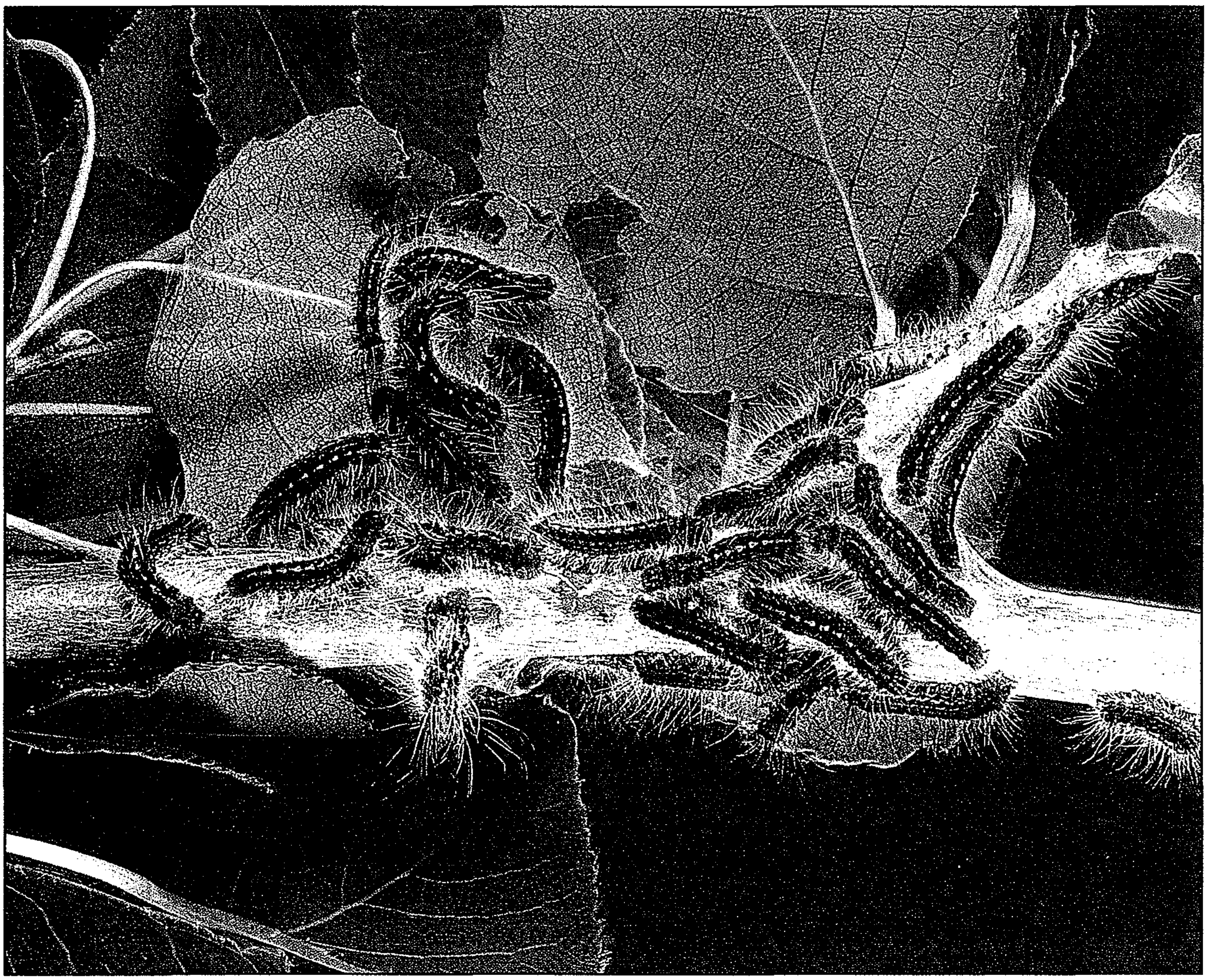
Forest insect- and disease-caused depletions to forests of west-central Canada: 1982-87

J.P. Brandt and P. Amirault

Northwest Region • Information Report NOR-X-333



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Cover photo:

Feeding forest tent caterpillar (*Malacosoma disstria* Hübner) larvae.

FOREST INSECT- AND DISEASE-CAUSED DEPLETIONS TO FORESTS OF WEST-CENTRAL CANADA: 1982–87

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ABSTRACT

Major forest insect- and disease-caused depletions to the forest resources of Alberta, Saskatchewan, Manitoba, and the Northwest Territories were determined as 3 765 000 m^3/year between 1982 and 1987. A set of depletion rules were constructed for the major forest pests of the prairie provinces and were used to create depletion estimates. Significant depletions were caused by spruce budworm (*Choristoneura fumiferana* [Clem.]), jack pine budworm (*C. pinus pinus* Free.), forest tent caterpillar (*Malacosoma disstria* Hbn.), mountain pine beetle (*Dendroctonus ponderosae* Hopk.), spruce beetle (*D. rufipennis* [Kby.]), and wood decay. Depletion estimates were not determined for dwarf mistletoe, pests of young stands, and fungi such as needle casts of conifers, stem rusts of conifers, and cankers of conifers and hardwoods. The impact of Dutch elm disease on commercial forests was negligible. Spruce budworm defoliation resulted in 1900 m^3/year of volume loss due to growth reduction and 9900 m^3/year due to mortality. Jack pine budworm caused volume losses of 80 600 m^3/year in growth reduction and 425 700 m^3/year in mortality. Forest tent caterpillar defoliation caused 1 801 400 m^3/year in growth reduction; with the depletion estimates used, there was no mortality associated with forest tent caterpillar. Volume depletions for mountain pine beetle and spruce beetle were 64 400 m^3/year and 7900 m^3/year, respectively. Wood decay volume loss was 1 373 200 m^3/year.

RESUMÉ

Les insectes et les maladies causent des dommages énormes aux ressources forestières de l'Alberta, de la Saskatchewan, du Manitoba et des Territoires du Nord-Ouest. Les pertes ont été estimées à 3 765 000 m^3 par année pour la période de 1982 à 1987. Des formules ont été établies pour le calcul des pertes attribuables aux principaux ravageurs forestiers des provinces des Prairies; elles ont été utilisées pour estimer ces pertes. La tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* [Clem.]), la tordeuse du pin gris (*C. pinus pinus* Free.), la livrée des forêts (*Malacosoma disstria* Hbn.), le dendroctone du pin ponderosa (*Dendroctonus ponderosae* Hopk.), le dendroctone de l'épinette (*Dendroctonus rufipennis* [Kby.]) et la carie du bois ont causé des pertes importantes. La maladie hollandaise de l'orme, par contre, a eu un impact négligeable dans les forêts commerciales. Par ailleurs, les pertes dues au faux-gui, aux ravageurs des jeunes plantations et aux maladies fongiques, comme les rouilles de la tige, les rouges et les chancres chez les conifères et les chancres chez les feuillus, n'ont pas été estimées. De façon plus précise, les défoliations par la tordeuse des bourgeons de l'épinette et la tordeuse du pin gris ont causé des pertes annuelles en volume estimées à 1 900 et 80 600 m^3 respectivement pour la réduction de la croissance et à 9 900 et 425 700 m^3 pour la mortalité. Dans le cas de la livrée des forêts, le volume perdu annuellement serait de 1 801 400 m^3 au niveau de la croissance seulement; cet insecte n'aurait pas causé de mortalité. Pour ce qui concerne le dendroctone du pin ponderosa et le dendroctone de l'épinette, les pertes en volume leur étant attribuables ont été estimées à 64 400 et 7 900 m^3/an respectivement. Enfin, pour les caries du bois, le volume perdu serait de 1 373 200 m^3/an.

CONTENTS

FIGURES

TABLES

Note

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Natural Resources Canada.

INTRODUCTION

This report describes the impact of major forest insects and diseases on commercial forests of Alberta, Saskatchewan, Manitoba, and the Northwest Territories in terms of tree mortality and reduction in tree growth for the period 1982 to 1987. The depletion estimates reported are estimates of insect- and diseased-caused losses. Forest managers will be able to use this information to assist them in their decisions concerning the management and allocation of timber resources.

Commercial forests in the study area are made up of different species found in pure stands or in various mixed stands. In Alberta, tree species found in commercial forests are lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), jack pine (*P. banksiana* Lamb.), white spruce (*Picea glauca* [Moench] Voss), Engelmann spruce (*P. engelmannii* Parry), black spruce (*P. mariana* [Mill.] B.S.P.), balsam fir (*Abies balsamea* [L.] Mill.), alpine fir (*A. lasiocarpa* [Hook.] Nutt.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), tamarack (*Larix laricina* [Du Roi] K. Koch), trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), and white birch (*Betula papyrifera* Marsh.). In Saskatchewan, tree species found in commercial forests are the same as those of Alberta except for Engelmann spruce, Douglas-fir, and alpine fir, which are not found in this province. In Manitoba, tree species are similar to Saskatchewan with the exception that red pine (*Pinus resinosa* Ait.) and eastern white cedar (*Thuja occidentalis* L.) are present. White spruce is the only commercial tree species in the Northwest Territories that is utilized to any extent (Bohning 1986).

Many insect and disease pests have been excluded from this depletion exercise. These pests have been excluded because limited data are available on their impact on the forests within the study area. Pests that fall into this category include pests of young stands and many fungi such as needle casts of conifers, stem rusts of conifers, and cankers of conifers and hardwoods. Dutch elm disease is a serious pest of native and planted elm trees in Manitoba and Saskatchewan, but the impact of this pest on commercial forests is negligible because it attacks elm located in noncommercial forested areas such as shelterbelts, riparian forests, and urban forests. Dwarf mistletoe has also been excluded from this report. The Forest Protection branch of Manitoba Natural Resources completed a study on the impact of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) on jack pine forests of Manitoba (Slivitzky et al. 1991). That study indicated that out of 140 000 ha surveyed by aircraft, 12 000 ha or 9% of the area was infested. The authors concluded that dwarf mistletoe had a large impact on stand productivity in the areas surveyed and that volume losses were as high as 20% of the net operable volume in one forest management unit. Net operable volume is defined as the volume of operable stands that contains a minimum of $\geq 55\ m^3/ha$ in mature or overmature stands.

In this report, the determination of insect-caused depletion estimates have been limited to significant insect pests. Three defoliators are included, with two species found on conifers: spruce budworm (*Choristoneura fumiferana* [Clem.]), and jack pine budworm (*C. pinus pinus* Free.), and one species found on hardwoods: forest tent caterpillar (*Malacosoma disstria* Hbn.). Two bark beetle species cause significant damage to commercial forests in the study area: mountain pine beetle (*Dendroctonus ponderosae* Hopk.), and spruce beetle (*D. rufipennis* [Kby.]). Mountain pine beetle attacks lodgepole pine, primarily in forests along the mountains of western Alberta. Spruce beetle attacks Engelmann and white spruce and is found throughout the study area.

The calculation of disease-caused depletion estimates has also been limited to a number of significant diseases. These diseases have been broadly classified as wood decay. Wood decay can be further broken into categories of root rots and trunk rots. On coniferous species in this area, root rots such as *Inonotus tomentosus* (Fr.) Gilbertson, *Pholiota alnicola* (Fr.) Sing., *Armillaria* spp., *Scytinostroma galactinum* (Fr.) Donk, and *Coniophora puteana* (Schum.:Fr.) Karst. are considered important, as are the trunk rots *Phellinus pini* (Thore:Fr.) Pil., and *Haematostereum sanguinolentum* (Alb. & Schw.:Fr.) Pouzar. On hardwood species, the *Armillaria* spp. and *Pholiota spectabilis* (Fr.:Fr.) A.H. Sm. (≡*Gymnopilus spectabilis* [Fr.] Sing.) are notable root rots. Important trunk rots include *Phellinus tremulae* (Bond.) Bond. & Boriss., *Radulodon americanus* Ryv., *Pholiota destruens* (Brond.) Quel., and *Peniophora polygonia* (Pers.:Fr.) Boud.

The process of calculating depletion in an area as large as this study area is complicated because several jurisdictions are involved. Depending on the province, forest inventory is summarized by either forest and lead species (Alberta), physiographic areas (C-zones) and growth types (Saskatchewan), or species and diameter class (Manitoba). Forest inventory work is ongoing in the Northwest Territories. Assessing impacts of pests and associated depletions on forests will become easier as forest inventory coverages and techniques improve.

METHODS

Inventory

Forest inventory data utilized in the calculation of the 1982–87 depletion estimates for spruce budworm, jack pine budworm, and forest tent caterpillar were from the Canadian Forest Resource Data System (CFRDS). These data exist as part of the national inventory at the Petawawa National Forestry Institute (PNFI) in Chalk River, Ontario. The inventory used for this depletion exercise was last updated in 1986 (Forestry Canada 1989), and Gray and Nietmann (1989) provide a thorough description of this inventory. Inventory data used for depletion estimates of wood decay were from each of the three prairie provinces' provincial inventories. Table 1 gives gross merchantable volume by predominant tree genus and province. Power and D'Eon (1991) give a complete description of CFRDS as it relates to the depletion exercise described in this report. There are three important classifiers used in the CFRDS inventory: maturity, forest type, and predominant genus. Maturity is a qualitative expression of stand development based on stand age or management decisions. Forest type describes whether a stand is softwood, mixed wood, or hardwood. Predominant genus is used to describe the most prevalent genus within the cover type.

Growth data applied to the CFRDS inventory were from Bickerstaff et al. (1981). These data were used in the calculation of depletion estimates for

Table 1. Gross merchantable volume from inventoried, stocked, productive, nonreserved forest land by province as of 1986 ('000 000 m^3)

Predominant genus or species	Alberta	Saskatchewan	Manitoba	Total
Spruce	920	205	264	1389
Pine	695	130	158	983
Fir	47	13	10	70
Cedar and other conifers	–[a]	–	1	1
Douglas-fir	2	–	–	2
Larch	3	4	10	17
Unspecified conifers	16	184	–	200
Total coniferous	1683	536	443	2662
Aspen/poplar	822	289	201	1312
Birch	33	22	20	75
Maple	–	1	–	1
Unspecified deciduous	117	58	15	190
Total deciduous	972	370	236	1578
Total	2655	906	679	4240

Source: Modified from Forestry Canada (1989).

[a] No significant value.

spruce budworm, jack pine budworm, and forest tent caterpillar.

In Alberta the most recent inventory was the Phase 3 Inventory from Alberta Forestry, Lands and Wildlife (1985). Forest inventory information was summarized by each of the ten administrative forests (Fig. 1) and lead species. There are five lead species: white spruce, black spruce, pine, total coniferous, and total deciduous. The total area and volume of individual stands fall into one of the lead species categories depending on the first species listed in the cover type designation. Total coniferous includes stands dominated by other conifers: balsam fir, Douglas-fir, and larch (*Larix* spp.). Total deciduous includes trembling aspen, balsam poplar, and white birch. Pine stands are dominated by either lodgepole or jack pine and white spruce stands by white or Engelmann spruce. Data from the Phase 3 Inventory are within 10% of the values generated by the national CFRDS inventory (compare Tables 1 and 2).

In Saskatchewan there are eight administrative regions. In terms of forest inventory subdivisions, the province is divided into fourteen distinct areas, each referred to as a timber supply area with growth data grouped by eight physiographic areas called C-zones. Stands are classified and forest inventory is compiled by growth types. Growth types include white spruce, black spruce, jack pine, pine–spruce, pine–aspen, tamarack, aspen, balsam poplar, white birch, and other hardwoods. Provincial inventory data are not included in this report because they are not readily comparable to the CFRDS inventory.

Manitoba has ten forest sections. Forest inventory is summarized by section, species, and diameter class. Table 3 summarizes gross merchantable volume by section and tree species for

Figure 1. Forest districts and regional boundaries of the three prairie provinces and the Northwest Territories.

Table 2. **Volume distribution by forest and species for Alberta from the Phase 3 Inventory completed in 1984 ('000 m^3)**

Forest	White spruce	Black spruce	Pine	Total coniferous[a]	Total deciduous	Total
Athabasca	42 391	12 782	46 570	106 468	68 854	175 322
Bow–Crow	32 869	3 519	73 589	119 091	12 241	131 332
Edson	54 391	18 977	146 594	233 303	40 259	273 562
Footner	146 187	13 538	16 326	182 571	135 521	318 092
Grande Prairie	84 124	12 364	78 503	185 382	166 625	352 007
Lac La Biche	44 503	13 061	24 203	86 017	83 336	169 353
Peace River	113 938	16 317	49 348	187 596	234 611	422 207
Rocky–Clearwater	43 645	9 996	100 977	161 303	34 485	195 788
Slave Lake	147 832	24 305	50 142	233 867	224 180	458 047
Whitecourt	62 509	26 813	86 574	185 342	87 072	272 414
Total	772 389	151 672	672 826	1 680 940	1 087 184	2 768 124

Source: Alberta Forestry, Lands and Wildlife (1985).

[a] Includes other coniferous species: balsam fir, Douglas-fir, and larch.

Manitoba. Species used to group volumes are jack pine, black spruce, white spruce, balsam fir, tamarack, eastern white cedar, trembling aspen, balsam poplar, white birch, and other hardwoods. As with Alberta, gross merchantable volume from Manitoba's forest inventory is comparable to the national CFRDS inventory (compare Tables 1 and 3).

The forests of the Northwest Territories have been divided into seven forest sections, three of which support forests of commercial significance: Upper Liard, Hay River, and Upper Mackenzie (Bohning 1986). Forest inventory work is ongoing. White spruce is the only commercial tree species in the Northwest Territories (Table 4) but jack and lodgepole pine, black spruce, trembling aspen and balsam poplar are also present.

Calculation of Depletion Estimates for Major Defoliators

Pest-caused depletion estimates of most major forest pests are calculated at PNFI using an automated system based on geographic-information-systems-produced defoliation maps from each of the federal forest regions across Canada and corresponding inventory data. For this report, defoliation maps were submitted to PNFI for spruce budworm, jack pine budworm, and forest tent caterpillar. The process used in calculating these depletion estimates involved a number of steps. The first step was to map defoliation caused by each of the insects. Maps were digitized for each year in which defoliation occurred and were combined to create a composite of all years (Figs. 2, 3, 4).

Table 4. **Wood volume estimates of white spruce in the Northwest Territories**

Forest Management Unit (FMU) or district	Area (ha)	Volume[a] ('000 m^3)
Hay FMU	1 392 125	317
Lower Liard FMU, survey area only	706 293	7 967
Mackenzie River Valley, southern section	3 048 430	11 347
Mackenzie River Valley, central section	1 851 850	2 098
Mackenzie River Valley, northern section	4 364 150	1 673
Slave FMU	943 019	566
Total	12 305 867	23 968

Source: Bohning (1986).

[a] Volumes based on white spruce with minimum height of 18.3 m and minimum DBH of 25.4 cm.

Table 3. Gross merchantable volume of forests in Manitoba by tree species and section in 1986 ('000 m^3)

Tree species	Mountain	Pineland	Lake Winnipeg East	Interlake	Saskatchewan River	Highrock	Churchill River	Nelson River	Hayes River	Total
Jack pine	7 423	4 152	38 950	10 124	15 095	22 610	5 614	15 878	40 991	160 837
Black spruce	19 652	7 712	25 941	12 562	15 426	48 695	9 269	43 677	46 972	229 906
White spruce	19 290	665	4 205	4 177	4 694	7 419	72	5 873	2 407	48 802
Balsam fir	2 141	730	2 665	2 846	312	435	–[b]	787	1 463	11 379
Tamarack larch	1 580	2 580	3 037	1 468	615	194	24	223	148	9 869
Eastern white cedar	2	676	12	17	–	–	–	–	–	707
Total softwood	50 088	16 515	74 810	31 194	36 142	79 353	14 979	66 438	91 981	461 500
Trembling aspen	63 750	10 279	27 814	28 056	7 303	18 259	409	15 137	14 373	185 380
Balsam poplar	17 243	2 351	1 198	3 145	1 896	1 551	35	1 746	1 770	30 935
White birch	5 385	1 168	2 641	2 393	1 162	2 812	708	2 108	3 587	21 964
Other deciduous	1 984	416	207	435	364	–	–	–	–	3 406
Total hardwoods	88 362	14 214	31 860	34 029	10 725	22 622	1 152	18 991	19 730	241 685
Total	138 450	30 729	106 670	65 223	46 867	101 975	16 131	85 429	111 711	703 185

Source: Personal communication, Bob Lamont, Forestry Branch, Manitoba Natural Resources, 1986 data provided in 1990 in a letter to the author.

[a] No significant value.

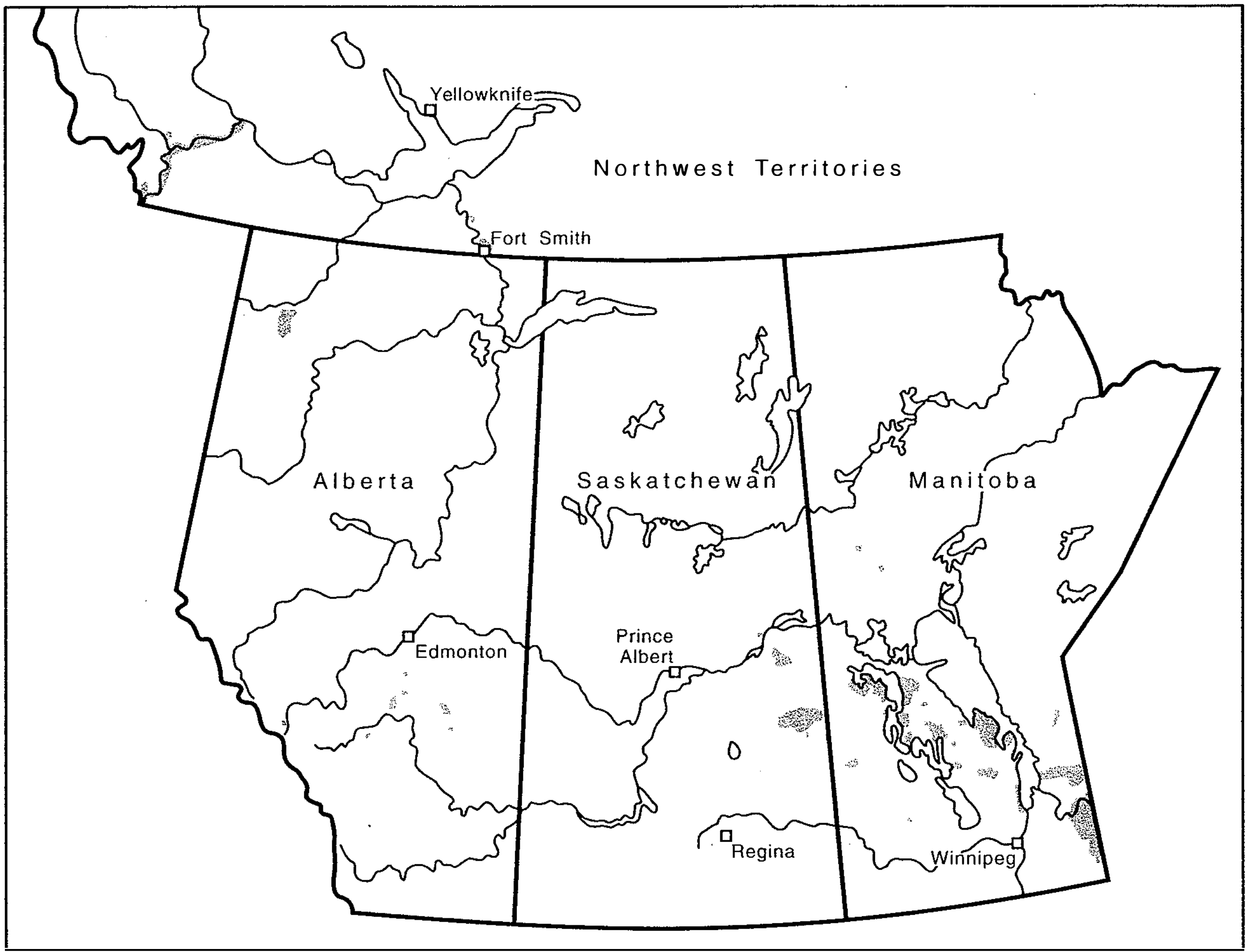

Figure 2. Moderate-to-severe defoliation by spruce budworm, 1982–87.

Defoliation sequences were then generated for every defoliation polygon using the defoliation maps. Once sequences were assigned to defoliation polygons, a list of all defoliation sequences were compiled for each pest. Defoliation sequences are vectors containing elements, each corresponding to a single year's defoliation and representing defoliation severity. Defoliation severity was coded using numbers from zero to six representing no, light, light-to-moderate, moderate, moderate-to-severe, and severe defoliation, respectively. Defoliation polygons are polygons generated by digitizing defoliation maps. Defoliation sequences are assigned to defoliation polygons to describe each polygon's unique defoliation history.

Impact class codes were manually assigned to the defoliation sequences and the depletion factors were determined for growth loss and mortality factors for mortality due to defoliation. Impact classes are defined by Power and D'Eon (1991) as a series of levels that categorize the effect that pest activity has on its host. Impact classes describe sequences of defoliation that impact the host, both in terms of volume loss due to growth reduction and volume loss due to mortality. Within each impact class, there can be a number of different combinations of defoliation sequences within a period of time. Impact class assignment is dependent on each pest but independent of stand characteristics and regions. When calculating depletion estimates, the same impact classes are utilized for growth loss and mortality. Depletion factors are the percentage of volume loss experienced by the host depending on the impact (impact class) the pest has on the host. These are specific to each impact class. Depletion factors are estimated individually for different pests and may vary by region. Often experience and research are used to determine the best approximation of current volume loss due to pest activity.

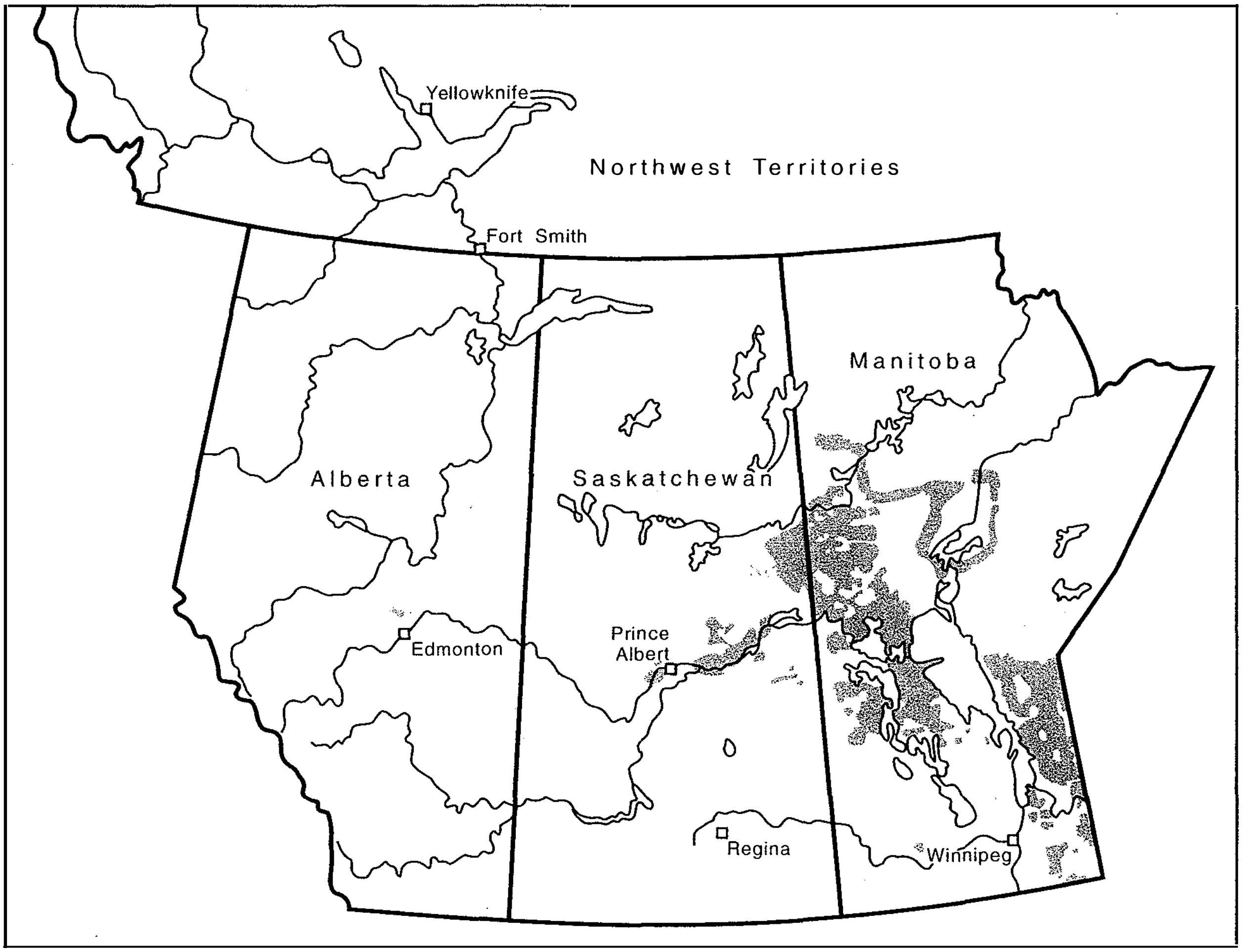

Figure 3. Moderate-to-severe defoliation by jack pine budworm, 1982–87.

Impact class codes were assigned according to a set of rules, each specific to an impact class. For spruce budworm there were six impact classes and for jack pine budworm and forest tent caterpillar there were seven. Depletion and mortality factors were determined for all three major defoliators by reviewing relevant literature as well as consulting experts.

The next step required the assignment of the eligible volume from each CFRDS inventory cell defoliated (as indicated by the defoliation maps) according to an algorithm. The algorithm was based on a number of rules related to the percentage of the cell that was defoliated, the percentage of the cell that contained the host tree species, and the volume of the host. The eligible volume from each defoliated cell was then depleted using its associated sequence, impact class code, and depletion and mortality factor. Further discussion on the entire process of quantifying pest-caused forest depletion estimates is given by Power and D'Eon (1991).

Defoliators

Spruce Budworm

The host rules[1] for spruce budworm in this study were submitted in the following manner. In Alberta and Saskatchewan, immature stands of

[1] Host rules define the relationship between the pest, host tree, and the forest stand as a whole (e.g., a pest preference for immature versus mature forests). Host rules can be specific to regions, provinces, and forest types. A complete description of host rules is given by Power and D'Eon (1991).

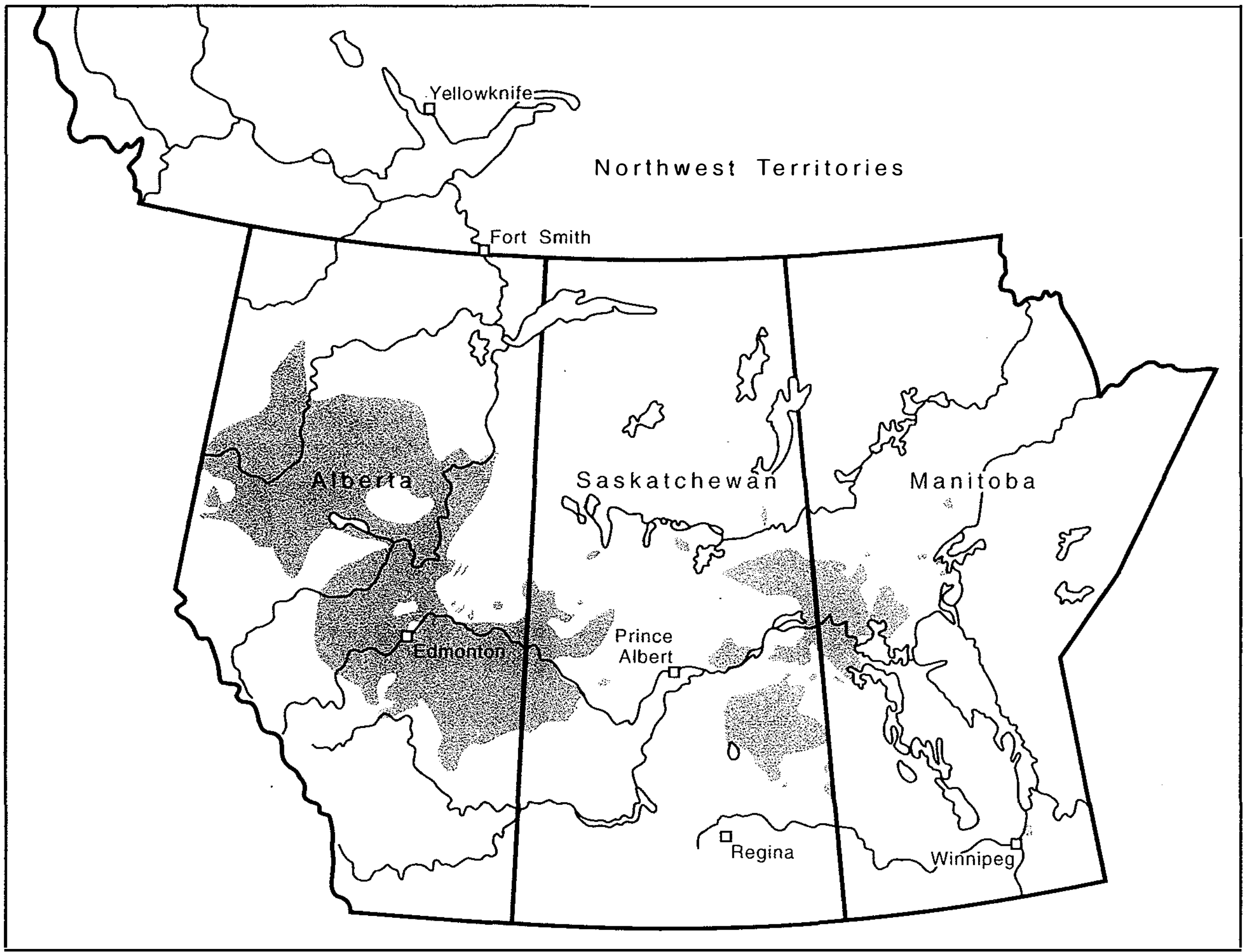

Figure 4. Areas of aspen defoliated predominantly by forest tent caterpillar, 1982–87.

white spruce and balsam fir were considered susceptible to outbreaks of spruce budworm but they were not as frequently or as severely attacked as mature stands of these species. Black spruce was not considered a susceptible species and consequently forests of black spruce were excluded from the depletion calculations in Alberta and Saskatchewan. Volume depleted due to balsam fir defoliation was included in depletion estimates but only had a limited effect because extensive areas of balsam fir are not present in this region (fir volume represents 4.3% of the total spruce–fir volume in Alberta and Saskatchewan).

In Manitoba, the host rules applied to the depletion estimates were those used by Gross (1985) for Ontario and included white spruce and balsam fir, and black spruce where it grew in association with other host species (i.e., pure black spruce stands were excluded). White spruce and balsam fir were also included where they grew in association with nonhost species if they comprised more than 10% of the stand.

The impact classes and depletion factors are listed in Table 5. Annual growth loss (%) for various impact classes differ from those used by Gross. Gross's values for growth loss were developed from Kulman (1971) and appear too high for this study area for the first 1–3 years of defoliation. For 4–7 years of defoliation, Gross and Kulman underestimated the growth loss for this region. Growth loss percentages were derived and are shown in Table 5 for white spruce and balsam fir. Annual growth loss is the expected growth loss for trees defoliated in a given year. For all maturity classes (immature, mature, and overmature) of both softwood and mixed-wood white spruce stands defoliated by spruce budworm, the depletion factors (%) by impact class were A, 1; B, 4; C, 11; D, 20; and E, 32%. For all maturity classes of both softwood and mixed-wood balsam fir stands defoliated by spruce

Table 5. **Rules used to assign stands to impact classes and their associated growth losses for spruce budworm defoliation**

Rule	Impact class	Annual growth loss expected (%)	
		White spruce	Balsam fir
Less than 2 consecutive years of moderate-to-severe defoliation	0	0	0
Two consecutive years or 3 out of 4 years of moderate-to-severe defoliation, with at least 1 year occurring between 1982 and 1987	A	5	15
Four out of 5 years of moderate-to-severe defoliation, with at least 2 years occurring between 1982 and 1987	B	20	30
Five out of 6 years of moderate-to-severe defoliation, with at least 2 years occurring between 1982 and 1987	C	40	60
Six out of 8 years of moderate-to-severe defoliation, with at least 3 years occurring between 1982 and 1987	D	55	80
Seven out of 10 years of moderate-to-severe defoliation, with at least 3 years occurring between 1982 and 1987	E	70	90

Source: Personal communication, Dr. Herb Cerezke, Forestry Canada, Edmonton, Alberta, January 1993, conversation with the author.

budworm, the depletion factors (%) by impact class were A, 3; B, 8; C, 18; D, 31; and E, 46%. White spruce and balsam fir depletion factors were calculated by summing annual growth loss for each impact class and dividing it by six (the number of years in the study period). The depletion factor for each impact class represents the annual expected growth loss for any year in the study period. For a forest to be assigned to an impact class, it is assumed that it has first experienced all lower impact classes.

Cumulative mortality (%) of white spruce was determined for the study area based on work done by Cerezke (1978) in Manitoba. No mortality occurred in white spruce and balsam fir in impact classes O, A, and B. In impact class C, no mortality occurred in white spruce and 8% mortality occurred in balsam fir. The percentages of cumulative mortality in stands assigned to impact class D were 10 and 20% for white spruce and balsam fir, respectively. The percentages of mortality assigned to impact class E were 25 and 45% for white spruce and balsam fir, respectively. These mortality factors are similar to those of Stevenson (1970) for Alberta, but slightly lower than those reported in other areas of Canada (Elliot 1960; Howse et al. 1980). White spruce mortality usually begins after 6–7 consecutive years of moderate-to-severe defoliation (impact class D) and ranges from 10 to 25%.

Cumulative mortality (%) of balsam fir was determined for the study area based on work by Elliot (1960), Hildahl and DeBoo (1975), Howse et al. (1980), and Batzer (1973). Balsam fir mortality usually begins after only 4 consecutive years of moderate-to-severe defoliation (impact class C) and ranges from 8 to 45%. Mortality for 4–6 years of defoliation closely matched the mortality in the previously cited studies. For 7–8 years of defoliation, our estimates of mortality were conservative compared to other cited studies.

In the Northwest Territories, growth loss caused by spruce budworm was treated somewhat differently than other defoliation and defoliation-caused mortality in the prairie provinces. The CFRDS inventory does not extend into the Northwest Territories and therefore could not be used. Defoliation maps for the period 1982–87 were overlain to determine areas in each impact class. Expected growth was determined as the product of defoliated area and mean annual increment

(0.8 m^3/ha from Bickerstaff et al. [1981]). Depletion factors were then applied to expected growth estimates to determine the estimated depletion (Table 6).

Jack Pine Budworm

Jack pine budworm feeds primarily on jack pine but also feeds on lodgepole, red, and Scots pine (*P. sylvestris* L.) in the study area. Jack pine budworm defoliation occurred principally in Saskatchewan and Manitoba in jack pine stands. Therefore, only jack pine stands were included in calculations; other pine species were excluded. Jack pine budworm causes little damage to immature stands; consequently, they were excluded from the list of susceptible stands (pers. com., Dr. Jan Volney, January 1993, conversation with author). Mature and overmature stands were considered susceptible to both defoliation and defoliation-caused mortality and were included in calculating volume loss due to growth reduction and mortality.

The impact classes assigned to defoliation sequences and the associated depletion factors for growth loss and mortality were the same throughout the study area. Growth loss caused by moderate-to-severe jack pine budworm defoliation ranged from 50 to 91% for 1–3 consecutive years of defoliation (Jacquith et al. 1958; Kulman et al. 1963; and Cerezke 1986). These rates are similar to those used in the current study (Table 7). Depletion factors were determined using the same method as utilized for spruce budworm. For the mature and overmature maturity levels of both softwood and mixed-wood jack pine stands defoliated by jack pine budworm, the depletion factors (%) by impact class were A, 0; B, 8; C, 18; D, 31; E, 46; and F, 62%. No mortality occurred in jack pine stands in impact classes O, A, B, and C. The percentages of mortality in stands assigned to impact classes D, E, and F were 13, 23, and 50, respectively. These figures are in general agreement with work by Knowles and Warner (1987).

Forest Tent Caterpillar

In the study area, forest tent caterpillar feeds primarily on trembling aspen and balsam poplar. Other tree species that are defoliated occasionally are white birch, bur oak (*Quercus macrocarpa* Michx.), plains cottonwood (*Populus deltoides* var. *occidentalis* Rydb.), and Manitoba maple (*Acer negundo* L.). Trembling aspen growing in pure stands and mixed-wood stands, regardless of age, were used in the calculation to determine depletion estimates. All other species were excluded.

Rules used to assign impact classes to defoliation sequences and their associated annual growth loss (%) are given in Table 8. For 1–3 consecutive years of defoliation (impact classes A, B, and C), the expected annual growth loss ranges from 50 to 75%. These values represent an average of many studies and are similar to those reported by Barter and Cameron (1955), lower than those reported by Batzer et al. (1954), Rose (1958), Hildahl and Reeks (1960), and Lachance et al. (1984), and higher than those of Ives (1971). For 4–6 consecutive years of defoliation, the only information source was Ives (1971), and those values were used.

Depletion factors were calculated using the same method as utilized for spruce budworm. For both hardwood and mixed-wood aspen stands defoliated by forest tent caterpillar, the depletion factors (%) by impact class were A, 8; B, 19; C, 32; D, 45; E, 60; and F, 76%.

Mortality occurs occasionally in trembling aspen and balsam poplar stands defoliated by forest tent

Table 6. Depletion caused by spruce budworm defoliation in the Northwest Territories, 1982–87

Impact class	Area (ha)	Expected growth (m^3)[a]	Depletion factor (%)	Depletion (m^3)[b]
0	12 548	60 230	0	0
A	45 879	223 219	1	2 232
B	7 171	34 416	4	1 377
C	1 724	8 275	11	910

[a] Mean annual increment (0.8 m^3 $ha^{-1}yr^{-1}$) × 6 years × area.

[b] Expected growth × depletion factor.

Table 7. Rules used to assign stands to impact classes and their associated growth losses for jack pine budworm defoliation

Rule	Impact class	Annual growth loss expected (%)
No defoliation	0	0
One year of no more than moderate defoliation	A	0
One year of moderate-to-severe defoliation or 2 out of 3 years with at least 1 year occurring between 1982 and 1987	B	50
One year of moderate-to-severe defoliation and an additional year of no more than moderate defoliation occurring between 1982 and 1987	C	60
Two consecutive years of moderate-to-severe defoliation or 3 out of 4 years with at least 2 years occurring between 1982 and 1987	D	75
Three consecutive years of moderate-to-severe defoliation or 4 out of 5 years with at least 3 years occurring between 1982 and 1987	E	90
Four consecutive years of moderate-to-severe defoliation or 5 out of 6 years with at least 4 years occurring between 1982 and 1987	F	95

Table 8. Rules used to assign stands to impact classes and their associated growth losses for forest tent caterpillar defoliation

Rule	Impact class	Annual growth loss expected (%)
No defoliation	0	0
One year of at least moderate defoliation within the reporting period or 2 consecutive years prior to the study period (1982–1987)	A	50
Two consecutive years of moderate-to-severe defoliation or 3 out of 4 years with at least 2 years occurring between 1982 and 1987	B	64
Three consecutive years of moderate-to-severe defoliation or 4 out of 5 years with at least 3 years occurring between 1982 and 1987, or 5 out of 7 years with at least 4 years occurring between 1982 and 1987	C	75
Four consecutive years of moderate-to-severe defoliation or 5 out of 6 years with at least 4 years occurring between 1982 and 1987	D	80
Five consecutive years of moderate-to-severe defoliation or 6 out of 7 years with at least 5 years occurring between 1982 and 1987	E	90
Six consecutive years of moderate-to-severe defoliation or 7 out of 8 years with at least 6 years occurring between 1982 and 1987	F	95

caterpillar (Barter and Cameron 1955; Churchill et al. 1964). In the study area, forest tent caterpillar caused moderate-to-severe defoliation throughout the reporting period but no mortality was observed. In determining volume loss for this exercise, defoliation-caused mortality was excluded.

Bark Beetles

Mountain Pine Beetle

Figures for timber volume depleted by mountain pine beetle were obtained from estimates in the annual forest insect and disease survey (FIDS) reports for 1982–87 (Moody and Cerezke 1983, 1984, 1985, 1986; Cerezke and Moody 1987; Cerezke and Emond 1989). The volume depleted is the product of the number of killed lodgepole pine and the volume per tree (about 0.33 m^3/tree). Estimates for Alberta include mortality within the forest reserve only; estimates for Saskatchewan are from Cypress Hills Provincial Park.

Spruce Beetle

Estimates of spruce attacked by spruce beetle were obtained from the previously cited FIDS reports for 1982–87. The Alberta Forest Service provided information for the annual regional reports based on aerial surveys and timber volume harvested during salvage operations.

Diseases

Wood Decay

Trunk and root rot fungi can produce serious defects and volume reductions in living trees. Volume loss caused by wood decay was calculated using methodology specific to a single province because forest inventory information was collected differently in each province and decay rates varied.

The methodology used to calculate growth loss due to decay in Alberta was proposed by the Forest Measurement Section of Alberta Forestry, Lands and Wildlife and used inventory and cull data, which came in the form of an "Age Class Cull Report by Forest" (pers. com., Dave Morgan and Doug Gibbard, 7 November 1990, letter to the author). It is important to note that cull and decay are not the same. Cull includes losses to insects and disease, abiotic factors, and decay. Decay is caused by rot organisms, principally fungi. In this report, however, it is reasonable to associate cull losses with decay. To illustrate the procedure involved to calculate growth loss due to decay, an example is used for the leading species in the Athabasca Forest, black spruce.

The Age Class Cull Report by Forest for the Athabasca Forest gives information on the leading species, age class (years), area (ha), gross coniferous volume (m^3), pulp coniferous volume (m^3), coniferous cull (%), gross deciduous volume (m^3), pulp deciduous volume (m^3), and deciduous cull (%). This information is used to generate Table 9, listing the variables used in volume loss calculation due to decay. For each leading species there was also a component of deciduous cull, which was calculated in the same way. The case of the black spruce type in the Athabasca Forest serves as an example only; calculations were repeated for each forest in Alberta.

The methodology used to estimate growth loss due to decay in Saskatchewan was developed with the assistance of the Timber Management Section of Saskatchewan Parks and Renewable Resources (pers. com., David Lindenas, 14 December 1990, letter to the author). An example, wood decay in the Bronson Timber Supply Area, is used to illustrate the methodology used to calculate wood decay loss in Saskatchewan (Table 10). The Province of Saskatchewan classifies its forest inventory by growth types. All growth types have softwood and hardwood components. Area and growth rates for each component were provided by the Timber Management Section. Annual increment plus decay is the product of area and mean annual increment. Using a rot factor and annual increment plus decay, the product is the estimated annual increment. The difference between annual increment plus decay and estimated annual increment is estimated annual decay. This procedure was repeated for all timber supply areas in Saskatchewan to determine the total annual wood decay for the reporting period.

The Forestry Branch of Manitoba Natural Resources provided assistance in developing the methodology used to calculate growth loss due to wood decay in Manitoba (pers. com., Bob Lamont, 24 September 1990, letter to the author). The calculation involved four steps: determination of gross merchantable volumes for each tree species; estimation of volume loss due to decay as the product of gross merchantable volume by tree species and decay (approximated by Manitoba Natural Resources' cull factors); estimation of annual volume loss to decay as the dividend of age (by

Table 9. Coniferous cull by median age for the leading species, black spruce, in the Athabasca Forest as calculated from the Age Class Cull Report by Forest

Median age class (years)[a]	Area (ha)[b]	Area weight (%)[c]	Weighted age (years)[d]	Coniferous cull (m^3)[e]
30	846.4	0.002	0.06	0
50	33 806.4	0.076	3.80	17
70	166 269.8	0.372	26.04	944
90	108 037.7	0.242	21.78	4 214
110	66 393.9	0.149	16.39	5 902
130	29 019.1	0.065	8.45	6 180
150	36 950.6	0.083	12.45	7 753
170	4 560.9	0.010	1.70	2 092
190	613.7	0.001	0.19	245
220	14.6	–[f]	0.00	6
Total	446 513.1		90.86	27 353

Source: Age Class Cull Report by Forest (personal communication, Doug Gibbard, Forest Measurement Section, Alberta Forestry, Lands and Wildlife, 7 November 1990, letter to the author with accompanying report).

[a] Mid-point of the age class from the Age Class Cull Report by Forest.

[b] Area is taken directly from the Age Class Cull Report by Forest.

[c] Area weight (%) is the proportion of area in each age class from the Age Class Cull Report by Forest.

[d] The product of median age class and area weight.

[e] The result of subtracting the pulp coniferous volume (m^3) from the gross coniferous volume (m^3) by age class in the Age Class Cull Report by Forest.

[f] No significant value.

Note: Estimated annual cull $= \frac{\text{Total cull}}{\text{Total weighted age}} = \frac{27\,353\ m^3}{90.86\ \text{yrs}} = 301.0\ m^3/\text{yr}.$

Estimated coniferous cull (for black spruce) = Annual cull × 6 yrs.

diameter class) and estimated volume loss due to decay; and determination of total volume loss as the product of estimated annual volume loss to decay and the length of the reporting period (6 years). This general procedure was used to produce the estimates listed in Table 11 for all major tree species in Manitoba.

Sources of Error in Depletion Estimates

While the depletion estimates generated in this report are the best estimates available for the study area, there are a number of sources of error in the methodology used to arrive at these estimates. These sources of error should be discussed so that the reader is fully aware of all the problems associated with the depletion estimates and uses the information provided in this report with care when reporting or discussing them. There are four main sources of error that influence the accuracy of the depletion estimates: field survey methodology by FIDS personnel and provincial survey staff; data processing, including mapping and digitization; information on the impact of pests within the region; and inventory data.

All information contained within this report is based on field surveys of forest insect and disease conditions in the region. Field surveys for pests such as spruce budworm, forest tent caterpillar, jack pine budworm, mountain pine beetle, and spruce beetle were mapped by staff from either fixed-wing or rotary-wing aircraft. These infestations are sketch-mapped, usually at a scale of 1:250 000, and are regarded as the permanent record of the infestation. Mapped infestations are large (thousands of ha); smaller infestations (less than a few hundred ha) may be missed or not mapped. Infestation boundaries are irregular and some areas may not be mapped correctly or stands may be mistakenly included or deleted. Field staff may have problems

Table 10. Decay estimation for the Bronson Timber Supply Area in Saskatchewan

Growth type	Component	Area (ha)	MAI[a] ($m^3 ha^{-1} yr^{-1}$)	Annual increment decay (m^3)[b]	Rot factor	Estimated annual increment (m^3)[c]	Estimated annual decay (m^3)[d]
White spruce	Softwood	2 565	1.2	3 078	0.9936	3 058	20
	Hardwood	2 565	1.2	3 078	0.9222	2 839	239
Black spruce	Softwood	179	1.2	215	0.9691	208	7
	Hardwood	179	0.3	54	0.9222	50	4
Jack pine	Softwood	1 087	1.8	1 957	0.9975	1 952	5
	Hardwood	1 087	0.1	109	0.9222	101	8
Spruce–pine	Softwood	193	1.3	250			
	Black spruce			125	0.9691	121	4
	Jack pine			125	0.9975	125	0
	Hardwood	193	0.1	19	0.9222	18	1
Pine–aspen	Softwood	3 296	1.0	3 296	0.9975	3 288	8
	Hardwood	3 296	1.2	3 955	0.9222	3 647	308
Tamarack–larch	Softwood	13	0.7	9	0.9972	9	0
	Hardwood	13	–[e]	–	–	–	–
Trembling aspen	Softwood	90 227	0.4	36 091	0.9936	35 860	231
	Hardwood	90 227	2.6	234 590	0.9222	216 339	18 251
White birch	Softwood	261	0.3	78	0.9936	78	–
	Hardwood	261	1.5	392	0.9798	384	8

Source: Personal communication, David Lindenas, Timber Management Section, Saskatchewan Parks and Renewable Resources, 5 April 1990, letter to the author.

[a] Mean annual increment.

[b] Annual increment decay is the product of area and mean annual increment.

[c] Estimated annual increment is the product of annual increment and rot factor.

[d] Estimated annual decay is calculated by subtracting estimated annual increment from annual increment decay.

[e] Not applicable.

Table 11. Decay estimation for major tree species in Manitoba, 1982–87

Species	Diameter class (cm)	Estimated age (years)	Gross merchantable volume (m³)	Decay (%)	Volume loss to decay (m³)	Age divisor (years)	Estimated annual decay (m³)	Total estimated decay (m³)
Jack pine	10–24	≤160	141 615 680	10	14 161 568	120	118 013	708 078
	26+	161+	19 220 580	15	2 883 087	180	16 017	96 102
Black spruce	10–24	≤200	218 436 780	4	8 737 471	150	58 250	349 500
	26+	201+	11 470 730	8	917 658	220	4 171	25 026
White spruce	10–24	≤120	23 173 280	3	695 190	90	7 724	46 344
	26+	121+	25 629 150	8	2 050 320	150	13 669	82 014
Balsam fir	10–24	≤100	9 462 360	12	1 135 483	75	15 140	90 840
	26+	101+	1 914 880	20	382 976	120	3 191	19 146
Tamarack	10–24	≤90	9 138 430	8	731 074	68	10 751	64 506
	26+	91+	729 760	10	72 976	110	663	3 978
Eastern white cedar	10–24	≤200	517 870	30	155 361	150	1 036	6 216
	26+	201+	189 800	70	132 860	240	554	3 324
Trembling aspen	10–24	≤110	131 504 420	10	13 150 442	83	158 439	950 634
	26+	111+	53 877 220	20	10 775 444	130	82 888	497 328
Balsam poplar	10–24	≤110	17 324 910	10	1 732 491	83	20 873	125 238
	26+	111+	13 609 670	20	2 721 934	130	20 938	125 628
White birch	10–24	≤130	18 370 620	10	1 837 062	98	18 746	112 476
	26+	131+	3 593 210	20	718 642	150	4 791	28 746
Other hardwoods	10–24	≤130	1 828 470	10	182 847	98	1 866	11 196
	26+	131+	1 577 780	20	315 556	150	2 104	12 624

Source: Personal communication, Bob Lamont, Forestry Branch, Manitoba Natural Resources, 3 May 1990, letter to the author.

reaching affected areas and thus estimating pest infestations. Aircraft are not always available for mapping, and road access is sometimes limited; this impedes thorough and complete mapping. All of these problems lead to an underestimate of the losses caused by insects and diseases.

Aerial sketch maps are digitized and stored as spatial data in a geographic information system (GIS) database. A number of errors are introduced during this process. First, due to the unavailability of mylar 1:250 000 scale topographic maps, paper maps have been used for the digitization process. Paper maps shrink and expand with changes in relative humidity and digitization of infested areas may over- or underestimate depletion areas. Second, the base coverage (GIS term: back coverage) on which all spatial data is overlaid was digitized from a 1:6 000 000 scale map of Canada. Small errors may be introduced when overlaying coverages on to this larger scale base coverage (i.e., an infestation may appear in a lake on the base coverage when in fact it is beside the lake). In the future, it may be possible to use a base coverage that has been digitized from 1:250 000 scale mylar maps, but these are currently not available.

Review of the scientific literature reveals that impact information on the major pests of this region is not complete for many pests and there are conflicting data reported in the literature. In many cases information from outside the region was used to determine the impact of pests on their hosts. The result this factor has on the depletion estimates is unknown, and some pests have not been included in the depletion estimates because no data are available. The number of forest pests in this region is extensive (Hiratsuka 1987; Ives and Wong 1988), and they do affect forest yields. Total depletion has been underestimated because many pests have been excluded in the calculations.

Inventory data and the growth and yield data on which inventory data is based influences the determination of depletion estimates. The inventory data used in this report was last updated in 1986 and is, on average, 10 years old; parts of the inventory, however, are more than 35 years old (Gray and Nietmann 1989). Some insect- or disease-infested areas that appear in the inventory may have been harvested or burnt since the last inventory and the associated depletion estimates will be overestimated. More commonly, stands will have grown since the last inventory and depletion estimates will be underestimated.

Growth data applied against infested areas are from Bickerstaff et al. (1981) and a number of problems arise because of their use. First, the estimated mean annual increments are derived from yield curves of unmanaged stands that may or may not have been subjected to endemic insects and disease populations. Epidemic insect and disease populations and the losses they cause are not covered in the mean annual increments. Second, depletion estimates are probably underestimated because the potential growth may be higher than originally estimated. This is related to the concept of a pest-free forest discussed by Gross (1985) where he assumed that growth data incorporated insect and disease effects and that if these were eliminated growth would be higher. If this were true then the depletion estimates generated in the current report would be higher (i.e., the methodology used in this report is conservative when compared to the ideal situation). Finally, the original growth data may produce variable (i.e., overestimate or underestimate) depletion estimates depending on the relationship between the current annual increment of the tree or stand and the average mean annual increment of the stand at maturity (Power and D'Eon 1991).

Generally, considering all sources of error, the depletion estimates for this report were deliberately underestimated. Forest insect- and disease-caused losses were probably higher, but to what degree is unknown.

PEST-CAUSED DEPLETION ESTIMATES

Defoliators

Spruce Budworm

Spruce budworm defoliation of commercial forests occurred in all jurisdictions between 1982 and 1987 (Table 12). In Manitoba and Saskatchewan, defoliation occurred yearly on white spruce and balsam fir. In Alberta, most defoliation occurred outside the forest reserve in predominantly white spruce stands except for defoliation that occurred in 1987. In the Northwest Territories, defoliation

Table 12. Moderate-to-severe defoliation caused by spruce budworm in the study area, 1982–87 (ha)

Year	Alberta	Saskatchewan	Manitoba	N.W.T.
1982	600[a]	2 000	31 380	1 000
1983	1 000[a]	12 700	40 500	11 800
1984	1 500[a]	15 100	142 700	10 900
1985	1 400[a]	15 000	77 500	12 500[b]
1986	390[a]	18 500	34 318	13 000
1987	5 790	31 600	15 540	2 600[c]

Source: Moody and Cerezke (1983, 1984, 1985, 1986), Cerezke and Moody (1987), and Cerezke and Emond (1989).

[a] Defoliation occurred outside forest reserve.

[b] Light-to-moderate defoliation.

[c] An additional 11 200 ha was classed as light-to-moderate defoliation.

occurred yearly and was predominantly confined to white spruce stands.

Depletion estimates for spruce budworm defoliation and spruce budworm-caused mortality were calculated by province. In Alberta, no depletion estimates were calculated because defoliation was present only in 1987.

In Saskatchewan, there were varying levels of spruce budworm defoliation. Defoliation area peaked at 31 600 ha in 1987 and occurred primarily in the Hudson Bay Region. The area in each impact class was derived by overlaying mapped defoliation areas for each year (Table 13). The target inventory within the defoliated areas was extracted and the growth data were applied to the appropriate fir and spruce stands using the host rules. Defoliated stands were assigned to an impact class; these impact classes were determined by the stands' defoliation history. There is a percent growth loss associated with each impact class. Based on these calculations, estimated growth loss as a result of spruce budworm defoliation in Saskatchewan from 1982 to 1987 was 3100 m^3 of white spruce and 1000 m^3 of balsam fir. These growth loss volumes represent 0.09 and 0.08% of the total white spruce and balsam fir growth (3 396 029 and 1 231 380 m^3), respectively. Mortality loss due to spruce budworm defoliation was 39 100 m^3 of white spruce and 13 800 m^3 of balsam fir, which represents 19.5 and 18.5% of the total affected white spruce and balsam fir volume (211 681 and 70 420 m^3, respectively).

Manitoba had the largest amount of spruce budworm defoliation of any jurisdiction in the study area. In 1984 the area affected peaked at 142 700 ha. The most damaging spruce budworm outbreaks occurred in the Lake Winnipeg East (Forest Management units 30 and 31) and Interlake sections (Forest Management units 40 and 41). As with Saskatchewan, the area in each impact class was derived by overlaying mapped defoliation areas for each year. The target inventory within the defoliated areas was extracted and the growth data were applied to the appropriate fir and spruce stands using the host rules. Estimated growth loss due to spruce budworm defoliation in Manitoba for the period 1982–87 was 800 m^3 of white spruce and 2100 m^3 of balsam fir. These values represent 0.03 and 0.26% of the total white spruce and balsam fir growth (2 833 233 and 791 815 m^3), respectively. Estimated mortality loss due to spruce budworm defoliation in Manitoba was 3000 m^3 of white spruce and 3300 m^3 of balsam fir representing 23.7 and 14.3% of the total affected white spruce and balsam fir volume (21 264 and 14 124 m^3, respectively).

There is a significant difference in losses between Manitoba and Saskatchewan. While the area defoliated in Manitoba was higher than Saskatchewan the area of impact classes B–E (impact class A is excluded because little depletion occurs) in Manitoba was less than Saskatchewan (Tables 12 and 13). Two other factors contributed to the lower losses in Manitoba. First, the mean annual increments used to calculate depletion estimates were lower in Manitoba (1.4–1.5 m^3/ha) than in Saskatchewan (1.7–2.0 m^3/ha) according to Bickerstaff et al. (1981). Second, the source of the CFRDS inventory was 6–10 years old in those areas

Table 13. Spruce budworm defoliation by impact class and province, 1982–87

Impact class	Impact class area (ha)		
	Alberta	Saskatchewan	Manitoba
0	0	147 749	989 487
A	0	47 054	307 689
B	0	30 696	27 519
C	0	6 662	5 643
D	0	1 858	4 724
E	0	1 200	579

of Saskatchewan where defoliation occurred and 6–15 years old in those areas of Manitoba where defoliation occurred (Gray and Nietmann 1989). Volume estimates for Manitoba would likely be underestimated because inventory data were older in that province.

In the Northwest Territories, the estimated growth loss resulting from spruce budworm defoliation in white spruce forests was 4500 m^3 (Table 6). Mortality loss was not calculated for the Northwest Territories because none of the defoliated areas were assigned an impact class higher than impact class C.

Total growth loss from spruce budworm defoliation and defoliation-caused mortality to white spruce and balsam fir was 70 700 m^3, of which 50 500 m^3 was white spruce and 20 200 m^3 was balsam fir. Growth loss was 11 500 m^3 and mortality loss was 59 200 m^3.

Jack Pine Budworm

Jack pine budworm caused significant defoliation, particularly in Manitoba and Saskatchewan (Table 14). Light-to-moderate defoliation also occurred in a few stands in central Alberta. This was significant because it was the first time defoliation was detected in Alberta (Moody and Cerezke 1986). In 1983, defoliation increased dramatically to 154 000 ha from no defoliation in the previous year. By 1985, defoliation peaked reaching a maximum area of 2 178 770 ha. As quickly as the jack pine budworm infestation had increased, this infestation subsided to a total area of only 2670 ha by 1987. There was no jack pine budworm defoliation reported in the Northwest Territories. Jack pine budworm defoliation was negligible in Alberta and consequently no volume loss estimates were calculated for growth reduction or mortality.

In Saskatchewan, varying degrees of defoliation was caused by jack pine budworm. Table 15 summarizes the defoliated areas by impact class area. The estimated growth loss based on the mapped areas, the target inventory, and growth data for the defoliated stands was 59 100 m^3 and the estimated mortality loss was 247 800 m^3. These losses represent 0.61% of the total growth (9 735 187 m^3) and 12.6% of the total affected volume (1 974 428 m^3).

In Manitoba, the intensity of jack pine budworm defoliation was more severe and had a greater impact on the jack pine forests than in other provinces. Estimated growth loss for the reporting period was 424 300 m^3 of jack pine. This value represents 9.70% of total jack pine growth (4 372 542 m^3). Estimated mortality loss due to jack pine budworm was 2 306 300 m^3 of jack pine, which represents 14.1% of the total affected jack pine volume (16 353 882 m^3).

Throughout the study area, total growth loss in jack pine stands from jack pine budworm defoliation and defoliation-caused mortality was 3 037 500 m^3, of which 483 400 m^3 was attributed to growth loss and 2 554 100 m^3 was attributed to mortality loss.

Forest Tent Caterpillar

Extensive aspen defoliation is a common occurrence in the study area. While defoliation can be caused by a number of insects, the most prominent insect is forest tent caterpillar. Large aspen tortrix (*Choristoneura conflictana* [Walker]) is the second

Table 14. **Moderate-to-severe defoliation caused by jack pine budworm in the study area, 1982–87 (ha)**

Year	Alberta[a]	Saskatchewan	Manitoba	N.W.T.
1982	–[b]	–[b]	–[c]	–[b]
1983	–[b]	–[b]	154 500	–[b]
1984	–[b]	26 800	761 000	–[b]
1985	<70	131 200	2 047 500	–[b]
1986	70	176 000	132 090	–[b]
1987	70	2 500	100	–[b]

Source: Moody and Cerezke (1983, 1984, 1985, 1986), Cerezke and Moody (1987), and Cerezke and Emond (1989).

[a] All defoliation in Alberta was outside the forest reserve.

[b] No defoliation recorded.

[c] Defoliation occurred but area not reported.

Table 15. **Jack pine budworm defoliation by impact class and province, 1982–87**

Impact class	Impact class area (ha)		
	Alberta	Saskatchewan	Manitoba
A	0	157	0
B	0	728 400	5 543 282
C	0	0	57 573
D	0	390 944	1 786 736
E	0	1 330	168 725
F	0	0	21 222

most prevalent insect, except in the northern portion of the region where it dominates. Other defoliators of aspen mentioned in the FIDS reports are Bruce spanworm (*Operophtera bruceata* [Hulst]), aspen leafroller (*Pseudexentera oregonana* Walsingham), speckled green fruitworm (*Orthosia hibisci* Guenee), linden looper (*Erannis tiliaria* [Harris]), and lightheaded aspen leafroller (*Anacampis niveopulvella* [Chambers]). These insects were categorized as being of minor importance.

The total area of aspen defoliation commonly amounted to millions of hectares annually (Table 16). Direct comparisons from year to year are confounded by inconsistent reporting. In some cases the entire area throughout which defoliation occurred was reported, while in other cases only the area of defoliated aspen stands was estimated; thus, the gross and net columns in Table 16. Aspen defoliation reporting is also complicated by vast non-forest areas (i.e., grasslands) with scattered aspen stands. Areas of defoliated aspen is shown in Figure 4.

Areas defoliated by forest tent caterpillar are summarized by impact class and province in Table 17. The target inventory within the defoliated areas was extracted and the growth data were applied to the appropriate aspen stands. Defoliated stands were assigned to impact classes, which were determined by the stands' defoliation history. A percent growth loss was associated with the impact class. Based on these calculations, the estimated growth loss due to forest tent caterpillar defoliation in

Table 16. Moderate-to-severe aspen defoliation in the study area, 1982–87 ('000s ha)

Year	Alberta		Saskatchewan		Manitoba		N.W.T.	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net
1982	13 000	4 290[a]	2 100	693[a]	600	198[a]	–[b]	–
1983	3 998	1 319[a]	350[c]	70	600	198[a]	–	–
1984	1 335	–	3	–	634	77	–	–
1985	2 262	155	–	31	–	20	–	–
1986	4 950	316[d]	1 773	177[d]	–	17	–	–
1987	6 611	1 322[e]	1 250	250[e]	–	4	–	–

Source: Moody and Cerezke (1983, 1984, 1985, 1986), Cerezke and Moody (1987), and Cerezke and Emond (1989).

[a] 33% of gross defoliation as suggested by Moody and Cerezke (1983, 1984).

[b] No defoliation recorded.

[c] 80% of this defoliation occurred on noncommercial land and 20% on commercial land (Moody and Cerezke 1984).

[d] 10% of gross defoliation as suggested by Cerezke and Moody (1987).

[e] 20% of gross defoliation as suggested by Cerezke and Emond (1989).

Table 17. Forest tent caterpillar defoliation by impact class and province, 1982–87

Impact class	Impact class area (ha)		
	Alberta	Saskatchewan	Manitoba
0	1 555 825	4 930 521	12 761
A	5 628 718	5 393 366	1 308 571
B	6 438 124	1 047 646	399 989
C	4 530 333	157 746	44 963
D	2 174 243	1 644	7 581
E	357 372	0	1 216
F	303 843	0	0

Alberta, Saskatchewan, and Manitoba was 10 280 000, 434 200, and 94 200 m^3, respectively. These growth loss volumes represent 13.46, 2.00, and 0.48% of total aspen growth in Alberta, Saskatchewan, and Manitoba, respectively.

Bark Beetles

Mountain Pine Beetle

Mountain pine beetle was most active in southern Alberta and Saskatchewan's Cypress Hills from 1977 to 1986. The primary host of this insect is lodgepole pine, which is killed by a combination of beetle girdling and the activity of blue-stain fungi (primarily *Ophiostoma clavigerum* [Robins.-Jeff. & Davids.] Harrington, *O. huntii* [Robins.-Jeff.] de Hoog & Scheffer, and *O. minus* [Hedge.] H. & P. Sydow), which the beetle transmits (Yamaoka et al. 1990).

In Alberta, mountain pine beetle infestations were confined mainly to southern Bow–Crow Forest but were also found in Cypress Hills Provincial Park. Depletion estimates for Cypress Hills Provincial Park were not included in provincial depletion estimates (5308 trees, 1752 m^3). Prior to this study, from 1977 to 1981, mountain pine beetle had caused lodgepole pine mortality amounting to 683 067 m^3 (Hiratsuka et al. 1980, 1981, 1982). The outbreak peaked in 1981 causing 1 250 000 m^3 in mortality loss. Annual mortality throughout the outbreak period is presented in Table 18. The estimated volume depleted totalled 385 100 m^3.

In Saskatchewan, the first mountain pine beetle infestation was detected in 1980 in Cypress Hills Provincial Park. Table 19 lists the number of infested trees removed during control operations. The total volume depleted was 1061 m^3.

Spruce Beetle

Spruce beetle was active at outbreak levels in northwestern Alberta during the first 3 years of the study; only endemic levels of this pest were reported elsewhere within the study area. Forest harvest activities were increased in infested areas in order to salvage as much timber as possible. A minimum of 47 500 m^3 of white spruce was killed by spruce beetle activity during the outbreak (Moody and Cerezke 1985).

Diseases

Wood Decay

Wood decay can be classified into two broad groups: root rots and trunk rots. On coniferous species in the study area, root rots such as *I. tomentosus, P. alnicola, Armillaria* spp., *S. galactinum*, and *C. puteana* cause significant damage. Notable trunk rots of conifers include *P. pini* and *H. sanguinolentum.* On hardwood species, the following root rots are considered important: *Armillaria* spp. and *P. spectabilis.* Prominent trunk rots of hardwoods include *P. tremulae, R. americanus, P. destruens*, and *P. polygonia* (Hiratsuka 1987).

In Alberta, wood decay caused wood volume losses of 579 000 m^3 in coniferous trees and 1 687 800 m^3 in deciduous trees (Table 20). Average decay rates of conifers in the age classes 80–120 years, 121–160 years, and 161+ years ranged

Table 18. Summary of mountain pine beetle damage in Alberta's forest districts, 1977–87

Year	Estimated mortality of lodgepole pine (no. of stems)	Estimated volume of killed lodgepole pine[a] (m^3)
1977	200[b]	66
1978	4 200[b]	1 386
1979	173 700[b]	57 321
1980	641 800[b]	211 794
1981	1 250 000[c]	412 500
1982[b]	576 000[d]	190 080
1983	236 000[d]	77 880
1984	224 700[d]	74 151
1985	130 000[d]	42 900
1986	271[d]	89
1987	0[d]	0
Total 1982–87	1 166 971	385 100
Total 1977–87	3 236 871	1 068 167

[a] 0.33 m^3/tree.

[b] Hiratsuka et al. (1981) in which 820 000 trees were estimated to have been killed between 1977–80 on provincial forest lands.

[c] Personal communication, Dr. Herb Cerezke, Forest Entomolgist, Forestry Canada, Edmonton, Alberta, January 1993, letter to the author.

[d] Moody and Cerezke (1983, 1984, 1985, 1986), Cerezke and Moody (1987), and Cerezke and Emond (1989).

Note: Trees killed in provincial parks, Indian reserves, and other noncommercial areas were not included.

Table 19. Summary of mountain pine beetle damage in Saskatchewan, 1980–87

Year	Estimated mortality of lodgepole pine (no. of stems)	Estimated volume of killed lodgepole pine[a] (m^3)
1980	128	42
1981	767	253
1982	2222	733
1983	905	299
1984	84	28
1985	3	1
1986	0	0
1987	0	0
Total 1982–87	3214	1061
Total 1980–87	4109	1356

Source: Personal communication, Madan Pandila, Saskatchewan Department of Natural Resources, March 1990, letter to the author.

[a] 0.33 m^3/tree.

Table 20. Estimated annual decay and total estimated decay in all forest districts in Alberta, 1982–87 (m^3)

Lead species	Estimated annual coniferous decay	Estimated annual deciduous decay	Total estimated coniferous decay	Total estimated deciduous decay
White spruce	34 900	34 800	209 400	208 800
Black spruce	4 000	1 100	24 000	6 600
Pine	29 300	10 000	175 800	60 000
Total coniferous	300	100	1 800	600
Total deciduous	28 000	235 300	168 000	1 411 800
Total	96 500	281 300	579 000	1 687 800

between 0.24–3.78, 0.42–5.16, and 0.49–5.38%, respectively. These decay rates were low compared to the decay rates listed in the following studies. Denyer and Riley (1954) reported slightly higher decay rates for white and black spruce in the same age classes as 1.5–2.0, 2.6–3.5, and 4.5–6.0%. Etheridge (1958) reported decay rates of 9.9–11.5% for spruce 121–160 years old and 12.7–49.3% for spruce >161 years old. Lodgepole pine decay rates are 5% for stands 101–170 years old and 8% for stands >170 years old (Loman and Paul 1963). Basham (1967) studying jack pine decay rates in northwestern Ontario reported decay rates of 2.7–6.9% for stands 81–120 years old, 12.2% for stands 121–160 years old, and 38.8% for stands >161 years old.

Average decay rates for deciduous trees in Alberta in the age classes 80–120 years, 121–160 years, and >161 years ranged between 0.89 and 3.49, 1.14 and 4.77, and 1.34 and 5.44%, respectively. These decay rates were low compared to various other trembling aspen and balsam poplar decay studies (Meinecke 1929; Black and Kristapovich 1954; Basham 1958; Paul and Etheridge 1958; Thomas et al. 1960; Bailey and Dobie 1977; and

Maier and Darrah 1989). Hiratsuka and Loman (1984) and Basham (1987) noted that some earlier studies may have included stain as well as decay resulting in inconsistencies between studies.

The estimated volume losses due to wood decay in Saskatchewan were 208 800 m^3 of coniferous and 2 405 400 m^3 of deciduous timber (Table 21). As in Alberta, decay rates provided by Saskatchewan Parks and Renewable Resources were low compared to some of the previously cited studies. Decay rates in coniferous trees were between 0.23 and 1.96% and were not rated by age class but by the average decay rate over all age classes. Similar decay rates for deciduous trees were between 4.04 and 16.06%.

In Manitoba, wood decay caused wood volume losses of 1 494 600 m^3 in coniferous trees and 1 863 600 m^3 in deciduous trees (Table 22). Decay rates provided by Manitoba Natural Resources were high, compared to the previously cited literature; consequently, the lower decay rates in the literature were used.

Table 21. Estimated annual decay and total estimated decay in all timber supply areas in Saskatchewan, 1982–87 (m^3)

Tree species	Estimated annual decay	Total estimated decay
White spruce	7 100	42 600
Black spruce	19 400	116 400
Jack pine	8 300	49 800
Tamarack	0	0
Trembling aspen	391 200	2 347 200
Balsam poplar	8 900	53 400
White birch	600	3 600
Manitoba maple	200	1 200
Total	435 700	2 614 200

Table 22. Estimated annual decay and total estimated decay (m^3) in all sections in Manitoba, 1982–87

Tree species	Estimated annual decay	Total estimated decay
Jack pine	134 000	804 000
Black spruce	62 400	374 400
White spruce	21 400	128 400
Balsam fir	18 300	109 800
Tamarack	11 400	68 400
Eastern white cedar	1 600	9 600
Trembling aspen	241 300	1 447 800
Balsam poplar	41 800	250 800
White birch	23 500	141 000
Other hardwoods	4 000	24 000
Total	559 700	3 358 200

SUMMARY

Forest insect- and disease-caused depletions to the forest resources of Alberta, Saskatchewan, Manitoba, and the Northwest Territories were determined as 3 765 000 m^3/year and represent an estimate of the damage caused by spruce budworm, jack pine budworm, forest tent caterpillar, mountain pine beetle, spruce beetle, and wood decay for the period 1982 to 1987 (Table 23). Spruce budworm defoliation resulted in 1900 m^3/year of volume loss due to growth reduction and 9900 m^3/year due to mortality. Jack pine budworm caused volume losses of 80 600 m^3/year in growth reduction and 425 700 m^3/year in mortality. Forest tent caterpillar defoliation caused 1 801 400 m^3/year in growth reduction; there was no mortality associated with forest tent caterpillar. Volume depletions for mountain pine beetle and spruce beetle were 64 400 and 7900 m^3/year, respectively. Wood decay volume loss was 1 373 200 m^3/year.

The authors have assumed that pest-related depletions to the forests in the study area have been accounted for in the calculations of annual allowable cut (AAC) for each province or territory. As discussed earlier in the report, insect and disease losses may or may not be captured in permanent sample plots from which growth and yield data were collected and used to calculate AAC; caution must be exercised when interpreting the values contained in Table 24. If insect and disease losses are not captured in information collected from these plots then these losses represent 9.1% of the total AAC for the study area, which is about one-third of the fire losses and less than half the harvest. These losses occurred when insect and disease activity was relatively low; the only major outbreaks were forest tent caterpillar and jack pine budworm. At the provincial or territorial level insect and disease losses had a greater impact in some areas. For example, in Manitoba, insect and disease losses represent 12.4% of the AAC or 23.4% of the economically accessible AAC (4 407 000 m^3) (Runyon 1991). If insect and disease losses, fire losses, and harvest volumes are added for Manitoba, the surplus, in terms of the economically accessible AAC, is only 1 096 100 m^3. Therefore, Manitoba is close to allocating all of its available timber supply. A similar situation exists for the Northwest Territories where severe and prolonged infestations of spruce budworm in combination with other depletions is almost at the same level as the AAC. Alberta and Saskatchewan have a surplus of timber but insect and disease losses are significant, about half the level of harvest volumes.

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Table 23. Average annual volume loss by major pest for the study area, 1982–87 (m^3)

Province	Volume loss factor	Pest: Spruce budworm	Jack pine budworm	Forest tent caterpillar	Mountain pine beetle	Spruce beetle	Wood decay	Total
Alberta	Growth	–[a]	–	1 713 300	–	–	–	1 713 300
	Cull	–	–	–	–	–	377 800	377 800
	Mortality	–	–	–	64 200	7 900	–	72 100
Saskatchewan	Growth	600	9 900	72 400	–	–	–	82 900
	Cull	–	–	–	–	–	435 700	435 700
	Mortality	8 800	41 300	–	200	–	–	50 300
Manitoba	Growth	500	70 700	15 700	–	–	–	86 900
	Cull	–	–	–	–	–	559 700	559 700
	Mortality	1 100	384 400	–	–	–	–	385 500
N.W.T.	Growth	800	–	–	–	–	–	800
	Cull	–	–	–	–	–	N/A[b]	N/A
	Mortality	–	–	–	–	–	–	0
Total		11 800	506 300	1 801 400	64 400	7 900	1 373 200	3 765 000

[a] Not available.
[b] Not applicable.

Table 24. Annual allowable cut, insect and disease losses, fire losses, and harvest volumes for the study area, 1982–87 (m^3)

Province	Annual allowable cut	Insect and disease	Fire[a]	Harvest
Alberta	26 646 000[b]	2 163 200	258 700[c]	7 166 100[c]
Saskatchewan	6 600 000[b]	568 900	2 028 900	1 245 200[d]
Manitoba	8 321 000[b]	1 032 100	1 754 900	523 900[d]
N.W.T.	3 900[e]	800	1 300	1 400[d]
Total	41 570 900	3 765 000	4 043 800	8 936 600

[a] Modified from Forestry Canada (1992).

[b] Runyon (1991).

[c] Personal communication, Hideji Ono, Alberta Environmental Protection, 12 October 1993, letter to the author.

[d] Modified from Canadian Council of Forest Ministers (1993).

[e] Canadian Council of Forest Ministers (1993).

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