Research Report

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Aerial overview survey of the mountain pine beetle epidemic in British Columbia: Communication of impacts

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Abstract

In western Canada, the current outbreak of mountain pine beetle (*Dendroctonus ponderosae*) is of unprecedented proportions. Annual aerial overview surveys (AOS) are the primary means of accounting for the area and severity of mountain pine beetle impacts. Typically, reports of impacted areas do not consider severity—the proportion of trees killed within a given area. A common misconception is that all impacted areas will experience 100% pine mortality.

We examined a time series of AOS data collected in British Columbia from 1999 to 2005. The year-to-year trends indicated that the AOS data effectively captured the infestation's increasing area, severity, and spatial variability. The cumulative area impacted between 1999 and 2005 was estimated at 11 million ha; 39% of this area was attacked in only one year. The approximate year of death was estimated by assuming a 50% severity threshold. Approximately 6.5 million ha experienced mortality. The results of this study emphasize the importance of reporting severity, as well as considering the cumulative effects of the infestation over time.

KEYWORDS: *aerial overview survey,* Dendroctonus ponderosae*, GIS, infestation, mountain pine beetle, severity, strategic survey, tessellation, time series.*

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Introduction

In western Canada, the current outbreak of mountain pine beetle (*Dendroctonus ponderosae*) is of unprecedented proportions. In 1999, the area impacted by the beetle in British Columbia was estimated to be 164 000 ha; by 2006, it had increased to approximately 9.2 million ha (Westfall 2007). From a forest management perspective, estimates of the location and extent of mountain pine beetle red attack are critical. However, the degree of precision required for these estimates varies according to the management objective under consideration and the nature of the mountain pine beetle infestation. The information required for managing mountain pine beetle is provided by a hierarchy of different data sources that are used to map red attack damage. Each data source offers a different level of detail on the location and extent of beetle damage (Wulder et al. 2006b).

Aerial overview surveys (AOS; colloquially known as "sketch maps") are conducted annually in British Columbia. They are designed to cover the maximum possible area, and provide rapid, province-wide reconnaissance on a number of forest health threats, including mountain pine beetle infestation. As the AOS includes information on the extent and severity of attack—the proportion of trees killed within a given area—both characteristics should be considered when reporting mountain pine beetle impacts. Typically, the gross area impacted is reported without distinguishing severity. A common misconception is that all areas impacted will experience 100% pine mortality. To address these issues and gain a better understanding of the province-wide impacts of the current mountain pine beetle outbreak, we obtained annual AOS data of mountain pine beetle infestations across British Columbia from 1999 to 2005. The overall goal of this research is to explore and present the full potential of AOS data for communicating the impacts of the mountain pine beetle outbreak in British Columbia. Specifically, our objectives are to:

- compare area summaries from annual AOS spatial data to data reported in annual forest health reports;
- assess if the AOS data captures temporal and spatial variability in the severity and area impacted;
- estimate the cumulative area of impact and assess the amount of area captured in multiple years of survey data;
- assess temporal trends in severity codes over time; and
- estimate the approximate year of death for the majority of pine within a specified analysis unit.

The goal of this research is to explore and present the full potential of aerial overview surveys data for communicating the impacts of the mountain pine beetle outbreak in British Columbia.

Background

Manifestation of mountain pine beetle attack

Once a host tree has been attacked and killed by mountain pine beetle, its foliage will remain green for an initial period known as the green attack stage (Wulder et al. 2006a). The foliage will gradually fade, and within 12 months after attack 90% of the trees will have red foliage (Amman 1982; Henigman et al. [editors] 1999). This is the visually distinct red attack stage that is captured by the AOS. Within 3 years of the initial attack, most of the trees will have lost all of their needles—the grey attack stage (BC Ministry of Forests 1995). Variability in the rate of foliage discolouration depends on species and site conditions (Safranyik 2004).

AOS data

Aerial overview surveys are conducted using fixed-wing aircraft flying at speeds of 150–170 km/hr, at altitudes ranging from 500 to 1000 m (BC Ministry of Forests 2000). Trained forest health personnel record the extent and severity of red attack damage—and other forest health issues—onto hardcopy base maps produced at a scale of 1:100 000 or 1:250 000. The information on the maps is manually digitized according to established standards (BC Ministry of Forests 2000). Figure 1 provides an example of the systematic spatial coverage of the AOS data in 2005.

From 1914 to 1995 the Canadian Forest Service conducted the AOS program, but the British Columbia Ministry of Forests has assumed responsibility for the surveys since then (BC Ministry of Forests 1995). Other jurisdictions also use AOS as an effective, low-cost method for detecting and mapping mountain pine beetle red attack damage (BC Ministry of Forests 2000; Alberta Sustainable Resource Development 2004; Schraeder-Patton 2003).

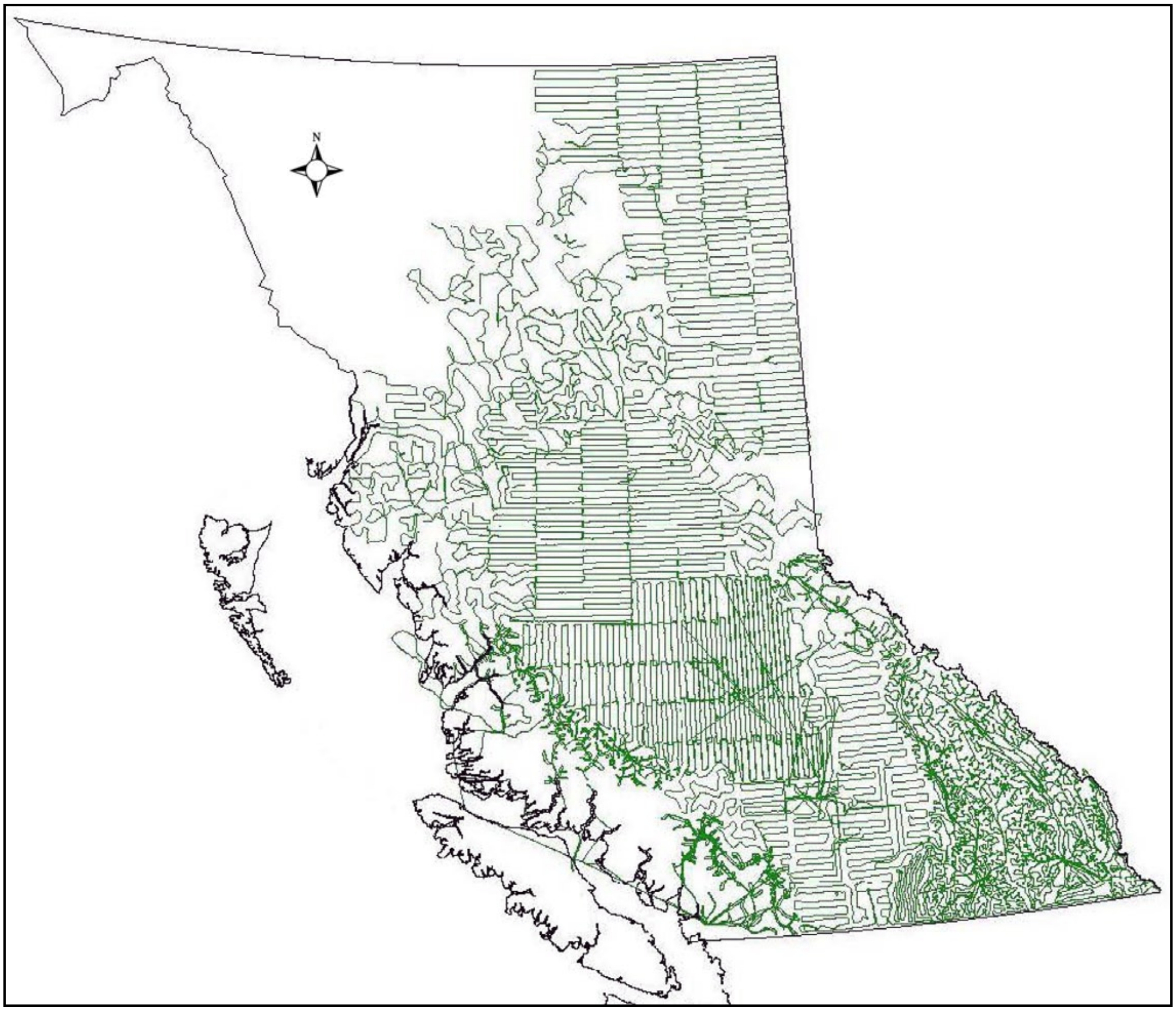


FIGURE 1. Distribution of flight lines used to acquire Aerial Overview Survey (AOS) data in 2005.

Due to the inherent speed and efficiency of AOS data collection, forest managers have access to the information within 3 months of survey completion (Wulder et al. 2006b). In the context of mountain pine beetle, the data is used to characterize the general location of damage, approximate the gross area of damage, and indicate trends in damage from one year to the next. The data facilitates strategic planning and the allocation of resources for mitigation, and provides an initial stratification of the landscape for determining locations for more intensive surveys (BC Ministry of Forests 2003a). The information is also used for timber supply forecasting and for adjusting the annual allowable cut (BC Ministry of Forests 2003b).

Weaknesses of the AOS data include errors of omission when damage is very light, a lack of rigorous positional accuracy, and variability in estimates of attack magnitude. Location inaccuracies result from off-nadir viewing, variations in lighting conditions, and interpreter experience and fatigue, among others (Aldrich et al. 1958; Leckie et al. 2005). Harris and Dawson (1979) found that amongst several interpreters, estimates of red attack damage varied from the actual amount of red attack damage by a range of –42% to 73%. They also compared estimates of AOS red attack damage to those of aerial photography interpretations. The total area identified as red attack from the AOS was 34% larger than the area of attack interpreted from air photos, while the number of red attack trees estimated from the AOS was 39% less than the number of red attack trees estimated from the photos. The underestimation of attacked trees increased with increased red attack density. This discrepancy is largely a function of scale—the field of view of the AOS interpreter is much larger than that of a photo interpreter. As a result, the AOS interpreter can see large areas of red attack damage, but cannot readily discern individual trees. Conversely, the increased spatial resolution afforded by the air photos allows the photo interpreter to delineate units of impact that are more spatially discrete.

The strengths of the AOS program include its cost-effectiveness and the speed with which the data can be collected and made available. Its flexibility (e.g., aircraft can fly below cloud cover that might otherwise impede the use of satellite remotely sensed data) allows the survey to be conducted within the appropriate biological window for mountain pine beetle (i.e., the period when the attack damage is most visible). By utilizing their expertise at identifying tree species and their knowledge of pest habitats and past infestations, in combination with expansive views of the landscape, AOS interpreters can identify damage. Furthermore, the AOS is the only consistently collected forest health survey data that exists for the majority of the provincial land base, providing valuable historical context to infestations over time and space. As a result, no other currently available data source combines the synoptic view and level of detail afforded by this program (Wulder et al. 2006a, 2006b).

Figure 2 indicates how the different AOS severity ratings for mountain pine beetle may be interpreted: a large area with a small number of dispersed red attack trees is rated as light severity (1–10% of the trees attacked); and a smaller area with many spatially clustered red attack trees is rated as severe (31–50% of trees attacked). Areas with light and severe ratings could cover equivalent geographic areas, but the implications of each in terms of mortality, planning, and management, will prompt a different management response. Although the area occupied by individual severity classes is recorded in annual forest health surveys, communication of survey results typically emphasizes the total area impacted, regardless of severity. A common misconception is that there is 100% mortality of pine across all areas impacted by the beetle. For example, in 2006, 9.2 million ha of forest were impacted by the beetle, with 50% of this area having a severity rating of trace or light (Westfall 2007). Reporting only the total area impacted by mountain pine beetle does not provide the full context of the state of the infestation.

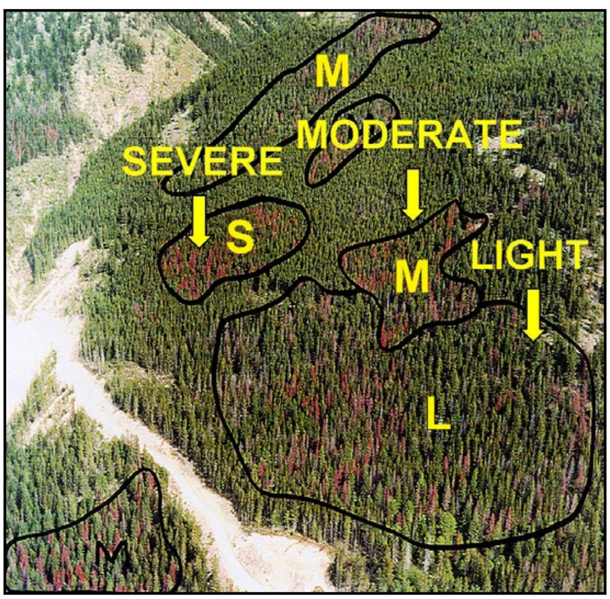


FIGURE 2. Enlargement of original 70-mm photograph with examples of light, moderate, and severe mortality of lodgepole pine caused by mountain pine beetle.

Study area

The 95 million ha province of British Columbia has approximately 59 million ha of forests, of which 83% is dominated by coniferous tree species. The most prevalent species, lodgepole pine (*Pinus contorta*), covers approximately 14.8 million ha (BC Ministry of Forests 2004). The distribution of mountain pine beetle is determined by the distribution of suitable host species and climatic conditions (Swaine 1925). Research has indicated that the mountain pine beetle is expanding into new geographic areas outside its known range (Carroll et al. 2004). This expansion is primarily a result of two factors: (1) intensive fire suppression activities that have caused the amount of mature lodgepole pine forest to triple in the past century (Taylor and Carroll 2004); and (2) several years of favourable climatic conditions that have increased climatically suitable areas for brood development (Carroll et al. 2004). In the early 1900s, approximately 17% of pine forests in British Columbia were in age classes susceptible to mountain pine beetle attack; currently 55% are considered susceptible (Taylor et al. 2006).

Data

The AOS data are collected to an established standard (BC Ministry of Forests 2000) and are made freely available to all users by the BC Ministry of Forests and Range.[1] The areas delineated by the AOS interpreters are manually digitized as polygons into a Geographic Information System (GIS) compatible format and are distributed by the BC Ministry of Forests and Range in ArcView™ shapefile format (BC Ministry of Forests 2000). Shapefiles contain attributes for all forest health issues covered by the AOS, including mountain pine beetle. We downloaded AOS data from 1999 to 2005 for our analysis. The AOS contains five severity classes ranging from trace to very severe. Larger areas of infestation are delineated by the interpreter and assigned a severity rating according to the percentage of killed trees present (Table 1). Small infestations of up to 50 trees are recorded by interpreters as spot infestations (points) and are always classified as severe. These spot infestations are provided as separate shapefiles and were not included in our analysis.

Between 1999 and 2003, only three severity classes were used: light, moderate, and severe. In 2003, surveyors noticed "large areas of previously uninfested pine that had developed a very unusual pattern of widely scattered, very low intensity mortality" (Westfall 2005:3). By recording these areas as spot infestations (points only—no area) the surveyors believed they were underestimating the mortality. Conversely, by delineating them as polygons and coding them as light, they believed they were overestimating mortality. Therefore, in 2004 two additional severity classes were added: trace (< 1% mortality) and very severe (> 50% mortality). All categories of severity were considered in our analysis.

Other data sources used in the analysis of the AOS data included a GIS layer of forest district boundaries representing 32 unique administrative areas used to manage the province's forest resources, and a seamless forest inventory dataset that identified the location and extent of all pine species—potential hosts for mountain pine beetle (BC Ministry of Forests 2004). Although the date of the forest inventory data varied across the province, the majority of data represent pre–1999 forest conditions.

Methods

Polygons that specifically identified the location and extent of red attack damage were selected and extracted from each year of AOS data to a separate vector layer. A numeric attribute was added to each polygon within the vector layer to correspond to each of the severity classes (Table 1). These vector-based shapefiles were converted to 1 ha raster grid files based on their numeric severity code. The entire landmass of British Columbia was tessellated into 1 ha grid cells, resulting in a raster that was 12 885 rows by 15 940 columns. The cells in the provincial grid were then populated with the severity codes from each year of rasterized AOS data. Grid cells thaat were located on the boundary between two grid cells were assigned to the polygon with the greatest area in the grid cell.

A range of analyses was then conducted on this time series of AOS data to meet the objectives of this research. Annual summaries of red attack damage by severity code were generated and compared against those totals reported in the annual forest health reports. This served as a quality control mechanism to ensure the rasterization of the data did not change the distribution or amount of

TABLE 1. Severity codes used in the AOS program and mid-point values used to calculate cumulative severity.

Severity	Numeric values for rasterization and analysis	Proportion of trees killed within a specified area (%)	Mid-point of range used to calculate cumulative severity over time (%)
Trace (T)	1	< 1	0.5
Light (L)	2	1–10	4.5
Moderate (M)	3	11–30	20.5
Severe (S)	4	31–100 (1999–2003)	65.5 (1999–2003)
		31–49 (2004–2005)	40.5 (2004–2005)
Very Severe (VS)	5	≥ 50	75

1 *www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview* (Accessed July 2006).

red attack damage area. Temporal and spatial variability in severity codes were examined by overlaying the forest district boundaries and generating summaries by year and district. The cumulative area of attack was identified. The sequence of severity codes within each grid cell and for each year was also examined for trends of increasing or decreasing severity.

Trees killed by mountain pine beetle may still provide viable wood products for a limited period of time. Shelf life[2] estimates vary, while research on this issue is ongoing (Lewis and Hartley 2006). Determining the year the tree was attacked and killed is important in estimating shelf life. By combining the AOS data for 1999–2005, we estimated the year of death for each 1 ha grid cell in the provincial tessellation. Using the mid-points of the infestation severity classes to indicate a proportion of attack for a given 1 ha cell (Table 1), we summed the values and determined when mortality in each cell exceeded 50%. Because it takes an average of 1 year for the characteristic red foliage to appear, we assigned the year previous as the year of death.

Results and discussion

Table 2 summarizes the comparison of total area by year and severity, between the annual forest health reports and our provincial tessellation. Through this comparison, some discrepancies between the provincial reports and our data emerged. These differences were not statistically significant (two-sample paired *t*-test; Table 2) and were primarily attributable to the omission of spot infestations from our analysis. Point features representing spot infestations were not included in the analysis because they are assumed to have an area of only 0.25 ha or 0.5 ha, depending on the number of red attack trees present at the point (BC Ministry of Forests 2000). By not including these areas, we would have moderately underestimated severe areas; conversely, if we had rasterized these spot infestations to 1 ha and included them in our analysis, we would have grossly overestimated the areas rated as severe.

The greatest discrepancy in estimates of total impacted areas was for years 1999 and 2000. The

TABLE 2. Comparison of AOS area by severity rating. Non-parenthetical numbers represent data used in this analysis, parenthetical numbers are those reported in the annual forest health survey reports.

	AOS area (ha)						
Year	**Trace[a] (< 1%)**	**Light (1–10%)**	**Moderate (11–30%)**	**Severe (31–50%)**	**Very severe[a] (≥ 50%)**	**Total area impacted**	***t*-test results**
1999	n/a	68 397	44 526	31 139	n/a	144 062	$t = 1.243$
		(71 444)	(45 004)	(48 973)		(165 421)	$p = 0.282$
2000	n/a	77 339	92 554	94 473	n/a	264 366	$t = 1.01$
		(77 467)	(92 554)	(114 889)		(284 910)	$p = 0.371$
2001	n/a	358 905	241 052	171 560	n/a	771 517	$t = 1.031$
		(358 989)	(241 301)	(185 207)		(785 497)	$p = 0.361$
2002	n/a	885 308	499 964	571 615	n/a	1 956 887	$t = 0.529$
		(885 888)	(492 160)	(590 592)		(1 968 640)	$p = 0.624$
2003	n/a	2 608 308	751 681	510 737	n/a	3 870 726	$t = 0.007$
		(2 608 202)	(751 801)	(706 814)		(4 066 817)	$p = 0.994$
2004	1 960 043	2 469 705	1 852 163	583 703	152 682	7 018 296	$t = 1.446$
	(1 960 313)	(2 469 999)	(1 852 981)	(585 841)	(152 750)	(7 021 884)	$p = 0.221$
2005	2 268 747	2 332 465	2 148 509	1 196 636	784 202	8 730 559	$t = -1.341$
	(2 273 060)	(2 332 551)	(2 148 886)	(1 197 533)	(784 039)	(8 736 069)	$p = 0.251$

[a] These categories were not used before 2004.

[2] Shelf life is the length of time since attack within which mountain pine beetle killed trees are still economically merchantable.

province reported a total of 165 421 ha impacted by mountain pine beetle in 1999 and 284 910 ha in 2000. Our data indicated 144 062 ha and 264 366 ha were impacted in each of these years, respectively (Table 2). Spot infestations represented 19 099 ha in 1999 and 20 418 ha in 2000. In 1999, 74 695 separate spot infestations of mountain pine beetle were identified. If we had rasterized these points to 1 ha and included them in our data, we would have reported an additional 74 695 ha as severe in 1999 (55 596 ha more than the actual 19 099 ha represented by these spots).

The total area impacted by the beetle increased from 144 062 ha in 1999 to 8 730 559 ha in 2005. During this same period, the amount of area identified as lightly infested increased from 68 397 ha (47% of the total impacted area) to 4 601 212 ha (53% of the total

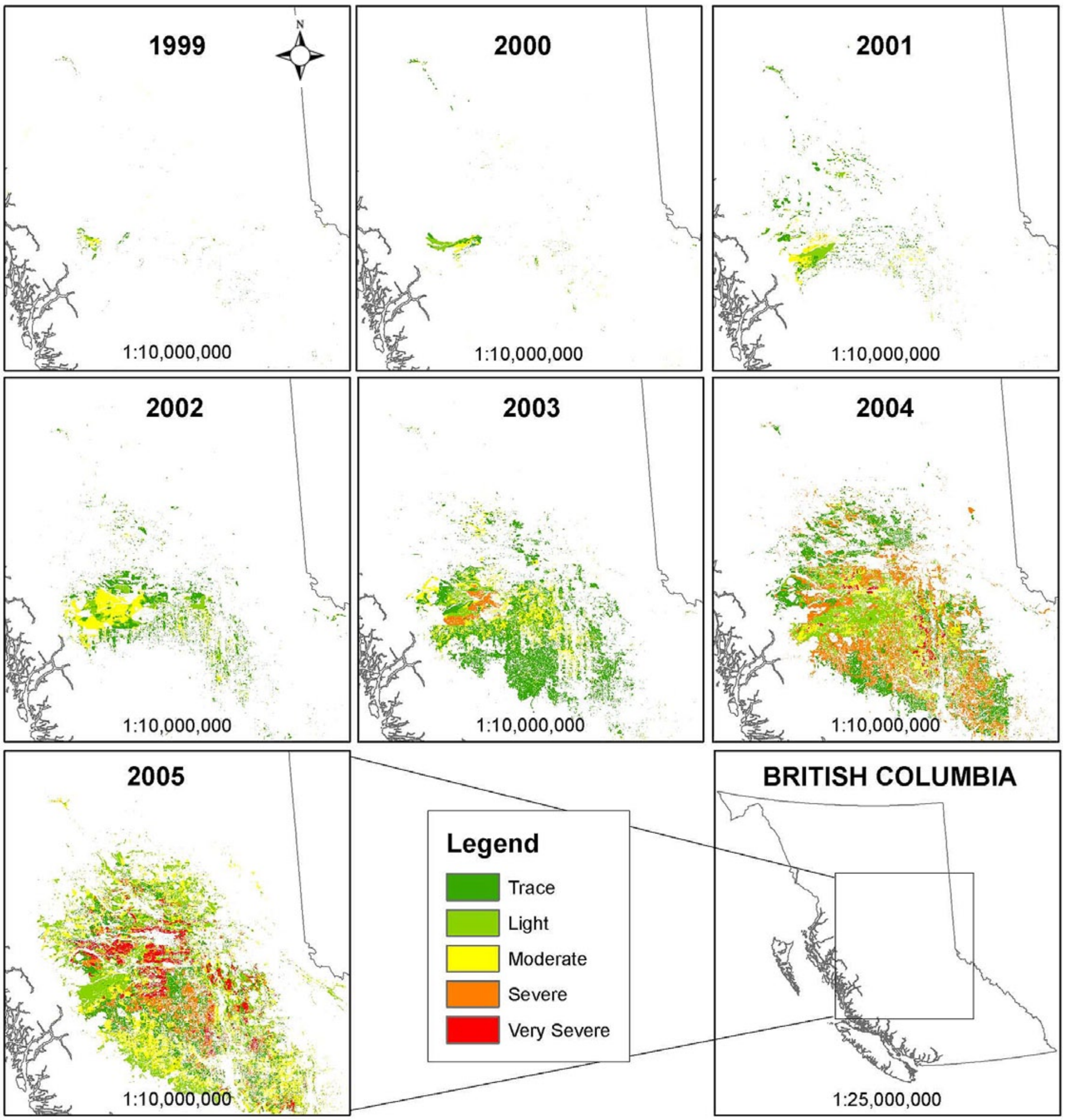


FIGURE 3. Expansion of area impacted by mountain pine beetle in British Columbia from 1999 to 2005.

impacted area, combining trace and light severity classes) (Table 2). The proportion of impacted area classified as severe changed less dramatically: 31 139 ha in 1999 (22% of the total impacted area) to 1.98 million ha in 2005 (23% of the total impacted area, including both severe and very severe). Figure 3 shows the increasing area impacted by the beetle from 1999 to 2005.

Figure 4 indicates the differential spatial distribution of impacted area by forest district. For example, the Nadina Forest District experienced a large increase in total impacted area by 2002, while the Central Cariboo Forest District's greatest impacted area occurred in 2005. Figure 4 demonstrates the utility of the AOS program for forest management, as it identifies forest districts that require proportionally more resources to conduct detailed surveys and address the infestation. However, the information would be further enhanced if severity was also considered. For example, Figure 4 illustrates the total area impacted in 2003, shaded by severity rating. For example, Quesnel has more moderate and severe areas than Chilcotin, which has a large area rated as light. Depending on the management strategy being implemented, forest districts with significant increases in areas rated as trace or light from one year to the next might not need the same level of resources for mitigation of the beetle as districts with large increases in moderate or severe rated areas. At a strategic level, the AOS data is useful for capturing the spatial and temporal variability of mountain pine beetle impacts across the province.

TABLE 3. The number of years a given area experienced attack.

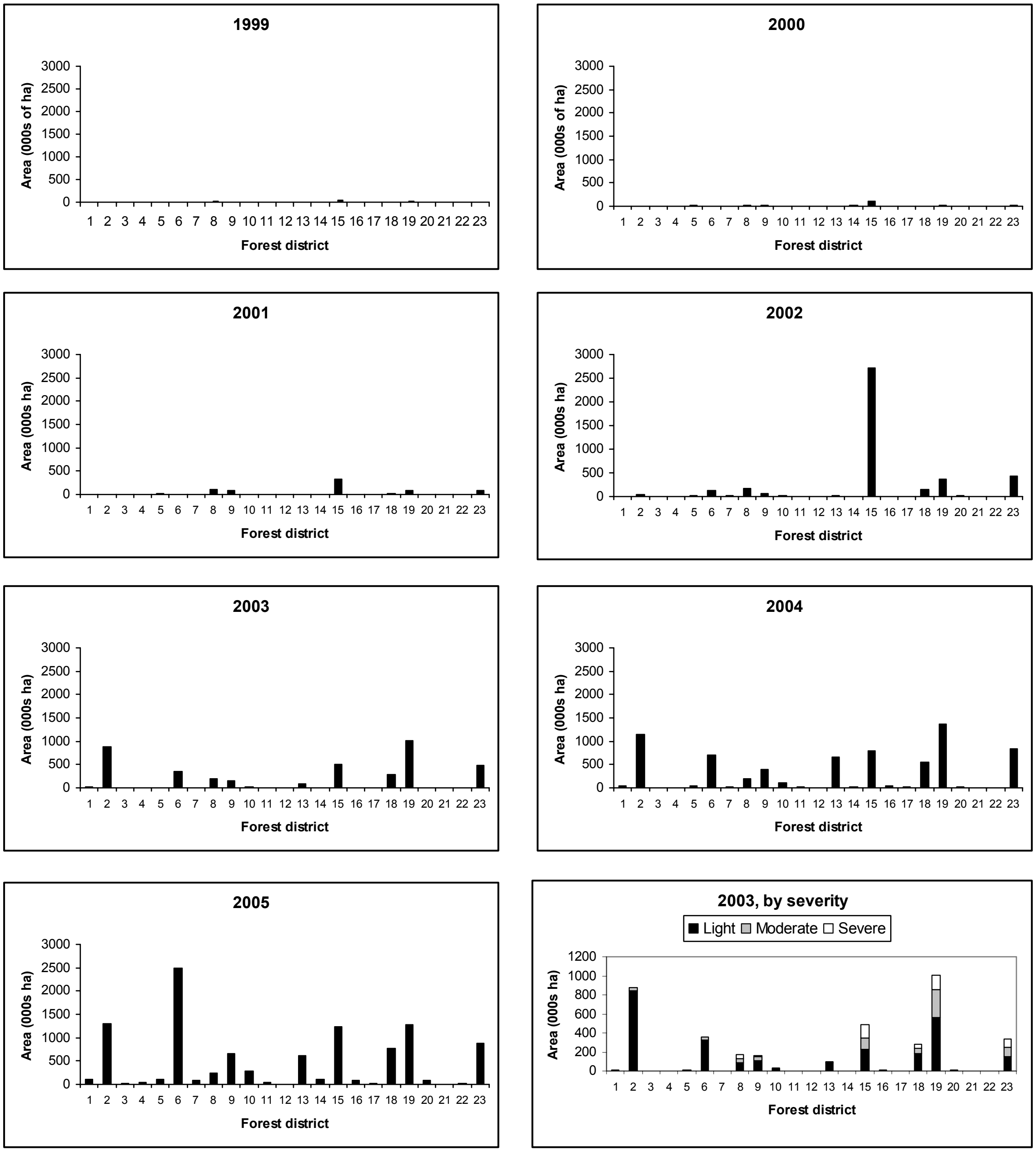
Number of years of attack	Area (ha)
1	4 277 639
2	3 157 317
3	2 431 206
4	922 714
5	186 650
6	68 992
7	3 753
Total	11 048 271

A British Columbia Ministry of Forests report (2003a) discusses the difficulty in calculating the cumulative area of mountain pine beetle attacks and suggests that the same area of infestation may be captured by the AOS in multiple years. For example, if the area impacted each year is summed, the total area impacted between 1999 and 2005 will exceed 22 million ha; lodgepole pine are estimated to occupy only 14.8 million ha in British Columbia (BC Ministry of Forests 2004). The time series of AOS data used in our analysis allowed us to determine the location and extent of areas captured in multiple years, and to estimate the cumulative area of impact without "double-counting" areas. The location of persistent impacts is shown in Figure 5 and areas impacted are summarized in Table 3. The total cumulative area of attack between 1999 and 2005 is estimated to be 11 048 271 ha. The area mapped as having mountain pine beetle impacts in all 7 years of AOS data was 3753 ha. Our analysis indicated that approximately 39% of the accumulated area was attacked in only one year, with 89% attacked in three or fewer years.

We also examined the trends in severity codes over time. Table 4 provides a summary of the amount of area experiencing no change, an increase, or a decrease in severity rating over 1, 2, 3, 4, or 5 years between 1999 and 2005. Given that there were seven possible years of attack in the timeframe analyzed, there were a maximum of six transitions between years. However, due to the small area that was attacked in all 7 years (< 4000 ha; Table 3), effectively, the maximum number of transitions was five.

TABLE 4. A summary of the trends in transitions between years of AOS data.

Number of transitions between years	Decreasing severity (ha)	Increasing severity (ha)	No change in severity (ha)
1	1 720 529	3 525 951	2 420 315
2	323 928	590 163	507 406
3	28 492	13 562	33 761
4	850	169	1 168
5	0	0	32
Total	2 073 799	4 129 845	2 962 682



Code	Forest District	Code	Forest District	Code	Forest District
1	Arrow Boundary	9	Fort St. James	17	Peace
2	Chilcotin	10	Kamloops	18	Prince George
3	Chilliwack	11	Kootenay Lake	19	Quesnel
4	Columbia	12	Kalum	20	Rocky Mountain
5	Cascades	13	100 Mile House	21	Squamish
6	Central Cariboo	14	Mackenzie	22	Skeena Stikine
7	Headwaters	15	Nadina	23	Vanderhoof
8	North Island–Central Coast	16	Okanagan Shuswap		

FIGURE 4. Variation in the spatial distribution of mountain pine beetle impacted areas, by forest district.

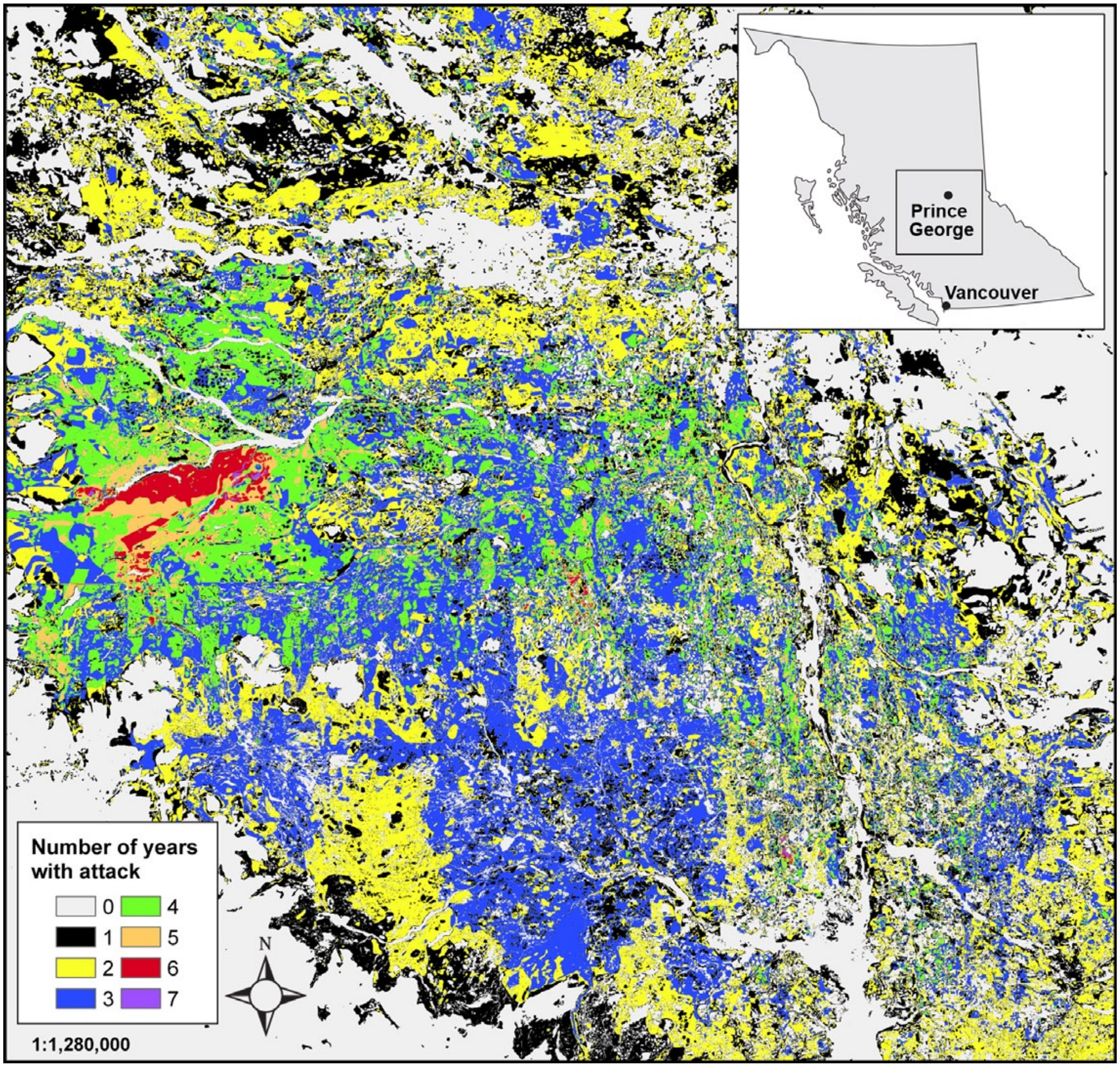


FIGURE 5. Number of years in which mountain pine beetle attack was recorded at that location in the AOS data.

There were 2.4 million ha where there was no change in severity rating over a single transition from one year to another; conversely, there were only 32 ha where the severity rating remained unchanged for all five transitions between years (Table 4). In other trends, 1.7 million ha experienced a decline in severity, while 3.5 million ha experienced an increase in severity over a single transition between years. The expectation over time was that the severity of an infestation in an area might increase as the mountain pine beetle population continued to grow. Some of the decreases in severity observed in our analysis may be attributed to changes in the severity classification system in 2004 with the addition of a new trace category. For example, in our analysis of the AOS data, we found that 354 756 ha assigned a severity of light in 2003 were assigned a severity of trace in 2004. Also, positional errors and the generalized nature of the AOS boundary delineation likely accounted for decreasing severity from one year to the next. More difficult to explain are the 28 492 ha of impacted area which our analysis revealed were assigned decreasing severity over 3 years, perhaps highlighting the subjectivity of the severity rating system.

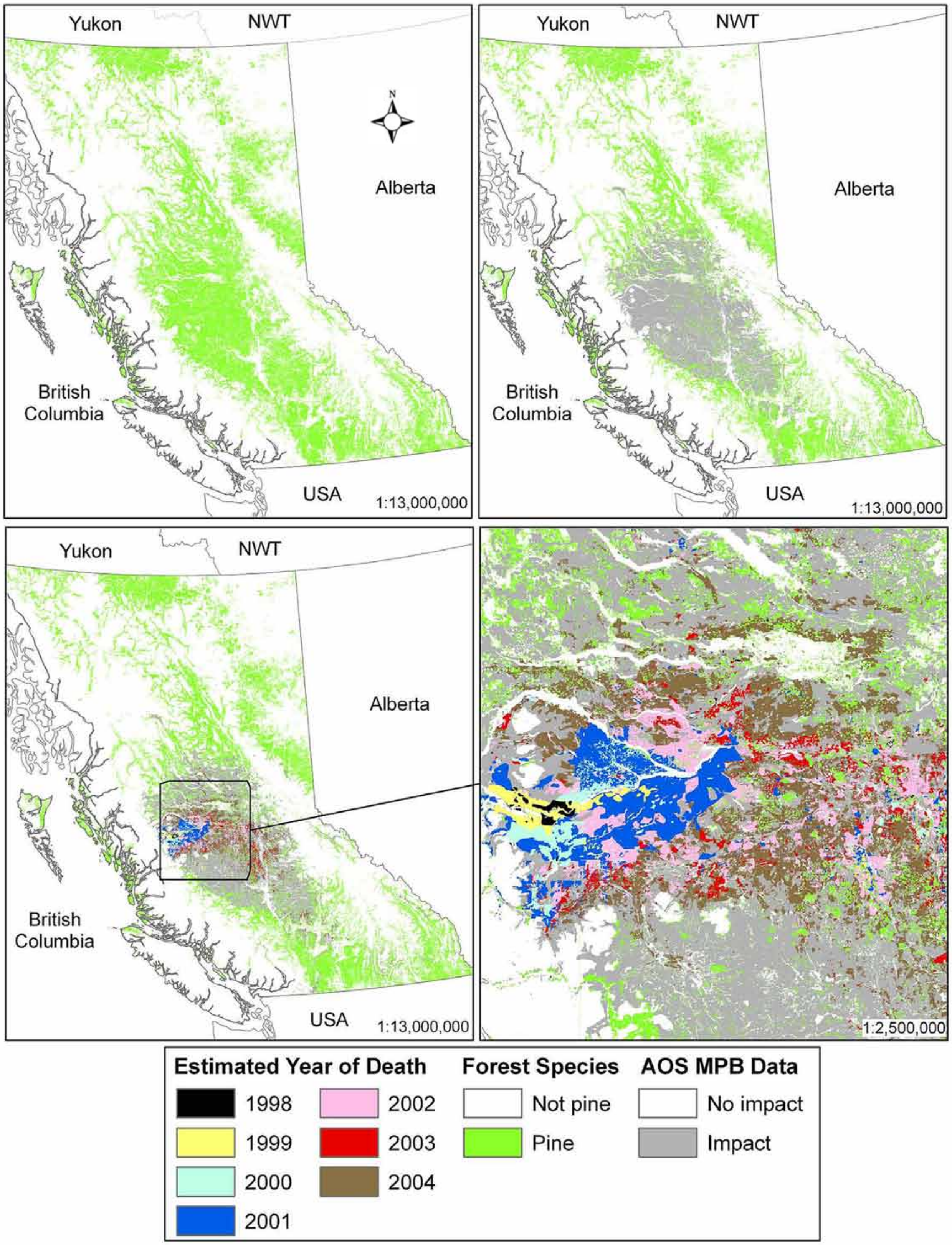


FIGURE 6. Distribution of pine species, area impacted by mountain pine beetle, and estimated year of death.

We estimated the year in which the majority of pine within a 1 ha grid cell could be considered dead. The AOS data indicated that the total cumulative area impacted by the beetle between 1999 and 2005 was 11 048 271 ha (Table 3). Based on the assumptions used in our analysis and a summation of the severity code mid-points (Table 1), the amount of area that experienced pine mortality from 1998 to 2004 was 6 565 667 ha (Table 5). In some areas, the sum of the severity codes exceeded 100% (2 322 524 ha). The greatest annual increase in mortality was in 2003, when the area of estimated mortality was 2 819 056 ha, an increase of almost 50% over 2004. This likely reflects the prolonged nature of the infestation in many of the central areas of the British Columbia. Figure 6 illustrates the total area of pine in British Columbia, the total area attacked by mountain pine beetle (as indicated in the AOS), and the estimated year of death. This figure illustrates that there is a large area of impact that may yet exceed the > 50% severity threshold we used to define mortality. With this approach, complementary maps of mountain pine beetle impacts can also be produced, indicating the cumulative impacts and mortality over the span of the current outbreak. Other thresholds could be used (e.g., 25% or 75%) to provide alternative representations of mortality under different scenarios. It should also be reiterated that difficulties with spatial positioning of AOS polygons exist, and that the 1 ha tessellation illustrates broad landscape trends and is not indicative of the actual conditions present at the geographic location represented by a given cell.

Conclusions

The total area impacted by the mountain pine beetle is often reported without a breakdown of area by severity rating. The total area alone is not necessarily representative of the area killed by the beetle. A better indication of actual mortality may be extracted by examining the severity ratings and their accumulation over a number of years. Furthermore, if severity is not reported, the perception of damage may be in excess of reality. If we consider each year separately, the area of mortality is, on average, two-thirds less than the total area impacted by the beetle each year. This implies that although a large forested area of British Columbia has been impacted by the beetle, there are still large volumes of viable pine on the land base. Because forest districts will have different severity rates, management approaches need to be developed that will respond to the severity of the infestation rather than the total area impacted.

We recommend that: (1) when producing tabular results, areas impacted by mountain pine beetle should be reported by severity class; and (2) when producing maps of the AOS data, where possible, impacts should be shaded according to severity to accurately represent the nature of the data. The AOS provides useful information for synoptic applications, and the full temporal and attributional range of this information should be utilized.

TABLE 5. Estimated year of death and corresponding area (assuming a 50% severity threshold). Areas where severity summed to > 100% are also shown.

Year	Total impact area (ha)	Area of pine mortality (sum of severity code mid-points > 50%)	Percent of total impact area	Area where severity code mid-points summed to > 100%
1998	144 062	31 139	22	0
1999	264 366	111 209	42	14 403
2000	771 517	262 997	34	33 810
2001	1 956 887	718 303	37	166 575
2002	4 064 539	1 158 009	28	423 444
2003	7 018 296	1 464 954	21	613 879
2004	8 730 559	2 819 056	32	1 070 413
Total	22 950 226	6 565 667		2 322 524

Acknowledgements

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Test Your Knowledge . . .

Aerial overview survey of the mountain pine beetle epidemic in British Columbia: Communication of impacts.

How well can you recall some of the main messages in the preceding Research Report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Annual aerial overview surveys in British Columbia:
   - A) Are conducted from fixed-wing aircraft and collect data on a variety of forest health concerns
   - B) Provide operational data used for harvest planning
   - C) Are used to count the number of trees infested with mountain pine beetle

2. Shelf life measures:
   - A) The length of time required for mountain pine beetle to successfully attack and kill a host tree
   - B) The length of time since attack within which mountain pine beetle killed trees are still economically merchantable
   - C) The length of time it takes for the foliage of an attacked tree to turn a characteristic red colour

3. Which two factors have contributed to mountain pine beetle spread?
   - A) Warm winter temperatures and urban forests
   - B) Fire suppression and several years of favourable climatic conditions
   - C) Plantation forestry and fire suppression

ANSWERS

1. A 2. B 3. B