the decline of the Red Wine herd (Schaefer et al. 1999; Schmelzer et al. 2004). Differences in behavior and calf survival in response to jet overflights have also been noted for Red Wine caribou (Harrington and Veitch 1991, 1992). Significant mortality has occurred, through hunting and wolf predation, when Red Wine caribou intermingle with George River caribou (Schaefer et al. 1999, 2001); this may occur in the other herds, particularly the Lac Joseph herd. Currently, the most significant threat to sedentary caribou is believed to be illegal hunting, but other proposed developments, including those related to hydroelectric, commercial forestry, highway and snowmobile trail construction have the potential to further threaten these caribou (Schmelzer et al. 2004).

Commercial cutting history

Prior to the startup of Labrador Linerboard company operations in 1969, harvesting history was sporadic and limited to small-scale enterprises, domestic use, and construction of the military base. Elsewhere in the areas of Port Hope Simpson and Cartwright, larger scale operations (Wilton 1965; Richardson 1974) were short-lived.

Labrador's forest planning now occurs at the district level (Fig. 1). The current Annual Allowable Cut (AAC) District 19A is 200,000 m^3 (Hillyard 2004). Early operations in the areas between the Churchill and Goose Rivers cut some 15,500 ha between 1970 and 1974. These cuts have regenerated to balsam fir and black spruce, with some sites having abundant white birch (Simon and Schwab 2005b). The combined AAC for Districts 20 and 21 is 75,000 m^3, with the annual area harvested ranging from 100 to 700 ha. Forests near Cartwright have seen domestic use since 1775, but only about 240 ha have been cut for commercial interests in the past ten years. In District 22, only a portion of the current AAC (13,000 m^3) is used, mainly by domestic cutters. The AAC for District 23 is 12,000 m^3, but the timber stands are widely dispersed (Hillyard 2004). From 1985 to 1989, > 1,000 ha were cut in a renewed domestic and export business. From 1990 to 2000 a further 1,800 ha were harvested. In the past five years, some 1,800 ha were cut, mainly for pulpwood to supply mills in Newfoundland.

Forest ecosystem management and recent forest management

The management of Canada's forest resources has always been important, but since the National Forest Accord of the 1980s there has been a strategic focus that has evolved into The National Forest Strategy, 2003–2008 (National Forest Strategy Coalition 2003, 2005). Aboriginal forest-based ecological knowledge (Bombay 1996) has been reported, while The First Nations Forestry Program has been active in Labrador (Innes and Moores 2003; Millar 2003).

Since 1990, there has been more focus on sustainable management, with commitments to ecosystem-based management, an open public consultation process and an adaptive management approach to concerns (Nazir and Moores 2001). Forest research is shifting from descriptive to a more adaptive management approach, identifying ecosystem management, forest practices, society's values and forest stress and change as major priorities (Moores 2002). There has been a steady improvement in both the strategic and five-year operating plans from the earliest forest ecosystem management public planning processes throughout insular Newfoundland to subsequent plans (Bajzak and Roberts 1998; Roberts et al. 1998b, c), sustainability and mode of forest cutting (Titus et al. 1997, 1998).

An ecosystem-based forest management plan for central Labrador (Forest Management District 19; FMD 19) consisting of a Forest Ecosystem Strategic Document and a five-year operating plan was produced by stakeholder partnership and public consultation in 2003 (Forest Management District 19A Planning Team 2003). One of the main partnerships was with the Innu Nation, which has created the Forest Guardian Program, which focuses on the layout and evaluation of forest operations with a focus on harvest unit size, shape, buffering, retention, erosion, and protection. Follow-up monitoring and research are other concerns that are being addressed as comanagement objectives (Forest Management District 19A Planning Team 2003). Ecological Research and Monitoring in the District 19 plan is focused on: (1) conservation of biological diversity; (2) maintenance of the productive capacity of forest ecosystems; (3) maintenance of forest ecosystem health and vitality; (4) conservation and maintenance of soil and water resources; (5) maintenance of the forest's contribution to global carbon cycles, (6) maintenance and enhancement of long-term multiple socioeconomic benefits to meet societal needs, and; (7) effective legal, institutional, and economic frameworks for forest conservation and sustainable management. In other management districts, Hillyard (2004) has outlined similar objectives and activities.

To incorporate society's social needs, forest management must plan for a suite of often competing social, economic and ecological values at large scales (Moores and Dolter 2002; Burton et al. 2003; Messier et al. 2003). Simulation modeling is a feasible tool for ascertaining complex value responses to alternative management scenarios (Messier et al. 2003). However, it is not possible for a single model to simulate all values across all scales. Hence, forest planners in Labrador have partnered with a research team that will assemble a management toolkit that will incorporate different models in a generalized framework. The toolkit will include stand- and landscape-level models to simulate forest structure, while indicator models will be linked with forest structure outputs to track indicators over time. Detailed stand structures will be simulated using SORTIE, an individual-tree model that uses four submodels: seedling recruitment, light availability, growth and mortality (Pacala et al. 1996; Coates et al. 2003). A landscape model will be constructed using SELES (spatially explicit landscape event simulator, fall and fall 2001), which is a high-level domain-specific language used to construct landscape models. Landscape models trade fine-scale detail for the ability to capture large-scale processes (e.g., fire and seed dispersal) that are beyond the capabilities of SORTIE. These models will be linked so that outputs from one model can be inputs for the other, allowing ecological processes to be scaled up or down. The future forest structure forecast by these models will be used to predict biodiversity indicators using a BAP (biodiversity assessment program) toolbox that assesses the effects of disturbance on biodiversity values at three levels: ecosystem, landscape and species (van Damme et al. 2003).

The SFM toolkit will evaluate several scenarios: natural processes only, the current management regime, enhanced timber production, and several others to be determined through stakeholder consultations. To be successful, model parameters should reflect the local ecological processes, while researchers and stakeholders must communicate to ensure important indicators and scenarios are modeled and results are understood. Ongoing research to parameterize models includes seedling recruitment, tree growth as a function of light and competition, fire cycles, gap dynamics, caribou habitat selection. Sociological research is also being conducted to evaluate stakeholder attitudes before and after modeling scenarios are presented; this will be used to guide further forest management efforts.

Parks and natural areas

There are a number of national historic sites in Labrador, which include aspects of cultural and ecological significance, including Red Bay, Battle Harbour and Hopedale or Arvertok, which highlights the transformation in the Inuit community caused by the arrival of the Moravian missionaries in 1782. Three provincial parks and ecological reserves in Labrador include (see the Parks & Natural Areas Division website at http://www.env.gov.nl.ca/parks/apa/panl/nl.html): (1) Duley Lake; (2) Grand Lake; (3) Pinware River Provincial Park. Ecological reserves in Labrador include the Gannet Islands Ecological Reserve and Redfir Lake–Kapitagas Channel Ecological Reserve (see the Parks & Natural Areas Division website). The latter, located in southwestern Labrador, conserves the only known natural stands of jack pine in the province, and the most easterly occurrence of this tree species in North America (Roberts BA, 2005, unpublished: *The jack pine of Ashuanipi Lake area, western Labrador*, supplied to Parks & Natural Areas Division website). The 3,100 km^2 Torngat Mountains National Park in northern Labrador has recently been established. An area of 21,000 km^2 in the Mealy Mountains is currently being evaluated for a new national park (Parks Canada 2005).

Conclusion

Labrador has had a long colorful history of research and development related to the forest and related environments. Considerable efforts to incorporate both traditional and Western sciences and to include stakeholder groups with different values in the planning of new developments have recently been made. The ecology of the forests and associated vegetation are related to landscape features, and include all aspects of plant–animal interactions one can expect in the Boreal to subarctic Region. A system of ecological reserves, parks and protected areas have been implemented to conserve many of the cultural and environmental features of this landscape as resources continue to be developed, and this review helps define many of the important components for further evaluation.

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