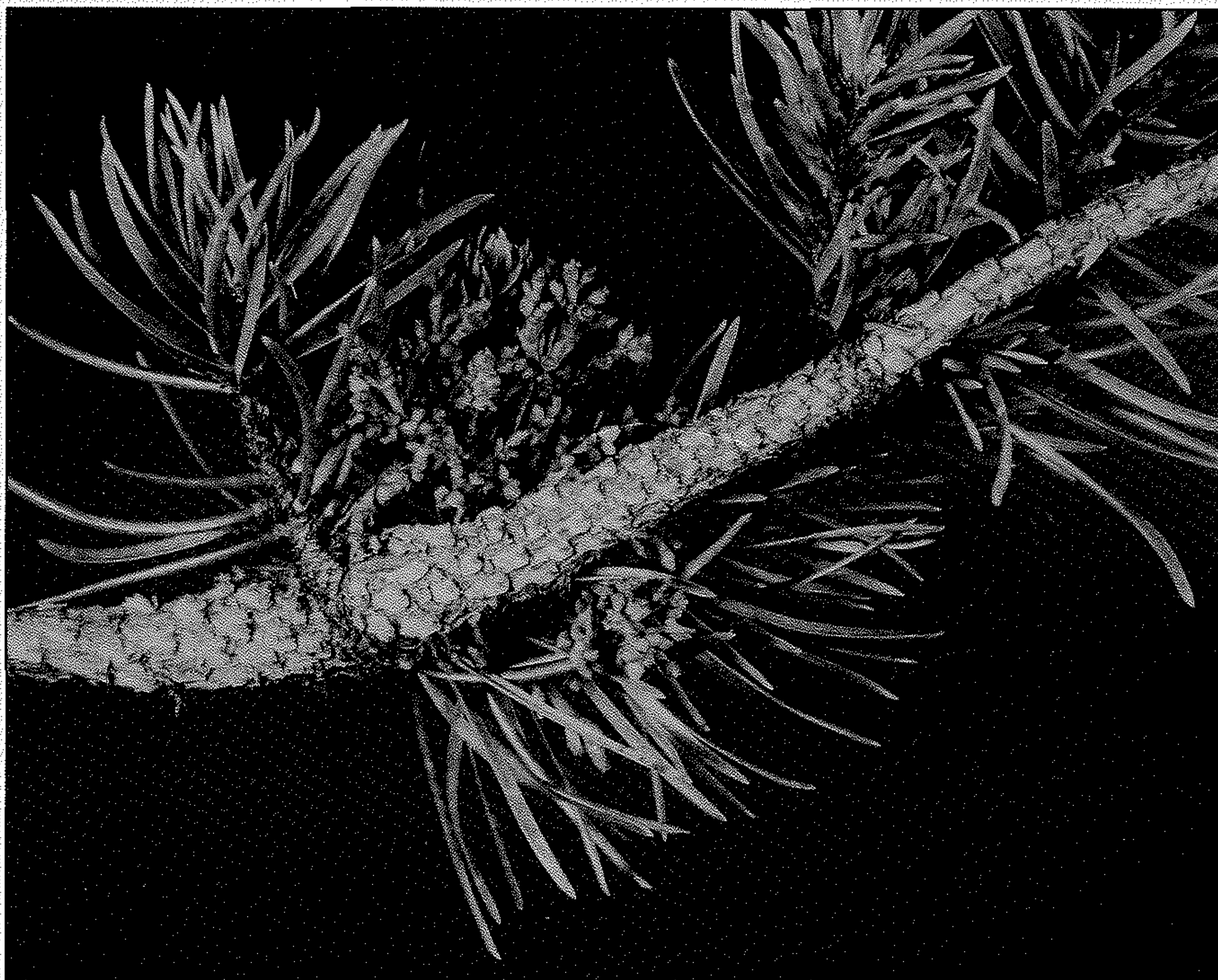
Forest insect- and disease-caused impacts to timber resources of west-central Canada: 1988-1992

J.P. Brandt

Northwest Region • Information Report NOR-X-341



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Cover photo:

Aerial shoots of lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) on a lodgepole pine branch.

FOREST INSECT- AND DISEASE-CAUSED IMPACTS TO TIMBER RESOURCES OF WEST-CENTRAL CANADA: 1988–1992

J.P. Brandt

INFORMATION REPORT NOR-X-341

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ABSTRACT

Methods were developed to calculate the impacts caused by major pests to the timber resources of Alberta, Saskatchewan, Manitoba, and the Northwest Territories. Impacts were quantified for volume losses due to growth reduction and tree mortality. Impacts were not determined for pests of young stands and for diseases caused by fungi such as needle casts and rusts, stem rusts, and cankers of conifers, and cankers of hardwoods. Spruce budworm (*Choristoneura fumiferana* [Clem.]) defoliation resulted in a volume loss of 134 000 m^3/year due to growth reduction and mortality. Jack pine budworm (*C. pinus pinus* Free.) caused a volume loss of 62 000 m^3/year due to mortality. Forest tent caterpillar (*Malacosoma disstria* Hbn.) caused volume losses of 1 625 000 m^3/year due to growth reduction and 2 444 000 m^3/year due to mortality. Large aspen tortrix (*C. conflictana* [Wlk.]) caused 24 000 m^3/year in growth reduction. Bruce spanworm (*Operophtera bruceata* [Hulst]) defoliation resulted in 163 000 m^3/year in growth reduction. Neither large aspen tortrix nor Bruce spanworm caused tree mortality. Volume losses due to mountain pine beetle (*Dendroctonus ponderosae* Hopk.) and Douglas-fir beetle (*D. pseudotsugae* Hopk.) were less than 1000 m^3/year. Volume loss due to spruce beetle (*D. rufipennis* [Kby.]) was 2000 m^3/year. Lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) infestations resulted in volume losses of 170 000 m^3/year due to growth reduction and 898 000 m^3/year due to mortality. Wood decay volume loss was 10 726 000 m^3/year. Forest insect- and disease-caused impacts to the timber resources of the study area totaled 16.2 million m^3/year between 1988 and 1992.

RÉSUMÉ

Nous avons élaboré des méthodes permettant de calculer l'incidence des principaux ravageurs sur les ressources en bois de l'Alberta, de la Saskatchewan, du Manitoba et des Territoires du Nord-Ouest. L'incidence a été quantifiée en termes de pertes de volume par réduction de croissance et par mortalité. Elle n'a pas été calculée pour les ravageurs des peuplements jeunes ni pour les maladies cryptogamiques comme les rouges, les rouilles des aiguilles et des tiges, les chancres des résineux et les chancres des feuillus. La défoliation par la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* [Clem.]) a entraîné une perte de volume de 134 000 m^3/an par réduction de croissance et mortalité. La tordeuse du pin gris *C. pinus pinus* Free.) a causé une perte de 62 000 m^3/an par mortalité. La livrée des forêts (*Malacosoma disstria* Hbn.) a causé des pertes 1 625 000 m^3/an par réduction de croissance et de 2 444 000 m^3/an par mortalité. La tordeuse du tremble (*C. conflictana* [Wlk.]) a causé une perte de 24 000 m^3/an par réduction de croissance. La défoliation par l'arpenteuse de Bruce (*Operophtera bruceata* [Hulst]) a entraîne une perte de 163 000 m^3/an par réduction de croissance. La tordeuse du tremble et l'arpenteuse de Bruce n'ont causé aucune mortalité chez les arbres. Les pertes de volume dues au dendroctone du pin ponderosa (*Dendroctona ponderosae* Hopk.) et au dendroctone du douglas (*D. pseudotsugae* Hopk.) ont été inférieures à

1000 m^3/an; celle due au dendroctone de l'épinette (*D. rufipennis* [Kby.]) a été de 2000 m^3/an. Les infestations de faux-gui du pin (*Arceuthobium americanum* Nutt. ex Engelm.) ont entraîné des pertes de 170 000 m^3/an par réduction de croissance et de 898 000 m^3/an par mortalité. Les caries ont causé une perte de 10 726 000 m^3/an. L'incidence globale des maladies et des insectes forestiers sur les ressources en bois, de 1988 à 1992, équivalaut à une perte de 16,2 millions de mètres cubes par année.

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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.

This report describes the impacts caused by major forest insects and diseases to the timber resources of Alberta, Saskatchewan, Manitoba, and the Northwest Territories in terms of wood volume losses due to tree mortality and growth reduction for the period 1988–1992.

There are two reasons for describing the impacts. First, without quantifying the effects, there is no way of assessing whether there is a need to invest time and resources into developing and implementing management techniques to alleviate pest damage. As well, this information assists with forest management decisions such as scheduling harvest and allocating timber resources.

At the national level, forest insect and disease impacts have been described several times in the last few decades (Davidson and Buchanan 1964; Sterner and Davidson 1982; Hall and Moody 1994). Reported annual losses have ranged from 27.1 million m^3 of wood for forest diseases alone in 1964, to 102.7 million m^3 of wood for forest insects and diseases during the period 1982–1987. In the study area of this report (Fig. 1), forest insect and disease impacts were first quantified as 3.8 million m^3/year by Brandt and Amirault (1994). The results of the initial regional report were based on surveys conducted by the Forest Insect and Disease Survey unit of the Northern Forestry Centre, staff of provincial or territorial resource departments, and an extensive literature review (Moody and Amirault 1992). The work completed for the current report is a continuation of the process initiated earlier for this study area.

Forests in the study area consist of tree species found in pure stands or in various mixed stands. In Alberta, commercial tree species found in forests

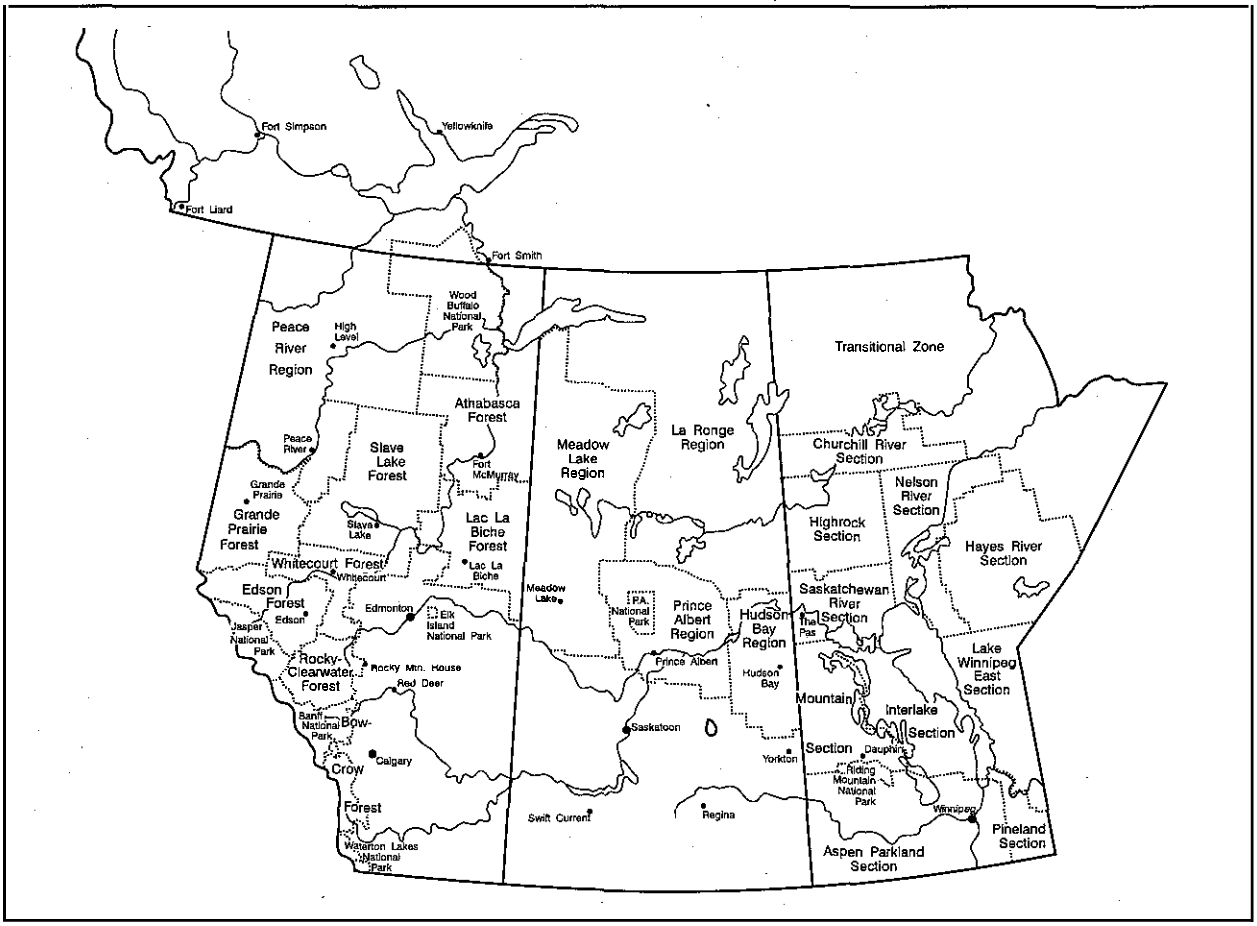

Figure 1. Forest districts and regional boundaries of the three prairie provinces and the Northwest Territories.

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, commercial tree species found in forests are the same as those of Alberta except Engelmann spruce, Douglas-fir, and alpine fir. In Manitoba, tree species are similar to Saskatchewan, except that red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and eastern white cedar (*Thuja occidentalis* L.) are present and there are no native stands of lodgepole pine. White spruce is the most important commercial tree species in the Northwest Territories (Bohning 1986), but trembling aspen and jack pine are also utilized to a limited extent.

Many insect and disease pests were excluded from this study for one of two reasons. First, certain pests might have been reported by the Forest Insect and Disease Survey as being active within forests during the study period, but exact distribution and sizes of infestation were not accurately determined. Pests that fall into this category include the pine needle cast (*Lophodermella concolor* [Dearn.] Darker), larch sawfly (*Pristiphora erichsonii* [Htg.]), yellow-headed spruce sawfly (*Pikonema alaskensis* [Roh.]), aspen leaf beetle (*Chrysomela crotchi* Brown), willow-and-poplar leaf beetle (*C. falsa* Brown), gray willow leaf beetle (*Tricholochmaea decora* [Say]), and spruce gall midge (*Mayetiola piceae* [Felt]). Second, limited data are available on the impacts of a number of pests on the timber resources within the study area. Pests that fall into this category include many of the pests previously listed, pests of young stands, and many diseases such as needle and stem rusts and stem cankers.

The determination of insect-caused impacts was limited to significant pests. Five defoliators were included: two species found on conifers; spruce budworm (*Choristoneura fumiferana* [Clem.]) and jack pine budworm (*C. pinus pinus* Free.); and three species found on hardwoods; forest tent caterpillar (*Malacosoma disstria* Hbn.), large aspen tortrix (*C. conflictana* [Wlk.]), and Bruce spanworm (*Operophtera bruceata* [Hulst]). Three bark beetle species were included because they cause damage to forests in the study area: mountain pine beetle (*Dendroctonus ponderosae* Hopk.), spruce beetle (*D. rufipennis* [Kby.]), and Douglas-fir beetle (*D. pseudotsugae* Hopk.). Mountain pine beetle attacks lodgepole pine, primarily in mountain forests of southwestern Alberta; spruce beetle attacks Engelmann and white spruce throughout the study area, and Douglas-fir beetle attacks Douglas-fir in forests of southwestern Alberta.

The calculation of disease-caused impacts was also limited to those of a few diseases. Lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.), a serious pest of lodgepole and jack pine, was included as was wood decay. Wood decay includes both root and trunk rots. On coniferous species in the study 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 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.

METHODS

Inventory

Forest inventory data used in the calculation of the impacts of spruce budworm, jack pine budworm, forest tent caterpillar, and lodgepole pine dwarf mistletoe were from five sources: the Canadian Forest Resource Data System (CFRDS), the three provincial inventories and the Northwest Territories inventory. The CFRDS was used to determine area of infestations because provincial and territorial inventories exist in different formats and do not allow a single method to be applied to all jurisdictions. The provincial and territorial inventories were used for estimates of mean stand volumes and mean annual increments for different tree species affected by various pests.

The CFRDS used for this exercise was last updated in 1991 (Natural Resources Canada 1991). Gray and Nietmann (1989) provide a thorough description of the 1986 CFRDS that is still applicable to the current inventory. Three important attributes are used in classifying forest stands by the CFRDS: maturity, forest type, and predominant genus. Maturity is a qualitative expression of stand development based on stand age. Forest type describes whether a stand is softwood, mixed wood (softwood and hardwood trees), or hardwood. Predominant genus is used to describe the most prevalent tree genus within the cover type.

Inventory data used for estimates of wood decay were from the inventories of the three prairie provinces and the Northwest Territories. Wood decay estimates in the Northwest Territories are not complete because inventory work is ongoing; estimates were only obtained for the Cameron Hills and the Liard River valley in the Northwest Territories.

In Alberta, mean stand volumes of white spruce, trembling aspen, jack pine, and lodgepole pine stands affected by various pests were 77, 100, 106, and 238 m^3/ha, respectively.[1] Estimates of mean stand volume are empirical for stands in those regions where the infestations occurred. Mean annual increments of white spruce, trembling aspen, jack pine, and lodgepole pine were 2.15, 2.19, 1.54, and 2.13 m^3/ha/yr, respectively.

Estimates of mean stand volume for white spruce and trembling aspen stands in Saskatchewan were 90 and 129 m^3/ha, respectively.[2] For the same tree species, mean annual increments were 1.13 and 2.15 m^3/ha/yr. Estimates of mean stand volume of jack pine stands infested by jack pine budworm and lodgepole pine dwarf mistletoe were 83 and 60 m^3/ha, respectively. The corresponding jack pine mean annual increments were 1.38 and 1.00 m^3/ha/yr.

In Manitoba, trembling aspen and jack pine mean stand volumes were 126 and 111 m^3/ha, respectively.[3] Mean annual increments for these tree species were 2.07, and 1.47 m^3/ha/yr.

The mean stand volume of white spruce in the Northwest Territories was 80 m^3/ha.[4] White spruce mean annual increment was 0.80 m^3/ha/yr (Bickerstaff et al. 1981). This estimate was used because no growth data are available for white spruce in the Northwest Territories.

Calculation of Impacts of Major Pests

Impacts of most major forest pests were calculated using an automated system based on defoliation or infestation maps produced by geographic information systems (GIS) and corresponding inventory data. The process used in calculating impacts of spruce budworm, jack pine budworm, and forest tent caterpillar in the four jurisdictions involved eight steps. A similar process was used for lodgepole pine dwarf mistletoe. Impacts of spruce budworm in Manitoba were not calculated using the automated system because the province has estimates of impacts in eastern Manitoba (Knowles et al. 1992). These impacts were extrapolated to determine impacts for the entire province.

Areas of insect-caused defoliation were sketched on 1:250 000 National Topographic Series maps during aerial or ground surveys in each year defoliation occurred. These maps were digitized using GIS and archived as a spatial data base for later use. When the data base was projected as a map in the GIS, it consisted of many polygons, each with a code for defoliation severity. The code consisted of ratings from 0 to 5 representing no, light, light-to-moderate, moderate, moderate-to-severe, and severe defoliation.

Next, a composite spatial data base was created, representing all defoliation that had occurred in the study area in the previous 10 years (i.e., 1983–1992 inclusive) and the CFRDS data for the same area. Beginning with the data base representing the area of defoliation in 1983, the 1984 data base was retrieved from the GIS and joined to the 1983 data base to create a data base representing

[1] Tom Lakusta. 1994. Alberta Environmental Protection, Land and Forest Services, Forest Resource Information Branch, Edmonton, Alberta. Personal communication.

[2] Bruce Walter. 1994. Saskatchewan Environment and Resource Management, Forest Lands Branch, Prince Albert, Saskatchewan. Personal communication.

[3] Keith Knowles. 1994. Manitoba Natural Resources, Forest Protection Section, Winnipeg, Manitoba. Personal communication.

[4] Craig Robinson. 1994. Northwest Territories Renewable Resources, Forest Management Division, Hay River, Northwest Territories. Personal communication.

2 years' area of defoliation. This process was repeated to create a data base representing all 10 years' area of defoliation. When the defoliation data base was projected as a map, it comprised polygons, each with a unique defoliation history and set of attributes. Next, the CFRDS data base was joined to the defoliation data base to create the composite data base. The CFRDS data base stored inventory data in cells. Each cell corresponded to a defined area on the composite map. Using a data base of jurisdictional boundaries, the composite data base was clipped to jurisdictional boundaries to allow calculations on a provincial or territorial basis.

Ten-digit series were used to describe the defoliation history of each polygon in the composite data base. Trees within areas experiencing different levels of defoliation are affected differently; consequently, the defoliation history of each polygon was described by a series. Digits in the series corresponded to a single year's defoliation and represented defoliation severity according to the 0–5 rating code. A list was created of all unique 10-digit series in each jurisdiction.

Impact-class codes were then manually assigned to all series in the list according to a set of rules developed for each pest (Tables 1–3). Impact classes are defined by Power and D'Eon (1991) as consecutive levels categorizing the effect (i.e., growth reduction and mortality) the pest has on the host. Several different series can be assigned to the same impact class.

Infested area within defoliated CFRDS cells (as indicated by the composite data base) was determined as the product of the percentage of the cell that was defoliated and the percentage of the cell that contained the host species.

Estimated standing volume on the infested area was the product of the infested area in each impact class and the mean standing volume of infested stands. Estimated growth on infested areas was the product of infested area in each impact class, the mean annual increment of infested tree species, and the number of years in the study.

Finally, depletion factors representing mortality and growth reduction were applied to the estimated volume and growth on infested areas to determine mortality and growth loss. Depletion factors represent the volume loss exhibited by trees. These factors depend on the effect the pest has on the host. Each impact class has a depletion factor for growth reduction and mortality. Depletion factors were estimated for each of the different pests by reviewing relevant literature as well as consulting experts.

The process used to determine lodgepole pine dwarf mistletoe impacts was the same as the above process, except for impact class assignment; one impact class was used because only severe mistletoe infections were mapped during surveys.

Defoliators

Spruce Budworm

In Alberta and Saskatchewan, immature stands of white spruce were considered susceptible to spruce budworm outbreaks, but they were not attacked as frequently or as severely as mature stands of this species. Even though black spruce is defoliated by spruce budworm in some cases, it was not considered a susceptible species and consequently was excluded from the impact calculations. Balsam fir was not included in impacts because extensive stands of this species are not present in the defoliated areas.

Impact classes and associated annual growth losses are listed in Table 1 and are the same as those used by Brandt and Amirault (1994). Annual growth losses for various impact classes differ from those used by Gross (1985). Gross's values for growth loss were developed from Kulman (1971) and are high for this study area for the first 1–3 years of defoliations.[5] For 4–7 years of defoliation, the growth losses reported by Gross (1985) and Kulman (1971) are comparable to those used for this region. For all maturity classes of both white spruce and white spruce–trembling aspen stands defoliated by spruce budworm, the depletion factors by impact class were A, 1; B, 5; C, 13; D, 24; and E, 38%. The depletion factor of an impact class was the quotient of the sum of annual growth loss in an impact class and all lower impact classes, and the number of years in the study period (i.e., 5). Depletion factors represent the annual expected growth loss for any year in the study period. For a forest to be assigned

[5] Herb Cerezke. 1993. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta. Personal Communication.

Table 1. Rules used to assign infested 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 during the study	A	5	15
Four out of 5 years of moderate-to-severe defoliation, with at least 2 years occurring during the study	B	20	30
Five out of 6 years of moderate-to-severe defoliation, with at least 2 years occurring during the study	C	40	60
Six out of 8 years of moderate-to-severe defoliation, with at least 3 years occurring during the study	D	55	80
Seven out of 10 years of moderate-to-severe defoliation, with at least 3 years occurring during the study	E	70	90

Source: Herb Cerezke. 1993. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta. Personal communication.

Table 2. Rules used to assign infested stands to impact classes and their associated mortality losses for jack pine budworm defoliation

Rule	Impact class	Mortality 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 occurring during or immediately prior to the study	B	0
One year of moderate-to-severe defoliation and an additional year of no more than moderate defoliation occurring during or immediately prior to the study	C	0
Two consecutive years of moderate-to-severe defoliation or 3 out of 4 years occurring during or immediately prior to the study	D	13
Three consecutive years of moderate-to-severe defoliation or 4 out of 5 years occurring during or immediately prior to the study	E	23
Four consecutive years of moderate-to-severe defoliation or 5 out of 6 years occurring during or immediately prior to the study	F	50

Table 3. Rules used to assign infested 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 occurring during the study or 2 consecutive years immediately prior to the study	A	50
Two consecutive years of moderate-to-severe defoliation or 3 out of 4 years with at least 1 year occurring during the study	B	64
Three consecutive years of moderate-to-severe defoliation or 4 out of 5 years with at least 2 years occurring during the study, or 5 out 7 years with at least 4 years occurring during the study	C	75
Four consecutive years of moderate-to-severe defoliation or 5 out of 6 years with at least 3 years occurring during the study	D	80
Five consecutive years of moderate-to-severe defoliation or 6 out of 7 years with at least 4 years occurring during the study	E	90
Six consecutive years of moderate-to-severe defoliation or 7 out of 8 years with at least 5 years occurring during the study	F	95

to an impact class, it is assumed that the forest 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 impact classes 0, A, B, and C. In impact classes D and E, the cumulative mortalities in stands were 10 and 25%, respectively. These mortality factors are similar to those reported by Stevenson (1970) for Alberta, but slightly lower than those reported elsewhere in Canada (Elliott 1960; Howse et al. 1980). Mortality usually begins after 6–7 consecutive years of moderate-to-severe defoliation (impact class D) and ranges from 10 to 25%.

In the Northwest Territories, mortality and growth losses caused by spruce budworm were calculated differently from those in other jurisdictions. The CFRDS inventory does not extend into the Northwest Territories; consequently, it could not be used to determine the infested area in each impact class. Infested area in each impact class was estimated based on defoliation area reported in the Northern Forestry Centre's annual Forest Insect and Disease Survey reports for the period 1988–1992 (Emond and Cerezke 1989, 1990; Cerezke et al. 1991; Cerezke and Gates 1992; Cerezke and Brandt 1993).

Jack Pine Budworm

Jack pine budworm feeds primarily on jack pine in the study area; therefore, other pine species were excluded in the calculations. Jack pine budworm causes little damage to immature stands; consequently, they were excluded from the list of susceptible stands.[6] Mature and overmature stands were considered susceptible to both defoliation and defoliation-caused mortality and were included in calculating volume loss due to mortality.

The impact classes assigned to infested stands and the associated expected mortality percentages (Table 2) were the same throughout the study area. The expected mortality percentages are in general

[6] Jan Volney. 1993. Forestry Canada, Northern Forestry Centre, Edmonton, Alberta. Personal communication.

agreement with work by Knowles and Warner (1987). Only mortality estimates were included in this report because the last jack pine budworm outbreak collapsed in 1987. No estimates of growth loss were included.

Forest Tent Caterpillar

In the study area, forest tent caterpillar feeds primarily on trembling aspen. Trembling aspen growing in pure stands and mixed-wood stands, regardless of age, was included in the calculation of impacts. All other species were excluded.

Rules used to assign impact classes to infested stands and their associated annual growth loss are given in Table 3. These rules have changed slightly from those used by Brandt and Amirault (1994). For 1–3 consecutive years of defoliation (impact classes A, B, and C), the expected annual growth losses range from 50 to 75%. These values represent an average of many studies and are similar to those reported by Barter and Cameron (1955), higher than those of Ives (1971), and lower than those reported by Batzer et al. (1954), Rose (1958), Hildahl and Reeks (1960), and Lachance et al. (1984). 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 used for spruce budworm. For both hardwood and mixed-wood aspen stands defoliated by forest tent caterpillar, the depletion factors by impact class were A, 10; B, 23; C, 38; D, 54; E, 72; and F, 91%.

Mortality occurs occasionally in trembling aspen stands defoliated by forest tent caterpillar (Barter and Cameron 1955; Churchill et al. 1964). Although other confounding factors might have been involved, forest tent caterpillar was the principal agent responsible for widespread aspen mortality in the study area. Cumulative mortality of aspen was based on work done by Churchill et al. (1964) in Minnesota. No mortality occurred in aspen in impact classes 0, A, and B. The expected mortalities of infested stands assigned to impact classes C, D, E, and F were 25, 30, 35, and 40%, respectively.

Large Aspen Tortrix

Large aspen tortrix feeds primarily on trembling aspen. Growth loss caused by large aspen tortrix defoliation was treated differently than defoliation caused by the three previous defoliators because of two related problems. First, maps showing the exact locations and intensities of defoliation were not produced; therefore, the CFRDS inventory could not be used. Instead, the methodology used for spruce budworm defoliation in the Northwest Territories was modified and applied to large aspen tortrix defoliation. Second, no information exists on the impact of large aspen tortrix defoliation on its host.

Defoliation area was first reported in 1988 and was subsequently observed in each year until 1992 (Emond and Cerezke 1989, 1990; Cerezke et al. 1991; Cerezke and Gates 1992; Cerezke and Brandt 1993). To approximate the area assigned to each impact class, the area reported in 1988 (year 1) was assigned to impact class A. The area defoliated in 1989 was assigned to impact classes A and B. The portion to B was that amount defoliated in the previous year. The portion to A was the remainder, which was assumed to be defoliated for the first time. The area defoliated in 1990 was assigned to impact classes B and C. The portion to C was that amount defoliated during 1988–1990. The portion to B was the remainder defoliated in 1990. The area defoliated in 1991 was assigned to impact classes C and D. The portion to D was that amount defoliated during 1988–1991. The portion to C was the remainder defoliated in 1991. The area in each impact class and year was summed.

For this study, it is assumed that both large aspen tortrix and forest tent caterpillar similarly severely defoliate trembling aspen (Prentice 1955; Ives and Wong 1988). Forest tent caterpillar defoliation and its impact have been well-documented; therefore, rules used to assign impact classes to large aspen tortrix defoliation areas and the associated annual growth loss were those used for forest tent caterpillar (Table 3).

To determine the growth loss of defoliated aspen, several steps were taken. First, the area in each impact class was multiplied by the estimated mean annual increment and the number of years in the study period to estimate expected growth. Depletion factors were then applied against expected growth to determine the estimated depletion. No mortality that could be attributed to large aspen tortrix was observed; consequently, mortality was excluded in the estimates.

Bruce Spanworm

The principal host of Bruce spanworm is trembling aspen, but it also feeds on balsam poplar, willow (*Salix* spp.), white birch, choke cherry

(*Prunus virginiana* L.), Manitoba maple (*Acer negundo* L.), and white elm (*Ulmus americana* L.). Growth loss caused by Bruce spanworm defoliation was estimated using a method similar to that developed for large aspen tortrix defoliation.

Bruce spanworm defoliation was reported primarily in 1989 and 1990 (Emond and Cerezke 1990, Cerezke et al. 1991); defoliation area (519 404 ha), however, was only reported in 1990. Bruce spanworn outbreaks are short-lived and populations increase rapidly (Ives and Wong 1988); consequently it was assumed that one-third of the 1990 area was defoliated in the previous year. A total of 171 403 ha was therefore assigned to impact class B; the remainder was defoliated for only one year and was assigned to impact class A.

No information exists on the impact of Bruce spanworm defoliation on trembling aspen. Ives and Wong (1988) reported that severe defoliation results in reduced radial growth of the host. It is assumed that both Bruce spanworm and forest tent caterpillar have similar effects on aspen. Rules used to assign impact classes to Bruce spanworm defoliation areas and the associated annual growth loss were therefore those used for forest tent caterpillar (Table 3).

No aspen mortality caused by Bruce spanworm defoliation was observed.

Bark Beetles

Mountain Pine Beetle

Estimates of timber volume loss due to mountain pine beetle were obtained from the Northern Forestry Centre's annual Forest Insect and Disease Survey (FIDS) reports for 1988–1992 (Emond and Cerezke 1989, 1990; Cerezke et al. 1991; Cerezke and Gates 1992; Cerezke and Brandt 1993). The volume depleted was the product of the number of killed lodgepole pine and the volume per tree (about 0.33 m^3/tree; Huang 1994a). Estimates for Alberta included some mortality within Waterton Lakes National Park.

Spruce Beetle

Estimates of spruce attacked by spruce beetle were obtained from the above-cited FIDS reports for 1988–1992.

Douglas-fir Beetle

Estimates of Douglas-fir beetle damage were obtained from surveys completed in 1993 (Brandt 1994). The volume depleted was the product of the number of killed Douglas-fir and the volume per tree (about 2.00 m^3/tree; Huang 1994b). All mortality occurred in Jasper National Park.

Diseases

Lodgepole Pine Dwarf Mistletoe

Information was lacking on the distribution of lodgepole pine dwarf mistletoe in all jurisdictions except Manitoba and parts of Alberta. In Manitoba, most mistletoe infestations were mapped by Manitoba Natural Resources between 1986 and 1989 (Slivitzky et al. 1991; Baker et al. 1992). Information from the Manitoba study was used to determine mistletoe impacts for that province. In Alberta, some areas of dwarf mistletoe mapped in the Bow-Crow Forest between 1984 and 1987by Alberta Land and Forest Services were used for this report. In other parts of Alberta and in Saskatchewan, surveys were conducted during 1994 to map severe infestations.

The distribution of severe infestations of dwarf mistletoe extends from southeastern Manitoba through central and northern Saskatchewan to Alberta. Dwarf mistletoe infects jack pine in Manitoba and Saskatchewan, and jack and lodgepole pines in Alberta. Pines of almost any age are infected by this disease (Baranyay 1970; Hawksworth and Johnson 1989).

Dwarf mistletoe affects its host in two ways. Infections stunt and deform branches, ultimately reducing radial and height growth, and older severe infections lead to branch and tree mortality. Growth reductions can be severe. In a study on the effects of dwarf mistletoe on lodgepole pine in Alberta, Baranyay and Safranyik (1970) noted growth reductions of 18–32%. The reduction in growth was influenced by site and length of time trees were infected. Volume losses were higher on dry sites than wet sites. When the age of the trees and the length of time trees were infected were factored in, growth reductions ranged from 31 to 42%. Mortality losses ranged from 0 to 26%. Stands with no mortality were those only recently infected; high mortality occurred in stands infected for longer periods of time. Similar growth and mortality losses were reported by Hawksworth and Hinds (1964). Baker et al. (1992) studied the effects of dwarf mistletoe on jack pine stands in Manitoba.

They reported volume losses of 53–70%, depending on the potential volume that could have been produced on the same sites if the stands were not infected with dwarf mistletoe. Volume losses reported in Manitoba include both growth and mortality losses.

Dwarf mistletoe depletion factors used for growth loss and mortality were 38 and 12% in lodgepole pine stands, and 40 and 15% in jack pine stands, respectively. For lodgepole pine, these values represent an average of mortality losses reported by Baranyay and Safranyik (1970). The depletion factors applied against jack pine stands were based on results reported by Baker et al. (1992).

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 one method for the entire study area (Tables 4–7).

Tree age at decay onset and decay estimates were obtained from the literature. The weighted average age for tree species older than tree age at decay onset was calculated from the inventories and was weighted by volume. Gross merchantable volumes used were the volumes of the various tree species older than the estimated minimum decay age. The decay divisor is the difference between the weighted average age and the minimum decay age. To estimate annual decay, the product of the gross merchantable volume and decay was divided by the decay divisor.

Estimates of decay and its onset in white spruce were based on work done by Denyer and Riley (1954), Etheridge (1958), and Basham and Morawski (1964). Similar estimates for black spruce, jack pine, lodgepole pine, and balsam fir were based on work by Morawski et al. (1958), Loman and Paul (1963), Basham and Morawski (1964), Basham (1967), Whitney (1976, 1989), and Lavallée (1986, 1987). At the time of this study, no references existed for estimates of Douglas-fir decay in Alberta or tamarack decay in the study area.

In trembling aspen, estimates of decay and its onset were based on work completed by Meinecke (1929), Black and Kristapovich (1954), Paul and Etheridge (1958), Basham (1958), and Basham and Morawski (1964). Balsam poplar decay estimates were based on a study by Paul and Etheridge (1958). Basham and Morawski (1964) reported the white birch decay estimates used in this report. No references existed for decay estimates of other hardwood species in the region at the time of this study; however, other hardwood species comprise only a minor component (4%) of merchantable volume in the study area.

Errors in Methods

A number of possible errors in the methods are discussed to assist the reader in judging the quality of information provided in this report. No attempt has been made to quantify these errors, but they can be discussed in relative terms. Errors that could influence the accuracy of the impacts are field-survey errors, data-processing errors including mapping and digitization errors, incorrect information on the impact of pests within the region, and errors in relating growth data and forest insect and disease impacts. Considering all errors, the depletion estimates in this report are likely an underestimate, but to what degree is unknown.

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, spruce beetle, and lodgepole pine dwarf mistletoe were mapped by staff from either fixed-wing or rotary-wing aircraft. In such surveys, mapped infestations are large (thousands of hectares); smaller infestations (less than a few hundred hectares) could be missed or not mapped. Further, infestation boundaries are irregular and some areas might not be mapped correctly or stands could be mistakenly deleted. As well, field staff could have problems reaching affected areas to estimate the area of pest infestations. Aircraft are not always available for mapping, and road access is sometimes limited; this impedes thorough and complete mapping. All these factors lead to underestimation of the impacts caused by insects and diseases.

A number of errors can also be introduced during the process of map digitization. Defoliation maps are digitized and stored in spatial data bases in a GIS. Due to the unavailability of mylar 1:250 000 scale topographic maps, paper maps were used for the digitization process in this study. Paper maps shrink and expand with changes in relative humidity, and digitization of infested areas can slightly over- or underestimate depletion areas. The base coverage (GIS term: back coverage) on which all spatial data were overlaid for this study was digitized from a 1:6 000 000-scale map of Canada.

Table 4. Decay estimation for major tree species in Alberta, 1988–1992

Tree species	Tree age at decay onset (years)	Volume-weighted average age (years)[a]	Gross merchantable volume above minimum age[a] ('000 m^3)	Decay divisor (years)	Decay (%)	Annual decay ('000 m^3)[b]
White spruce	90	132	594 169	42	4	566
Black spruce	80	122	83 681	42	3	60
Jack pine	60	105	60 739	45	8	108
Lodgepole pine	100	128	231 954	28	4	331
Balsam fir	40	140	29 911	100	6	18
Tamarack	80	140	2 416	60	5	2
Douglas-fir	80	140	1 620	60	5	1
Trembling aspen	40	89	621 570	49	25	3 171
Balsam poplar	40	89	122 198	49	12	299
White birch	40	89	25 152	49	12	62

[a] Phil Anderson. 1994. Alberta Environmental Protection, Land and Forest Services, Forest Resource Information Branch, Edmonton, Alberta. Personal communication.

[b] The product of gross merchantable volume and decay divided by the decay divisor.

Table 5. Decay estimation for major tree species in Saskatchewan, 1988–1992

Tree species	Tree age at decay onset (years)	Volume-weighted average age (years)[a]	Gross merchantable volume above minimum age[a] ('000 m^3)	Decay divisor (years)	Decay (%)	Annual decay ('000 m^3)[b]
White spruce	90	104	63 148	14	4	180
Black spruce	80	104	92 757	24	3	116
Jack pine	60	82	104 636	22	8	380
Balsam fir	40	87	14 990	47	6	19
Tamarack	80	106	3 708	26	5	7
Trembling aspen	40	70	269 071	30	25	2 242
Other hardwoods[c]	40	76	55 407	36	12	185

[a] David Lindenas. 1994. Saskatchewan Parks and Renewable Resources, Timber Management Section, Prince Albert, Saskatchewan. Personal communication.

[b] The product of gross merchantable volume and decay divided by the decay divisor.

[c] Other hardwoods include white birch, white elm, green ash (*Fraxinus pennsylvanica* var. *subintegerrima* [Vahl] Fern.), Manitoba maple, and balsam poplar.

Table 6. Decay estimation for major tree species in Manitoba, 1988–1992

Tree species	Tree age at decay onset (years)	Volume-weighted average age (years)[a]	Gross merchantable volume above minimum age[a] ('000 m^3)	Decay divisor (years)	Decay (%)	Annual decay ('000 m^3)[b]
White spruce	90	107	29 440	17	4	69
Black spruce	80	103	110 292	23	3	144
Jack pine	60	76	91 815	16	8	459
Balsam fir	40	69	8 921	29	6	18
Tamarack	80	105	8 449	25	5	17
Eastern white cedar	80	102	480	22	10	2
Trembling aspen	40	66	155 169	26	25	1 492
Balsam poplar	40	67	26 753	27	12	119
White birch	40	66	17 688	26	12	82
Other hardwoods[c]	40	67	14 774	27	12	66

[a] Gerry Becker. 1994. Manitoba Natural Resources, Forest Management, Winnipeg, Manitoba. Personal communication.

[b] The product of gross merchantable volume and decay divided by the decay divisor.

[c] Other hardwoods includes white elm, green ash, Manitoba maple, and bur oak.

Table 7. Decay estimation for major tree species in the Cameron Hills and Liard River valley in the Northwest Territories, 1988–1992

Tree species	Tree age at decay onset (years)	Volume-weighted average age (years)[a]	Gross merchantable volume above minimum age[a] ('000 m^3)	Decay divisor (years)	Decay (%)	Annual decay ('000 m^3)[b]
White spruce	90	122	34 261	32	4	43
Black spruce	80	126	7 829	46	3	5
Jack pine	60	79	1 008	19	8	4
Balsam fir	40	79	99	39	6	–[c]
Tamarack	80	131	51	51	5	–
Trembling aspen	40	77	61 359	37	25	415
Balsam poplar	40	83	14 055	43	12	39
White birch	40	66	979	26	12	5

[a] Craig Robinson. 1994. Northwest Territories Renewable Resources, Forest Management Division, Hay River, Northwest Territories. Personal communication.

[b] The product of gross merchantable volume and decay divided by the decay divisor.

[c] Value not significant.

Small errors can be introduced when overlaying coverages on to this larger-scale base coverage (i.e., an infestation can appear in a lake on the base coverage when it in fact is beside the lake). In future, it could be possible to use a base coverage that has been digitized from 1:250 000-scale mylar maps, but these are currently unavailable.

Review of the scientific literature reveals that impact information on the major pests of this region is incomplete 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, or pests were excluded because no information was available. The effect of this lack of information on impact estimates is unknown. The number of forest pests in this region is large (Hiratsuka 1987; Ives and Wong 1988), and the impacts of many of these pests have not been studied. Total impacts were underestimated because many pests were excluded in the estimates.

Inventory data influence the determination of impacts. The CFRDS used in parts of this study was last updated in 1991, but parts of this system are much older. Some insect- or disease-infested areas that appear in the inventory might have been harvested or burnt since the last inventory, and the associated impacts will not account for these changes. More commonly, stands will have grown since the last inventory and impacts will be underestimated. Some forested areas located at the transition zone between forests and agricultural land might not be inventoried; any impacts due to defoliation in these areas were not included in the estimates.

Estimates of growing stock and resulting annual increment used in determining what can be harvested from a forest are generated by measuring unmanaged stands. These stands have been subjected to endemic and possibly epidemic insect and disease populations during their lifetimes prior to measurement. The impacts of insects and diseases on growth and tree mortality are captured in the measurements, but it can be difficult to relate the impacts against the existing estimates of growing stock and growth. It is also difficult to relate the impacts estimated within this report to growth estimates determined for forest inventories. Once this relationship is fully understood, the information can be effectively used in forest management decisions.

PEST-CAUSED IMPACTS

Defoliators

Spruce Budworm

Spruce budworm defoliation occurred in all jurisdictions during the study (Fig. 2). Defoliation areas increased substantially in Alberta, Saskatchewan, and the Northwest Territories from those observed between 1982 and 1987, while defoliation area decreased in Manitoba (Brandt and Amirault 1994).

In Alberta, the largest amount of defoliation area occurred in 1992 (Table 8). Most defoliation occurred in three main outbreak areas: along the Chinchaga River and surrounding areas, near Hawk Hills, and along the Athabasca and House rivers. Estimated white spruce growth loss as a result of spruce budworm defoliation during the study period was 159 000 m^3 (Table 9). This growth loss represents 4.8% of the total estimated white spruce growth in the stands defoliated by spruce budworm. No mortality was observed in Alberta; consequently, a mortality factor was not applied to the estimated volume on the infested area in impact class D.

In Saskatchewan, spruce budworm defoliation area peaked at 87 000 ha in 1992. Defoliation occurred in two outbreaks: one near Hudson Bay, the other near Big River. The outbreak near Hudson Bay began in 1982 (Moody and Cerezke 1983), while the outbreak near Big River increased in size from when it was first detected in 1989–1992. Estimated white spruce growth loss during the study was 5000 m^3. This growth loss represents 1% of the total estimated white spruce growth in the stands defoliated by spruce budworm. Mortality due to spruce budworm defoliation was 33 000 m^3, representing 0.4% of the total estimated standing volume in white spruce stands defoliated by spruce budworm.

In Manitoba, spruce budworm defoliation area peaked at 58 016 ha in 1989. The most-damaging outbreaks occurred in the sections of Lake Winnipeg East (Forest Management Units 30 and 31) and Interlake (Forest Management Units 40 and

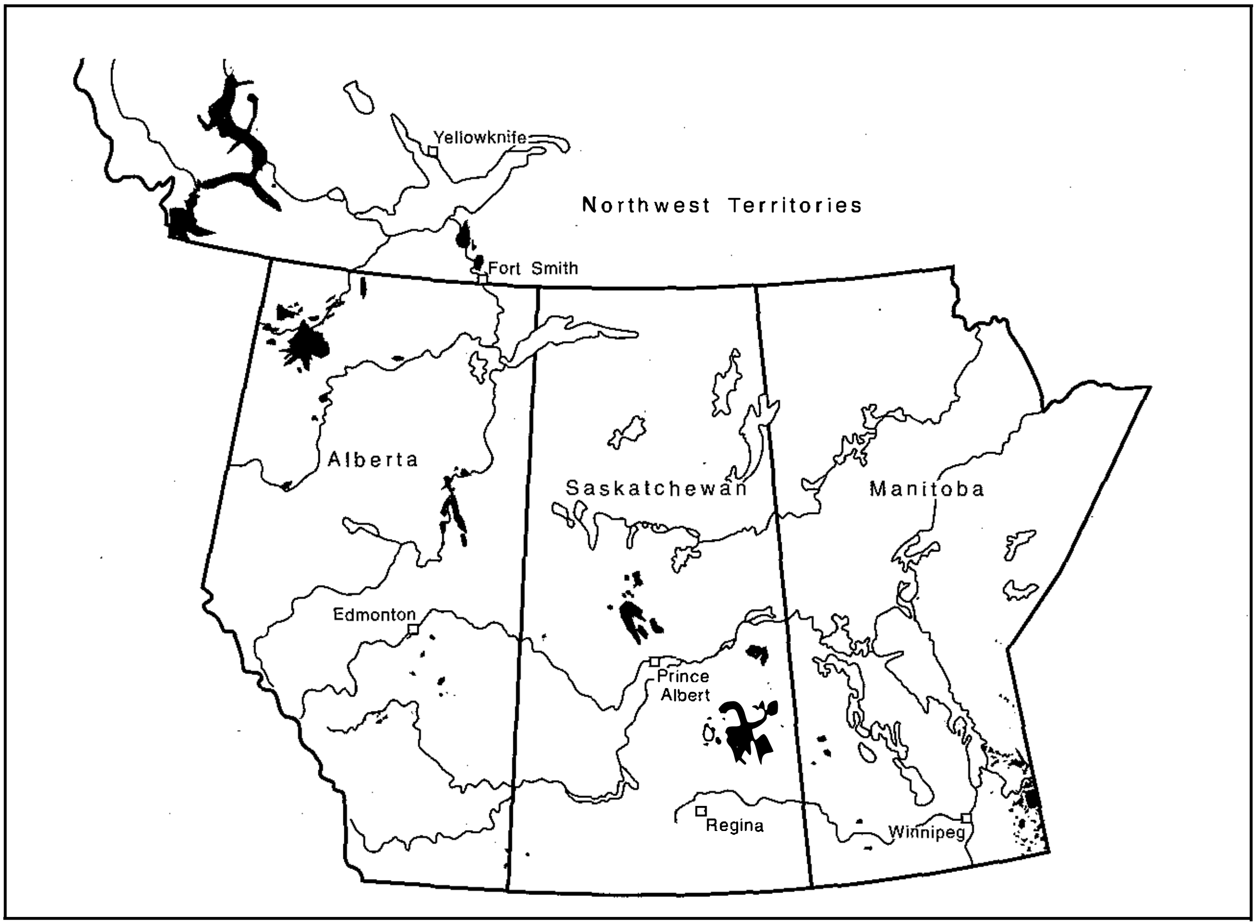

Figure 2. Areas of spruce and fir defoliated by spruce budworm, 1988–1992.

Table 8. Summary of spruce budworm defoliation in the study area, 1988–1992 (ha)[a]

Year	Alberta[b]	Saskatchewan	Manitoba	N.W.T.
1988	61 900	31 600	30 821	14 350
1989	85 850	34 650	58 016	98 600
1990	109 400	18 780	18 985	113 625
1991	141 200	15 600	30 000	130 000
1992	142 650	87 000	26 256	90 000

Sources: Emond and Cerezke (1989, 1990); Cerezke et al. (1991); Cerezke and Gates (1992); and Cerezke and Brandt (1993).

[a] Includes all areas with visible defoliation (≥35%).

[b] Includes small areas outside the forest reserve.

Table 9. Impacts caused by spruce budworm in Alberta, Saskatchewan, and the Northwest Territories, 1988–1992

Jurisdiction	Impact class	Infested area (ha)	Estimated volume on infested area ('000 m^3)[a]	Mortality loss ('000 m^3)[b]	Estimated growth on infested area ('000 m^3)[c]	Growth loss ('000 m^3)[d]
Alberta	0	43 613	3 358	0	469	0
	A	153 088	11 788	0	1 646	16
	B	25 846	1 990	0	278	14
	C	79261	6 103	0	852	111
	D	6 908	532	0[e]	74	18
	Total	308716	23 771	0	3 319	159
Saskatchewan	0	58 976	5 308	0	333	0
	A	23 005	2 070	0	130	1
	B	1 259	113	0	7	–[f]
	C	1 340	121	0	8	1
	D	984	89	9	6	1
	E	1 075	97	24	6	2
	Total	86 639	7 798	33	490	5
N.W.T.	0	194 664	15 573	0	779	0
	A	61 571	4 926	0	246	2
	B	17 832	1 427	0	71	4
	C	645	52	0	3	–
	D	1 034	83	8	4	1
	E	2 063	165	41	8	3
	Total	277 809	22 226	49	1 111	10

[a] Product of infested area and mean stand volume of infested white spruce stands. Estimated mean stand volumes are 77, 90, and 80 m^3ha^{-1} in Alberta, Saskatchewan, and the Northwest Territories, respectively.

[b] Product of mortality depletion factors and estimated volume on infested areas. Depletion factors by impact class are A–C, 0; D, 10; and E, 25%.

[c] Product of infested area, mean annual increment of the host, and the number of years in the study. Estimated mean annual increments are 2.15, 1.13, and 0.80 $m^3ha^{-1}yr^{-1}$ in Alberta, Saskatchewan, and the Northwest Territories, respectively.

[d] Product of growth loss depletion factors and estimated growth on infested areas. Depletion factors by impact class are A, 1; B, 5; C, 13; D, 24; and E, 38%.

[e] Although some mortality should have been evident in those infested areas in Alberta rated as impact class D, no mortality was observed.

[f] Value not significant.

41), but other infestations occurred in the Pineland Section (Forest Management Units 20 and 23). Knowles et al. (1992) estimated impacts due to spruce budworm defoliation on the Pine Falls Paper Company (formerly Abitibi-Price Inc., Pine Falls Division) Forest Management License (FML) in eastern Manitoba. The FML falls within Forest Management Units 31 and 35. The estimated loss due to growth reduction and mortality in white spruce, balsam fir, and black spruce was 242 000m^3 on about 30 000 ha. This value represents 15% of the total standing volume of white spruce, balsam fir, and black spruce stands defoliated by spruce budworm. The loss in the Pine Falls Paper Co. FML was extrapolated for infestations in Forest Management Units 20, 23, 30, 40, and 41.[7] The estimated volume loss in these areas was 168 000 m^3.

In the Northwest Territories, spruce budworm defoliation area increased from 14 350 ha in 1988 to a peak of 130 000 ha in 1991. Most defoliation occurred to white spruce stands located along the Liard, MacKenzie, and Slave rivers. The estimated growth loss resulting from spruce budworm defoliation was 10 000 m^3, representing about 0.9% of the total estimated white spruce growth in the stands defoliated by spruce budworm (Table 9). Mortality loss was estimated as 49 000 m^3. This mortality represents 0.2% of the total estimated white spruce growth in the stands defoliated by spruce budworm.

Total volume loss due to spruce budworm defoliation and defoliation-caused mortality in the study area was 666 000 m^3.

Jack Pine Budworm

Jack pine budworm caused significant defoliation, particularly in Manitoba and Saskatchewan (Fig. 3) between 1983 and 1987 (Moody and Cerezke 1984, 1985, 1986; Cerezke and Moody 1987). Since the last outbreak collapsed in 1987, very little defoliation has occurred. Tree mortality in Saskatchewan and Manitoba during 1988 and 1989 was the only effect of the last outbreak that was evident.

In Saskatchewan, the estimated mortality loss was 2000 m^3 on about 176 ha. This loss represents 13.3% of the total estimated standing volume of jack pine (15 000 m^3) defoliated by jack pine budworm.

The intensity of jack pine budworm defoliation during the 1983–1987 outbreak was more severe and had a greater impact on the jack pine forests in Manitoba than in Saskatchewan. Estimated mortality loss due to jack pine budworm was 308 000 m^3 on about 20 561 ha. This loss represents 13.5% of the total estimated standing volume of jack pine (796 800 m^3) defoliated by jack pine budworm.

Throughout the study area, the total loss in jack pine stands due to jack pine budworm defoliation-caused mortality was 310 000 m^3.

Forest Tent Caterpillar

Extensive aspen defoliation is a common occurrence in the study area. While aspen defoliation can be caused by a number of insects, the most prominent is forest tent caterpillar. The total area of aspen defoliation commonly amounted to millions of hectares annually (Table 10). 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 (necessitating the "gross" and "net" columns in Table 10). Areas of forest tent caterpillar-defoliated aspen are shown in Figure 4.

In Alberta, the net area of forest tent caterpillar defoliation during the study decreased from that reported in Brandt and Amirault (1994). Outbreaks occurred in east-central Alberta and near Peace River and Grande Prairie. Peak defoliation area occurred in 1988 and gradually declined until the outbreak collapsed in 1991. Defoliation area in Alberta was more than twice that observed in Saskatchewan and nine times greater than that in Manitoba. Estimated trembling aspen growth loss due to forest tent caterpillar defoliation was 4 199 000 m^3 (Table 11). This growth loss represents 13.3% of the total estimated growth of aspen defoliated by forest tent caterpillar in Alberta. Mortality loss was estimated as 4 190 000 m^3, representing about 1.5% of the total estimated standing volume of aspen defoliated by forest tent caterpillar.

In Saskatchewan, the net area of forest tent caterpillar defoliation increased from that observed in Brandt and Amirault (1994). Most defoliation occurred in west-central Saskatchewan, but some also occurred near Hudson Bay. Defoliation area

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[7] Keith Knowles. 1994. Manitoba Natural Resources, Forest Protection Section, Winnipeg, Manitoba. Personal communication.

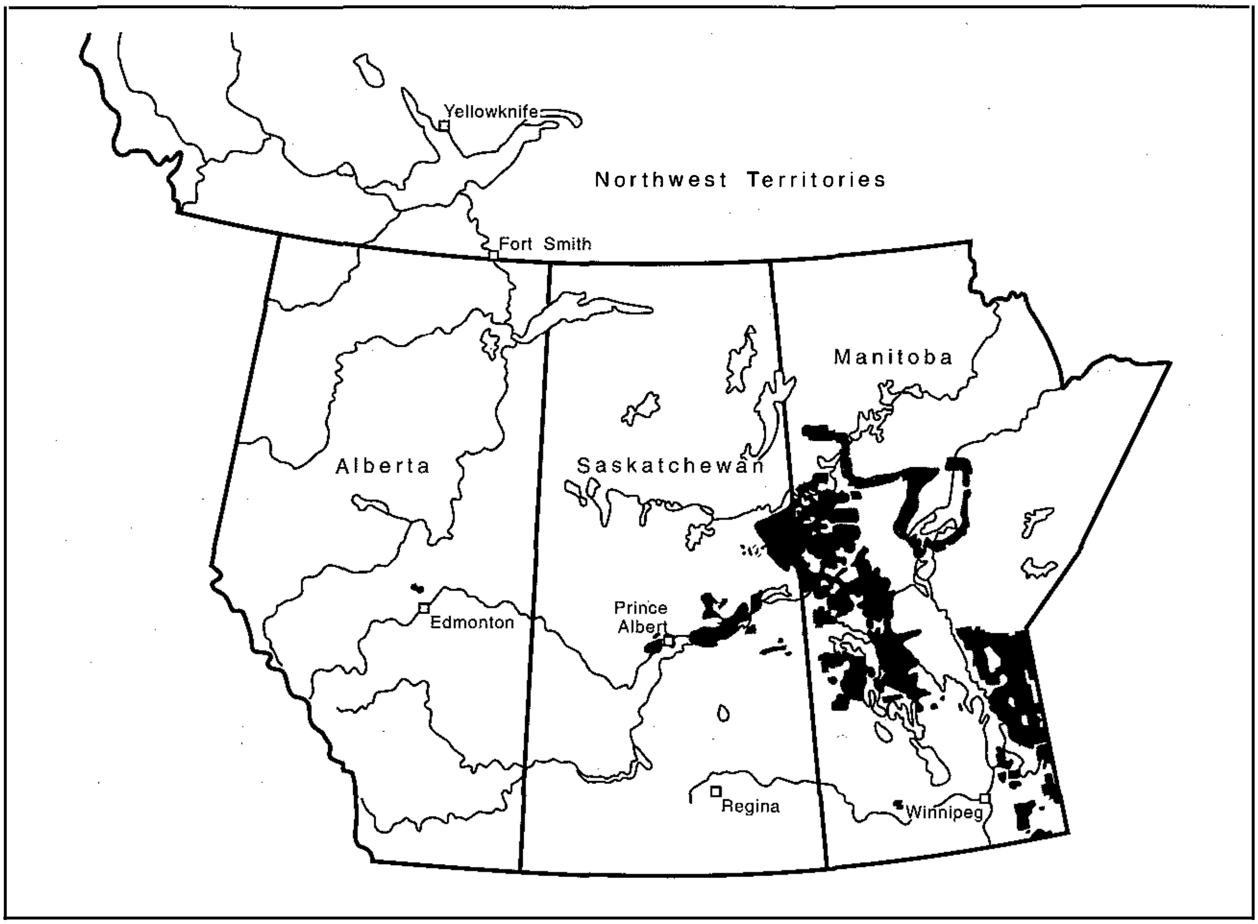

Figure 3. Areas of jack pine defoliated by jack pine budworm, 1982–1987.

was greatest in 1988 and gradually declined until the outbreak collapsed in 1990. Estimated trembling aspen growth loss due to forest tent caterpillar defoliation was 3 616 000 m^3. This volume represents 18.6% of the total estimated growth of aspen defoliated by forest tent caterpillar. Mortality loss was estimated as 8 023 000 m^3, representing about 3.4% of the total estimated standing volume of aspen defoliated by forest tent caterpillar.

In Manitoba, forest tent caterpillar defoliation area was about the same as in Brandt and Amirault (1994). Unlike Alberta and Saskatchewan, defoliation in Manitoba was scattered throughout the province in fairly small areas. Defoliation area peaked in 1989 at 325 000 ha. Estimated growth loss due to defoliation was 308 000 m^3, representing 7.1% of the total estimated growth of aspen defoliated by forest tent caterpillar. Estimated mortality loss due to defoliation was 3000 m^3. This volume loss represents less than 0.1% of the total estimated standing volume of aspen defoliated by forest tent caterpillar.

Total volume loss due to forest tent caterpillar defoliation and defoliation-caused mortality in the study area was 20 339 000 m^3. Growth loss was 8 123 000 m^3 and mortality loss was 12 216 000 m^3.

Large Aspen Tortrix

The most-severe defoliation by large aspen tortrix occurred in Manitoba between 1988 and 1992, when 2849, 18 650, 15 540, and 12 691 ha of aspen were defoliated, respectively. The estimated growth loss resulting from this defoliation was 122 000 m^3, representing 23.7% of the total estimated growth of large aspen tortrix-defoliated aspen in Manitoba (Table 12).

Bruce Spanworm

A Bruce spanworm outbreak occurred in Alberta in 1989 and 1990. Peak defoliation area reached 519 404 ha in 1990. The largest area of defoliation (352 346 ha) was located in the vicinity of Claresholm, Rocky Mountain House, and Castor. Other large areas were near Hinton, Obed,

Table 10. Summary of forest tent caterpillar defoliation in the study area, 1988–1992 ('000 ha)

	Alberta		Saskatchewan		Manitoba		N.W.T.	
Year	Gross	Net	Gross	Net	Gross	Net	Gross	Net
1988	13 830	2 766[a]	4 660	932[a]	528	53	–[b]	–[b]
1989	–[c]	1 180[a]	–[c]	791	–[c]	325	–[b]	–[b]
1990	–[c]	609	1 305	261	–[c]	15	–[b]	–[b]
1991	646	129[a]	–[c]	–[d]	–[c]	58	–[b]	–[b]
1992	–[c]	–[d]	–[c]	–[d]	–[c]	51	–[b]	–[b]

Source: Emond and Cerezke (1989, 1990); Cerezke et al. (1991); Cerezke and Gates (1992); and Cerezke and Brandt (1993).

[a] Estimated by the authors as 20% of the total area mapped.

[b] No defoliation.

[c] Gross area not reported.

[d] Defoliation occurred but the area was not reported.

Table 11. Impacts caused by forest tent caterpillar in the study area, 1988–1992

Jurisdiction	Impact class	Infested area (ha)	Estimated volume on infested area ('000 m^3)[a]	Mortality loss ('000 m^3)[b]	Estimated growth on infested area ('000 m^3)[c]	Growth loss ('000 m^3)[d]
Alberta	0	689 627	68 963	0	7 551	0
	A	1 162 990	116 299	0	12 735	1 274
	B	872 884	87 288	0	9 558	2 198
	C	128 742	12 874	3 219	1 410	536
	D	32 366	3 237	971	354	191
	Total	2 886 609	288 661	4 190	31 608	4 199
Saskatchewan	0	150 645	19 433	0	1 619	0
	A	633 522	81 724	0	6 810	681
	B	773 168	99 739	0	8 312	1 912
	C	239 138	30 849	7 712	2 571	977
	D	8 022	1 035	311	86	46
	Total	1 804 495	232 780	8 023	19 398	3 616
Manitoba	0	139 958	17 635	0	1 449	0
	A	261 829	32991	0	2 710	271
	B	15 592	1 965	0	161	37
	C	76	10	3	1	–[e]
	Total	417 455	52 601	3	4 321	308
N.W.T.	0	0	0	0	0	0

[a] Product of infested area and mean stand volume in infested trembling aspen stands. Estimated mean stand volumes are 100, 129, and 126 m^3ha^{-1} in Alberta, Saskatchewan, and Manitoba, respectively.

[b] Product of mortality depletion factors and estimated volume on infested areas. Depletion factors by impact class are A–B, 0; C, 25; D, 30; E, 35; and F, 40%.

[c] Product of infested area, mean annual increment of the host, and the number of years in the study. Estimated mean annual increments are 2.19, 2.15, and 2.07 $m^3ha^{-1}yr^{-1}$ in Alberta, Saskatchewan, and Manitoba, respectively.

[d] Product of growth loss depletion factors and estimated growth on infested areas. Depletion factors by impact class are A, 10; B, 23; C, 38; D, 54; E, 72; and F, 91%.

[e] Value not significant.

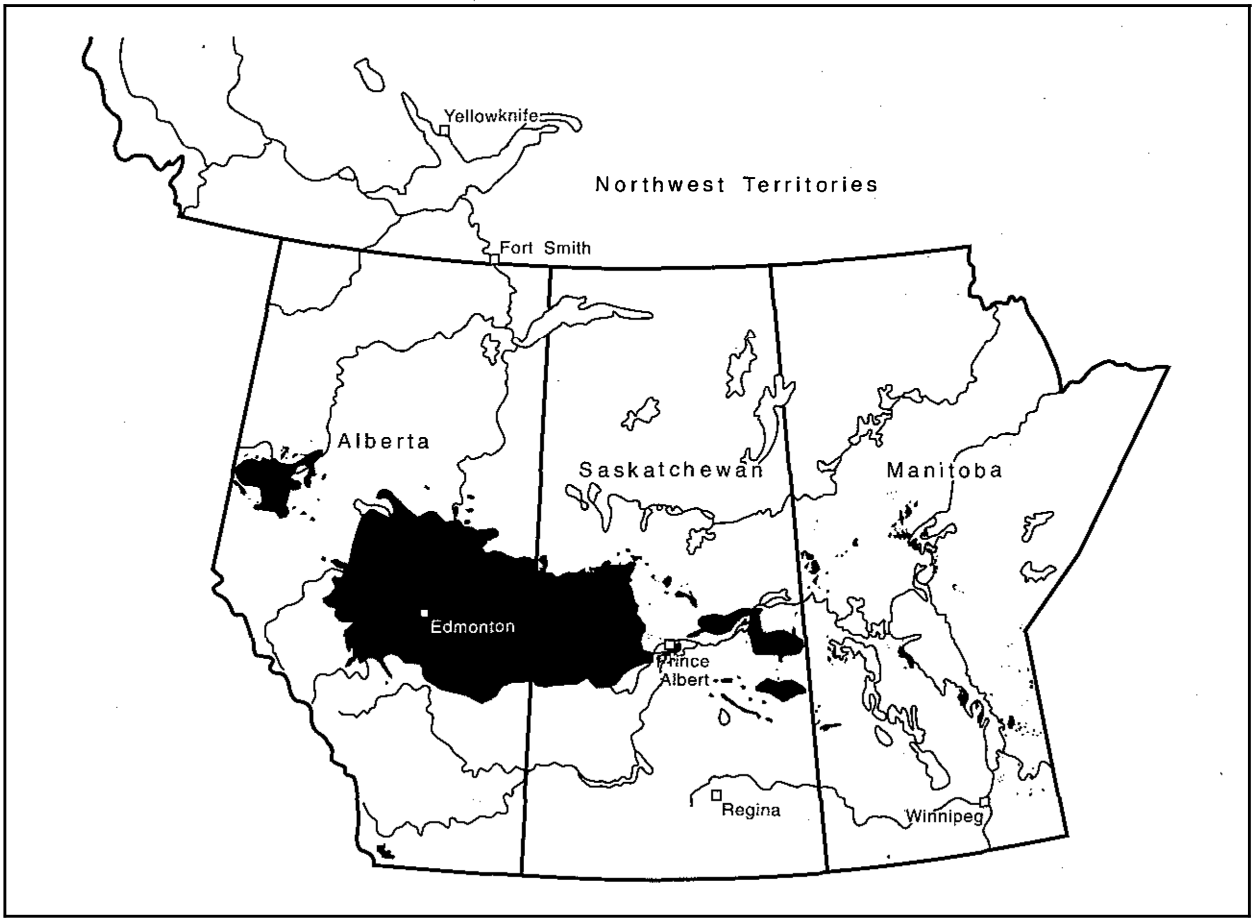

Figure 4. Areas of trembling aspen defoliated by forest tent caterpillar, 1988–1992.

Table 12. Impacts caused by large aspen tortrix in Manitoba, 1988–1992

Impact class	Infested area (ha)	Estimated growth ('000 m^3)[a]	Depletion factor (%)	Depletion ('000 m^3)[b]
A	18 650	193	10	19
B	15 540	161	23	37
C	12 691	131	38	50
D	2 849	30	54	16
Total	49 730	515	N.A.[c]	122

[a] Product of infested area, mean annual increment (2.07 $m^3 ha^{-1} yr^{-1}$), and 5 years (the length of the study).

[b] Product of expected growth and the depletion factor.

[c] Not applicable.

Whitecourt, Manning, Keg River, north of Edson, and south and west of Grande Prairie. In other years during the study, small localized areas of defoliation occurred in Alberta and Saskatchewan but defoliation area was not reported (Emond and Cerezke 1989; Cerezke and Gates 1992; Cerezke and Brandt 1993). The estimated growth loss on reported areas in Alberta was 813 000 m^3 (Table 13). This represents 14.3% of the total estimated growth of aspen defoliated by Bruce spanworm in Alberta.

Bark Beetles

Mountain pine beetle

Since the last mountain pine beetle outbreak collapsed in 1986, mountain pine beetle activity has remained low. The greatest mortality occurred in 1989, when about 630 lodgepole pine trees were killed. Most of this mortality took place in the Bow-Crow Forest. Annual mortality during the study is presented in Table 14. The estimated volume depleted totaled 241 m^3.

Spruce Beetle

An outbreak of spruce beetle occurred in northwestern Alberta during the study, with only endemic levels of this pest reported elsewhere. Forest-harvest activities were increased in infested areas in order to salvage as much timber as possible. Salvage operations during 1992–1993 harvested about 10 000 m^3 of white spruce killed by spruce beetle during the outbreak (Brandt 1994).

Douglas-fir Beetle

A Douglas-fir beetle infestation was present in Jasper National Park during the study. The infestation was first detected in 1991. By the end of 1992, 911 Douglas-fir were killed by the beetle. Most dead trees were located near the Jasper townsite along the Athabasca River and in other areas north and south of the townsite. The estimated volume depleted was about 2000 m^3 (Table 15).

Diseases

Lodgepole Pine Dwarf Mistletoe

The following dwarf mistletoe infestation areas reported for each province were based on aerial surveys. Only severely infected trees with broomed branches and dead trees were visible from the air. The areas of less-severely infected trees could not be determined. Unless these areas can be accurately mapped, there is no way of estimating the impacts due to growth reductions occurring on these sites. The impacts estimated in this report are for the mapped areas only.

In Alberta, 112 125 ha of jack pine forests and 54 329 ha of lodgepole pine forests were severely infected by dwarf mistletoe (Table 16). Infestations on jack pine were located in 10 general areas. Three were along the Peace River southwest of Fort Vermilion, southeast of Manning near the Whitemud Creek and the Peace River confluence, and just north of Peace Point in Wood Buffalo National Park. The others were: near the confluence of the Loon and Wabasca rivers; northeast of Muskwa Lake along the Trout River; north and east of Lesser Slave Lake; along the Athabasca River between Whitecourt and east of Smith; near Marie Lake; north and west of Primrose Lake Range; and north of Fort McMurray to Lake Athabasca from just west of the Athabasca River to the Alberta–Saskatchewan

Table 13. Impacts caused by Bruce spanworm in Alberta, 1988–1992

Impact class	Infested area (ha)	Estimated growth ('000 m^3)[a]	Depletion factor (%)	Depletion ('000 m^3)[b]
A	348 001	3 811	10	381
B	171 403	1 877	23	432
Total	519 404	5 688	N.A.[c]	813

[a] Product of infested area, mean annual increment (2.19 $m^3ha^{-1}yr^{-1}$), and 5 years (the length of the study).

[b] Product of expected growth and the depletion factor.

[c] Not applicable.

Table 14. Summary of mountain pine beetle damage in Alberta, 1988–1992

Year	Estimated mortality of lodgepole pine (no. of stems)	Estimated volume of killed lodgepole pine[a] (m^3)
1988	60[b]	20
1989	630[c]	208
1990	0[d]	0
1991	40[e]	13
1992	0[d]	0
Total	730	241

Sources: Emond and Cerezke (1989, 1990); Cerezke et al. (1991); Cerezke and Gates (1992); and Cerezke and Brandt (1993).

[a] 0.33 m^3/tree.

[b] Mortality occurred outside the forest reserve in Waterton Lakes National Park.

[c] Mortality occurred outside the forest reserve in Waterton Lakes National Park (30 trees) and in Bow-Crow Forest (600 trees).

[d] Only pheromone-baited trap trees were killed.

[e] Mortality included pheromone-baited trap trees and adjacent unbaited trees.

Table 15. Summary of Douglas-fir beetle damage in Jasper National Park, 1988–1992

Year	Estimated mortality of Douglas-fir (no. of stems)	Estimated volume of killed Douglas-fir[a] (m^3)
1988	0	0
1989	0	0
1990	191[b]	384
1991	192[b]	386
1992	528	1061
Total	911	1831

Source: Brandt (1994).

[a] 2.00 m^3/tree.

[b] A total of 383 trees were killed in 1990 and 1991. The division between these 2 years is arbitrary.

Table 16. Impacts caused by lodgepole pine dwarf mistletoe in the study area, 1988–1992

Jurisdiction	Host species	Infested area (ha)	Estimated volume on infested area ('000 m^3)[a]	Mortality loss ('000 m^3)[b]	Estimated growth on infested area ('000 m^3)[c]	Growth loss ('000 m^3)[d]
Alberta	Jack pine	112 125	11 885	1 783	863	345
	Lodgepole pine	54 329	12 930	1 552	579	220
Saskatchewan	Jack pine	123 982	7 439	1 116	620	248
Manitoba	Jack pine	12 000[e]	266[e]	40	88	35
N.W.T.	None	0	0	0	0	0

[a] Product of infested area and mean stand volume in infested pine stands. Estimated lodgepole pine mean stand volume is 238 m^3ha^{-1}. The estimated jack pine mean stand volumes are 106 and 60 m^3ha^{-1} in Alberta and Saskatchewan, respectively.

[b] Product of mortality depletion factor (jack pine, 15%; lodgepole pine, 12%) and estimated volume on infested areas.

[c] Product of infested area, the mean annual increment of the host, and the number of years in the study. Estimated mean annual increments are 1.54, 2.13, 1.00, and 1.47 $m^3ha^{-1}yr^{-1}$ for jack and lodgepole pine in Alberta, and for jack pine in Saskatchewan and Manitoba, respectively.

[d] Product of growth loss depletion factor (jack pine, 40%; lodgepole pine, 38%) and estimated growth on infested areas.

[e] Values for Manitoba are from Slivitzky et al. (1991).

Table 17. Total decay for major tree species in the study area, 1988–1992 ('000 m^3)

Tree species	Total estimated decay				Total
	Alberta	Saskatchewan	Manitoba	N.W.T.	
White spruce	2 830	900	345	215	4 290
Black spruce	300	580	720	25	1 625
Jack pine	540	1 900	2 295	20	4 755
Lodgepole pine	1 655	–[a]	0	–[a]	1 655
Balsam fir	90	95	90	–[a]	275
Douglas-fir	5	0	0	0	5
Tamarack	10	35	85	–[a]	130
Eastern white cedar	0	0	10	0	10
Total softwoods	5 430	3 510	3 545	260	12 745
Trembling aspen	15 855	11 210	7 460	2 075	36 600
Balsam poplar	1 495	–[b]	595	195	2 285
White birch	310	–[b]	410	25	745
Other hardwoods	N.A.[c]	925	330	N.A.	1 255
Total hardwoods	17 660	12 135	8 795	2 295	40 885
Total	23 090	15 645	12 340	2 555	53 630

[a] Value not significant.

[b] Value included in other hardwoods.

[c] Not applicable.

border (Fig. 5). Other areas of dwarf mistletoe on jack pine that were not mapped were along the Saskatchewan River from areas near Bruderheim to Whitney Lakes Provincial Park. Estimated jack pine growth loss during the study period was 345 000 m^3. Jack pine mortality due to dwarf mistletoe was 1 783 000 m^3. Affected lodgepole pine forests were located in seven general areas: south of Eaglesham just north of the Smoky River; south of Grande Prairie along the Wapiti River; near Muskeg River; in Banff and Jasper national parks; in the Bow-Crow Forest near Sundre; in the Bow-Crow Forest north of Waterton Lakes National Park to south of the Bow River; and in Cypress Hills Provincial Park. Estimated lodgepole pine growth and mortality loss during the study period were 220 000 and 1 552 000 m^3, respectively.

In Saskatchewan, 123 982 ha of jack pine forests were severely infected by dwarf mistletoe. These infestations occurred in Canwood, Fort à la Corne, and Nisbet provincial forests and scattered throughout a diagonal band across the province from Amisk Lake in the east to Lake Athabasca in the northwest (Fig. 5). Estimated jack pine growth loss and mortality during the study period were 248 000 and 1 116 000 m^3, respectively.

In Manitoba, 12 000 ha of jack pine forests were severely infected by dwarf mistletoe (Slivitzky et al. 1991). Areas of infection occurred in jack pine stands located near Bélair, in the Interlake Section, and in the Saskatchewan River Section nearly opposite to those areas of pine infected in eastern Saskatchewan. Estimated growth and mortality loss due to dwarf mistletoe during the study period were 35 000 and 40 000 m^3, respectively.

Throughout the study area, total volume loss due to lodgepole pine dwarf mistletoe was

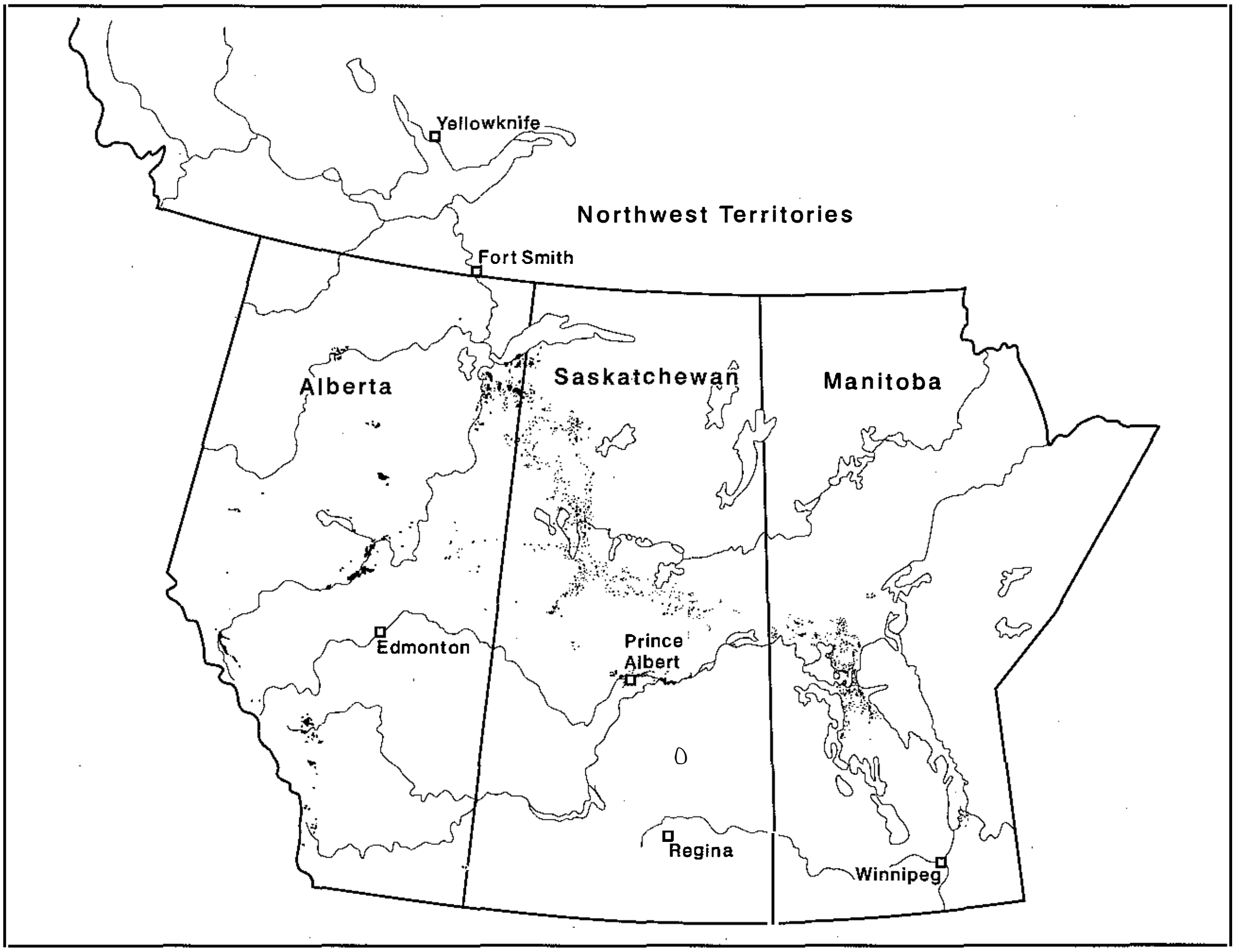

Figure 5. Areas of pine forests in Alberta, Saskatchewan, and Manitoba severely infected by lodgepole pine dwarf mistletoe in 1994.

5 327 000 m^3, of which 848 000 m^3 and 4 491 000 m^3 were attributed to growth and mortality loss, respectively.

Wood Decay

In Alberta, total estimated wood decay amounted to 23 228 000 m^3 during the study period (Table 17). Wood decay in coniferous species was 5 430 000 m^3, and 17 660 000 m^3 in deciduous species. These values represent 0.5 and 2.3% of the total gross merchantable volumes of decayed coniferous and deciduous tree species, respectively. Total estimated wood decay in Saskatchewan was 15 645 000 m^3, of which 3 510 000 m^3 were in coniferous tree species and 12 135 000 m^3 were in deciduous tree species. These values represent 1.3 and 3.7% of the total gross merchantable volumes of decayed coniferous and deciduous tree species, respectively. In Manitoba, wood decay caused losses of 3 545 000 m^3 in coniferous tree species and 8 795 000 m^3 in deciduous tree species, representing 1.4 and 4.1% of the total gross merchantable volumes of decayed coniferous and deciduous tree species, respectively. In the Northwest Territories, total estimated wood decay amounted to 2 555 000 m^3 during the study. Wood decay in coniferous species was 260 000 m^3, and 2 295 000 m^3 in deciduous species. These values represent 0.6 and 3.0% of the total gross merchantable volumes of decayed coniferous and deciduous tree species, respectively.

Total volume loss in the study area due to wood decay was 53 630 000 m^3 between 1988 and 1992.

DISCUSSION AND SUMMARY

The largest impacts in the study area were caused by wood decay organisms (10.7 million m^3/year), forest tent caterpillar (4.1 million m^3/year), and lodgepole pine dwarf mistletoe (1.1 million m^3/year) (Tables 18 and 19). The balance of the impacts, totaling less than 1 million m^3/year, were caused by Bruce spanworm, spruce budworm, jack pine budworm, large aspen tortrix, and spruce beetle. The total forest insect- and disease-caused impacts to the timber resources of the study area were 16.2 million m^3/year or about 81 million m^3 over the 5-year period from 1988 to 1992. These impacts represent an estimate of the damage caused by major forest pests in the study area. Mortality accounted for 21% of the total impacts, while growth reductions accounted for 13% and the remainder was cull due to decay.

The impacts reported during the current study are substantially higher than those reported in the previous study (Brandt and Amirault 1994). Differences between the two studies exist for two reasons. First, the number of pests and their activity have both changed during the current study. For example, lodgepole pine dwarf mistletoe impacts were included because of the recent availability of information on its distribution. Also, spruce budworm defoliation area increased from that observed in Brandt and Amirault (1994). Second, methods used to estimate impacts have improved. An example of this is the approach used to estimate wood-decay impacts. The current method incorporates the age-class structure of different species in each jurisdiction and uses the most current inventory information available.

The impacts reported occurred over 58 million ha of stocked, timber-productive forest lands containing 4812 million m^3 of gross merchantable wood (Canadian Council of Forest Ministers 1994). In comparison, national estimates for the period 1982–1987 are 102.7 million m^3/year (Hall and Moody 1994) over 216 million ha containing 23 154 million m^3 of wood in 1986 (Forestry Canada 1992). Impacts in the study area are comparable to the impacts at the national level. National estimates are not available for the current study period.

Some salvage operations were conducted to harvest timber dead and damaged due to pest activity. Estimates of salvage levels, where available, were small. Many salvage operations harvested trees affected by spruce budworm and included areas in Saskatchewan near Hudson Bay and in Manitoba on the Pine Falls Paper Co. Forest Management License. In Alberta, salvage operations were conducted for trees killed by spruce beetle.

Forest insects and diseases are only two causes of losses to the timber resources of the study area (Table 20); others include fire and harvesting. Insect and disease losses constitute 36, 41, 3, and 92% of the total losses in Alberta, Saskatchewan, Manitoba, and the Northwest Territories, respectively. In three

Table 18. Average annual volume losses caused by major insects in the study area, 1988–1992 ('000 m^3)

		Pest								
Jurisdiction	Volume loss factor	Spruce budworm	Jack pine budworm	Forest tent caterpillar	Large aspen tortrix	Bruce spanworm	Mountain pine beetle	Spruce beetle	Douglas-fir beetle	Total
Alberta	Growth	32	0	840	0	163	0	0	0	1 035
	Mortality	0	0	838	0	0	–[a]	2	–	840
	Total	32	0	1 678	0	163	–	2	–	1 875
Saskatchewan	Growth	1	0	723	0	0	0	0	0	724
	Mortality	7	–	1 605	0	0	0	0	0	1 612
	Total	8	–	2 328	0	0	0	0	0	2 336
Manitoba	Growth	82[b]	0	62	24	0	0	0	0	168
	Mortality	–	62	1	0	0	0	0	0	63
	Total	82	62	63	24	0	0	0	0	231
N.W.T.	Growth	2	0	0	0	0	0	0	0	2
	Mortality	10	0	0	0	0	0	0	0	10
	Total	12	0	0	0	0	0	0	0	12
Total		134	62	4 069	24	163	–	2	–	4 454

[a] Value not significant.

[b] Value is the loss due to mortality and growth reduction.

Table 19. Average annual volume losses caused by major diseases in the study area, 1988–1992 ('000 m^3)

Jurisdiction	Volume loss factor	Pest: Lodgepole pine dwarf mistletoe	Pest: Wood decay	Total
Alberta	Growth	113	N.A.[a]	113
	Mortality	667	N.A.	667
	Cull	N.A.	4 618	4 618
	Total	780	4 618	5 398
Saskatchewan	Growth	50	N.A.	50
	Mortality	223	N.A.	223
	Cull	N.A.	3 129	3 129
	Total	273	3 129	3 402
Manitoba	Growth	7	N.A.	7
	Mortality	8	N.A.	8
	Cull	N.A.	2 468	2 468
	Total	15	2 468	2 483
N.W.T.	Growth	0	N.A.	0
	Mortality	0	N.A.	0
	Cull	N.A.	511	511
	Total	0	511	511
Total		1 068	10 726	11 794

[a] Not applicable.

Table 20. Insect and disease losses, fire losses, and harvest volumes for the study area, 1988–1992 ('000 m^3)

Jurisdiction	Insect and disease	Fire[a]	Harvest[b]	Total
Alberta	7 273	419[c]	12 743	20 435
Saskatchewan	5 738	4 906	3 260	13 904
Manitoba	2 714	88 100[d]	1 634	92 448
N.W.T.	523	–[e]	45	568
Total	16 248	93 425	17 682	127 355

[a] Modified from Canadian Council of Forest Ministers (1994).

[b] Canadian Council of Forest Ministers (1994).

[c] Hideji Ono. 1994. Alberta Environmental Protection, Land and Forest Services, Forest Protection Division, Edmonton, Alberta. Personal communication.

[d] Keith Knowles. 1994. Manitoba Natural Resources, Forest Protection Section, Winnipeg, Manitoba. Personal Communication.

[e] Not available.

of the four jurisdictions, insect and disease losses are higher than harvest levels; only in Alberta are insect and disease losses less than harvest levels. Furthermore, insect and disease losses would have been higher than fire losses if not for the unusually high loss in Manitoba due to the extraordinary circumstances in 1989 when fire destroyed large areas of forests.

Efforts will continue to improve methods of estimating forest insect and disease impacts. Critical among these efforts will be continuing research on estimating pest impacts at the stand level, improving mapping capabilities, and updating inventory data. Also, the relationship between pest impacts and estimates of growing stock and growth must be explored; such information can assist in forest-management decision-making and in sustaining the study area's timber resources for future generations.

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