AN EVALUATION OF THE THREAT POSED BY THE BALSAM WOOLLY APHID TO ABIES FORESTS IN BRITISH COLUMBIA

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FOREST RESEARCH LABORATORY
VICTORIA, BRITISH COLUMBIA
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CANADA
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INTRODUCTION

The balsam woolly aphid was first recorded on the west coast of North America in 1928 (Annand, 1928). By 1930 it was causing significant damage to grand fir, *Abies grandis* (Dougl.) Lindl., in Oregon's Willamette Valley. By the time the aphid was observed in the coastal forests of British Columbia in 1958, it had infested 600,000 acres in Oregon and Washington. By 1965 the aphid in British Columbia had been found throughout 900 square miles on the mainland and over 150 square miles on Vancouver Island. The forests within the infested area contain about one-sixth of the province's balsam inventory.

Whereas the timber within the infested area has a high industrial and recreational value, a large part of the balsam inventory outside the currently infested area forms much of the resource base for a proposed expansion of the pulp industry. Consequently, the present study was undertaken to determine the existing hazard to the thus far uninfested balsam forests of British Columbia.

The climatic analysis presented here was based on the extensive research of Greenbank (1963) into the limitations imposed by climate on the distribution and abundance of the aphid in eastern Canada.

THE PROBLEM IN BRITISH COLUMBIA

In British Columbia there are three common species of *Abies* each of which occupies a somewhat distinct area although their ranges do overlap. *A. grandis* occurs mainly on the eastern coastal fringe of southern Vancouver Island, and on the adjacent small islands and mainland coast (Fig. 5). *A. amabilis* (Dougl.) Forbes occurs west of the *A. grandis* over the remainder of Vancouver Island, on the mainland coast and throughout the coast mountains north to Alaska (Fig. 6). *A. lasiocarpa* (Hook.) Nutt. is not common along the coast, but occurs throughout much of the remaining forested land of the province (Fig. 7). (USDA, 1965).

The above-named species also occur through Washington and Oregon where they are all infested by the balsam woolly aphid. Observations of the ability of the three hosts to withstand aphid feeding in the western United States, indicate that *A. grandis* can survive a heavy infestation for up to 15 years, whereas *A. amabilis* and *A. lasiocarpa* may only survive for 3 or 4 years (Mitchell, 1966).

In British Columbia the aphid has infested, with few exceptions, *A. grandis* on Vancouver Island, whereas on the mainland both *A. amabilis* and *A. grandis* have been infested (see Fig. 8). Only one *A. lasiocarpa* growing in its natural state has been reported to be infested, although trees in nurseries and gardens have been killed.

The history of the aphid in B. C. has probably been too short for dispersal over most of the suitable area to have occurred. We are thus faced with the problem of predicting what the pest's potential range may be and what part of that range would be most susceptible to the spread, establishment, and proliferation of the aphid. The spread of the eggs and crawlers is without doubt influenced by prevailing and local winds, the opportunity for phoresy or accidental transport, topography, and natural barriers. However, the one factor that can limit the range of a pest within the range of its hosts is the regional climate.

THE EFFECT OF WINTER CLIMATE

The temperature at which an insect is killed by cold depends upon its super-cooling point. The super-cooling point in turn depends partly on the insects' opportunity to cold harden during a gradual temperature decline; sudden drops in temperature frequently cause high mortality.

Most descriptions of the life history of the balsam woolly aphid report that it overwinters in a dormant phase of the first instar nymph. Whereas other stages of development are killed by temperatures between 3° and -4° F., the dormant neosistentes can survive substantially lower temperatures (Balch, 1952; Greenbank, 1963). Greenbank found that in New Brunswick temperatures below -25° F. normally killed more than 60% of the overwintering neosistentes and temperatures below -32° F. killed over 90%. He also noted that some individuals established near the base of the trees survived probably because of the protection provided by snow.

When a species of insect exhibits different degrees of cold hardiness, the lower super-cooling points usually occur in the portion of the range where the winter is most severe. Consequently, the data provided by Greenbank should provide a safe basis for considering the effect of winter minima that occur throughout B. C. on the spread of the aphid from the moderate coastal region. The probability of an annual occurrence of temperatures below -32° F. was calculated from the data of all weather stations in British Columbia having continuous records for 20 or more years, with 1940 set as the base date of the analysis. When the probability values were plotted at their respective station locations, the province could be divided clearly into three zones (Fig. 1). One zone consists of the coastal region where minimum temperatures lethal to the dormant neosistentes never occur, and the southern interior where such temperatures occur occasionally at some of the higher localities (east of the dotted line on Fig. 1). The largest and coldest zone comprises the northeastern interior where on the average two of every three winters will produce lethal temperatures; in the northeast of the zone they occur every winter, in the southwest of the zone every second winter. The third zone where lethal minima occur on an average of once every four years, consists of the transitional region between the other two zones.

Although a large part of the cold zone receives much of its annual precipitation in the spring and summer, some areas would normally receive enough snow to protect the aphids on the lower bole of trees. However, some years the temperature drops sharply while the ground is still bare, and deep snow is more characteristic of the western side of the mountains than the interior plateau. Although Greenbank (1963) has shown the insulative quality of snow to be considerable, a heavy fall of wet snow in the coastal mountains may have contributed to a marked decline in lower bole infestations observed on Mt. Seymour in the early spring of 1966.

The effect of temperatures near freezing upon the aphid is not clear. Three consecutive nights with minima between 28° and 30° F. in late May 1966 caused a noticable decline in egg production and hatching among a previously active population on Vancouver Island. On the other hand, minima in the high twenties and low thirties failed to maintain dormancy among overwintering neosistentes in the same locality the following winter. Whereas only the dormant neosistentes can survive the winter in New Brunswick (Greenbank, 1963), on Vancouver Island the nymphs moulted to the second instar in January and occasional eggs were found in late February. The threshold for development has been reported between 32° F. (Merker and Eichhorn, 1955) and 35.5° F. (Greenbank, 1963) so the number of frost-free days provides at least an indication of the time available for uninterrupted development in different regions (Fig. 2).

In the region where the winters are most severe the frost-free period is uniformly short, compressing the development and spread of the aphid into a short period of time when conditions are favourable. However, on the coast the occurrence of frost varies considerably in time and place in relation to the topography thus dividing the zone into a mosaic of widely differing developmental conditions.

THE EFFECT OF SUMMER CLIMATE

The rate at which the aphid develops from egg to adult depends largely upon temperature. In warm localities the time required to complete the life cycle is short and the aphid may pass through four or five generations in one year (Mitchell et. al., 1961). In cold areas the aphid may be restricted to one generation per year. Greenbank (1963) found that the amount of heat available, expressed in degree-day units above a threshold temperature, provided a rough measure of how much development may occur during a season. Although Greenbank found the threshold for development to be 35.5° F., the developmental rate up to 45° F. was so slow that he felt confident using the heat accumulation above 42° F. Whereas Figure 3 is a simplification of a map of accumulated degree-days above 43° F. prepared by the B. C. Resources Conference in 1956, it is not significantly different from a map based on 42° F. prepared by the Canada Land Inventory that came to my attention recently. Greenbank (1963) found that about 600 degree-days above 42° F were required for the overwintering neosistentes to complete development and produce progeny. Therefore, the data on the accumulated heat in Britisbh Columbia indicates that nowhere in the province should the aphid fail to complete at least one generation per year if the neosistentes can survive the winter. However, there is little likelihood of more than one generation per year over vast areas as approximately 1500 additional degree-days above 42^{0} F would be required for the completion of a summer generation. The coastal region, particularly the southwestern portion, has a high accumulation of heat, which coupled with the mild winters should provide the aphid with an opportunity to complete three or more generations per year.

OVERALL ANALYSIS OF THE HAZARD

When the data displayed in Figures 1 to 3 are combined, the province can be divided into three main areas with climates that suggest quite different levels of suitability for the balsam woolly aphid (Fig. 4). The area where the climate is most suitable and thus where the threat or hazard presented by the aphid is greatest, encompasses the southwest coast and much of the southern interior. This region is surrounded by an area where the hazard is considered to be reduced by the cooler coastal climate to the west and the mountain climate to the east. The remainder of the province has a climate that may be suitable for the development and survival of the aphid some years, but which may be lethal in other years. The aphid hazard in this latter region should be considered low.

The foregoing rating of the *Abies* forests in B. C. is a subjective one based upon the suspected overall effect of the climate on spread, establishment, development, and survival of the aphid. This rating was devised by extrapolating from data collected elsewhere and by exercising judgement, so should be considered only as a temporary guide.

THE HIGH-HAZARD ZONE

The zone rated as having the highest aphid hazard has the longest frost-free period, the greatest summation of heat above the insects' developmental threshold, and except in a few isolated locations never experiences extreme winter cold. Consequently, even at higher elevations the aphid can complete at least one summer generation per year and overwinter successfully without snow protection. In some parts of the zone, such as the southeast coast of Vancouver Island, the aphid could pass through three or more generations per year and some years may continue to develop slowly all through the winter. The effect of a sudden decline in temperature on a nondiapausing population is not known, but temperatures reported to be lethal to non-dormant stages rarely occur on the coast. The normal situation in the high-hazard zone would be high overwinter survival.

The three most common host species found in western North America all occur in the high-hazard zone, although *Abies lasiocarpa* is not common.

On the other hand, most of the A. grandis in B. C. grows in the high-hazard zone. As A. grandis is the least susceptible of the three species to aphid-induced mortality (Mitchell, 1966) the pest can persist in isolated pockets for many years. This host tolerance coupled with the highly suitable climate makes southwestern B. C. a significant locus of aphid infestation in this province.

The current area of known infestation almost all lies within the high-hazard zone and the adjacent uninfested forests must be considered highly susceptible to invasion and mortality. However, natural spread into the interior may be restricted. The prevailing southwest wind during the spring and fall should tend to disperse the aphid inland, but the mountains and the snow fields they harbour should present a substantial barrier (solid black in Fig. 1 represents elevation over 3000 ft.). The northeast wind that often occurs during summer would tend to disperse the aphid within rather than from the present infested zone except for some westward spread into the A. amabilis forests of central Vancouver Island. Dispersal within the high-hazard zone and into some adjacent areas by means other than wind is likely to be higher than elsewhere because of the proximity of the infestation to populated areas and the large amount of both recreational and commercial traffic. However, on the mainland the spread should be to the east rather than northward up the coast where it should be impeded by the many long inlets and the absence of cross-winds.

On the other hand, the small area of high hazard in the southeastern interior is probably fairly safe from natural invasion due to the barriers presented by areas of grassland, successive north-south oriented mountain ranges and valleys, the rather patchy distribution of A. grandis, and the relatively high elevation distribution of A. lasiocarpa.

THE MODERATE-HAZARD ZONE

The moderate-hazard zone is for the most part an area of transition between the most and least favourable climates for aphid establishment and survival. Along the outer coast the conditions may be only slightly less favourable than those in the high-hazard zone. The frost-free period is about the same and there is no possibility of winter temperatures lethal to the neosistentes. However, the outer coast does not accumulate as much heat and many areas receive heavy rain and fog. Therefore, the number of generations per year should be fewer and the buildup of the population slower than in the warmer and drier inner coast region.

The transition between the high-hazard zone and the less suitable climate to the northeast occurs mainly in the coast mountains where the higher elevation and the progressively increasing continental influence shortens the frost-free period, increases the severity of the winters, and reduces the summation of heat. However, the aphid should be able to establish and survive in this region although population increase may be slower than on the coast.

A. amabilis and A. lasiocarpa completely replace A. grandis in the transition zone and on the outer coast. Consequently, tree mortality may occur within a few years of invasion by the aphid and although the pest population may not increase as rapidly as in the high-hazard zone, damage may be more spectacular than in A. grandis.

THE LOW-HAZARD ZONE

Most of the province has been given a low hazard rating. Throughout the southern and western part of this zone the length of the frost-free period and the heat sum is not much inferior to the moderate-hazard zone, but the winters are considerably more severe. On the average, winter temperatures lethal to the neosistentes occur once every 5 or 6 years in some locations and once every 3 years in others.

Throughout the remainder of the low-hazard zone there is only sufficient summer heat for one generation per year and that may be hampered by late frost in the spring or an early frost in August. Furthermore, lethal temperatures occur on an average of twice every three winters and in many locations occur every year. Aphid populations would have the least possible opportunity to invade, establish, and survive in most of the Abies forests in this zone.

SUMMARY

The balsam woolly aphid is now well established in the high-hazard zone and it is clear from the pest's history under similar climatic conditions in Washington and Oregon that natural agents are not going to bring it under control. The pattern of winds and the high level of travel in the woods suggest that aphid dispersal within the high-hazard zone will be great. Outside of the high-hazard zone the A. amabilis forests on Vancouver Island are probably in the greatest danger of being invaded and as in the adjacent areas there is little likelihood of natural control. Significantly, all of the new discoveries of infested Abies in 1966 and so far in 1967 have been either relatively short extensions of the infested area into the adjacent moderate-hazard zone on Vancouver Island or have occurred at new locations within the high-hazard area.

The distance that the aphid may spread in one year is difficult to predict, but research now in progress suggests that the vigor (rate of crawling), of the motile neosistentes declines rapidly, especially at temperatures over 65° F, and this may restrict successful dispersal somewhat. Whereas, dispersal within a stand is a continuous process that tends to proliferate localized infestations, long-distance dispersal requires the escape of the crawlers from the intertree space. The settling of crawlers near their hatching site, the death of others that drop to the forest litter but never reach a suitable host, and the barrier presented by the foliage, substantially reduce the number of crawlers that enter the atmosphere. Then, wind dispersal above the forest would result in the deposition of many of the transported crawlers in the forest canopy. As the dispersal process should cause a reduction in the ability of individuals to crawl, most of the initial establishment in a remote location should occur in the crown region. Consequently, dispersing crawlers blown long distances into areas of more unsuitable climate would only have opportunity to complete one generation in the crown and many of their progeny would be exposed to severe winter temperatures. It is noteworthy that after 40 years in Washington and Oregon the aphid is still confined to the western region where the climate is similar to that of the high-hazard zone described here. The eastern portions of Washington and Oregon where A. lasiocarpa occurs, have a climate similar to that in the moderate to low hazard zones in B. C., and to date the aphid has not become established there.

Although mathematical descriptions of dispersal are largely inadequate, it is a truism that the number of organisms declines with time and distance from a source. This dilution combined with vigor decline, and a heterogeneous distribution of hosts, suggest that aphid spread would more often be gradual than spectacular. Furthermore, dispersal must decrease as the number of generations per year decreases. Therefore, the further inland the aphid spreads the slower should be its subsequent spread. However, we should not lose sight of the fact that certain atmospheric processes that are related to particular topographic features can concentrate airborne particles in locations similar to those in which they were generated.

In conclusion, the balsam woolly aphid will persist and spread throughout much of the high-hazard zone although the patchy distribution of its hosts in the eastern part of the zone, the intrusion of grassland, and the north-south orientation of the mountains and valleys should retard the spread beyond the dotted line on Fig. 1. Probably the most serious threat is to the high-value Abies amabilis in the central portion of Vancouver Island. In the western part of the high-hazard zone and the more favourable parts of the moderate-hazard zone the aphid can be expected to behave much the same as it has in Washington, and require similar changes in the management of Abies stands. However, the spread, establishment, and proliferation of the aphid in the northern portion of the province should be minimal.

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FIGURE 1

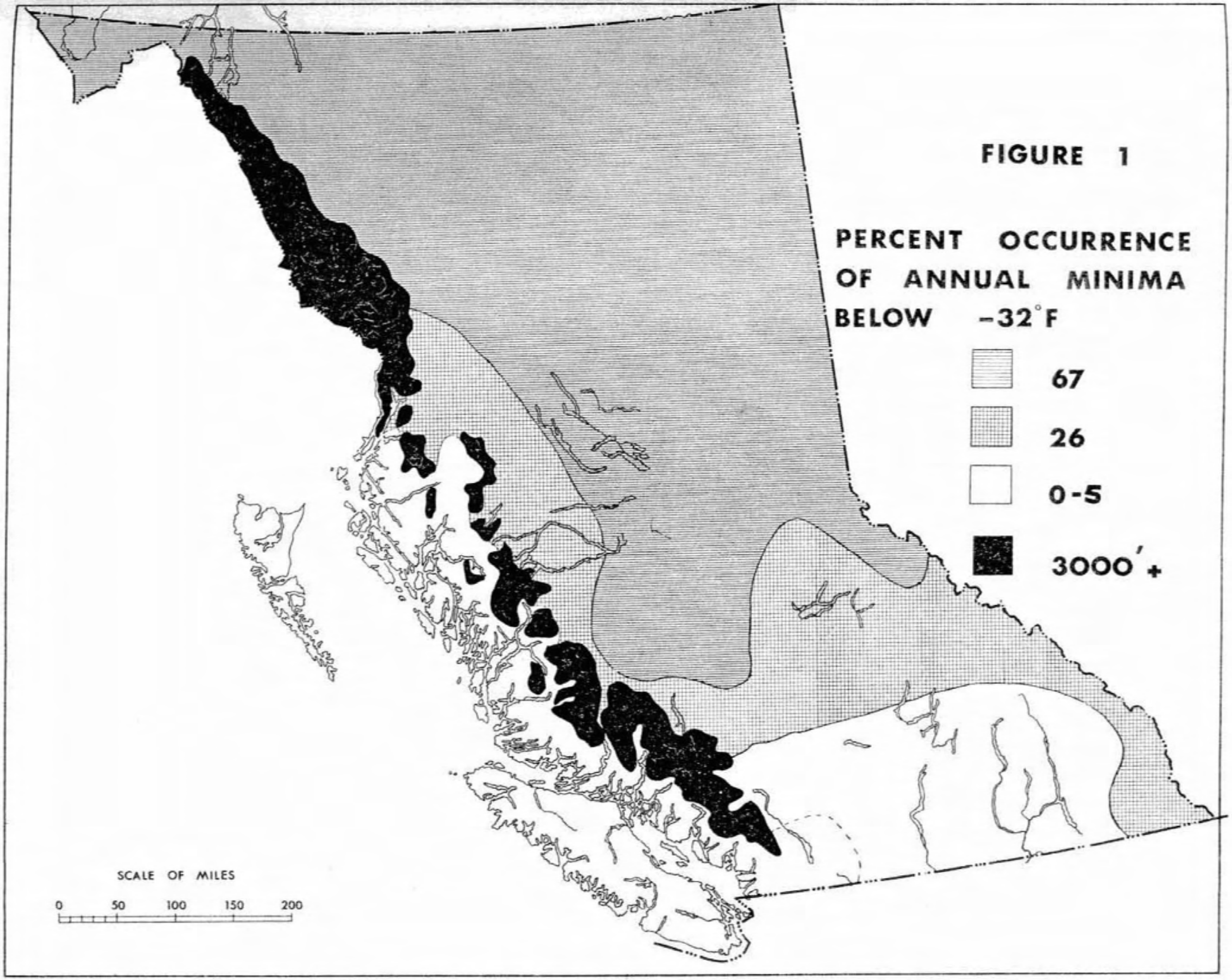
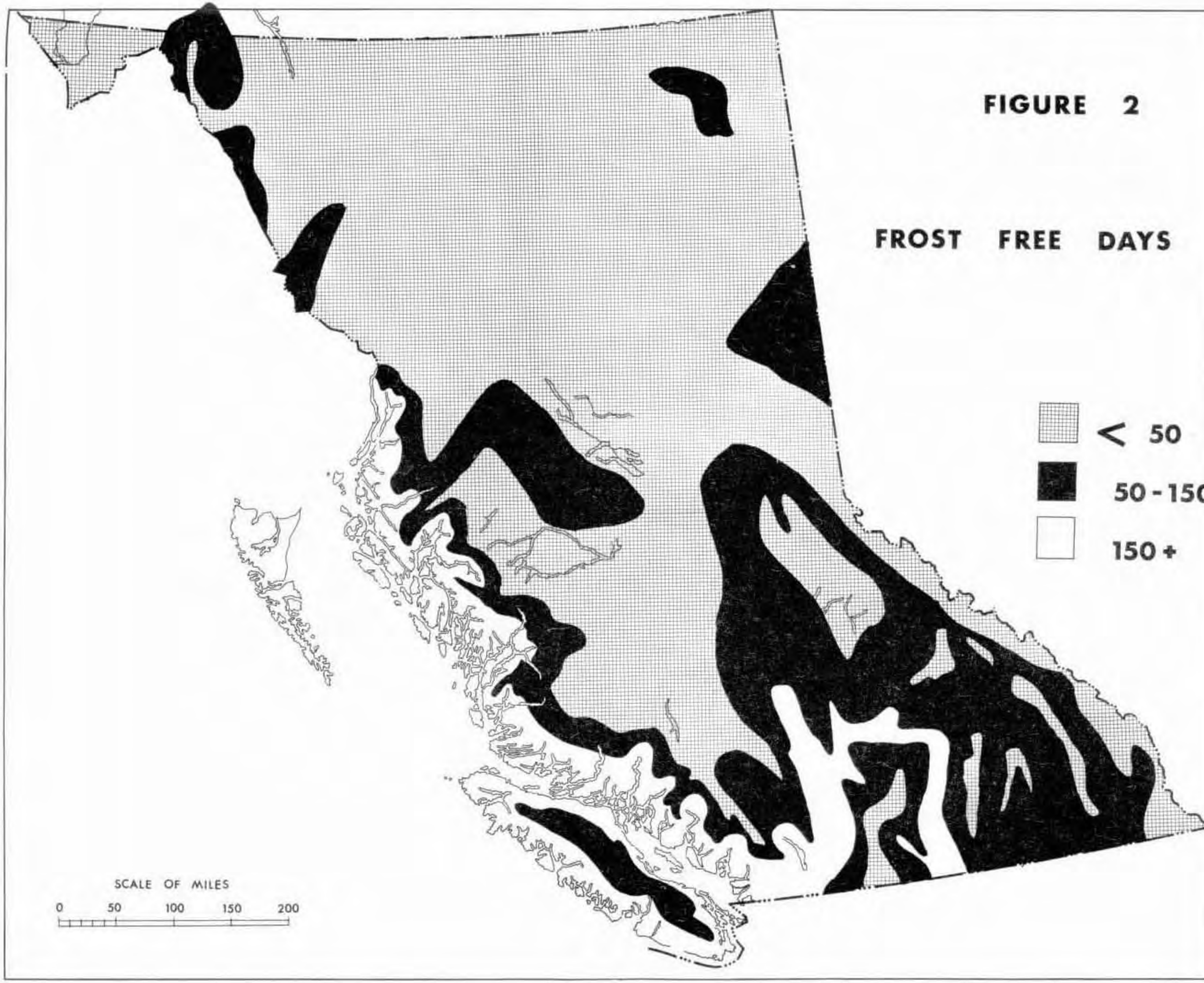

PERCENT OCCURRENCE
OF ANNUAL MINIMA
BELOW −32°F
67
26
0-5
3000′+
SCALE OF MILES
0
50
100
150
200

FIGURE 2

FROST FREE DAYS



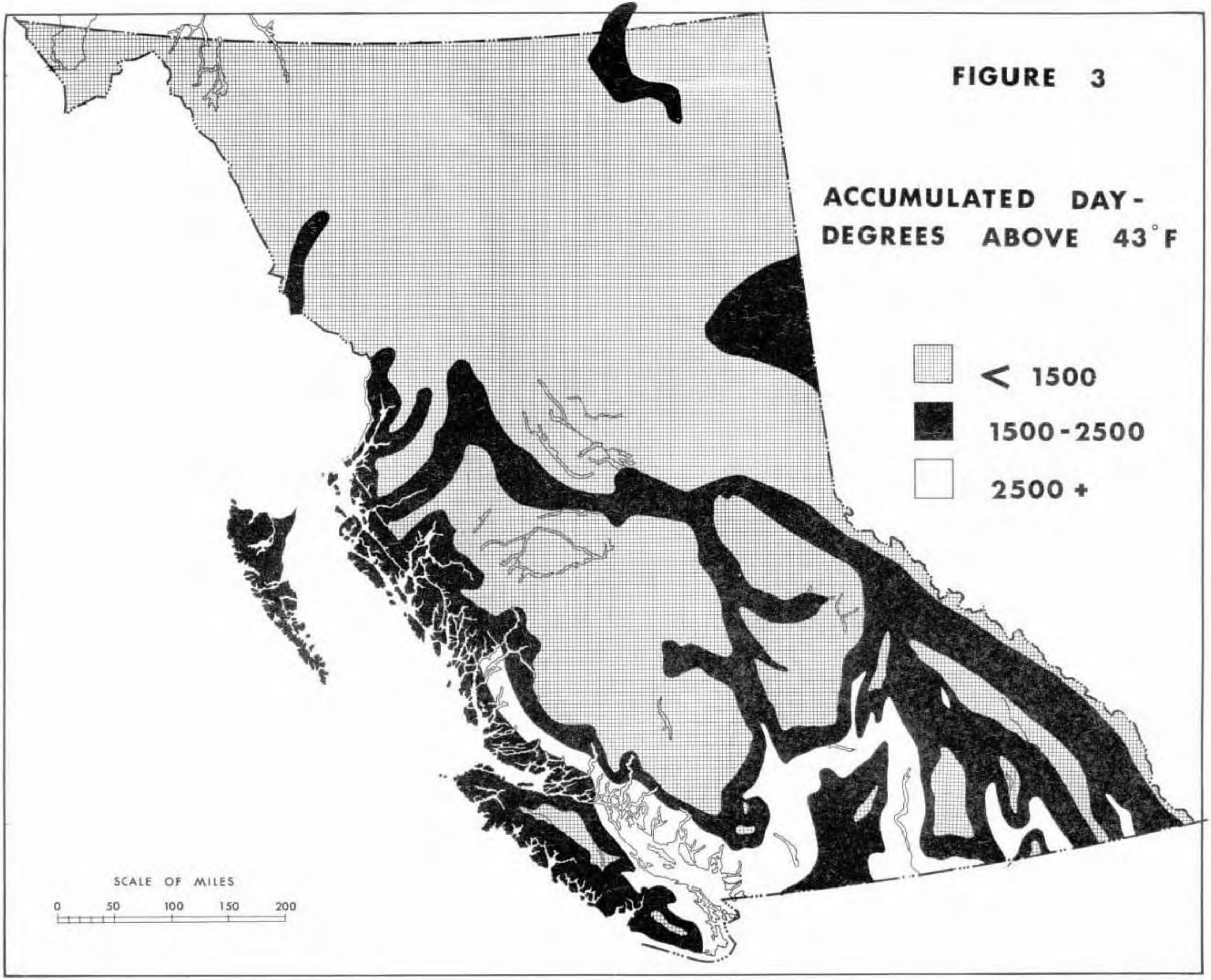


FIGURE 3
ACCUMULATED DAY-DEGREES ABOVE 43°F
< 1500
1500-2500
2500 +
SCALE OF MILES
0 50 100 150 200

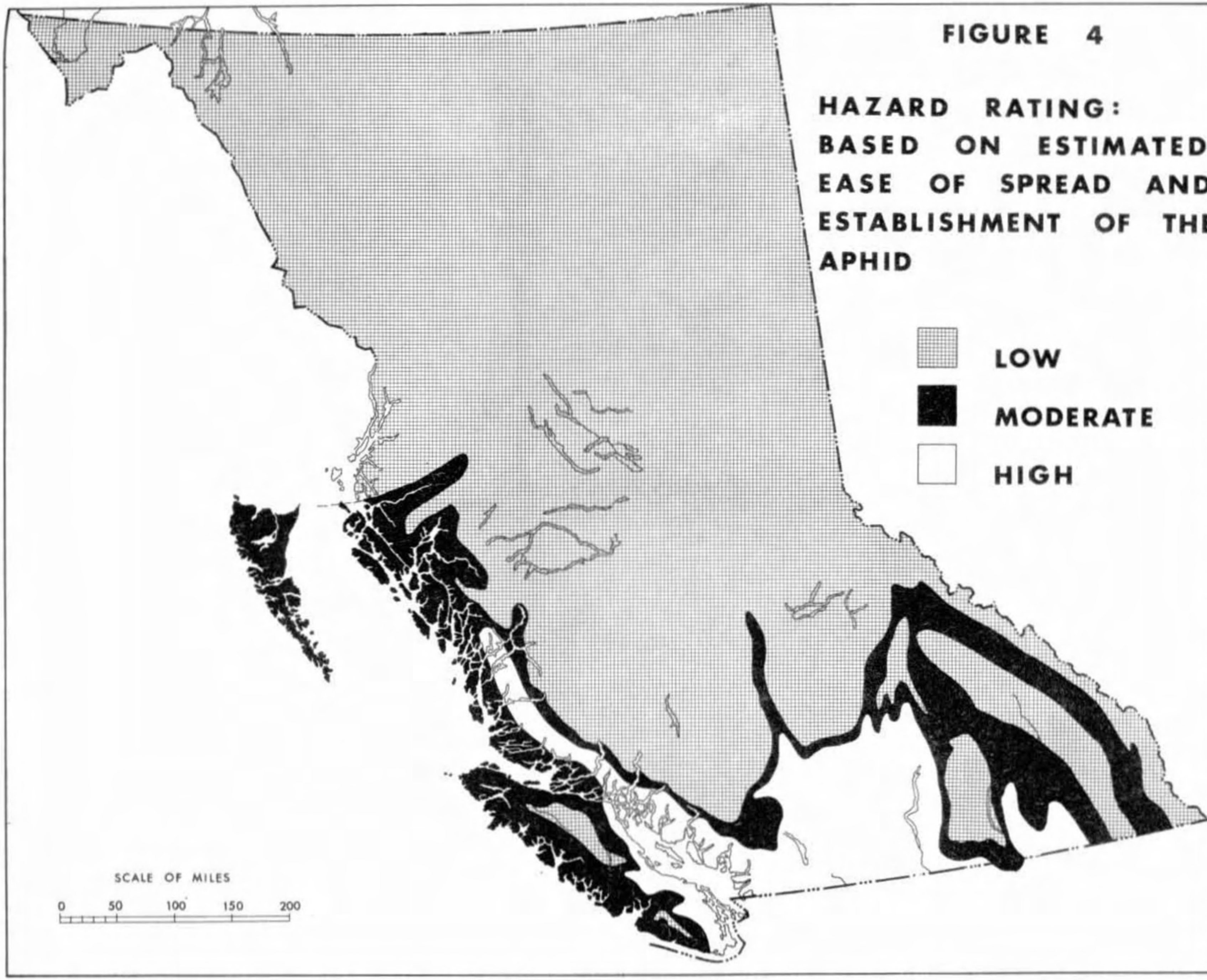


FIGURE 4

HAZARD RATING: BASED ON ESTIMATED EASE OF SPREAD AND ESTABLISHMENT OF THE APHID


FIGURE 5
ABIES GRANDIS
SCALE OF MILES
0
100
200

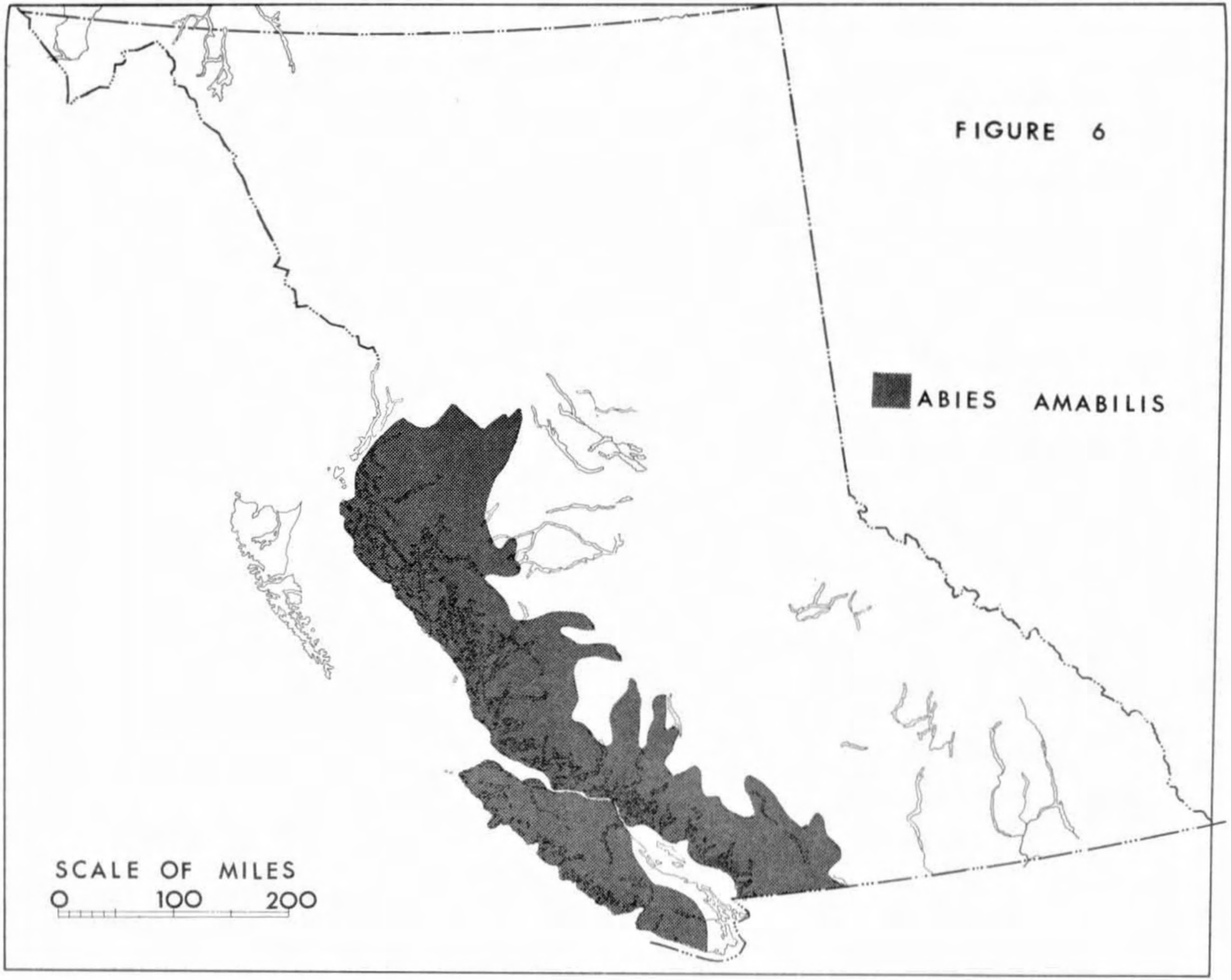


FIGURE 6
ABIES AMABILIS
SCALE OF MILES
0 100 200

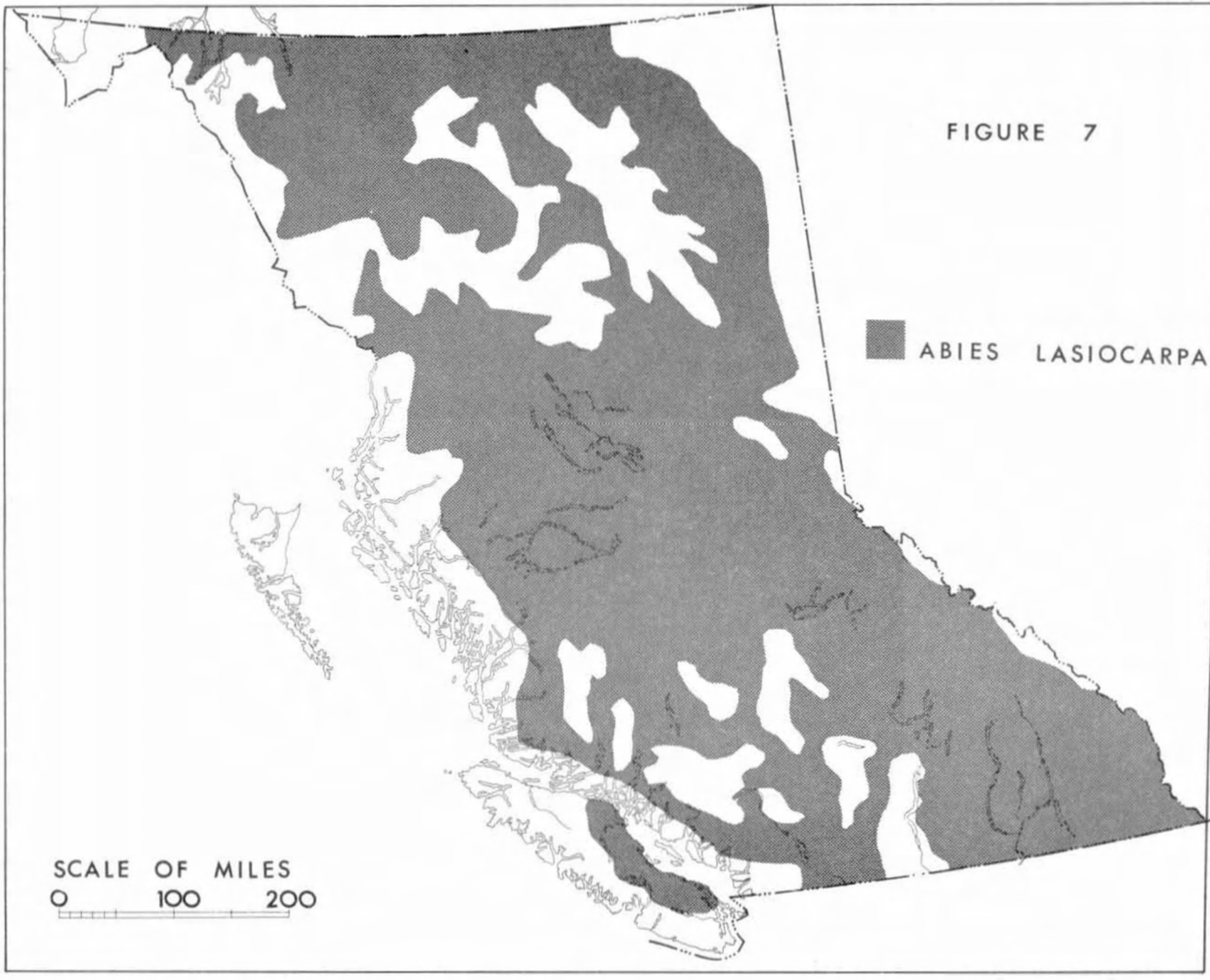


FIGURE 7
ABIES LASIOCARPA
SCALE OF MILES
0 100 200

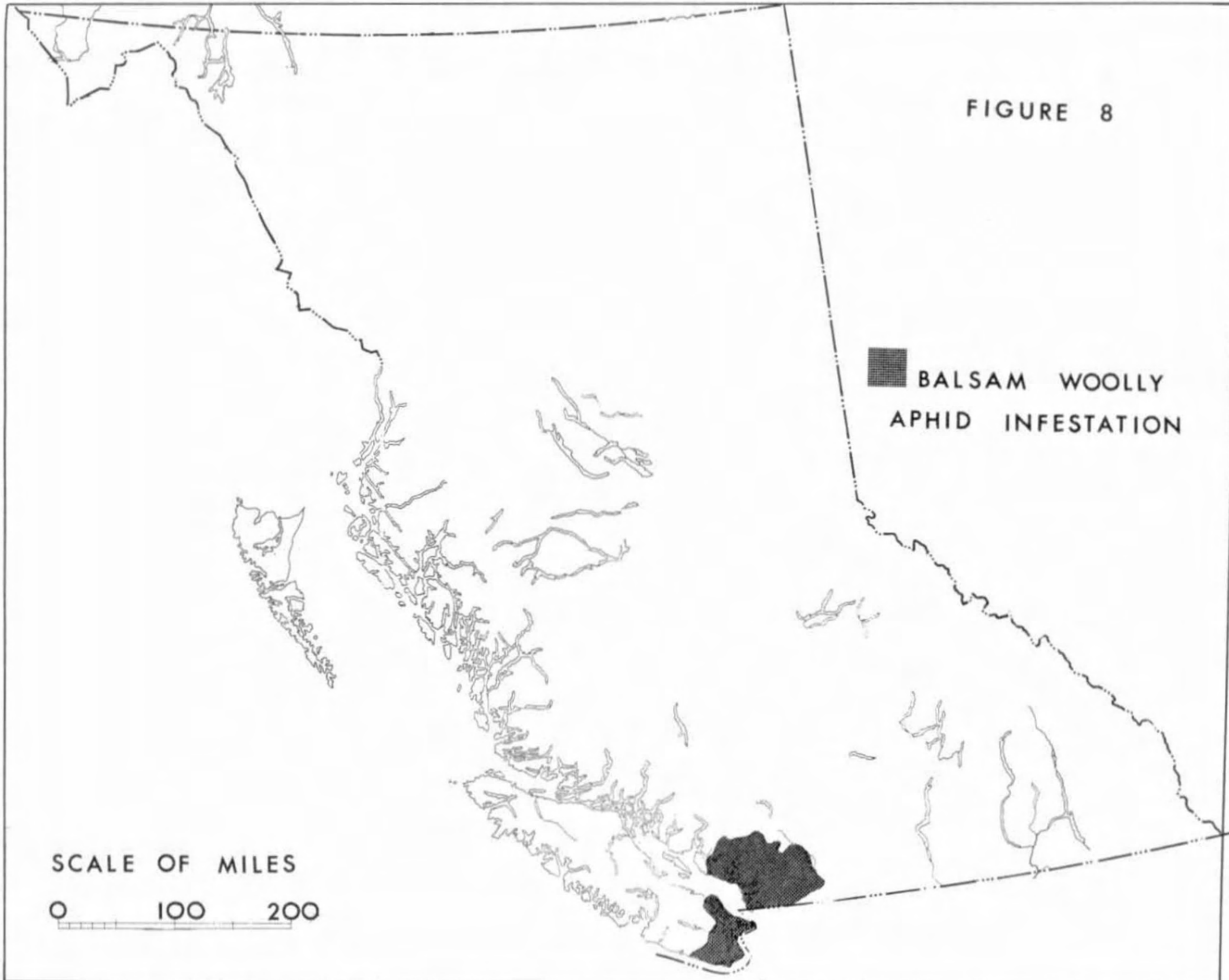


FIGURE 8
BALSAM WOOLLY APHID INFESTATION
SCALE OF MILES
0 100 200