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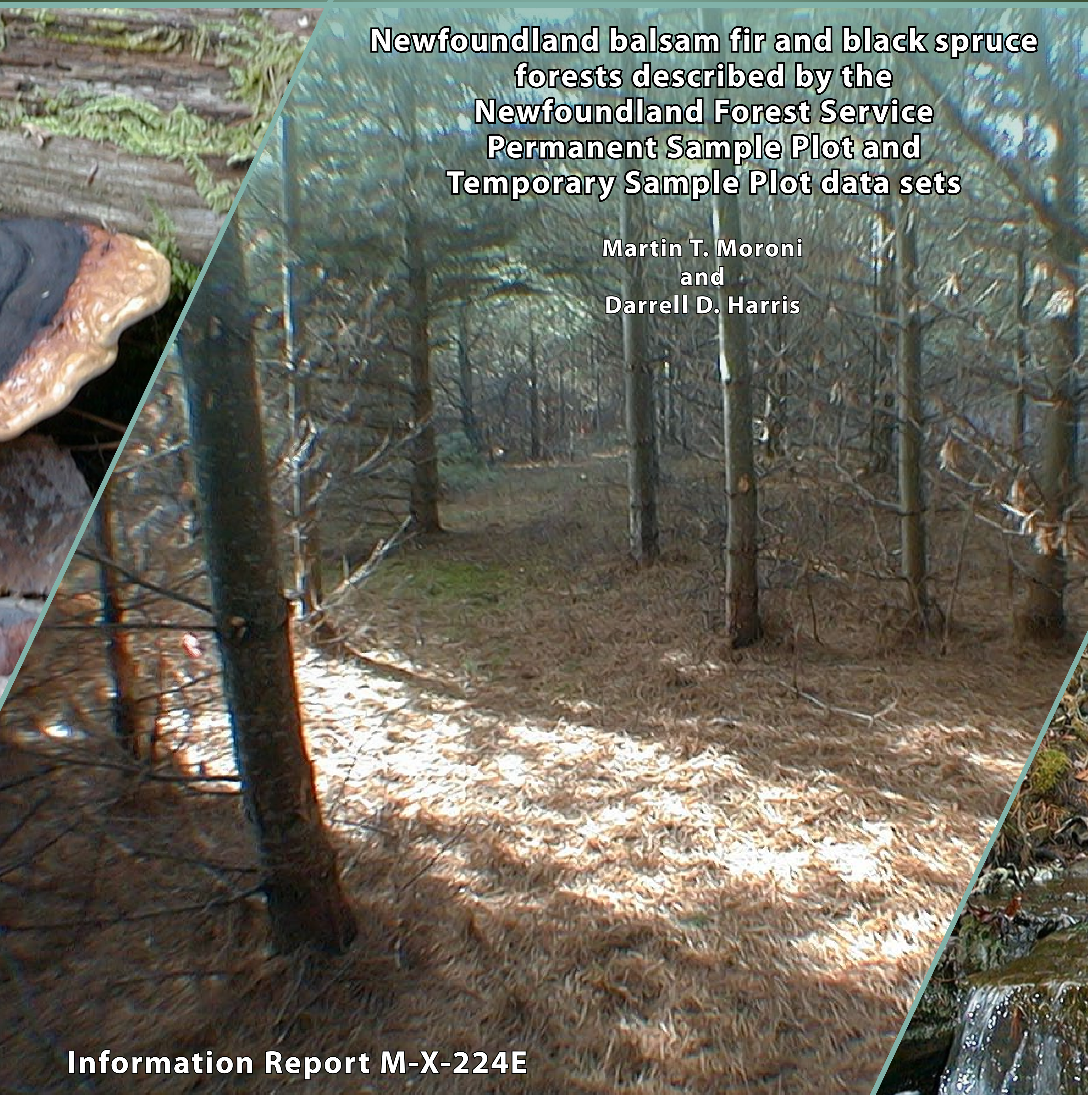

Information Report M-X-224E

Canada

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by

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Information Report M-X-224E

ISSN 1195-3799
ISBN 978-1-100-18385-5
Catalogue No. Fo103-2/224E-PDF

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Editing, design, layout by C.M. Simpson, ELS

Abstract

The Newfoundland Forest Service (NFS) has collected extensive data on the forests of Newfoundland over the past 30 years from intensive measurements of permanent (PSP) and temporary (TSP/TPS) sample plots. The NFS and the Canadian Forest Service cooperated to examine black spruce (*Picea mariana* (Mill.) B.S.P.; spruce) and balsam fir (*Abies balsamea* (L.) Mill; fir) dominated forests described by the NFS PSP and TSP/TPS data sets from the central and western regions of insular Newfoundland. Spruce forests tend to be denser (more stems/ha) than fir forests and composed of smaller diameter trees than fir. Furthermore, fir forests tend to contain higher densities of both 19–25 and >25 cm diameter-at-breast-height (dbh) trees. Although spruce density was not affected by region, the density of >9 cm dbh trees in central fir stands tended to rank higher than in western fir, but western fir forests tended to contain higher densities of larger trees (19–25, and >25 cm dbh). The PSPs were designed to calibrate and validate stand growth projection models, which predict how stand structure (diameter distributions, average stand height, density, self thinning) changes with stand development. The PSPs thus target fully stocked portions of forest stands, avoiding regions with poor growth, large numbers of non-target species, and gaps. Conversely, TSPs and TPSs were designed to sample average forest conditions to provide structural descriptions of Newfoundland's forest populations. Thus, PSPs tended to represent denser stand conditions with a greater proportion of the dominant species than TSP or TPS plots. Thus, the sampling design for the various NFS sample plots should be considered when they are used to examine variables or questions other than those they were designed to answer.

Résumé

Les mesures intensives menées depuis 30 ans par le Newfoundland Forest Service (NFS) dans les placettes d'échantillonnage permanentes (PEP) et les placettes d'échantillonnage temporaires (PET/PEPT) lui ont permis d'amasser d'abondantes données sur les forêts de Terre-Neuve. Le NFS et le Service canadien des forêts ont uni leurs efforts pour faire un examen des forêts dominées par l'épinette noire (*Picea mariana* (Mill.) B.S.P.; épinette) et le sapin baumier (*Abies balsamea* (L.) Mill; sapin) visées par les séries de données que le NFS a recueillies dans ses PEP et ses PET/PEPT du centre et de l'ouest de l'île de Terre-Neuve. Les pessières (forêts d'épinettes) sont généralement plus denses (tiges/ha) que les sapinières, et elles sont composées d'arbres de moindre diamètre. En outre, les sapinières présentaient généralement de plus grandes densités d'arbres de diamètre à hauteur de poitrine (DHP) de 19–25 cm ou de >25 cm. La densité des pessières ne variait pas selon les régions, tandis que les sapinières du centre de la province présentaient généralement une plus forte densité d'arbres de DHP >9 cm que les sapinières de l'ouest, même si celles-ci présentaient généralement une plus forte densité de gros arbres (DHP de 19–25 cm ou de >25 cm). Les PEP ont été conçues de façon à permettre l'étalonnage et la validation de modèles de projection de croissance visant à prédire l'évolution de la structure des peuplements (distribution des diamètres, hauteur moyenne du peuplement, densité, éclaircie naturelle) au fil de leur développement. Ainsi, les PEP ciblent les portions de peuplement ayant une densité relative adéquate et évitent les secteurs présentant une faible croissance, un grand nombre d'essences non ciblées et des trouées. À l'inverse, les PET et les PEPT ont été conçues en fonction de conditions forestières moyennes, pour offrir une description de la structure des populations forestières de Terre-Neuve. Ainsi, comparativement aux PET ou aux PEPT, les PEP étaient établies dans des peuplements généralement plus denses, et les essences dominantes y étaient proportionnellement plus nombreuses. C'est pourquoi le plan d'échantillonnage des diverses placettes d'échantillonnage du NFS doit être pris en compte lorsqu'on se sert de ces placettes pour examiner des variables ou des questions autres que celles pour lesquelles elles ont été conçues.

Introduction

Over the past 14 years, the Government of Newfoundland and Labrador Forest Service (NFS) has developed a valuable data set based on Permanent Sample Plots (PSP) and Temporary Sample Plots (TSP and TPS) that provide information on the boreal forests covering insular Newfoundland (hereafter Newfoundland). The NFS has used these sample plots to conduct extensive measurements of these forests for diameter, density (stems ha^{-1}), and species composition. These data are a valuable resource for land managers interested in a range of disciplines, including wildlife (Smith *et al.* 2009) and carbon cycling (Kurz *et al.* 2009).

The Newfoundland boreal forest is dominated by balsam fir (*Abies balsamea* (L.) Mill.; hereafter fir) and black spruce (*Picea mariana* (Mill.) B.S.P.; hereafter spruce) and represents the eastern extent of the Canadian Boreal Forest Region (Rowe 1972). However, these species have a much wider distribution. In Canada, fir extends its range from Newfoundland and Labrador to Alberta and is present in the northeastern states of the USA, including Minnesota, Iowa, Wisconsin, Michigan, New York, and many of the New England states. Black spruce ranges in a broad band from northern Massachusetts to northern Labrador on the Atlantic coast and west across Canada to the west coast of Alaska (Burns and Honkala 1990).

Fir is the climax tree species throughout most of Newfoundland, but its distribution is concentrated in the western portion of the island. This is largely because of the prevailing, moisture-laden, westerly winds from the Gulf of St. Lawrence that bring 1.0–1.5 m of annual precipitation to western Newfoundland, reducing the occurrence of fire (Wilton and Evans 1974). In contrast, central Newfoundland is characterized by an inland, quasi-continental climate, with warm dry summers that result in a high fire danger; regular burning has led to the establishment of extensive stands of spruce in this region (Wilton and Evans 1974).

Newfoundland is divided into four forest management regions: central, western, northern (northern peninsula), and eastern (Fig. 1). The largest regions, with the most sample plots, are the western and central regions. Although fir is most prevalent in the west and spruce most prevalent in the central region, significant amounts of both species occur in both regions; fir dominates the northern and eastern regions. In addition, diameter distributions of dead trees from PSPs are larger in western than central Newfoundland, indicating live diameter distributions are larger in western Newfoundand (Moroni and Harris 2010).

This report examines black spruce and balsam fir live-tree data sets of the NFS PSPs and TSPs/TPSs, focusing on: (1) describing diameter distributions and tree species compositions in these forests, (2) comparing diameter distribution and species composition between central and western NL to determine if these forests vary regionally, and (3) comparing black spruce and balsam fir forest diameter distributions and species compositions.

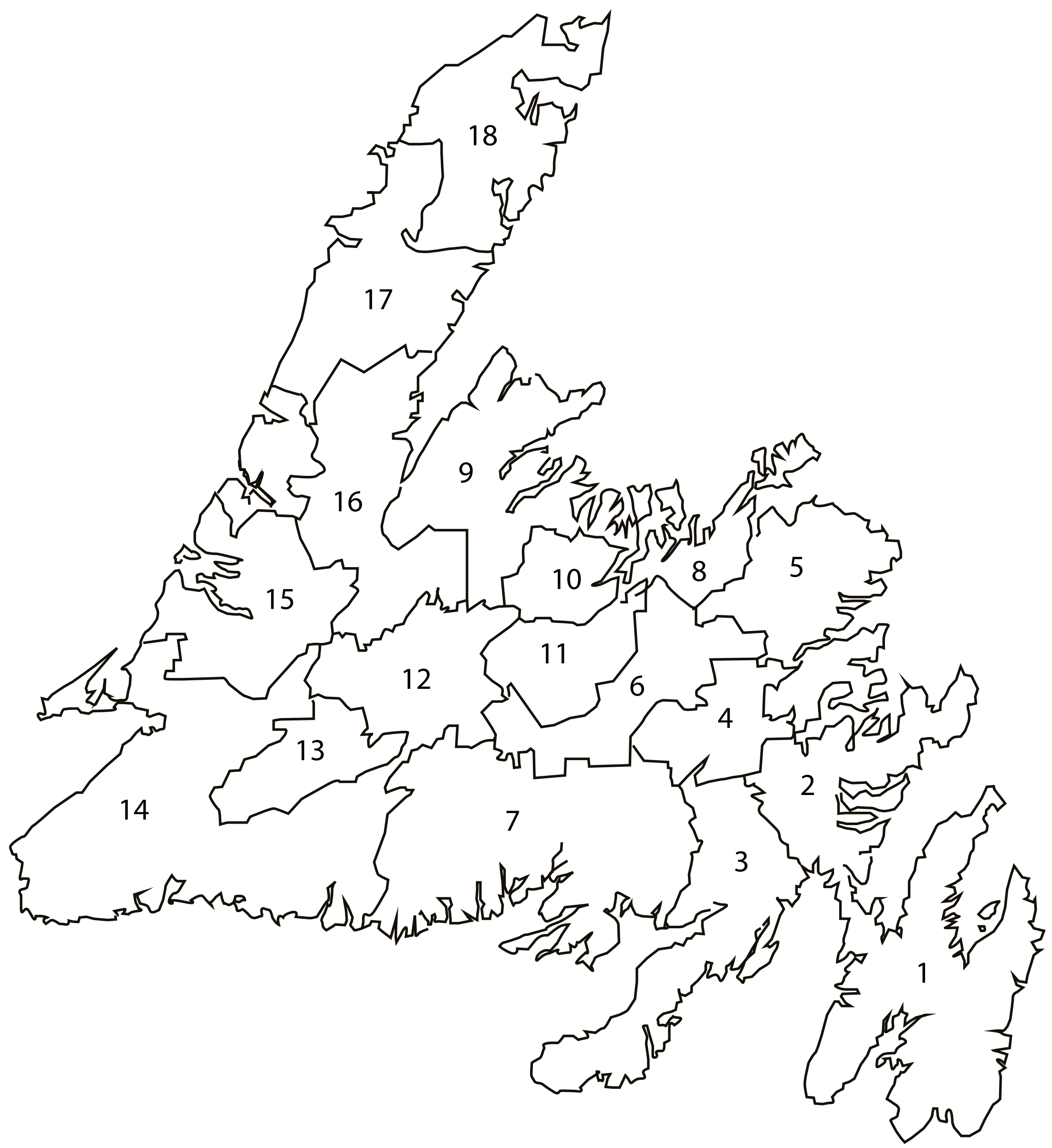

Figure 1. Locations of the Newfoundland Forest Service districts and regions. Districts are numbered 1 to 18, regions are composed of districts. The central region comprises districts 3–13, and the western region comprises districts 14–16. The eastern region is represented by districts 1 and 2, and the northern region by districts 17 and 18.

Materials and Methods

Description of Data Programs

Permanent Sample Plots

In 1985, the NFS implemented a PSP program for Newfoundland to provide growth data for calibration and validation of stand-growth projection models. The initial focus was predominently on immature stand types in natural and managed forests throughout Newfoundland. In 1992, the program was expanded to include stands in all developmental stages (i.e., regenerating, immature, semimature, mature, and overmature) with approximately 1000 PSPs currently established in natural and managed stands of all developmental stages and scheduled for remeasurement every 4–5 years. In this report, we examine stem densities in mature and older (>60-year-old) forests only.

The expanded PSP program was designed to examine the eight major softwood-producing stand types in Newfoundland. These eight major stand types were distinguished on the basis of development stage (or age class) and management status (Vanguard Forest Management Services 1992). Each stand type was ranked for sampling based on relative importance to commercial timber supply and level of financial investment. For example, precommercially thinned stands received a very high sampling priority because they contribute significantly to wood supply and have received substantial financial investment.

The allocation of plots within the eight major stand types was based on two main criteria: the sampling priority assigned to the stand type and the inherent variability within each stand type. From a list of potential PSP locations, stands were selected to ensure they were: characteristic of the targeted stand type, well distributed across ecoregion(s) (Meads and Moores 1994), and not scheduled for management treatment in the near term. Selected stands were verified by field crews, and if suitable, the field crew selected the location for plot establishment to ensure the plot would fall wholly within the targeted stand type.

Following site validation, a path was marked on a bearing from an easily located landmark to the selected stand. Permanent sample plots form a rectangle, with four corner posts labeled A–D (Fig. 2). Corner A is established in the targeted forest at the stand end of the marked path. Facing into the plot, away from the landmark in the direction of the marked path, Corner D is located 14.00 m on a bearing 90° to the right of Corner A. Corners B and C are located on the bearing of the path from Corners A and D, respectively, at a distance, or plot length, depending on the examined stand type and density. Plot length of mature and overmature stands was 28.57 m, creating 0.04-ha plots. Immature and semimature stand plot length was determined by the plot length required to tag a minimum of 75 trees that met minimum tagging criteria; however, plot size was restricted to seven standard plot sizes ranging from 0.002 to 0.1 ha. Minimum tagging criteria varied by stand development stage. For mature and overmature stands, trees with a diameter at breast height (dbh) ≥8.0 cm were tagged. The dbh of tagged trees drops with stand age until the stand contains the smallest trees considered for tagging that exceed 1.3 m in height. This variable tagging threshold was developed as a practical response to dealing with the wide variability in tree density associated with typical stand development. This report examines the density of live trees with dbh >9 cm in >60-year-old stands only.

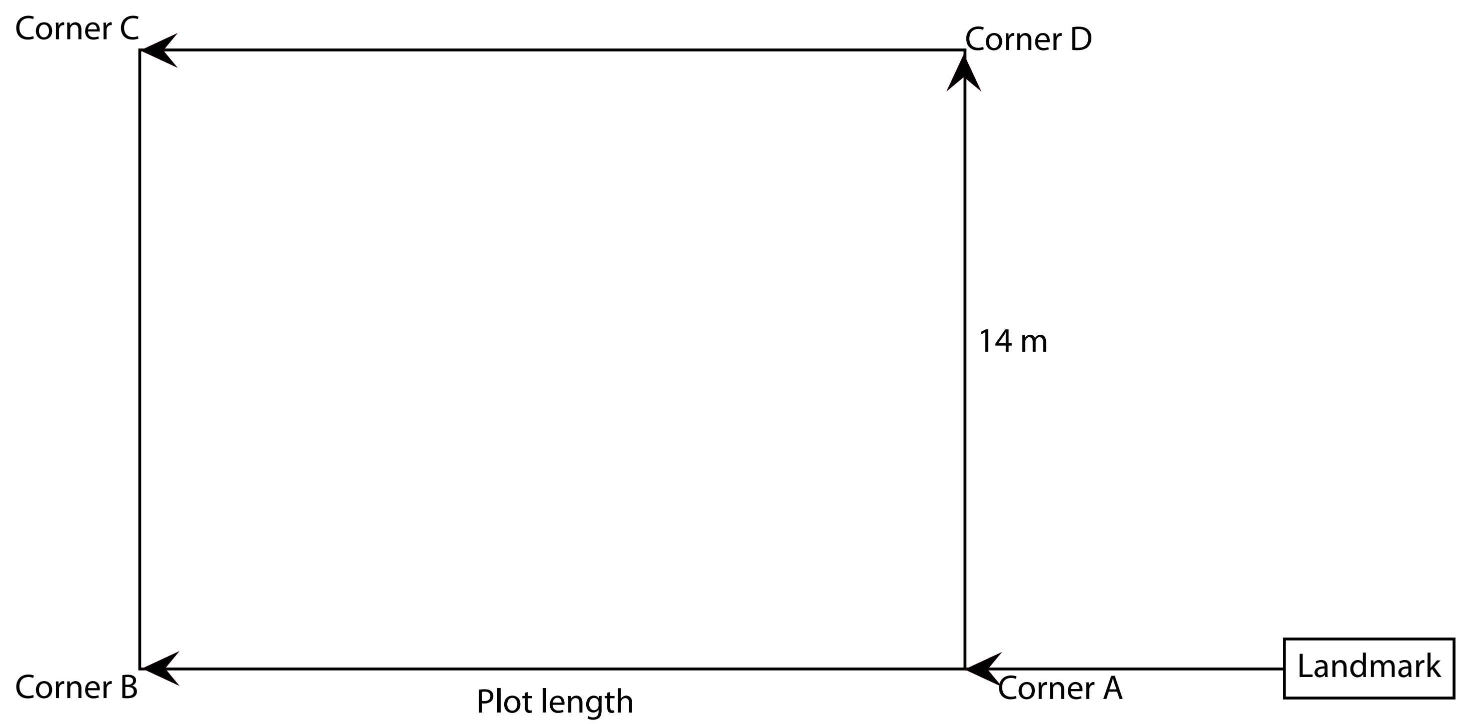

Figure 2. PSP plot layout

Temporary Sample Plots

In 1975, the NFS began implementing a temporary sample plot program to provide data to develop new timber volume estimates, and refine existing ones, on a district-by-district basis (Newfoundland and Labrador Department of Forest Resources and Agrifoods 2004b). The initial design was a single, randomly located, fixed-area plot (referred to as a TSP), which was replaced in 2001 with a line transect point sampling methodology (referred to as TPS). The new approach provided the same basic mensuration data as the original plot design but added information on individual stand conditions, expanding the utility of the temporary plots for validating growth and yield projections. By 2004, 8271 TSPs/TPSs had been measured in Newfoundland.

To determine the locations of these temporary plots, the forests of Newfoundland were stratified by observations from aerial photographs that divided the productive forest landbase on the basis of stand type, productivity class, and crown density class (Newfoundland and Labrador Department of Forest Resources and Agrifoods 2004b). The number of plots then allocated to individual strata was based on the area occupied by each stratum, commercial importance of the stratum, and the level of variability associated with the stratum. Candidate stands were selected for sampling based on accessibility (e.g., slopes <60°) while ensuring selected stands were distributed throughout the geographical range of each stratum.

To establish a TSP, a transect was marked from the randomly allocated plot center to an easily located landmark. The TSP formed a 0.02-ha square plot with four corner posts labeled A–D. Corner A was established 10 m north of the identified plot center. Corner B is located 14.14 m on a bearing of 135° from Corner A. Corner C is located 14.14 m on a bearing of 225° from Corner B. Corner D is located 14.14 m on a bearing of 315° from Corner C. The approach initiated in 2001 to establish a TPS involved the random establishment of a transverse line through the main body of targeted forest stands along which a series of sample point locations were identified and, at each sample point, individual trees were selected and measured using the Prism Plot method (Husch *et al.* 1982). Live trees with dbh >9 cm determined to be within the variable area plot (trees were determined to be in or out based on dbh and distance to standing stem center), were scored for species, dbh to the nearest cm, and total tree height (to the nearest 0.5 m). A selected number of trees are aged by increment bore (or felling and ring count). A minimum of six points to a maximum of 12 points were established in each stand. The distance between points varied depending on the size and orientation of the forest stand being measured. The data collected from all points were pooled and averaged to produce plot statistics.

For the purposes of this study, the TSP/TPS and PSP data sets were categorized into subsets to include only plots that were measured within the western and central regions, which are the largest regions with the most sample plots and with abundant sample plots of both fir and spruce. In addition, only TSP/TPSs and PSPs located in the major stand types of balsam fir or black spruce were examined. To remove variation in diameter distributions and species associated with immature stands, only sample plots supporting mature forests (>60 years average age) were examined here. PSPs and TSP/TPSs contain other data than is described here, such as dead wood in PSPs, and both record <9 cm dbh trees, but these data are not dealt with here.

Results

By far the most abundant plot type measured by the NFS that met our subset requirements was the fixed area pre-2001 TSPs, with 263–2030 plots per species and region combination (Table 1). These TSPs were relatively evenly distributed in fir-dominated stands between the central and western regions but, in spruce-dominated stands, were far more common in the central region, where spruce is the dominant forest type. The TPS plots were limited to ≤30 plots per species and region combination in all but the fir-dominated stands in the central region, which contained 144 plots (Table 1). The PSPs were dominated by fir-dominated stands in the western regions (n = 71 vs. 24 in the central region) and spruce-dominated stands in the central region (n = 116 vs. 16 in the western region; Table 1). Due to the low numbers of TPS plots, emphasis will be placed on TSP data for further discussion and comparison with the PSP data set.

Tree densities and diameter distributions (>9cm dbh only)

Densities of >9 cm dbh stems ranked PSP > TSP > TPS for all species and region combinations except for fir-dominated stands in the western region where the ranking was PSP > TPS > TSP (Table 1).

Although both TSPs and PSPs rank >9 cm dbh tree density as spruce > fir in both central and western regions, both TSPs and PSPs indicated the abundance of 19–25 cm dbh and >25cm dbh trees to be higher in fir-dominated forests than in spruce-dominated forests in both regions (Table 1). In contrast, densities of >9–19 cm dbh trees were higher in spruce-dominated forests than in fir-dominated forests for both regions.

The density of all trees with >9 cm dbh ranked higher (8%–12%) in the central region for fir-dominated forests in both TSPs and PSPs (Table 1). In addition, both TSPs and PSPs indicate the density of 19–25 cm dbh trees and >25 cm dbh trees in fir-dominated forests in the western region to be larger than in the central region. The density of 19–25 cm dbh trees in fir-dominated forests in the western region was 1.4 times densities in the central region, and the density of >25 cm dbh trees in fir-dominated forests in the western region was 1.8–3.6 times the densities in the central region. However, the density of 9–19 cm dbh trees in fir-dominated forests in the western region was 0.7–0.8 times the densities in the central region.

Although TSPs ranked >9 cm dbh tree density in spruce-dominated forests in the central region above densities in the western region, PSPs indicated the opposite ranking (Table 1). In addition, TSPs ranked the density of 19–25 cm dbh and >25cm dbh trees in spruce-dominated forests from the western region above densities in the central region, but ranked densities of 9–19 cm dbh trees in spruce-dominated forests of the western region below densities in the central region; with PSPs indicating the opposite for all dbh classes. However, the density of >25 cm dbh trees in spruce-dominated forests was low, and standard deviations of these means were large.

Standard deviations for the density of larger diameter stems (19–25 cm dbh) were large compared with the mean (Table 1). This is partially attributed to the inclusion of data from all plots, including those that did not have any larger diameter stems.

Tree species assemblages

Not surprisingly, the dominant species in all plots was the species defining the Stand Type (either fir or spruce) sampled (Table 2). However, there was a trend for PSPs to be populated with a larger proportion of stems of the dominant species. For both fir- and spruce-dominated forests, the second most abundant species recorded in the PSPs and TSPs was clearly the other softwood species, except for western NL fir PSPs, in which the abundance of white birch (*Betula papyrifera*) ranked just above black spruce. The only other species with an average >25 stems/ha were white birch in both fir- and spruce-dominated forests, and white spruce (*Picea glauca*) in fir forests. White birch abundance in fir-dominated forests was similar in the western and central regions (67–76 stems/ha), whereas white birch was more abundant in spruce-dominated forests in the central region.

Densities were low (<25 stems/ha recorded for all plot types) and standard deviation of the mean was high compared with the mean for densities of poplar (*Populus* sp.), white pine (*Pinus strobus*), trembling larch (*Larix laricina*), yellow birch (*Betula alleghaniensis*), other conifers, and other hardwoods in both fir- and black spruce-dominated forests, and white spruce (*Picea glauca*) in black spruce-dominated forests (Table 2). However, some potential trends in this data may be: yellow birch was only present in densities >0 stems/ha in the western region (9 stems/ha; Table 2). Poplar species density in spruce-dominated forests (0–12 stems/ha) ranked above densities in fir-dominated forests (0–4 stems/ha) and trembling larch densities in spruce-dominated forests (3–24 stems/ha) ranked above densities in fir-dominated forests (0–6 stems/ha). White spruce density in fir-dominated forests (8–50 stems/ha) ranked above densities in black spruce-dominated forests (1–13 stems/ha). Notably, white pine occurred in fir- and spruce-dominated forests in low abundances (≤1 stem/ha) in both the central and western regions.

Table 1. Average density of live stems per hectare by diameter range recorded for mature (>60-year-old) balsam fir and black spruce in the central and western regions of Newfoundland within PSP, TSP and TPS plots. Standard deviations in parentheses

Forest, region, and plot type	Stem diameter range (cm)				
	Number of TSPs	9–19	19–25	>25	Total >9
Balsam Fir					
Central Region					
TSP	991	119 (670)	175 (135)	60 (79)	1355 (652)
TPS	3	897 (622)	121 (78)	46 (76)	1064 (501)
PSP	24	1647 (804)	163 (117)	32 (72)	1842 (747)
Western Region					
TSP	907	907 (579)	240 (148)	107 (109)	1253 (562)
TPS	144	1127 (545)	195 (111)	61 (56)	1383 (526)
PSP	71	1193 (896)	226 (145)	116 (119)	1535 (765)
Black Spruce					
Central Region					
TSP	2030	1516 (832)	124 (136)	20 (46)	1660 (798)
TPS	25	1076 (365)	143 (83)	35 (31)	1254 (353)
PSP	116	1749 (681)	138 (139)	17 (34)	1903 (636)
Western Region					
TSP	263	1249 (725)	138 (124)	28 (50)	1415 (704)
TPS	30	1049 (458)	101 (64)	19 (19)	1169 (458)
PSP	16	2198 (1011)	94 (86)	13 (24)	2305 (942)

Table 2. Average density of live stems ha^{-1} recorded for individual species in mature (>60-year-old) balsam fir and black spruce located in the central and western regions of Newfoundland within PSP, TSP, and TPS plots. Standard deviations in parentheses.

Forest type, region, and plot type		Species										
		Balsam Fir	Black Spruce	White Spruce	White Birch	Trembling Larch	White Pine	Poplar sp.	Yellow Birch	Other Conifers	Other Hardwood	Total >9 cm
Balsam Fir												
Central												
TSP	991	960(634)	310 (376)	8 (35)	69 (106)	2 (19)	0 (5)	4 (31)	1 (15)	0 (0)	2 (17)	1355 (652)
TPS	3	659 (276	357 (298)	11 (19)	37 (55)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1064 (501)
PSP	24	1442 (790)	304 (315)	18 (47)	70 (117)	6 (26)	0 (0)	0(0)	0 (0)	n.a.	2 (10)	1842 (747)
Western												
TSP	907	966 (556)	189 (257)	27 (69)	67 (86)	2 (37)	0 (6)	0 (0)	0 (5)	0 (0)	2 (13)	1253 (562)
TPS	144	1081 (522)	172 (208)	35 (53)	78 (108)	3 (16)	0 (5)	0 (4)	9 (33)	0 (0)	4 (18)	1383 (526)
PSP	71	1330 (793)	73 (135)	50 (81)	76 (88)	0 (3)	0 (0)	0 (0)	1 (9)	n.a.	4 (20)	1535 (765)
Black Spruce												
Central												
TSP	2030	149 (256)	1421 (850)	2 (24)	49 (106)	24 (79)	1 (7)	10 (45)	0 (10)	0 (0)	4 (28)	1660 (798)
TPS	25	161 (152)	1011 (356)	1 (3)	59 (79)	4 (12)	1 (1)	12 (27)	0 (0)	0 (0)	6 (29)	1254 (353)
PSP	116	116 (201)	1733 (679)	0 (0)	34 (67)	13 (31)	1 (7)	5 (20)	0 (0)	n.a.	2 (11)	1903 (636)
Western												
TSP	263	356 (320)	1000 (773)	5 (26)	33 (60)	15 (57)	1 (10)	3 (26)	0 (0)	0 (0)	2 (14)	1415 (704)
TPS	30	378 (223)	751 (312)	9 (26)	20 (18)	3 (8)	1 (4)	0 (0)	0 (0)	0 (0)	7 (22)	1169 (458)
PSP	16	118 (245)	2048 (1072)	13 (50)	23 (41)	17 (38)	0 (0)	9 (20)	0 (0)	n.a.	6 (19)	2305 (942)

Discussion

While spruce-dominated forests tended to be denser than fir-dominated forests, the former tended to be composed of smaller diameter trees than the latter (Table 1). Fir-dominated forests tended to contain higher densities of both 19–25 and >25 cm trees, which are most valuable to wildlife (Smith et al. 2008); this confirms the finding of Moroni and Harris (2010), who reported denser 19–25 and >25 cm dead trees in fir-dominated forests than in spruce-dominated forests. However, the research of Moroni and Harris (2010) was based on PSP data, likely reporting snag abundance higher than the average abundances that would be found on the landscape because PSPs target fully stocked portions of the landscape only. Interestingly, the density of >9 cm dbh trees in fir-dominated forests in the central region tended to rank lower than densities in the western region, but fir-dominated forests in the western region tended to contain higher densities of larger trees (19–25 and >25 cm dbh); however, the standard deviations of live-tree densities were large when compared with means (Table 1). This is consistent with higher expected merchantable volumes of fir-dominated forests in the western region when compared with the central region (Meades and Moores 1994) as tree volumes are strongly positively correlated with dbh (Smith et al. 2009). Tree densities in spruce-dominated forests were not affected by region (Table 1), with relatively small differences in densities between the central and western regions for any diameter range and large standard deviations of estimated tree densities in forests from these regions.

Yellow birch is largely restricted to southwestern Newfoundland on sites growing in association with balsam fir and/or other hardwood-dominated forests on rich moist soils (Bearns 1968). Yellow birch was more common in fir-dominated forests in this study, likely because fir-dominated forests are more prevalent in western Newfoundland than are spruce-dominated forests. White pine is located throughout insular Newfoundland, except on the Great Northern Peninsula, most commonly growing with other conifers (Bearns 1968) as suggested by the data sets examined, although in low densities (Table 2). Bearns (1968) indicates that white spruce is scattered throughout Newfoundland in moist, gravelly, well-drained sites in fir- and spruce-dominated forests, but the data sets examined here ranked white spruce density in fir above spruce (Table 2). Larch tends to favor wet areas in both fir- and spruce-dominated forests (Bearns 1968), but the data sets examined ranked larch density in spruce-dominated forests above densities in fir-dominated forests. Also, although Bearns (1968) indicated poplar species occur in rich moist soils preferentially in fir forests, the data sets examined ranked poplar densities higher in spruce-dominated forests than in fir-dominated forests (Table 2).

The PSPs were designed to calibrate and validate stand-growth projection models, which predict how stand structure (diameter distributions, average stand height, density, self thinning) changes with stand development. Thus, PSPs targeted fully stocked portions of forest stands identified for plot establishment, avoiding regions with poor growth, large numbers of non-target species, and gaps. Conversely, TSPs and TPSs were designed to sample average conditions of targeted forest stands from strata that are used to characterize structural descriptions of Newfoundland's forest populations. As TPSs sample from multiple points along a transect running through the measured forest's polygon rather than one randomly located fixed-area plot, TPS plots have greater individual utility than individual TSPs. The TPS database will grow in value as it is populated with observations. It is not surprising that PSPs tended to represent denser stands with a larger proportion of the dominant species than TSP or TPS plots (Tables 1 and 2). TSP and TPS plots are more representative of average forest conditions. Lower stem densities in TPS plots compared with densities in TPS plots may be due to the limited distribution of TPS plots because of their recent implementation. Alternatively, intensive forest management may have preferentially removed denser stands from the landscape, which reduces the density measured in more recently established TPSs compared with longer established TSPs.

The Newfoundland Forest Service has collected extensive data on the forests of Newfoundland in the past 20 years from intensive measurements of permanent and temporary sample plots. The permanent and temporary sample plot programs differ in their objectives and sampling methodologies, with PSPs located in fully stocked regions of selected stands avoiding stand openings and TSP/TPSs designed to be more representative of average forest conditions. Therefore, it was not unexpected that all live and dead biomass measurements in PSPs were greater than for similar measurements in TSPs. In addition, individual TSPs may not represent the average conditions of the individual stand in which they are measured because a TSP is measured in a single random location within a targeted forest polygon, thus average forest conditions require data from multiple TSPs. Thus, the nature of the various Newfoundland Forest Service sample plot data sets should be considered when they are used to examine variables or questions other than those they were designed to answer.

Acknowledgments

Thanks to the Newfoundland and Labrador Department of Natural Resources for the use of their permanent and temporary sample plot data, especially Chris Cohlmeyer for help and advice with the procedures and data issues.

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