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Input and Analysis Using a Geographical Information System

CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

Canada

BC

Historical Western Hemlock Looper Outbreaks in British Columbia: Input and Analysis Using a Geographical Information System

by

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ABSTRACT

The western hemlock looper geographical information system in British Columbia was developed by Natural Resources Canada, Forest Insect and Disease Survey (FIDS) at the Pacific Forestry Centre. By bringing all historical pest information into one common database, the system provides a comprehensive, spatially based historical record of western hemlock looper infestations. The complete database spans 84 years, from 1911 to 1994. Looper defoliation occurred during 39 of those years, and is separated into 14 distinct outbreaks. A total of 165 maps were input to the FIDS's ARC/INFO geographical information system (GIS).

Comprehensive queries and timely summaries were completed on the spatial database, and more than 100 map and tabular products were developed. Products included defoliation maps for varying scales, regions, and years; overlay analysis maps for any number of consecutive or nonconsecutive years; thematic overlay maps including physiographic, ecological, and climatic themes; summary tabular database reports and graphs; and a defoliation frequency map determining risk of western hemlock looper, defined here as likelihood of pest occurrence in a given forested area.

Results indicate that the general areas of infestations in British Columbia included the upper Fraser River northwest of McBride, upper Columbia River, Quesnel Lake, Wells Gray Park, North Thompson River, lower Fraser River, Port Mellon, and parts of Vancouver Island. The most frequent infestations occurred along the North Thompson River between Valemount and Blue River, and along the upper Columbia River between Mica Creek and Revelstoke. The largest recorded infestion occurred in 1992 in the interior of British Columbia, covering more than 190 000 ha. Overlay analysis indicates that the biogeoclimatic zones where looper outbreaks occurred most frequently were ICHvk, ICHwk, ICHmw, ESSFwk, and ESSFvc. The historical analysis also indicates that most infestations only lasted for 1–2 years in any one area. Only two small areas (east of Indian Arm and south of Lake Cowichan) have recorded defoliation for 4 consecutive years. This is the greatest number of consecutive years of recorded defoliation for this insect in British Columbia.

The historical records of western hemlock looper outbreaks in the geographical information system (GIS) and other related products are important to various clients including provincial and industrial agencies, forest managers, and research scientists. These products can be used to anticipate the need for and frequency of possible control actions, and can facilitate pest management modelling. In addition, they provide a platform for many different kinds of geographical analyses.

ACKNOWLEDGEMENTS

Thanks to the following for their assistance with this project: Dennis Clarke, FIDS GIS and database manager; Peter Koot, Senior FIDS Ranger Kamloops Region, for his assistance in gathering historical data for the western hemlock looper spatial database; and the staff at E.S.R.I. Canada Ltd. Pacific Region, for providing technical assistance for ARC/INFO.

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1 INTRODUCTION

This report gives a brief history of the western hemlock looper in British Columbia and the method of data collection used by The Forest Insect and Disease Survey (FIDS). The report discusses the development of the geographical information system application, including design and goals, hardware and software used, information gathering processes, map projections, database construction, programming, and final results. Specific application examples are included to illustrate the capabilities of the system.

The system is based on the recorded location, frequency, and duration of all previous western hemlock looper outbreaks. It was developed at the FIDS Section of the Pacific Forestry Centre (PFC) in Victoria, British Columbia, and involved entry of FIDS historical records of western hemlock looper defoliation into a GIS. The efficiency of operations was substantially increased by utilizing automated tasks dev-eloped through a previous project (Parfett *et al.* 1994). Many products were derived from the western hemlock looper system, and are presented in this report to help foresters and others who require historical information on this insect.

The western hemlock looper (*Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera: Geometridae)) is one of the most destructive defoliators of conifers in British Columbia (Harris *et al.* 1982). FIDS has recorded information on defoliation caused by this insect since 1911, and many distinct infestation periods may be recognized. Until this system was developed, and the historical data on western hemlock looper outbreaks entered into the GIS, the patterns and overlap of the infestations had not been analyzed by computer. The goal of this project was to bring all forms of cartographic historical data into a common geographical information system, and to analyze the data to provide a guide for identifying and managing areas prone to hemlock looper attack.

2 HISTORY OF THE WESTERN HEMLOCK LOOPER OUTBREAKS

In British Columbia, the western hemlock looper (Figure 1) occurs primarily south of 56 degrees latitude, with concentrations along the coast and in the interior wet-belt areas. The preferred host is western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), but Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western redcedar (*Thuja plicata* Donn), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Engelmann spruce (*Picea engelmannii* Parry), white spruce (*Picea glauca* (Moench) Voss), true firs (*Abies* spp.), and occasionally western white pine (*Pinus monticola* Dougl.), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), western larch (*Larix occidentalis* Nutt.), and some broad-leaved species are also attacked. Outbreaks tend to occur in valley-bottom stands with a high proportion of mature, open-growing hemlock. The outbreaks are usually limited in size, but can develop in widely scattered localities at the same time. The outbreaks gen-erally last from 1 to 4 years. The first recorded outbreak of western hemlock looper in British Columbia was in 1911 in Stanley Park, Vancouver, and infestations have occurred in various regions of the province since (Harris *et al.* 1982; Erickson 1984).

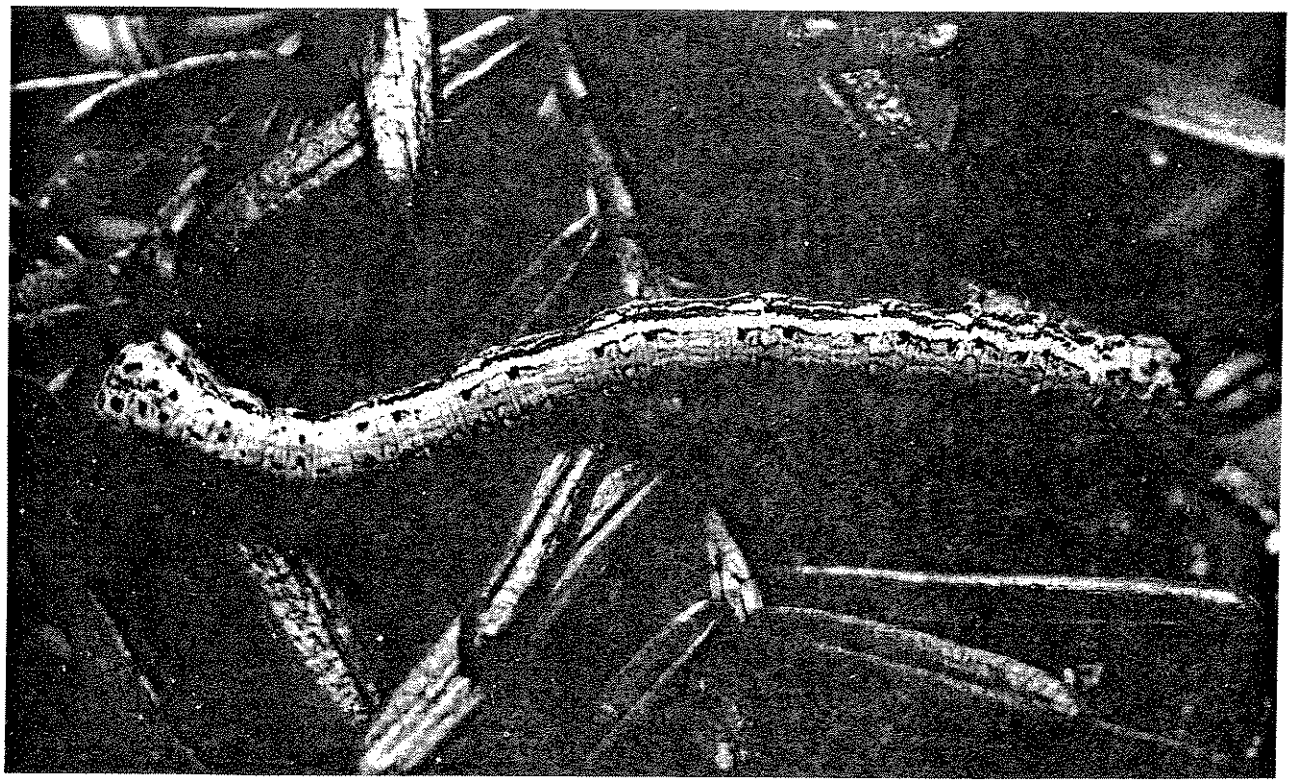

FIGURE 1. Western hemlock looper larva.

3 FOREST INSECT AND DISEASE SURVEY—AERIAL SURVEY RECORDS

FIDS has carried out routine aerial surveys of British Columbia forest regions since the 1960s, and previous ground surveys date back as far as 1909. Each summer, the Canadian Forest Service FIDS, in cooperation with the British Columbia Forest Service (BCFS), conducts flights over the six forest regions of the province. Aerially visible pest infestations are sketched onto National Topographic Series (NTS) maps. The maps usually range in scale from 1:100 000 to 1:250 000. These medium-scale maps cover relatively small sections of the province. Information recorded on the maps includes flight date, observer, pest type, and the degree of defoliation assigned (light, moderate, severe, or dead). Information on the sketch maps is verified through ground checks, which are conducted by FIDS rangers as required. The NTS map defoliation drawings are combined in the GIS to form a complete regional picture of the affected areas.

FIDS has acquired a large information base of historical insect and disease infestation data in various media, including paper maps, digital maps, verbal reports, and data tables.

4 DEVELOPMENT OF A GEOGRAPHICAL INFORMATION SYSTEM FOR WESTERN HEMLOCK LOOPER OUTBREAKS

4.1 Design and Goals of System

The development of the risk analysis system for western hemlock looper was based largely on a system that had previously been developed for the western spruce budworm (Parfett *et al.* 1994). In addition, discussions were held with interested scientists and researchers to learn how they would want to use and analyze the completed infestation database. The objective was to gather and place all western hemlock looper cartographic information into a standardized digital format so that statistical and analytical queries could be applied to the complete historical data set.

Various products were requested including maps and statistical reports encompassing infestation severities and infestation extent over specified numbers of years and specified regions. It would also be desirable to be able to perform specialized operations such as overlays and probability queries. The following list summarizes the development steps.

1. Design and set the goals of the system.
2. Build western hemlock looper historical database.
   a. Create new workspaces (data storage areas).
   b. Develop ARC Macro Language programs to semi-automate spatial processes (e.g., digitizing, data translation, editing, cleaning, projecting, output, analysis).
   c. Gather western hemlock looper historical information and interpret to maps. Data sources include FIDS's aerial mapping, annual FIDS regional reports, FIDS special reports, annual information reports, and historical field maps.
   d. Create NTS digital map templates in ARC/INFO for those mapsheets not already in system. Store templates in geographic, Universal Transverse Mercator (UTM) and Lambert Conformal Conic projection formats.
   e. Digitize some 76 historical western hemlock looper maps into ARC/INFO in UTM format.
   f. Manually label severity ratings of all western hemlock looper defoliations
   g. Run conversion programs to convert PFC FIDS's previous GIS system data (1986–1990 aerial surveys). Transfer 53 old system (OVERLAY) digital coverages into ARC/INFO system in UTM format. Join individual severity rating maps into single-year maps encompassing all severities.
   h. Calculate area size in hectares for all western hemlock looper polygons.
   i. Project all 165 maps projected into new projection type (Lambert).
3. Join individual mapsheet coverages into larger regional- and provincial-scale maps, and perform summary statistics.
4. Perform geographic analyses on historical western hemlock looper database (e.g., multiple year overlays, thematic overlays).
5. Present results of analyses as maps, tables, and graphs.

4.2 Hardware and Software Used

A GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modelling, and display of spatially referenced data for solving complex problems (Goodchild and Kemp 1991). Such a system is the primary tool of the historical western hemlock looper system. Since November 1991, FIDS has used the Environmental System Research Institute's (E.S.R.I.) ARC/INFO. This software operates on a Sun Sparcstation 2 platform (32 megabyte (Mb) memory, 16" colour monitor, 424 Mb internal disk drive, 3.5" 1.44 Mb floppy disk drive, and Solaris operating system). An Altek AC30 digitizing table, 150 Mb 1/4" SCSI cartridge tape drive, 1.2 and 2 gigabyte (Gb) disk drives, 7585B Hewlett Packard (HP) pen plotter, and QMS-PS 410 laser printer are also used.

4.3 Information Gathering

Historical sources of western hemlock looper information were compiled into a common information base. The complete database spans over 84 years from 1911 to 1994, and holds 165 digital maps.

Since many of the early infestation maps had not been digitized, and data gathering involved collecting paper maps, reports, and tables held at PFC, most of the data came from old annual FIDS regional reports and field maps, including Leech 1945, Wood 1982, Humphreys 1986, Andrews 1987, Erickson 1987, Turnquist 1987, Vallentgoed 1987, and Erickson 1992. Using an interpreted compilation map of the resultant data (many of the old data were taken from verbal reports), the western hemlock looper defoliation for each year was digitized and stored in the ARC/INFO GIS. A total of 76 maps spanning the years 1911–1983 were digitized.

Another large proportion of data gathering involved transferring digitized surfaces from FIDS's outdated OVERLAY GIS to the new ARC/INFO system. A total of 53 western hemlock looper maps spanning the years 1983–1991 were stored in the old information system. Conversion programs were run to convert the raster-based OVERLAY surfaces to an ASCII format file, which in turn was converted into an ARC/INFO vector-based file format. Finally, a series of in-house programs were run to add identification, severity, and area database items to the coverages, and to ensure that the converted coverages were accurate. These programs enabled graphic display and made interactive correction of any errors that arose during the conversion process possible.

The most recent western hemlock looper data, comprising 36 maps for the years 1992–1994, were already in digital ARC/INFO format.

In addition to the 165 NTS looper maps stored in the GIS, regional- and provincial-scale maps of western hemlock looper for each year of defoliation are also stored. These smaller-scale regional and provincial map coverages are compilations of the individual NTS maps and are useful for regional and provincial overviews of insect activity.

4.4 Map Projection

Projections associate earth locations from a curved surface to a location on a flat, two-dimensional map surface. Any representation of the earth on a flat surface distorts at least one property of shape, area, distance, or direction (E.S.R.I. 1991). Different projections produce different distortions; therefore, an appropriate projection for the proposed application had to be selected. The topographic mapsheets, from which most of the western hemlock looper infestation data were digitized, are UTM projection maps.

UTM projections are designed for large- to medium-scale applications and are zone-specific, with different reference systems for each zone. British Columbia covers five of these zones, each of which is 6 degrees wide (zones 7–11). The UTM coverages are useful in an individual mapsheet application (e.g., topographic mapsheet overlay operations), but when small-scale summary analyses that cross zone boundaries are required, the coverages are better converted into a single reference system to maintain accuracy. Therefore, the data had to be translated to a second projection, and the Lambert projection was selected as a common reference system for regional and provincial analyses of western hemlock looper. Since this projection is commonly used by other organizations, data sharing would also be improved. The UTM and Lambert projection parameters are described in Appendix 1.

4.5 Database Construction

ESRI's proprietory database management system, INFO, was used in association with ARC/INFO to organize the western hemlock looper data. The information base was built up as each digital coverage created in the system generated attribute tables, each of which is associated with a particular feature class (e.g., polygon, arc, point, node). In this project, all defoliation was represented by polygons (a polygon is an areal feature defined by the arcs

that make up its boundary, and contains a label point). Database information describing a defoliation polygon was linked to each label in the Polygon Attribute Table (PAT). The following primary feature items were automatically created in INFO:

area	(in square metres)
perimeter	(in metres)
cover#	(internal id number)
cover-id	(id number)

Additional database items were added to the coverage PAT manually.

pest	(pest code, e.g., whl)
region	(forest region, e.g., nn)
nts_name	(map name, e.g., seymour arm)
nts	(map number, e.g., 82m)
scode	(severity, e.g., 1)
year	(year of attack, e.g., 1990)
ha	(area, e.g., 350.55)

The item **scode** was added to indicate the assigned severity of a defoliation polygon (i.e., 1 = light, 2 = moderate, 3 = severe, 4 = dead, 5 = not infested). This value was added manually for each polygon. The item **ha** was added to calculate the area of a polygon in hectare units. The hectares were determined by dividing the item, area (in square metres), by 10 000.

4.6 ARC Macro Language Programs

ARC/INFO commands can be processed in batches through programs created using the ARC Macro Language (AML). Many programs were developed by FIDS to automate frequent tasks, and these tools proved to be considerable time-savers. In addition to programs written to help set up the database, programs were developed that automatically performed routine display and query operations on the western hemlock looper geographical information base. AML programming also provided inexperienced users with a front-end user interface. More specialized queries and operations can be performed interactively at the command level of the system.

4.7 Accuracy and Limitations of Data and Analysis

Digital data involve certain limitations and possible sources of error. Errors may originate from the following sources: transformation from spherical to planar geometry (flattening the earth onto a two-dimensional surface); accuracy of measuring locations on the earth; cartographic interpretation of features; drafting error; analog to digital conversion (calibration); media stability (includes warping, stretching, folding, and wrinkling of paper map); digitizing processor error (cursor placement); rms error (root mean square registration accuracy); machine precision (coordinate rounding); and other unexplained errors (E.S.R.I. 1991). Note that data used in this project are displayed through the GIS to an accuracy of more than four decimal places. Results should be interpreted carefully, because the data are only as accurate as the data gathering techniques (e.g., aerial surveys).

Error in the system was minimized by employing the following procedures, where appropriate, when it was created. Where western hemlock looper information existed in more than one format or source, the data was compared for consistency of reporting (e.g., verbal reports checked against mapped defoliation). Defoliation map information was transferred from old, folded, or torn paper maps to new map sheets to improve locational and areal accuracy. The digitizing rms error was minimized, and digitizing procedures were carefully carried out. The digital coverages that were translated from OVERLAY to ARC/INFO were visually compared to check the translation. The resultant western hemlock looper historical database is, therefore, accurate enough for its intended purposes.

5 RESULTS

5.1 Outbreak Periods

Fourteen distinct western hemlock looper outbreak periods between 1911 and 1994 (Turnquist 1991) were identified for British Columbia. They are delineated as follows:

1.	**1911–14**	(SW B.C.)
2.	**1925–27**	(SW B.C.)
3.	**1927–29**	(SW B.C.)
4.	**1937–38**	(SE B.C.)
5.	**1944–47**	(SW B.C.)
6.	**1945–47**	(SE B.C.)
7.	**1954–55**	(SE B.C.)
8.	**1958–59**	(SW B.C.)
9.	**1961–64**	(SE B.C.)
10.	**1969–73**	(SW B.C.)
11.	**1972–76**	(SE B.C.)
12.	**1982–85**	(SE B.C.)
13.	**1987**	(SW B.C.)
14.	**1990–94**	(SE B.C.)

These outbreaks were grouped into five distinct geographic regions; Vancouver Island, Lower Fraser River–Port Mellon, Upper Columbia River, North Thompson River, and Upper Fraser River (Figure 2).

5.2 Western Hemlock Looper Defoliation Years: Summary

Minor discrepancies may be found when comparing historical FIDS western hemlock looper area information with the summarized GIS data in this report. Past statistics for infested areas were gathered using different methods (e.g., planimetered, dot-count area calculations). The area of western hemlock looper defoliation for British Columbia between 1911 and 1994 is shown in Figure 3 and in Table 1. The table identifies the outbreak and the year, separates defoliation into severity classes, and gives sum area totals for each year.

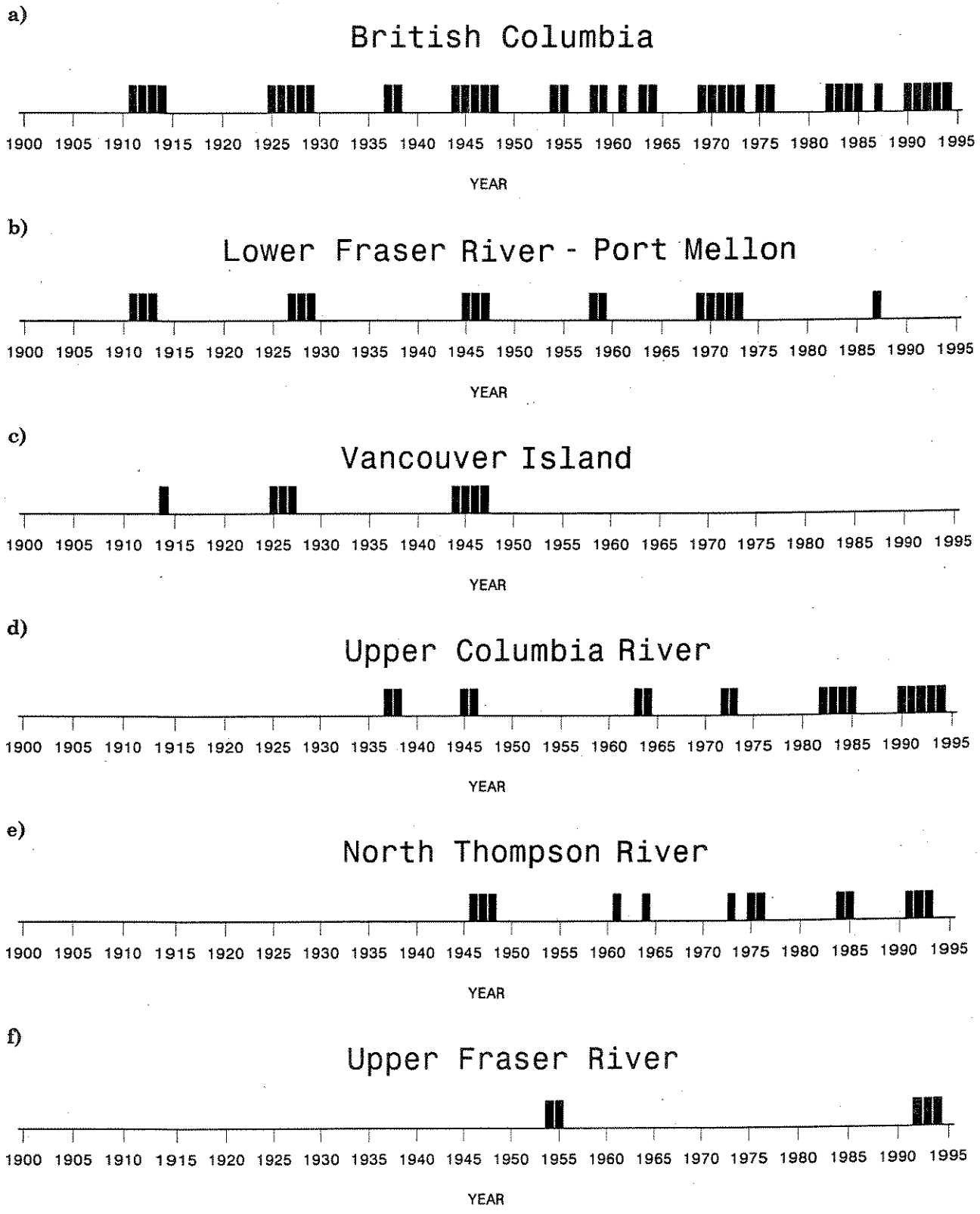

FIGURE 2. Periods and location of western hemlock looper outbreaks in British Columbia since 1911.

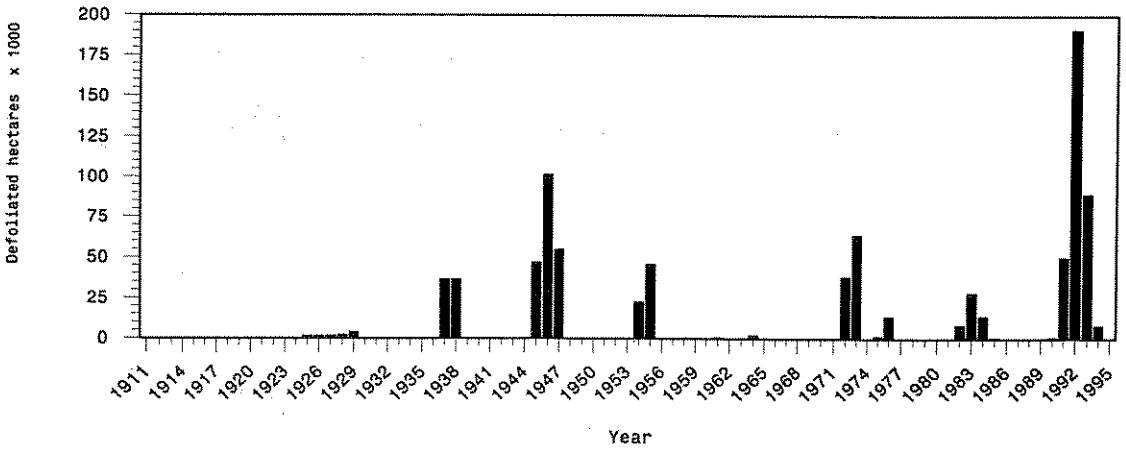

FIGURE 3. Totals of area defoliated by the western hemlock looper in British Columbia between 1911 and 1994.

TABLE 1. Duration, severity class, and totals of area defoliated by the western hemlock looper in British Columbia between 1911 and 1994

Outbreak	Year	Light	Moderate	Severe (ha)	Total defoliated area (ha)
1	1911-13			108	(each year) 108
1	1914				(unknown)
2	1925-26			1 423	(each year) 1 423
2 and 3	1927		235	1 423	1 658
3	1928	241	555	1 171	1 967
3	1929		1 387	2 312	3 699
4	1937			36 532	36 532
4	1938			36 532	36 532
5	1944		118	142	260
5 and 6	1945	383	118	46 521	47 022
5 and 6	1946	4 909	118	96 320	101 347
5 and 6	1947	3 981		50 610	54 591
7	1954	22 358			22 358
7	1955	45 515			45 515
8	1958	177			177
8	1959	177			177
9	1961	655			655
9	1963			154	154
9	1964	1 073		1 006	2 079
10	1969	77			77
10	1970	77			77
10	1971			259	259
10 and 11	1972	37 757		259	38 016
10 and 11	1973	37 789	22 466	3 466	63 721
11	1975	1 406			1 406
11	1976			13 396	13 396
12	1982	5 698	2 534	112	8 344
12	1983	10 703	12 923	4 463	28 089
12	1984	5 335	586	7 713	13 634
12	1985	334			334
13	1987			89	89
14	1990	917			917
14	1991	22 725	22 088	5 291	50 104
14	1992	32 681	79 659	78 717	191 057
14	1993	21 741	22 115	45 538	89 394
14	1994	2 754	4 633	569	7 956
Totals		259 463	169 535	434 126	863 124

The following series of maps (Figures 4–17) indicate the changes in area defoliated over time, and the shift in geographical location of the 14 outbreak periods in British Columbia. The areas are calculated from the maximum extent of the overlaid years comprising each outbreak.

FIGURE 4. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 1.

FIGURE 5. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 2.

FIGURE 6. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 3.

FIGURE 7. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 4.

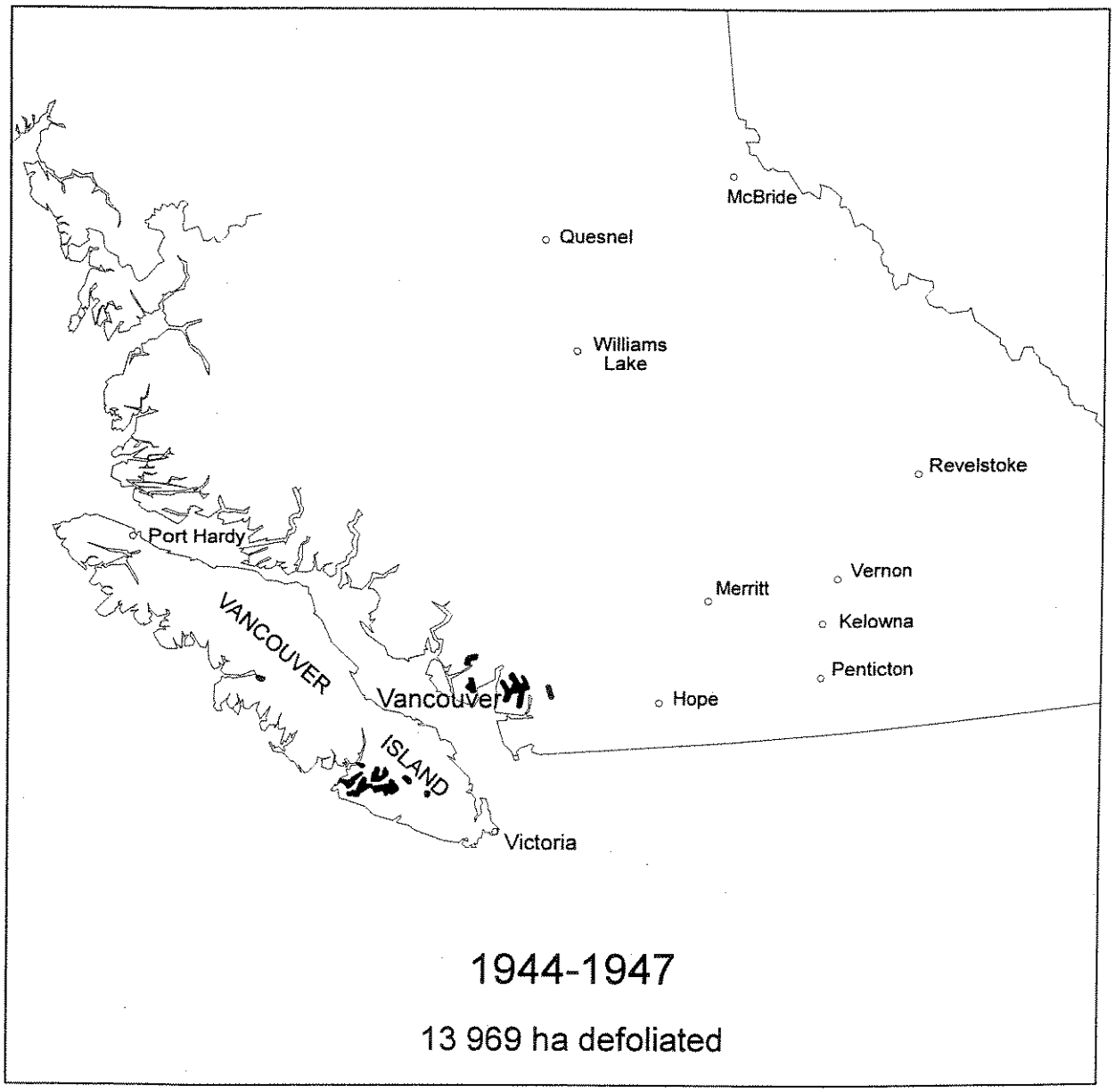

FIGURE 8. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 5.

FIGURE 9. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 6.

FIGURE 10. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 7.

FIGURE 11. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 8.

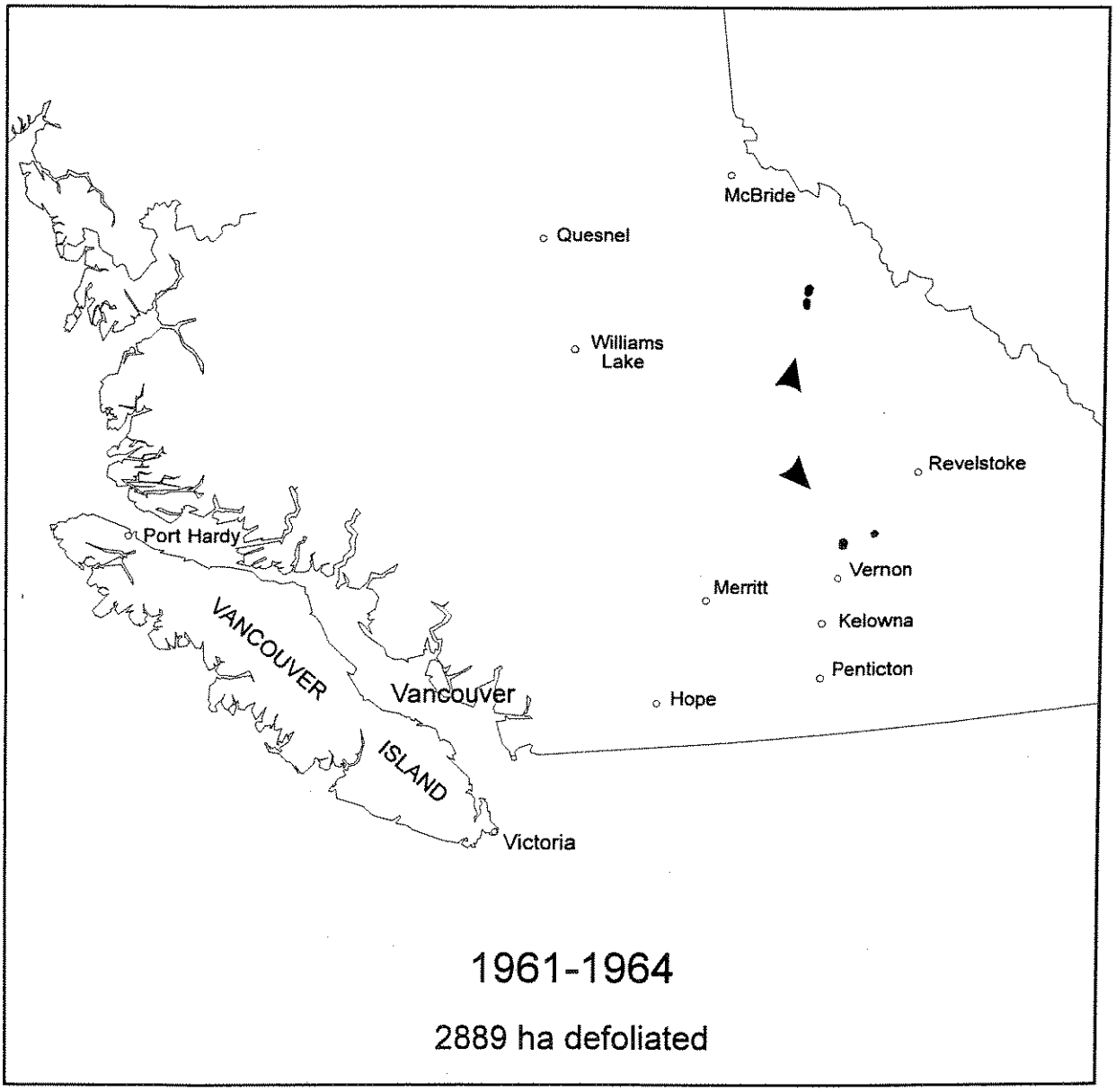

FIGURE 12. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 9.

FIGURE 13. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 10.

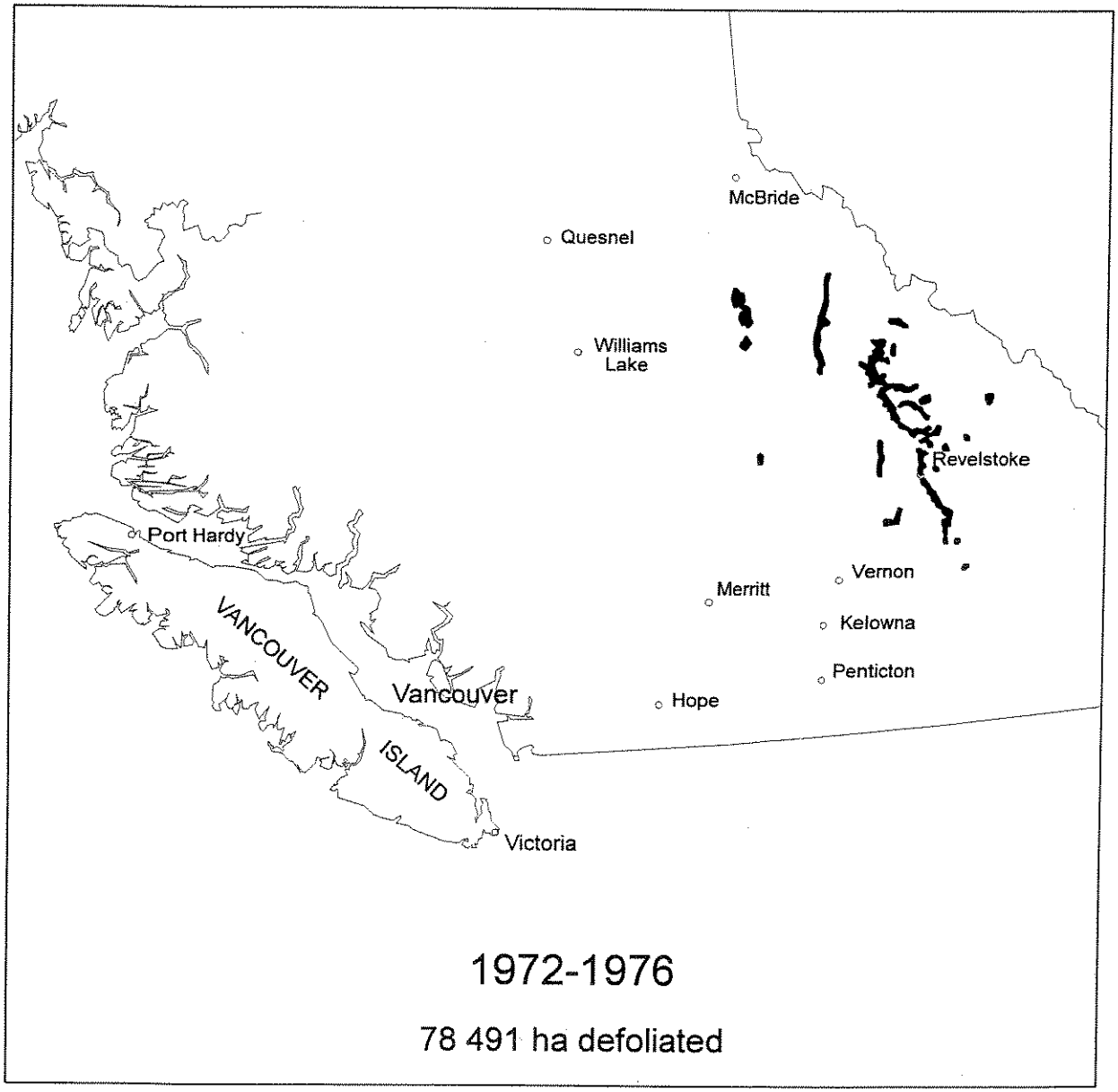

FIGURE 14. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 11.

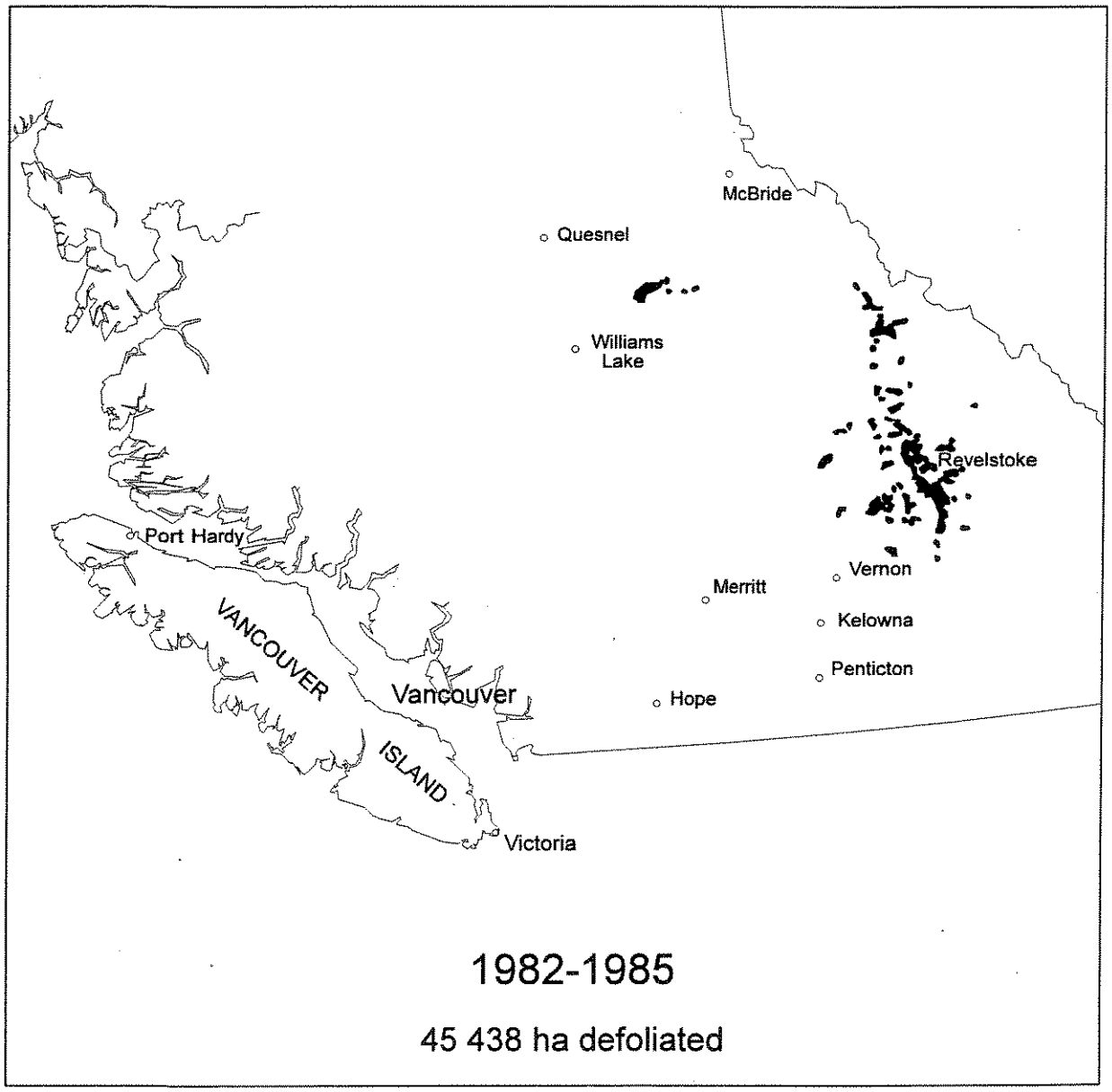

FIGURE 15. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 12.

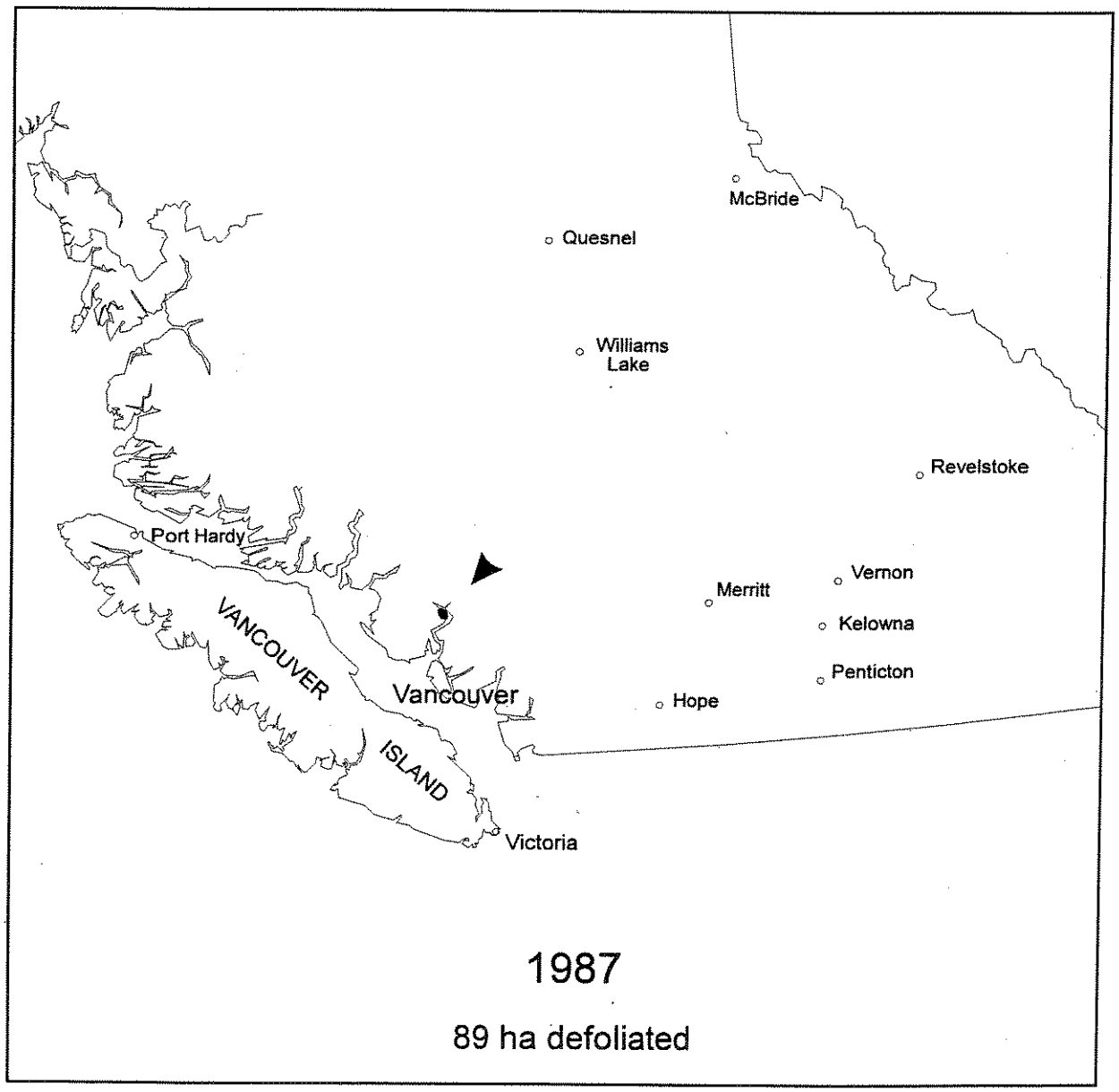

FIGURE 16. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 13.

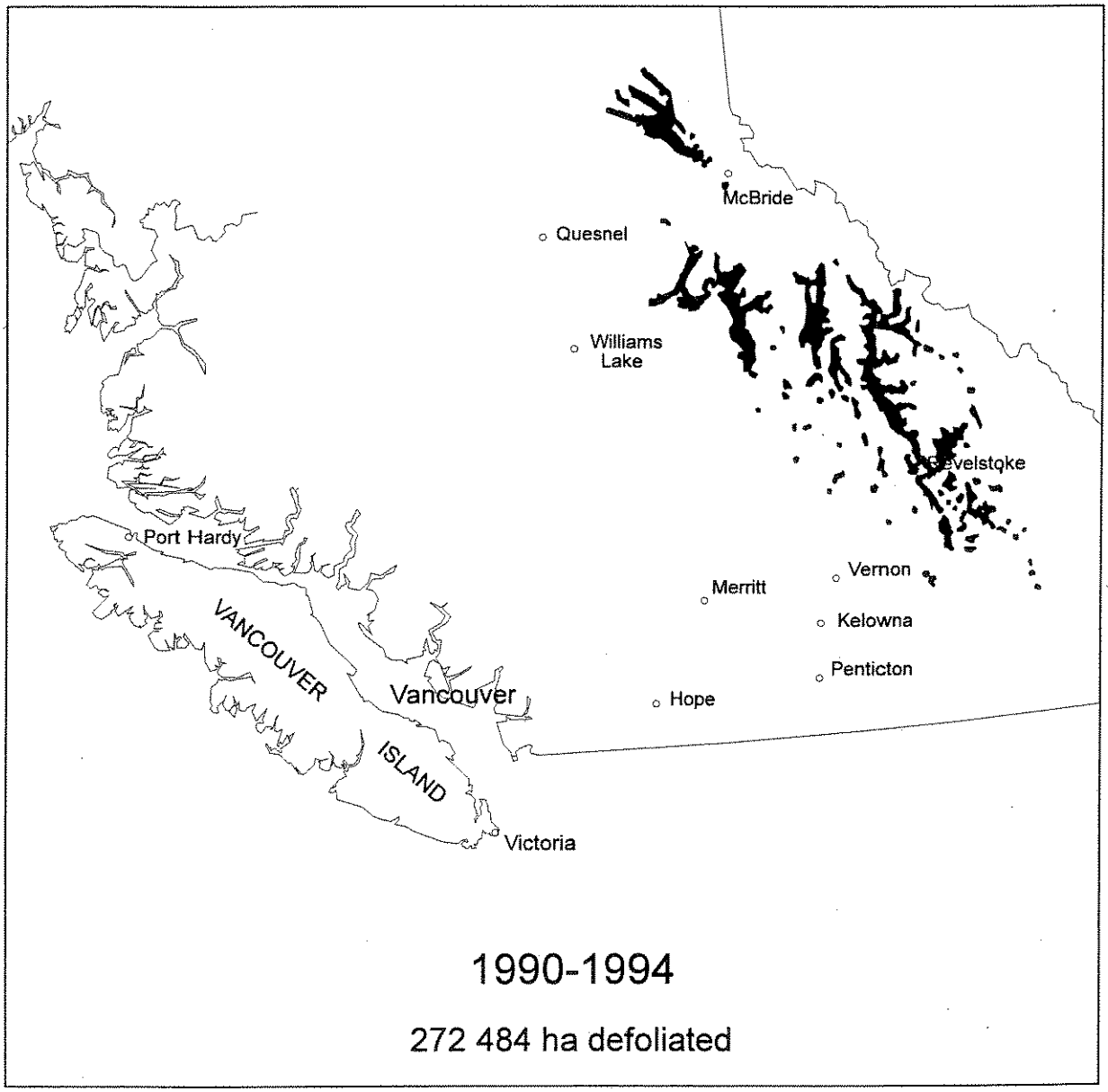

FIGURE 17. Geographical location and area of defoliation for recorded western hemlock looper outbreak periods in British Columbia—Outbreak 14.

6 PRODUCTS

FIDS can produce high-quality pest defoliation maps and tabular summary reports efficiently. The products are available in paper (black and white or colour, up to 84.1 cm x 118.9 cm in size), transparency, slide, diskette, or tape format. Map content, extent, scale, colour, shading, and text can all be user-defined. The following section describes FIDS GIS products and services available.

6.1 Historical Western Hemlock Looper Status Maps

Maps can be produced with accompanying database information that illustrates current or historical defoliated areas and severities. Statistical information includes the frequency (number of defoliated polygons on the map) and area (total area in hectares) of western hemlock looper defoliation. This information can be calculated for the individual severity ratings and for the sum total of the severities in the mapped region. Region, year, pest type, map boundary extent values, projection type, and scale can be displayed. Hard-copy maps and statistics can be obtained for regions and scales that include individual National Topographic Series mapsheets (Figure 18) at a medium scale (e.g.,1:250 000), joined NTS mapsheets, forest region, province of British Columbia at a small scale (e.g.,1:2 000 000), or any geographically referenced area within British Columbia (small to large scale).

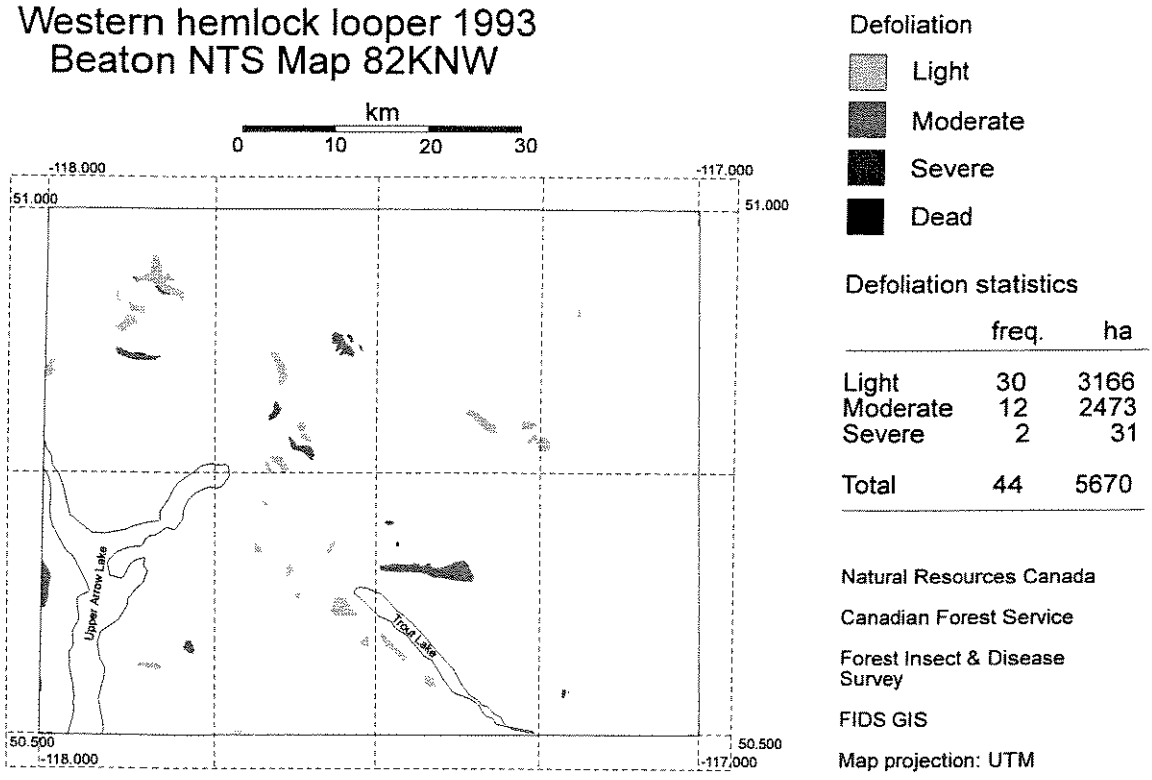

FIGURE 18. Aerially mapped western hemlock looper defoliation in 1993 for NTS mapsheet 82knw, Beaton.

6.2 Interactive Database Query

Database queries about the western hemlock looper can be made interactively on the graphics screen of the Sun Workstation. The following three commands are examples of information about the insect that can be retrieved directly from the ARCPLOT module of ARC/INFO:

Command **Description**

1. where - allows the user to position the mouse crosshairs anywhere on the map and return the x,y coordinate in map units.
   e.g., where (enter point)
   x = 56.34 (latitude)
   y = 123.23 (longitude)

2. area - finds the area of a polygon defined by three or more points using the mouse crosshairs. The user can obtain information about areas that are not directly associated with the coverage (e.g., defoliation area within a district).
   e.g., area (define the polygon)
   area = 134 600.340 (m^2)

3. identify - allows the user to point at a coverage feature (e.g., a defoliation polygon) with the mouse, and list its associated attributes.
   e.g., identify bc92isw1992 polys * (enter point)
   area = 4 207 789.500 m^2
   perimeter = 10 036.257 m
   bc92isw1992# = 60
   bc92isw1992-id = 45
   scode = 2
   ha = 420.779

6.3 NTS Overlay Maps

To produce hard-copy maps that are particularly useful to the forest rangers conducting annual aerial surveys, FIDS plots previously recorded defoliations directly onto NTS mapsheets with a pen plotter. This method displays the defoliation extent relative to the topographic features on the NTS mapsheets. While sketching current areas of defoliation on the NTS maps, the polygons of the previous years' defoliation can be used as a reference.

6.4 Theme Overlay Analysis

The western hemlock looper defoliation can be displayed or plotted relative to other data themes that may be pertinent to pest behaviour.

Thematic maps from various sources have been gathered and digitally stored in the FIDS GIS. The data sets range in scale from 1:50 000 to 1:2 000 000 and include themes such as Rowe's forest regions; Canada terrestrial ecozones; biogeoclimatic zones; atmospheric pollution indicator data; climatic data; and forest region and district boundaries, coastlines, water features, parks, roads, elevations, and places. These can be used in theme overlays with the western hemlock looper data. Note that some data were derived from small-scale maps (e.g., 1:2 000 000), and are most appropriate for use with similar-scale regional or provincial operations. A listing of available datasets is given in Appendix 2.

As an analysis exercise, the entire western hemlock looper historical database was spatially combined with biogeoclimatic zones to identify relationships. A summary table of the results is shown in Table 2, where each variant and the area of defoliation found within it, the number of polygons, and the percentage of the total area represented by that variant are listed. Area of pest defoliation and incidence are plotted against biogeoclimatic variant in Figure 19. The predominant variants are ICHvk (16%), ICHwk (15%), ICHmw (8%), ESSFwk (12%), ESSFvc (10%), and AT (14%), and account for 75% of the total. The area of pest incidence and defoliation in Alpine Tundra is higher than expected, and is largely due to data collection and classification methods. Since areas of AT often occur within or adjacent to the defoliation, but are too small to filter out at the working scale, they may be included when sketching the aerial defoliation. Also, the zone boundaries are transition zones, and western hemlock looper may unexpectedly appear in areas classified as tundra, but which contain hemlock looper host species as well.

TABLE 2. Biogeoclimatic variance and corresponding areas of historical western hemlock looper defoliation in British Columbia

Biogeoclimatic variance	BGCZ	Area (ha)	Polygons	% Area of total
AT		62 858.790	1 649	14.10
CWH dm	Dry Maritime CWH	841.261	7	0.19
CWH mm1	Moist Maritime CWH	71.945	3	0.02
CWH mm2	Moist Maritime CWH	167.674	4	0.04
CWH vh1	Very Wet Hypermaritime	17.852	1	0.00
CWH vm1	Very Wet Maritime	7 954.410	51	1.78
CWH vm2	Very Wet Maritime	3 997.690	86	0.90
CWH xm1	Very Dry Maritime CWH	100.904	1	0.02
CWH xm2	Very Dry Maritime CWH	38.761	2	0.00
ESSF wc1	Wet Cold ESSF	4 083.490	70	0.92
ESSF wc2	Wet Cold ESSF	10 893.870	243	2.44
ESSF wc2p	Wet Cold ESSF	6 841.910	144	1.53
ESSFdc1	Dry Cold ESSF	178.226	4	0.04
ESSFmm1	Moist Mild ESSF	718.654	8	0.16
ESSFvc	Very Wet Cold ESSF	45 625.790	1 483	10.23
ESSFwc	Wet Cold ESSF	33.725	3	0.00
ESSFwc1	Wet Cold ESSF	13 733.310	363	3.08
ESSFwc2	Wet Cold ESSF	5 904.540	43	1.32
ESSFwc3	Wet Cold ESSF	2 701.730	16	0.61
ESSFwcp	Wet Cold Parkland ESSF	452.804	32	0.10
ESSFwk1	Wet Cool ESSF	36 662.020	495	8.22
ESSFwk2	Wet Cool ESSF	17 248.830	284	3.87
ICH dw	Dry Warm ICH	1 545.850	8	0.35
ICH mk2	Moist Cool ICH	261.041	4	0.06
ICH mm	Moist Mild ICH	404.658	1	0.09
ICH mw2	Moist Warm ICH	137.633	4	0.03
ICH mw3	Moist Warm ICH	35 847.470	300	8.04
ICH vk1	Very Wet Cool ICH	71 030.830	1 804	15.93
ICH vk2	Very Wet Cool ICH	24 687.060	321	5.54
ICH wk1	Wet Cool ICH	66 696.150	935	14.96
ICH wk2	Wet Cool ICH	178.335	14	0.04
IDF mw2	Moist Warm IDF	0.782	1	0.00
IDF xh1	Very Dry Hot IDF	1 005.770	1	0.23
IDF xh2	Very Dry Hot IDF	1 405.860	2	0.32
MH mm1	Moist Maritime MH	3 292.920	67	0.74
MH mm1p	Moist Maritime MH	430.148	23	0.10
MH mm1	Moist Maritime MH	147.175	6	0.03
MS dm	Dry Mild MS	129.385	2	0.03
SBPSmc	Moist Cold SBPS	69.892	1	0.02
SBS mc	Moist Cold SBS	3 698.940	67	0.83
SBS mm	Moist Mild SBS	32.949	2	0.00
SBS vk	Very Wet Cool SBS	11 991.600	211	2.69
SBS wk1	Wet Cool SBS	1 795.970	4	0.40
Sum Totals		**445 918.610**	**8 770**	**100.00**

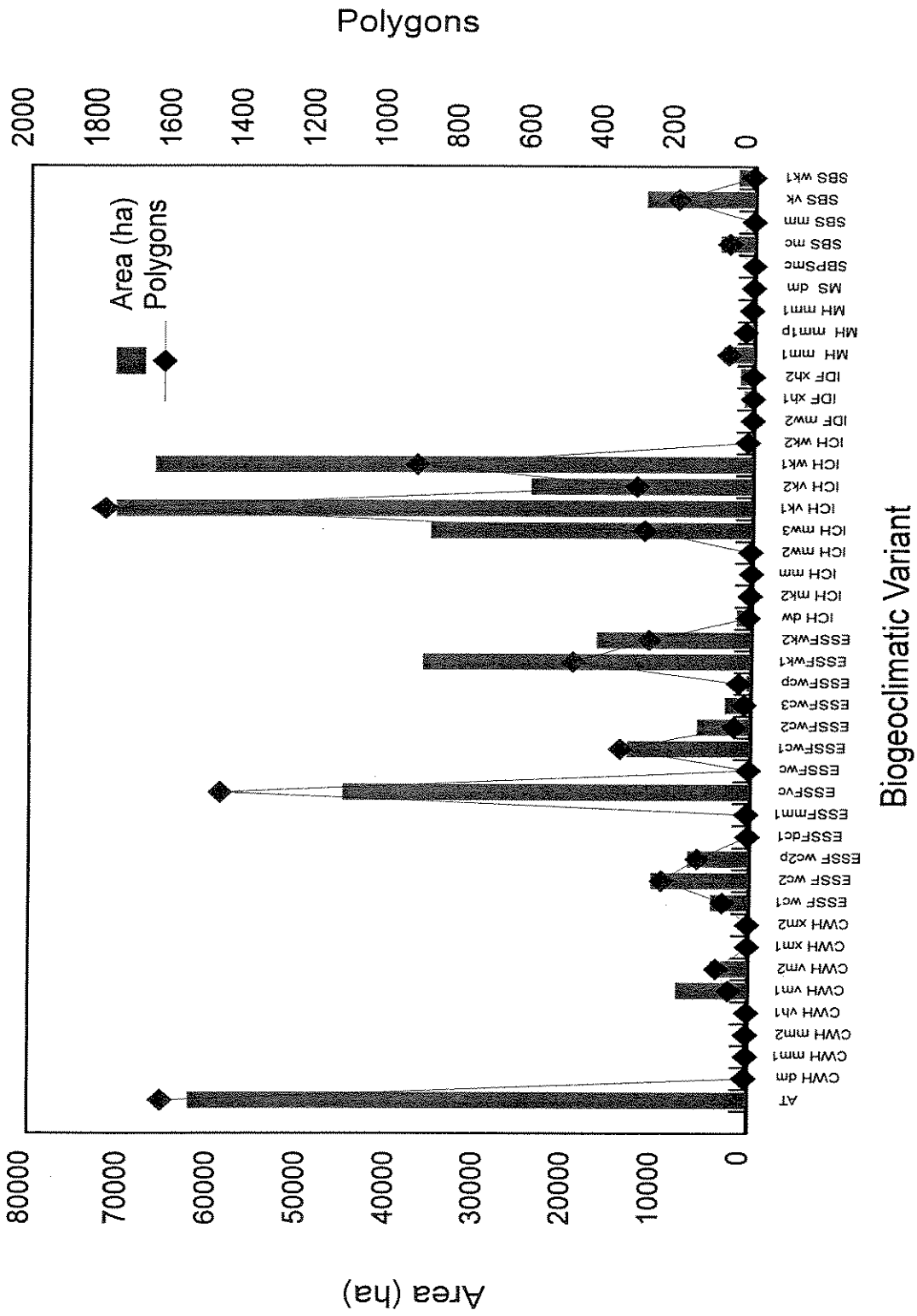

FIGURE 19. Biogeoclimatic variance in relation to1911–1994 western hemlock looper defoliation in British Columbia.

6.5 Cumulative Defoliation Analysis

ARC/INFO geometric combination commands, such as union, identity, and intersection, can be applied to a user-selected set of defoliated areas. Inclusive and exclusive areas for a specified period of historical record of defoliation can be derived. ARC Macro Language programs, developed for FIDS, enable a user to perform multiple-year defoliation analysis for any number of years. The years chosen can be consecutive or nonconsecutive. The program merges spatially coincident polygons together to produce a new coverage. The resultant polygons describe new relationships and identify in which years the delineated areas experienced defoliation, the total number of years defoliation occurred, and the maximum number of consecutive years of attack. Peaks and lows of outbreaks can be determined and displayed on the monitor, or a hard copy can be printed.

This type of cumulative analysis can be used to indicate trends in pest outbreaks for forest managers. Predictions about increase or decline of expected western hemlock looper defoliation and severity can be made. For example, an analysis using the past 5 years of defoliation data for western hemlock looper was performed for the Seymour Arm area, in the Revelstoke and Clearwater forest districts. The resultant map (Figure 20) shows the merged polygons for 1990 to 1994, and calculates the frequency and area statistics. Most of the stands in this area where defoliated for only 1 or 2 years (47 885 ha and 13 078 ha, respectively) in an area, and only a small proportion of the stands (725 ha) were defoliated for 3 years out of the 5-year period studied.

Permanent monitoring stations should be set up to detect incipient hemlock looper outbreak in those stands defoliated for the greatest number of years (3 years in the Seymour Arm example site). Pheromone traps (baited with the sex pheromone) would be used to monitor population fluctuation and impending outbreak. Forest managers would then use these data in their management plan.

Various statistical calculations can be performed on the entire historical data set (1911–1994) and presented as tables, maps, and graphs. The total number of years of western hemlock looper defoliation (nonconsecutive or consecutive) can be plotted against the area attacked over the 84-year period (Figures 21 and 22, respectively).

The frequency analysis showed that in the case of nonconsecutive years of defoliation 44% of the total area was defoliated for 1 year, decreasing slightly to 38% for 2 years, substantially to 11.5% for 3 years, to 4.7% for 4 years, and to less than 2% of the total area for between 5 and a maximum of 7 years. A similar trend for the number of areal features (stands delineated as polygons) defoliated indicates that 41% of the distinct areas were defoliated for 1 year, 25% for 2 years, 16% for 3 years, 10% for 4 years, 5% for 5 years, and less than 2% for 6 or 7 years. This analysis shows that any given stand has a high probability of being defoliated for only 1 or 2 years.

The number of consecutive years of western hemlock looper attack in British Columbia is shown in Figure 22. Selecting only consecutive years of defoliation in this second frequency analysis helps to distinguish separate outbreak periods. The graph indicates four groups of consecutive years of defoliation. For the historical unioned area, 48% was defoliated for 1 year, increasing slightly to 51% at 2 years, then sharply decreasing to only 0.77% at 3 years, and tapering off to 0.05% for a maximum of 4 years. A similar trend for the number of stands defoliated indicates that 50% of the stands were defoliated for 1 year, 49% for 2 years, 1.6% for 3 years, and less than 0.05% for 4 years. This analysis shows that any given stand of western hemlock looper host trees has a 99% chance of being defoliated for only 1 or 2 consecutive years.

In both cases of nonconsecutive and consecutive years of defoliation, the analysis shows that most defoliation occurs for 1 or 2 years.

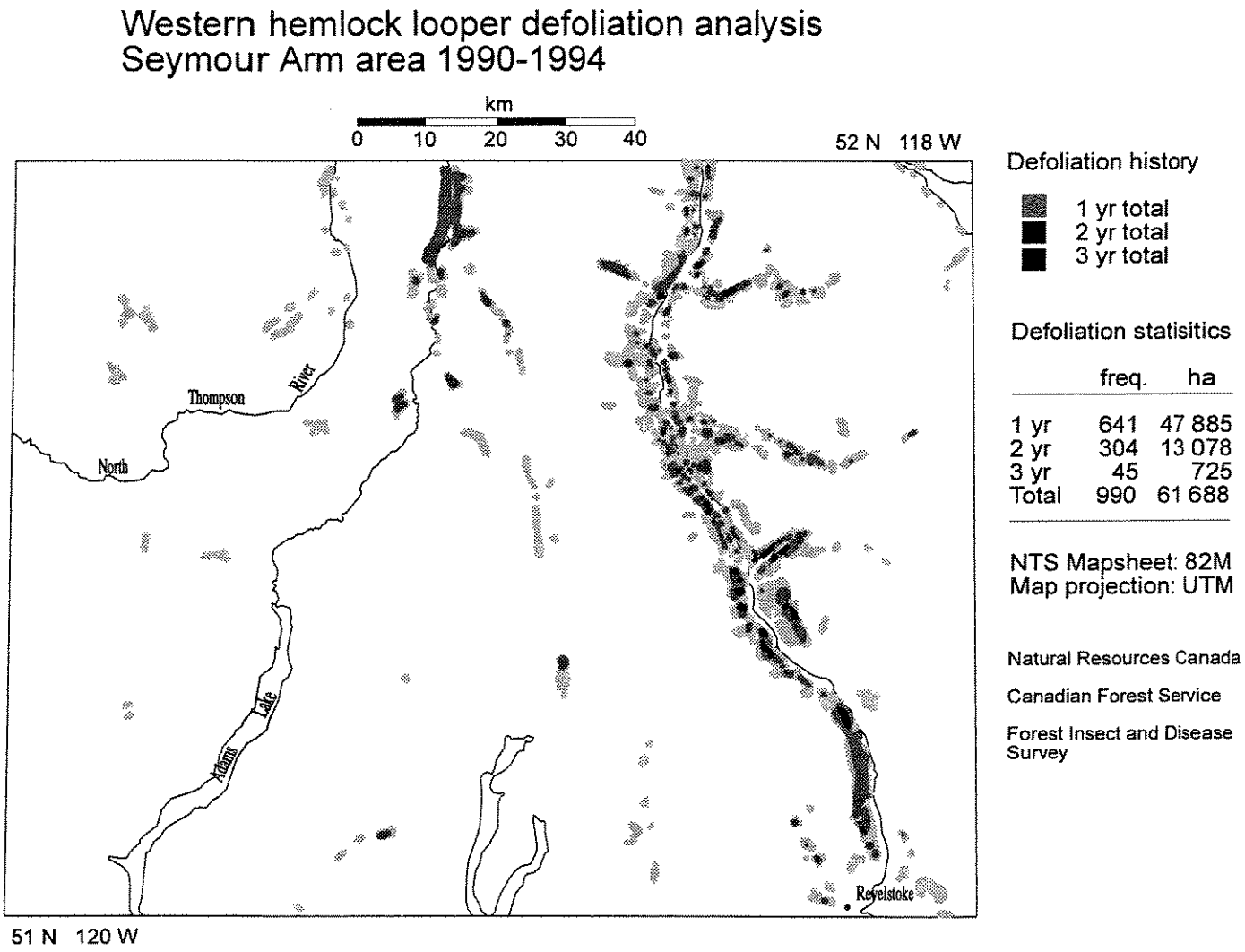

FIGURE 20. Analysis of the cumulative western hemlock looper defoliation for the Seymour Arm area for period 1990–1994.

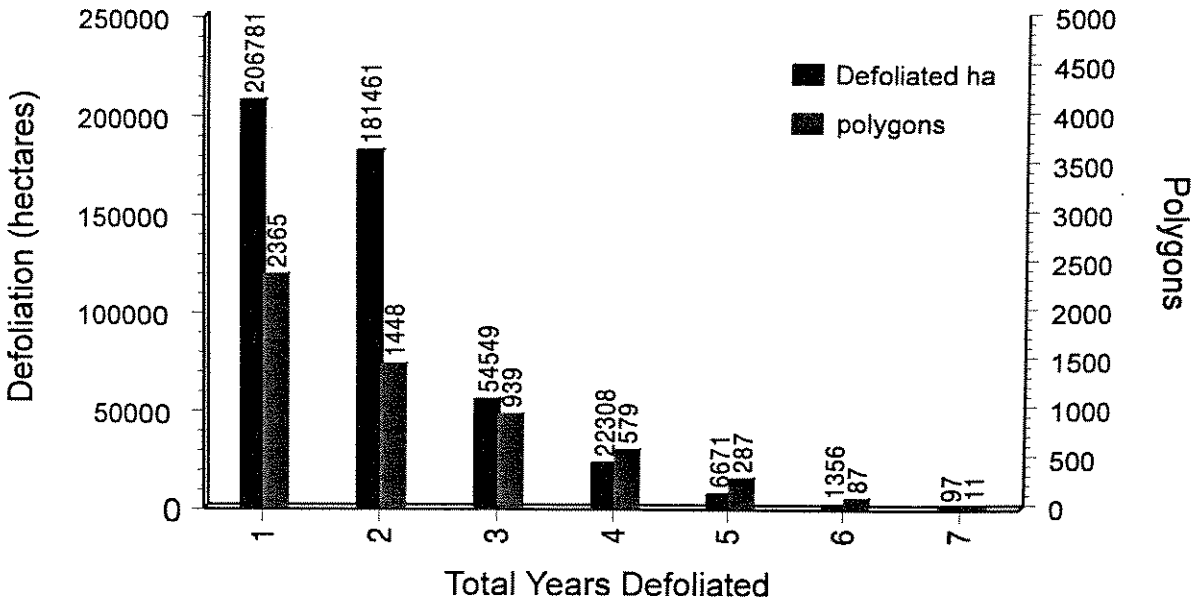

FIGURE 21. Area and number of stands with 1–7 nonconsecutive years of defoliation in British Columbia, from 1911 to 1994.

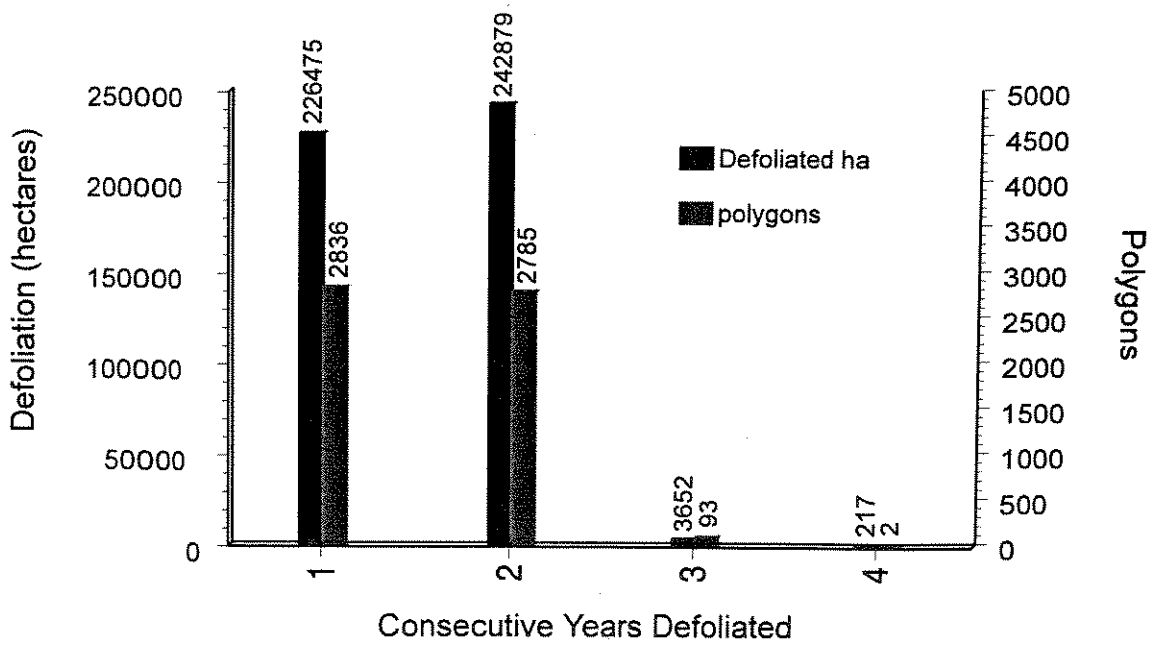

FIGURE 22. Area and number of stands with 1–4 consecutive years of defoliation in British Columbia, from 1911 to 1994.

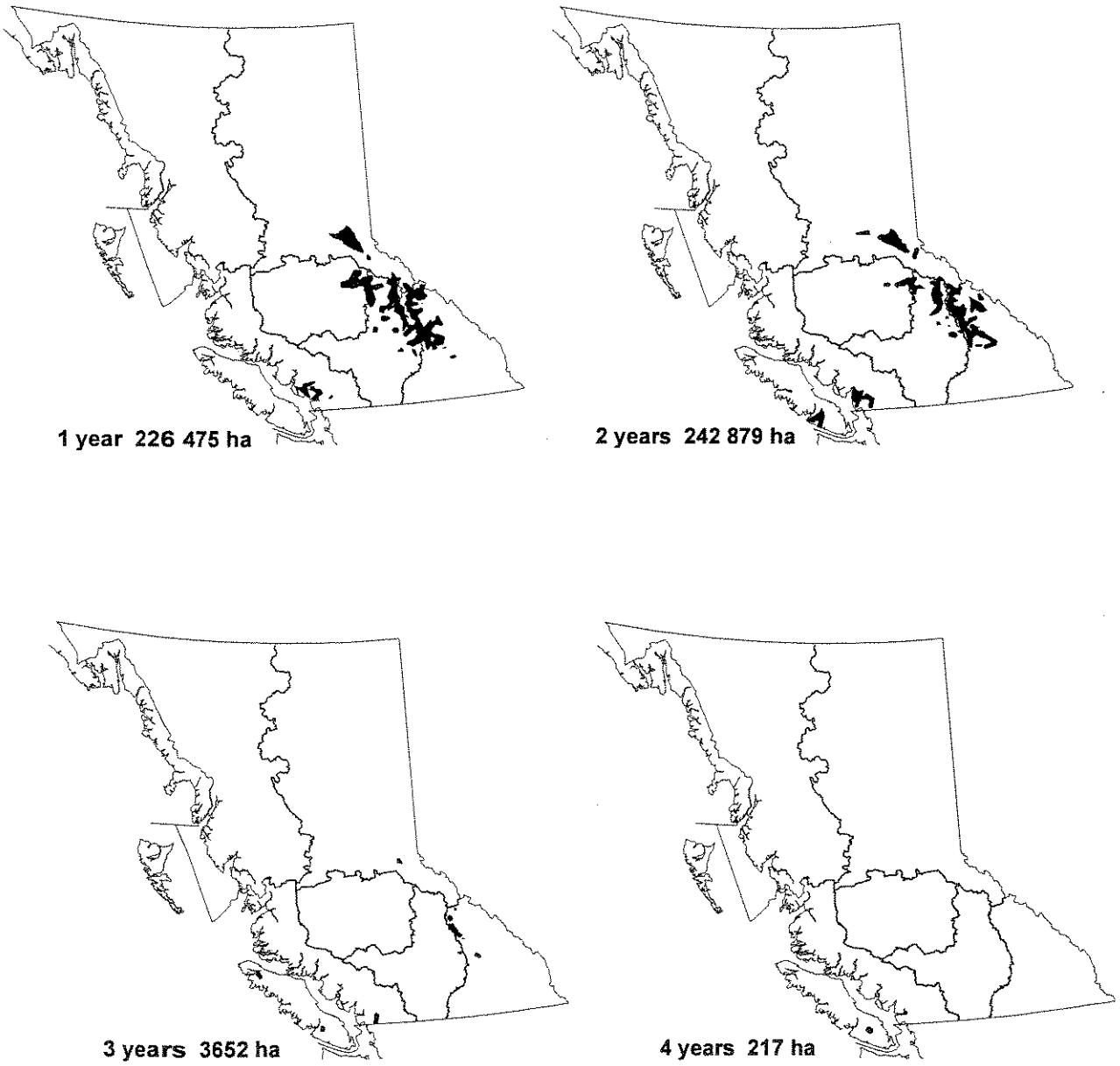

FIGURE 23. Location and patterns for consecutive years of western hemlock looper attack in British Columbia, from 1911 to 1994.

The consecutive analysis data is illustrated geographically in Figure 23. The historical western hemlock looper defoliation is mapped by number of consecutive years of defoliation. Clearly, most of the area has been defoliated for 1 or 2 consecutive years.

6.6 Risk Analysis

Using FIDS western hemlock looper data records from 1911 to 1994, 39 years of spatially referenced defoliation were recorded for British Columbia, and merged together in the GIS to produce a multiple-year coverage for that period. The total unioned area of defoliation for the whole period is calculated at just over 470 000 ha. This includes areas where light, moderate, or severe defoliation ratings were recorded. Areas with stand mortality are not included in the analysis. The likelihood of an area being defoliated in the future (risk) was then determined by analyzing past occurrences. Future attacks will most probably occur in areas proximate to past activity. Each resultant polygon in the merged map contains information identifying in which years the delineated area experienced defoliation, the total number of years defoliation occurred, and the maximum number of consecutive years of defoliation. Four classes of risk were delineated from the frequency analysis.

Risk	Total years of defoliation
1. Low	0
2. High	1 – 2 years
3. Higher	3 – 4 years
4. Highest	≥ 5 years

Analysis indicated that the most likely period of future defoliation in any one area will be 1 or 2 years, with a frequency of 82%, while 16% of the area will have a 3- to 4-year frequency and less than 2% will have a 5- to 7-year frequency of defoliation.

The western hemlock looper frequency analysis map developed by PFC FIDS is shown in Figure 24. Such maps reveal significant patterns of defoliation, and therefore disclose more information than can be gained simply from looking at the data in tabular form. The regions with the darkest shading indicate the most persistent areas of attack (> 5 years in total), and are highlighted in the larger-scale map inset. Large, detailed maps of specific areas of interest can be produced by FIDS at any scale. Intensively managed stands in areas of past looper defoliation should be given management guidelines for dealing with future outbreaks. Such analysis can help identify risk and focus forest health efforts where they are most needed.

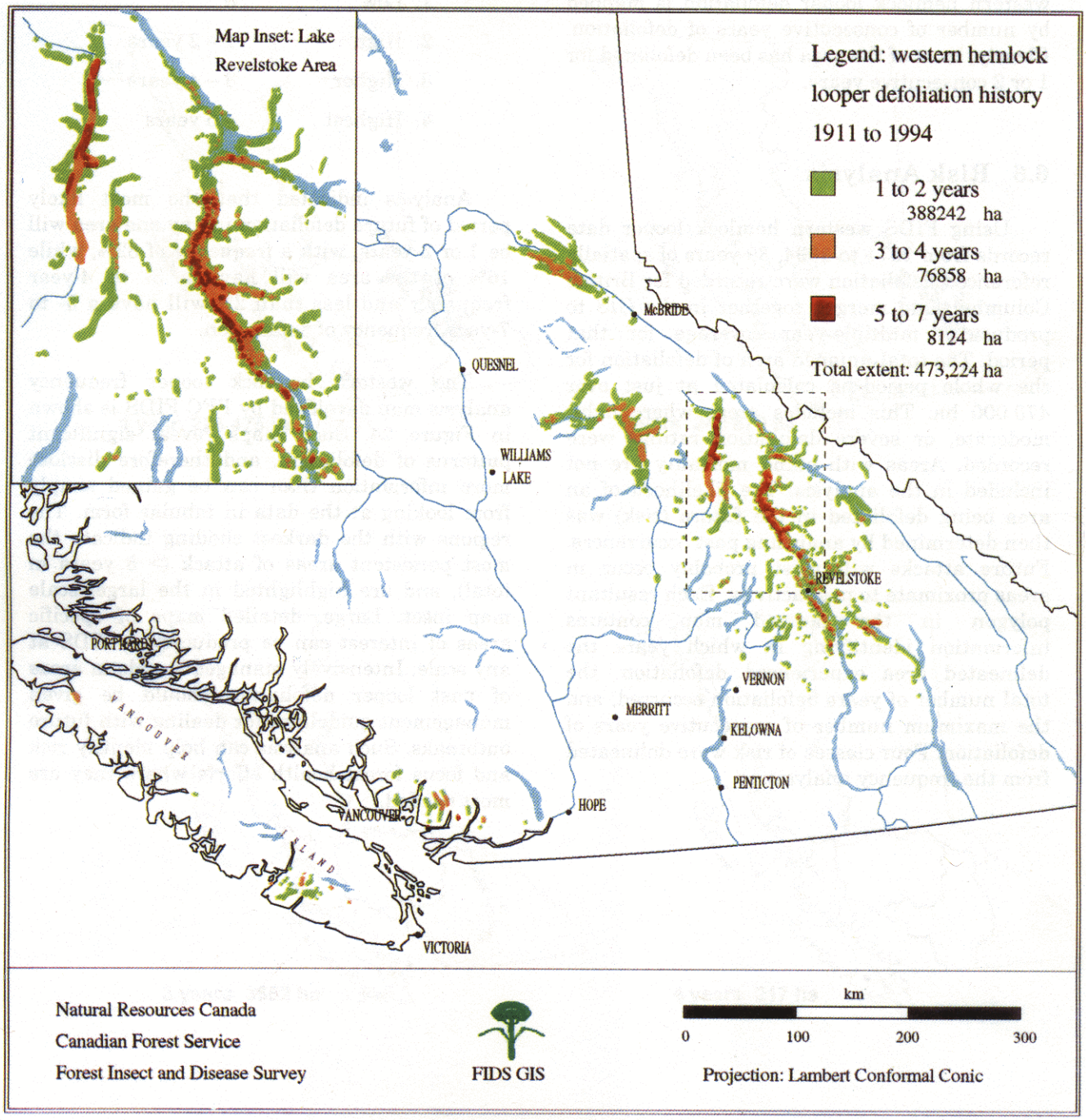

FIGURE 24. Western hemlock looper defoliation frequency analysis map.

7 CONCLUSIONS

- During the years 1911–1994, western hemlock looper defoliation was recorded in British Columbia about 50% of the time (39 years).
- The recorded history revealed that the general areas of infestations included the upper Fraser River northwest of McBride, upper Columbia River, Quesnel Lake, Wells Gray Park, North Thompson River, lower Fraser River, Port Mellon, and parts of Vancouver Island.
- Annual defoliation ranged from relatively few hectares to as much as 190 000 ha (the highest ever recorded) in the interior of B.C. (extensive regions in upper Fraser, North Thompson, and upper Columbia River areas), in 1992.
- Infestations occurred most frequently along the North Thompson River between Valemount and Blue River, and along the upper Columbia River between Mica Creek and Revelstoke.
- More than 99% of the total area and the total number of areal features (stands delineated as polygons) were defoliated for only 1 or 2 consecutive years.
- Only two small areas (east of Indian Arm and south of Lake Cowichan) showed defoliation for 4 consecutive years. This was the greatest number of recorded consecutive years of defoliation for western hemlock looper.
- Four classes of future defoliation risk were delineated:

LOW	no past defoliation recorded
HIGH	1–2 years past defoliation
HIGHER	3–4 years past defoliation
HIGHEST	$\geq$ 5 years past defoliation

8 SUMMARY

The western hemlock looper historical database was created using FIDS's geographical information system. Defoliation information for western hemlock looper was either digitized (years 1911–1983, 1992–1994) or transferred to ARC/INFO (years 1983–1991) for the period 1911–1994, with 14 distinct infestation periods being noted. The report provided a brief history of the western hemlock looper and the aerial survey procedures conducted by FIDS, and discussed the development stages of the western hemlock looper GIS. Spatial analysis of the historical data was performed.

Ad-hoc queries are made routinely through development of display and query interfaces. Tables and maps of various scales and media are now either available or can be obtained through the GIS. Overall distribution and overlap of the western hemlock looper defoliations were analyzed, and a frequency analysis map and risk classes were developed. Forest managers can use this information to help determine the likelihood of defoliation by western hemlock looper in specific areas. Several examples are included in the report to illustrate the capabilities of the western hemlock looper historical data information system.

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APPENDIX 1. UTM and Lambert projection parameters

Universal Transverse Mercator Projection:

A UTM projection is cylindrical in type and conformal in property. Local shape is accurate, while area is minimally distorted within each zone. Local direction is also accurate, and distance is constant along the central meridian but shows lateral distortion outwards. The parameters for the UTM maps are as follows:

projection:	Universal Transverse Mercator
units:	Metres
zones:	7 through 11

Lambert Projection:

Lambert projections are conic conformal in type and maintain accurate local shape and direction. They are recommended for continental and regional applications where total range in latitude does not exceed 35 degrees. They are particularly well suited to mid-latitude and east-west oriented maps. This secant projection is based on two standard parallels with areal distortion minimized at the parallels, reduced between them, and increased beyond them. Local angles are correct due to conformality, and scale is correct along the parallels. The parameters for the Lambert maps are as follows:

projection:	Lambert
units:	Metres
1st standard parallel:	51° 00' 00"
2nd standard parallel:	58° 00' 00"
central meridian:	–126° 00' 00"
latitude of projection origin:	48° 00' 00"
false easting (metres):	1 000 000
false northing (metres):	0

APPENDIX 2. FIDS GIS digital datasets

Data type	Source	Source scale
Air Information - Monitored Pollutants	Ministry of Environment, Lands & Parks, Air Resources Branch	n/a
ARNEWS/Biomonitoring Plots	Forest Insect & Disease Survey	lat/long ground survey (to 1 km)
Biogeoclimatic zones	Ministry of Forests, Research Branch	1:250 000
Canada Terrestrial Ecozones	Environment Canada, SOE	ecoregions = 1:3 M
Canadian Forest Service Resource Data System	Petawawa National Forestry Institute	n/a
Ecoclimatic zones	Environment Canada	
Ecoreserves	Ministry of Environment, Lands & Parks	1:2 M
Fire Locations (B.C. & Yukon historical)	PFC Fire Research	lat/long position
Forest Regions and Districts	Ministry of Forests, Research Branch	1:2 M
Frost Free Days	Atlas of B.C. (Farley,1979)	1:10 M
Lake Sensitivity to Acid Rain	Ministry of Environment, Lands & Parks, Water Management Branch	1:10 M
Latitude/Longitude Grid	Forest Insect & Disease Survey	n/a
National Topographic Series Map Templates	Forest Insect & Disease Survey	n/a
NOx	CANSAP 1981; ARNEWS foliar,lichen,soil studies; Moelp Air Stn Monitoring	1:10 M
Ozone	Canadian Institute for Research in Atmospheric Chemistry,1993	1:10 M
Parks	Ministry of Environment, Lands & Parks	1:2 M
pH of Precipitation	CANSAP, AES (Baldwin, 1985)	1:1 M
Precipitation Normals	Atlas of B.C. (Farley,1979)	1:10 M
Provincial Boundary B.C.	Ministry of Environment, Lands & Parks	1:2 M
Provincial Boundary Yukon	Environment Canada	n/a
Pulp, Paper and Plywood Mills, Smelting Plants	(Ministry of Finance and Corporate Relations,1993) (B.H. Levelton,1992)	lat/long positions (Gazeteer)
Rowes Forest Regions	Petawawa National Forestry Institute	> 3 M
Soils and Landscape	Agriculture Canada	1:250 000
SOx	CANSAP 1981; ARNEWS foliar,lichen,soil studies; Moelp Air Stn Monitoring	1:10 M
Spot Elevations	PFC Meteorology	5 to 10 km apart
Temperature Normals	Atlas of B.C. (Farley,1979)	1:10 M
Topography (roads, water, towns etc.)	Ministry of Environment, Lands & Parks	1:2 M
TSA's & TFL's	Ministry of Forests, Timber Harvesting Branch	1:2 M
Ultra-violet Index	(Ministry of Environment, Lands & Parks,1993)	1:10 M
Universal Transverse Mercator Grid (10km)	Petawawa National Forestry Institute	10 km grid