

Analysis of historic western spruce budworm defoliation in south central British Columbia

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Abstract

The western spruce budworm *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae) periodically defoliates interior Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco forests in British Columbia. Repeated budworm defoliation causes tree mortality, reduction in growth rates and reduced lumber quality. An overlay analysis using historic and recent annual aerial overview information was completed to describe population fluctuations of the western spruce budworm in the south central portion of British Columbia. The overlay analysis defined areas of chronic, intermittent and no budworm defoliation between 1916 and 2003 in potentially susceptible forest types. The majority of the defoliation records from south central BC during this time period occurred within the Kamloops Forest Region, where we identified five outbreak sub-regions that were geographically distinct. Stands within the Interior Douglas-fir biogeoclimatic zone were most susceptible and suffered the greatest amount of chronic, sustained budworm activity. Over 45% of the Interior Douglas-fir zone had recorded defoliation, with some outbreaks lasting over 9 years. Within the Interior Douglas-fir zone, the dry, cool subzone and very dry, hot subzone were most prone to sustained outbreak events. The moister ecosystems, such as the Interior Cedar Hemlock zone, had over 30% of its area defoliated. However, these outbreaks were less frequent and rarely lasted more than 3 years.

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1. Introduction

The western spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae), occurs widely throughout western North America, feeding primarily on Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and often, on true firs, *Abies* (Fellin, 1985). Other tree species such as Engelmann spruce, larch, hemlock and pine may be defoliated when growing on sites with Douglas-fir or other primary hosts, especially during outbreaks (Unger, 1986). The budworm is normally present at low levels in susceptible forest types, however insect populations periodically increase until tree defoliation is noticeable (Harris et al., 1985). These defoliation periods may last for several years, before subsiding to sub-

outbreak levels. During outbreaks, defoliation can cause tree mortality, growth defects, regeneration delays, reduced lumber quality and other stand impacts that are major management concerns (Alfaro and Maclauchlan, 1992; Alfaro et al., 1982, 1985).

Due to the budworm's preferential feeding on current year's buds and foliage, height growth is severely reduced or eliminated during years of defoliation. In addition, severe defoliation over several years often causes upper crown mortality, known as top-kill, and may lead to the formation of stem defects (Van Sickle et al., 1983; Alfaro and Maclauchlan, 1992). The budworm can have extremely devastating effects on Douglas-fir stands, by reducing overall growth and yield, increasing susceptibility to other insect pests and diseases, and limiting management options.

Western spruce budworm (WSB) defoliation can occur in most areas of the southern interior of British Columbia (BC) where interior Douglas-fir is found. First records of WSB defoliation occurred as early as 1909 in the Vancouver Forest Region (Table 1). However, defoliation was not recorded until

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Table 1
Total area historically infested by western spruce budworm in the southern portion of BC

Geographic region	Hectares affected	Year WSB first recorded
Kamloops Forest Region	1611029	1916
Cariboo Forest Region	591853	1974
Vancouver Forest Region	339367	1909
Nelson Forest Region	22803	1923

1974 in the Cariboo where it has only recently expanded substantially in area (>500 000 ha in 2003). During the last western spruce budworm outbreak (1985–1991) (Forest Insect and Disease Survey (FIDS) 1985–1991), the majority of mapped defoliation occurred in the Kamloops Forest Region, located in the southern interior of BC. This outbreak encompassed over 800 000 ha.

Since 1916, six to eight outbreaks of western spruce budworm have likely occurred in the Kamloops Forest Region (Parfett et al., 1994; Maclauchlan, 2003). Unlike other defoliators such as the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera: Geometridae), the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McD.) (Lepidoptera: Lymantriidae), or the eastern spruce budworm, *Choristoneura fumiferana* (Clemens) (Royama, 1984) which have more regular outbreak cycles (Fellin, 1985; Alfaro et al., 1999), the western spruce budworm tends toward less predictable population fluctuations. Outbreaks can last for several years or they may collapse after only 1 or 2 years. Climate and host appear to be major influences of insect populations at the landscape level scale (Thomson et al., 1984). In northern forests, a native needle blight, *Dothistroma septosporum* (Dorog.) Morelet, which has historically occurred at low levels, has recently been causing extensive defoliation and mortality to its host lodgepole pine, *Pinus contorta* var. *latifolia* Dougl. ex Loud. (Woods et al., 2005). A similar phenomenon could be occurring with the western spruce budworm and its primary host.

Historically, most western spruce budworm outbreaks have occurred in three Interior Douglas-fir subzones (Lloyd et al., 1990) located in the south central portion of BC, predominantly within the Kamloops Forest Region: the IDFdk (dry cool interior Douglas-fir), the IDFxh (very dry hot interior Douglas-fir) and the IDFmw (moist warm interior Douglas-fir). Infestations have also extended into the IDFdm (dry mild interior Douglas-fir), Interior Cedar Hemlock and to a very minor degree other biogeoclimatic zones. The Kamloops Forest Region encompasses over 6 million hectares and includes a large number of diverse ecosystems. Several hundred thousand hectares within the IDF are at risk to western spruce budworm (Maclauchlan and Buxton, 2003).

The biogeoclimatic ecosystem classification system (BEC) (Lloyd et al., 1990) used in this project incorporates both biotic and environmental factors, and is therefore applicable to many resource uses. Climate is the most important factor influencing the development of terrestrial ecosystems and vegetation best reflects the environment, biology and history of a site.

Western spruce budworm is a natural component of Douglas-fir ecosystems, yet the range and duration of recent

outbreaks appear to be increasing (Maclauchlan, 2003). The objective of this project was to conduct an overlay analysis of western spruce budworm defoliation within the Kamloops Forest Region, using digitized historical defoliation information, collected through annual aerial overview surveys (BC Ministry of Forests and Canadian Forest Service). Through the analysis of overview information we can then determine which ecosystems are more likely to incur budworm defoliation, and are more or less susceptible. Understanding the history of budworm outbreaks in susceptible ecosystems will assist us to more confidently predict the number and likelihood of outbreak events over the rotation of a stand. This information will enable forest managers to assess the vulnerability of Douglas-fir stands to western spruce budworm and prescribe the appropriate measures to mitigate impacts.

2. Methods

Outbreaks of western spruce budworm are natural and common disturbances in interior Douglas-fir forests of BC. In this project, we have used overlays of historical defoliation maps, forest cover and biogeoclimatic zones to define stand hazard or susceptibility as a function of: the total number of years of defoliation; the maximum consecutive number of years of defoliation; and biogeoclimatic zone and the association of these parameters with subzone.

Historical western spruce budworm defoliation records from annual aerial overview flights were obtained for the Kamloops Forest Region in digital format for the period 1916–1995 (Parfett et al., 1994) from the Forest Insect and Disease Survey, Pacific Forestry Centre, Canadian Forest Service. Digital data from 1996 to 2003 were obtained from the Kamloops Forest Region, BC Ministry of Forests (MOF). Biogeoclimatic data were obtained from the MOF (<ftp.for.gov.bc.ca/hre/external!/publish/bec-maps>). The 1916–1999 aerial overview information was mapped on topographic maps of various scales and the 2000–2003 information was mapped on 1:100 000 ortho-photographs.

Environmental Systems Research Institute (ESRI) ArcView version 3.2 was used to conduct the overlay analysis. The files for 1916–1995 were in ESRI ArcInfo export format. The 1996–1998 data were in IDGS (Intergraph/Microstation Design) format, and the 1999–2003 data were available in ESRI ArcView shapefiles. All spatial files were projected to Albers, NAD 83 and converted to ESRI ArcView shapefiles where necessary.

The overlay analysis was completed for each year using a “UNION” tool available from Xtools Extension (Oregon State Department of Forestry). A union combines features from different layers into one theme while maintaining the original features. The annual themes included an attribute that indicated the presence (or absence) of defoliation, which uniquely identified the year of defoliation into the attribute name. The Union script allowed this annual defoliation attribute(s) to be carried forward from the themes being analyzed. Therefore, one of the two themes was the result of the previous union and contained all of the unique defoliation attributes, and the other was the next year in the sequence. This allowed annual defoliation to be carried forward from the themes being

analyzed. This process continued until all years were included in the union. The resultant table was exported to MS Access 2000, where the total number of years of defoliation for each polygon (area of mapped defoliation) and the maximum number of years defoliated was determined. The final union was intersected with the biogeoclimatic theme and MOF Forest District. The area within the IDF, which was not defoliated by WSB, was determined by using the IDF biogeoclimatic theme and clipping outside the WSB union theme.

Geoprocessing tools were used to “dissolve” polygons which were 2 ha or smaller, and merge them into an adjacent larger polygon, resulting in a file half the size of the original. The final “dissolved” union contained over 80 000 records.

To further define impact and susceptibility, we divided the total number of years defoliated (over the life of the stand, not necessarily consecutive years of mapping) and maximum consecutive years defoliated into smaller time increments. The total number of years defoliated was divided into 5 year increments (1–5, 6–10, 11–15 and >15) and the maximum consecutive years defoliated was divided into 3 year increments (1–3, 4–6, 7–9 and >9). Western spruce budworm defoliation levels generally decline after 3 consecutive years. However, in outbreaks or specific stand types, defoliation may extend for prolonged periods (L.E. Maclauchlan, personal observation, 1987–1992).

3. Results and discussion

Fig. 1 illustrates the total area that has been defoliated at least once by the budworm (1916–2003), as well as areas in the IDF with no record of defoliation. The range of defoliation is

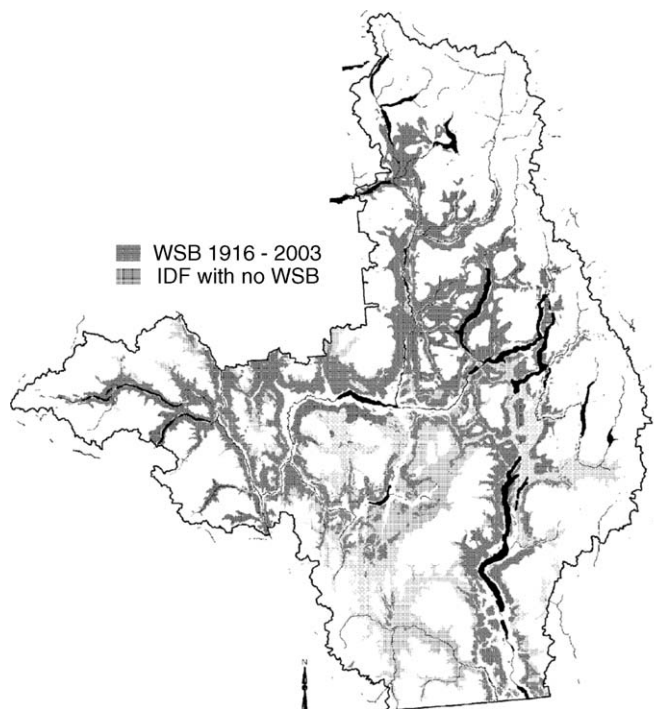


Fig. 1. Map of the Kamloops Forest Region showing range of the IDF, area of historic western spruce budworm defoliation (1916–2003) and area where no WSB has been mapped.

very extensive, and it has expanded greatly during the past 100 years, especially since 1980 (Fig. 2a–d). This increase in the area of defoliation may, in part, be related to the increased availability of host trees and increased susceptibility due to drought (Wulf and Cates, 1985) and past harvesting practices (Schmidt, 1985).

Within the Kamloops Region there appears to be five sub-regions where outbreaks commonly occur: the west, dry area (Lillooet); the central, dry Cache Creek area; the North Thompson area; the Merritt area; and, the Okanagan Shuswap (Fig. 2a–d). These sub-regions exhibit distinct outbreak periods that are not necessarily synchronized with adjacent outbreak areas. Some sub-regions can be characterized as having chronic, sustained outbreaks such as the west, dry area (Lillooet) that has had at least five outbreak periods between 1916 and 2003. Other areas, such as Merritt, have had only one recorded outbreak event (late 1990s through 2003). In total, three outbreak periods were recorded in the Okanagan Shuswap area: during the 1970s, 1980s, and 1990s. In the more northerly and southerly portions of the Okanagan Shuswap, only one outbreak event has occurred. The north is typically dominated by wetter, even-aged Douglas-fir ecosystems.

The overlay analysis revealed only two outbreak periods for the North Thompson with the outbreak spanning the 1980s being very prolonged, intense and extensive (L.E. Maclauchlan, personal observation, 1984–1989). The only other western spruce budworm activity recorded in the North Thompson area appeared to be localized and of short duration (1991–1992 and 1997–1998). The central, dry Cache Creek area has been through five distinct outbreak periods from the 1950s through to 2003. Interestingly, the five outbreak periods in this sub-region were not synchronized with adjacent outbreak areas. Often, as an outbreak subsided, defoliation activity in the areas east and west of Cache Creek would increase, resulting in discrete outbreaks. However, there were time periods when no defoliation was recorded in these sub-regions.

The greatest area of recorded defoliation was recorded between 1985 and 1992 (Fig. 2c), reaching a high in 1987 of over 800 000 ha (Erickson and Loranger, 1987). The IDF biogeoclimatic zone has the largest mapped area of historic budworm activity, nearly 1 million ha (Fig. 3), followed by the ICH and to a much lesser degree the Montane Spruce (MS), Ponderosa Pine (PP) and the Engelmann Spruce-Subalpine Fir (ESSF) zones (Lloyd et al., 1990). The relative hazard of these ecosystems is related to the abundance of Douglas-fir and elevational ranges spanned by each. Stands in the IDF are by far the most susceptible to western spruce budworm defoliation. Over 30% of the total defoliation recorded over the Kamloops Forest Region land base since 1916 has occurred in the IDF. Approximately 45% of the IDF (928 109 ha) (Fig. 3) has sustained defoliation at some time. The overlay analysis identified approximately 450 000 ha of non-defoliated stands in the IDF. Many of these stands are mixed species stands, with lodgepole pine comprising a significant component. Such stands are much less susceptible to defoliation by the budworm (personal observations) until the pine component is removed thus opening up the stand (Maclauchlan and Brooks, 2006).

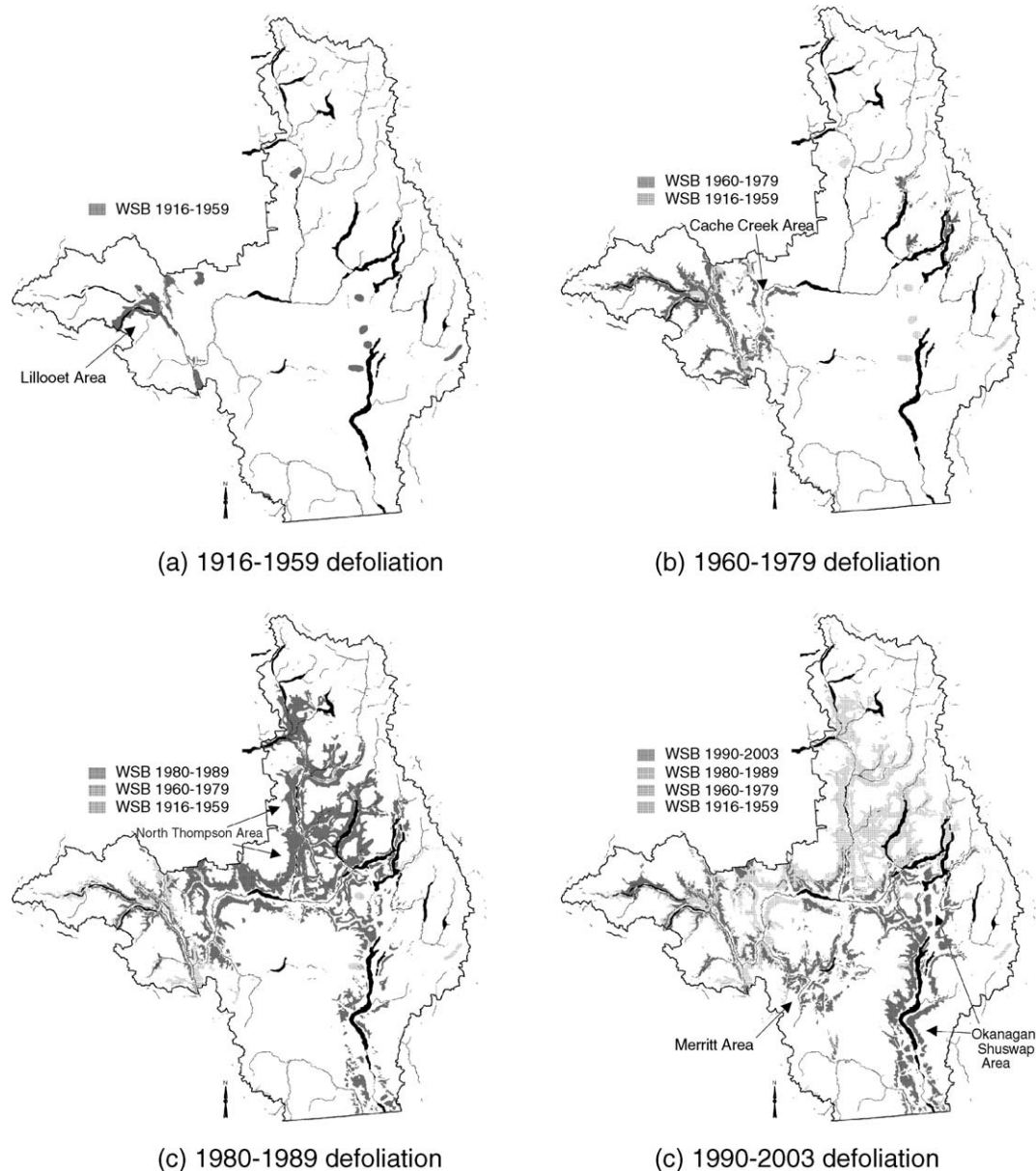


Fig. 2. Four maps of the Kamloops Forest Region showing the chronological sequence of budworm defoliation, as mapped from annual aerial overview surveys (1916–2003): (a) 1916–1959 defoliation; (b) 1960–1979 defoliation; (c) 1980–1989 defoliation; (d) 1990–2003 defoliation.

Other than in the IDF, only a very small area within other ecosystems had total defoliation records greater than 5 years (Table 2). In addition, the majority of the defoliation events were not sustained and on average lasted less than 3 years. However, in the IDF, significant areas did record longer sustained (consecutive) defoliation events some lasting at least 9 years (Table 2). Over 98 000 ha in the IDF had defoliation records totaling 6 years or more (Table 2) again highlighting the chronic nature of WSB in many parts of this ecosystem.

Over 30% (370 822 ha) of the ICH in the Kamloops Forest Region was defoliated at some time between 1916 and 2003; however the majority of this was not chronic (sustained) and less than 3000 ha had defoliation events that lasted longer than 3 years in duration. The ICH has a more moderate climate with higher precipitation than the IDF. Douglas-fir in the ICH is

more often seen growing in a single storied or in mixed species types, and therefore usually sustains less damage from budworm feeding. Conversely, Douglas-fir in the PP zone, a much drier and drought prone ecosystem, proportionally suffered more chronic budworm defoliation and damage (L.E. Maclauchlan, personal observation, 1989–1992).

The IDFdk and IDFxh, the driest, warmest subzones of the IDF, were most frequently defoliated by budworm, with 391 962 ha and 315 511 ha affected, respectively (Table 3 and Fig. 4). The IDFmw, a moister subzone of the IDF, was also periodically affected by budworm (156 578 ha) (Table 3 and Fig. 4). Although there was defoliation in this subzone, significantly fewer hectares experienced sustained, chronic budworm activity (Table 3 and Fig. 4) than the more seriously affected drier subzones.

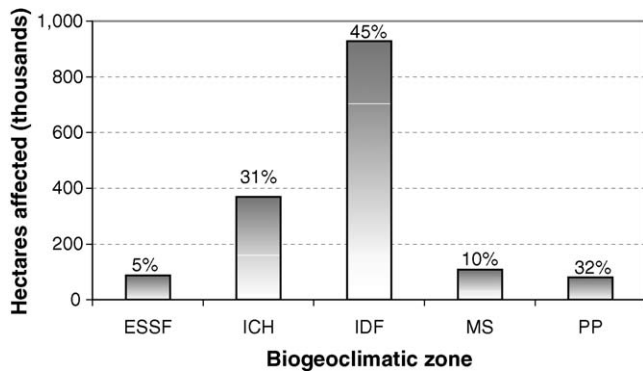


Fig. 3. Summary of the total hectares defoliated (1916–2003) in the Kamloops Forest Region by biogeoclimatic zone with percent of biogeoclimatic zone defoliated shown above bars. Biogeoclimatic zones on the x-axis include: Engelmann Spruce Subalpine Fir (ESSF); Interior Cedar Hemlock (ICH); Interior Douglas-fir (IDF); Montane Spruce (MS); Ponderosa Pine (PP).

Tree and stand damage occurs as a result of larval feeding and is directly related to larval density and duration of outbreak (number of years of feeding). The question remains as to the relationship between chronic, sustained periods of feeding and short, intermittent budworm feeding and impact. The number of years between feeding (outbreak) events could also influence tree vigour and growth (Shepherd, 1994). To more fully study the two patterns, we compared levels of consecutive and total years of defoliation within the IDF. Many sites, especially those in the subzones IDF_{xh} and IDF_{dk}, can sustain budworm populations and defoliation for as many as 10 years with up to 9 consecutive years of damage (Table 3). Over 50% and 39% of the IDF_{xh} and IDF_{dk}, respectively, have been defoliated at some time in the past 100 years (Fig. 4). A large proportion of the wetter IDF subzones (mw, ww and xw) have also been defoliated. However, combined, these wetter subzones represent only 16% of the total IDF area, while the IDF_{xh} and the IDF_{dk} together, comprise 81% of the IDF zone. Although both the wetter and drier IDF subzones incur proportionally similar amounts of defoliation, the actual area affected (hectares) is vastly greater within the dry subzones (Table 3). As well, the

Table 2

Summary of defoliation (1916–2003) from overlay analysis listing the total number of years of defoliation and the maximum number of consecutive years of defoliation

	Number of hectares affected in each BEC				
	ESSF	ICH	IDF	MS	PP
Total number of years of defoliation					
0	1681314	814185	1138181	928521	174005
1–5	86644	370373	829491	105745	75976
6–10	509	449	94136	2622	4913
11–15	0	0	4094	32	147
>15	0	0	389	0	0
Maximum consecutive years defoliation					
1–3	86676	368188	825000	103449	76721
4–6	476	2635	98052	4905	4122
7–9	0	0	4945	45	193
>9	0	0	112	0	0

The area of susceptible host by BEC (Biogeoclimatic Ecosystem Classification) having no record of defoliation is also shown (0 year).

Table 3

Total area (ha) of western spruce budworm defoliation in IDF subzones delineated by the total number of years defoliation and maximum number of consecutive years defoliation

	Number of hectares affected in each IDF subzone				
	mw	dk	xh	dm	xw
Total number of years defoliated					
0	111587	623647	313213	30457	3354
1–5	146790	361097	269443	14466	24597
6–10	9789	28848	44825	121	7169
11–15	0	1857	1243	0	0
>15	0	160	0	0	0
Maximum consecutive years defoliation					
1–3	136989	360153	271448	12777	26613
4–6	17896	30791	41816	1809	5140
7–9	1694	1018	2134	0	14
>9	0	0	112	0	0

The area of susceptible host by BEC having no record of defoliation is also shown (0 year).

maximum number of years of consecutive defoliation by the budworm in the wetter subzones is far less on average and fewer hectares overall are affected.

Although early defoliation records may be incomplete or less accurately mapped than more recent data, a very comprehensive view of budworm dynamics at a landscape level is nonetheless provided and can be utilized to meet management goals. This analysis shows which biogeoclimatic zones and subzones are more likely to experience regular and sustained periods of defoliation by the western spruce budworm. Results indicate that wetter ecosystems where Douglas-fir is less apt to grow in a multi-structured canopy, although still susceptible to budworm, tend to have infrequent and shorter duration outbreaks. Forest managers may use this information to evaluate the potential for one or more defoliation events occurring in a particular stand, based on ecosystem and history, and subsequently make appropriate prescriptions. Areas identified as high risk to budworm defoliation could be thinned to promote tree and stand vigour or direct control measures such as treatment with biological insecticides (e.g. *Bacillus thuringiensis* var. *kustaki*) could be conducted in years when high levels of defoliation are predicted.

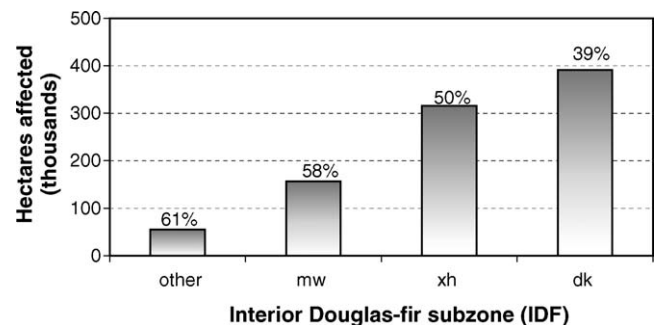


Fig. 4. Summary of the total area defoliated by western spruce budworm in Interior Douglas-fir (IDF) subzones. Percentages above bars show percent of total subzone affected. The Interior Douglas-fir (IDF) subzones included on the x-axis include: mw (moist, warm); xh (very dry, hot); dk (dry, cool).

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