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Using a Geographical Information System for the Input and Analysis of Historical Western Spruce Budworm in British Columbia

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Using a Geographical Information System for the Input and Analysis of Historical Western Spruce Budworm in British Columbia

by

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ABSTRACT

The British Columbia western spruce budworm geographical information system was developed by Natural Resources Canada, Forest Insect and Disease Survey (FIDS). By bringing all historical pest information into one common database, the system provides a comprehensive, spatially based historical record of western spruce budworm infestations. The complete database spans 85 years, from 1909 to 1993. Budworm defoliation occurred during 55 of those years. A total of 332 maps were input to the FIDS's ARC/INFO geographical information system (GIS). Another 164 map products were developed from the resultant data set.

FIDS's GIS enables comprehensive queries and timely summaries of the spatial database. Products include: defoliation maps for varying scales, regions, and years; overlay analysis maps for any consecutive or nonconsecutive years; theme overlay maps; and tabular database reports. A defoliation frequency map was developed to determine risk, defined here as likelihood of pest occurrence in a given area. This map is included in the report in 8.5 x 11 inch colour paper format.

The system and products are important to various clients including provincial and industrial agencies, managing foresters, and research scientists. It can increase awareness of western spruce budworm activity and facilitate pest modelling. In addition it provides a platform for many different kinds of geographical analyses.

This GIS project provides a basis from which systems for other pests could be developed.

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1 INTRODUCTION

The western spruce budworm is a major defoliator of Douglas-fir in British Columbia. Defoliation information has been recorded by the Forest Insect and Disease Survey (FIDS) since 1909 with seven distinct infestation periods having occurred. The patterns and overlap of the infestations had not been analyzed by computer until this historical western spruce budworm system was developed. The goals of this project were: 1) to bring all forms of historical budworm data into a common, geographical information system (GIS) and 2) to analyze the data to provide a useful guide in identifying and managing areas prone to budworm attack.

This system was developed under the FRDA II project, FC-FP-008, at the FIDS Section of the Pacific Forestry Centre in Victoria, British Columbia. It is based on recorded location, frequency, and duration of the western spruce budworm. The first task involved entering all historical records of western spruce budworm defoliation into FIDS's GIS. The second task entailed developing programs to perform automated display and query operations. Through automation, the efficiency of operations was improved, and the quality and quantity of stored data increased. Many products from the western spruce budworm system, such as maps and statistical tables, were considered beneficial to foresters and others interested in using the data.

This report gives a brief history of the western spruce budworm in British Columbia and the method of data collection by FIDS. The report discusses the development of the GIS 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.

2 HISTORY OF THE WESTERN SPRUCE BUDWORM

The western spruce budworm, *Choristoneura occidentalis* (Freeman), is a native of British Columbia and a destructive defoliator of conifers. This pest inhabits the coast, montane, and columbia forest types [RCP3]of southern British Columbia and feeds primarily on Douglas-fir. Budworm defoliation will cause reduction of growth rates, reduction of timber quality, and tree mortality (Alfaro and Maclauchlan 1992). The first recorded outbreak of western spruce budworm was in 1909 on Vancouver Island, and infestations have occurred in various regions of British Columbia since then (Furniss and Carolin 1977). An infestation is a period of high population and noticeable defoliation (Harris *et al*. 1985). Such occurrences are natural events in Douglas-fir forests.

3 FOREST INSECT AND DISEASE SURVEY – AERIAL SURVEY RECORDS

Aerial surveys of British Columbia forest regions have been carried out routinely by FIDS since the 1960s and, prior to these, ground surveys were conducted dating 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 province. Aerially visible forest infestations are sketched onto National Topographic Series (NTS) maps. These 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, ranger name, pest type, and assigned degree of defoliation (light, moderate, severe, or dead). The NTS map defoliation drawings are joined in the GIS to form a complete regional picture of the affected areas.

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

4 DEVELOPMENT OF A GEOGRAPHICAL INFORMATION SYSTEM FOR WESTERN SPRUCE BUDWORM

4.1 Design and Goals of System

The first stage in developing the GIS for western spruce budworm involved discussions with rangers and scientists to learn their desires and needs about the infestation data. The objective was to place all western spruce budworm information into a standardized digital format. Varied statistical and analytical queries could then be applied to the complete historical data set.

On completing the information base, various products were desired including maps and statistical reports of infestation severities and extent over specific years and a specific region. The typical areas studied were forest regions or the entire province. However, the option to zoom in on any large-scale region was also considered important. Finally, the ability to perform specialized operations such as overlays and probability queries was desired. The following summarizes the development steps.

1. Design and goals of system set
2. Western spruce budworm historical database built
   a. New system set up and workspaces created
   b. Western spruce budworm historical information gathered and interpreted to maps
   c. NTS digital map templates created in ARC/INFO for all mapsheets where western spruce budworm was historically located. Templates stored in geographic, Universal Transverse Mercator (UTM), and Lambert Conformal Conic (Lambert) projection formats
   d. Some 139 historical western spruce budworm maps digitized into ARC/INFO in UTM format
   e. Conversion programs developed for defunct OVERLAY GIS data
   f. Some 153 old system digital coverages transferred into new ARC/INFO system in UTM format

g. Desired database items in INFO set up
h. Severity ratings of all western spruce budworm polygons manually labelled
i. Area values in hectares for all western spruce budworm polygons calculated
j. All 292 maps projected into new projection type (Lambert)
k. Arc Macro Language programs to automate procedures developed
    i. Error check program
    ii. Automated digitizing program
    iii. Projection programs
    iv. Mapjoin[RCP4] programs
    v. Map screen display programs
    vi. Report creation program
    vii. Map output programs

3. Individual mapsheet coverages joined into larger regional- and provincial-scale maps and performed summary statistics
4. Geographic analyses performed on historical western spruce budworm database
5. Results of analyses presented in the form of 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 became the primary tool to achieve the goals for the historical budworm system.

The GIS software used by FIDS since November 1991 is Environmental System Resource Institute's (E.S.R.I.) ARC/INFO. It 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 Sun Operating System [SunOS]). Peripheral hardware includes an Altek AC30 Digitizing Table, a 150 Mb 1/4" SCSI Cartridge Tape Drive, a 1.2 gigabyte (Gb) Wren VII Disk Drive, a 7585B Hewlett Packard (HP) Pen Plotter, and a QMS-PS 410 Laser Printer.

4.3 Information Gathering

Historical sources of western spruce budworm information were compiled into a common database. The complete western spruce budworm geographical information database spans the years 1909–1993 and holds 496 digital maps. FIDS holds a listing and hard copy of all the western spruce budworm coverages in the system.

Many of the early infestation maps had not been digitized and data gathering involved collecting any paper maps, reports, or tables. Most data sources were annual FIDS regional reports and field maps. Using a map compiled from the data, the western spruce budworm defoliation for each year was digitized and stored into the ARC/INFO GIS. A total of 139 maps spanning the years 1909–1980 were digitized.

Another large section of data gathering involved transferring digitized surfaces from FIDS's outdated GIS, OVERLAY, to the new ARC/INFO system. More than 153 western spruce budworm maps spanning the years 1981–1991 had been digitized in the old information system. A program to convert the raster-based OVERLAY surfaces to an ASCII format was developed. Another program to convert the ASCII files into an ARC/INFO vector-based format was also written. Finally, in-house programs were developed to add severity[RCP5] and area database items to the coverages and to ensure that the converted coverages were accurate. These programs enabled graphic display and interactive correction of any errors that arose during the conversion process.

The most recent western spruce budworm data comprised 40 maps for 1992 and 1993, and were already in digital ARC/INFO format.

In addition to the 332 NTS maps stored in the GIS, 110 regional maps and 54 provincial maps of western spruce budworm defoliation are also stored. These smaller-scale regional and provincial map coverages, compilations of the individual NTS maps, are useful for regional and provincial overviews of budworm activity.

4.4 Map Projection

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

The western spruce budworm data were transferred into a second projection because UTM is limited. 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 six degrees in width (zones 7–11). The UTM coverages are useful in an individual mapsheet application (e.g., topographic mapsheet overlay operations). When small-scale summary analyses that cross zone boundaries are required, the coverages are better converted into a single reference system to maintain accuracy. The Lambert projection was selected as a common reference system for regional and provincial analyses of western spruce budworm. Its properties as well as its use by the Petawawa National Forestry Institute (PNFI) would improve data sharing. All the historical western spruce budworm coverages that had been input into the ARC/INFO system in UTM format, were copied and transferred into Lambert format. The UTM and Lambert projection parameters are described in Appendix 1.

4.5 Database Construction

E.S.R.I.'s proprietary database management system, INFO, used in association with ARC/INFO, was used to organize the western spruce budworm data. The information base was built up as each digital coverage created in the system generated attribute tables. Each attribute table was associated with a particular feature class (e.g., polygon, arc, point, node). The Polygon Attribute Table (PAT) stores database information associated with each defoliation polygon. 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)

Two additional database items were manually added to the coverage PAT. The first item, **ha**, was added to calculate the area of a polygon in hectares. The hectares were determined by dividing the item, area (in square metres), by 10 000. The second 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 manually added at the terminal for each polygon.

4.6 Arc Macro Language Programs

ARC/INFO commands can be processed in batches through programs created using the Arc Macro Language (AML). AML programs also provide the tools to develop a front-end user interface for inexperienced users. Specialized queries and operations can be made interactively at the command level of the system.

Using AML, FIDS developed programs to automate frequent tasks and save time. In addition to the programs to set up the database, other programs enabled routine display and query operations to be automatically performed on the western spruce budworm geographical information base.

4.7 Accuracy and Limitations of Data and Analysis

Certain limitations and possible sources of error about digital data must be recognized. Errors introduced to the system 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 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 was minimized when creating the system by employing the following procedures where appropriate. Where western spruce budworm information existed in more that one format or source, the data were 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 was carefully carried out. The digital coverages that were translated from OVERLAY to ARC/INFO were visually compared to check the translation. The resultant western spruce budworm historical database is accurate enough for its intended purposes.

5 RESULTS

5.1 Outbreak Periods

Seven distinct western spruce budworm outbreak periods were identified in British Columbia for the period 1909–1993 (Figure 1). They are delineated as follows:

1. 1909–1910
2. 1916–1920
3. 1923–1930
4. 1943–1946
5. 1948–1958
6. 1967–1981
7. 1982–1993

5.2 Western Spruce Budworm Defoliation Years Summary

The year, defoliation area, and data source are summarized by forest region (Cariboo, Nelson, Kamloops, and Vancouver) (Appendix 2). Minor discrepancies will be found when comparing historical FIDS western spruce budworm information with the summarized GIS data. The past area statistics were gathered using different methods (e.g., dot count area calculations). The total area of western spruce budworm defoliation for British Columbia between 1909 and 1993 is shown in Figure 2 in graphical and tabular form.

FIGURE 1. Western spruce budworm in British Columbia – outbreaks 1909–1993.

FIGURE 2. Western spruce budworm defoliation area totals for British Columbia 1909–1993.

The five maps shown in Figure 3 indicate the increase in area defoliated over time and the shift in geographical location of the seven outbreak periods.

FIGURE 3. Geographical location and area defoliation for each recorded western spruce budworm outbreak period in British Columbia.

Illustrated below is the budworm's annual progression in British Columbia for the last 12 years (Figure 4). The total area of defoliation is given for each year. This time series diagram is useful for understanding the pest's movement and intensity over time.

FIGURE 4. Geographical location of western spruce budworm annual progression 1982–1993.

6 PRODUCTS

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

6.1 Historical Western Spruce Budworm Status Maps

Maps can be produced with accompanying database information that illustrates current or historical defoliation areas and severities. Statistical information includes the frequency (number of defoliation stands or polygons on the map) and area (total area of defoliation polygons in hectares) of western spruce budworm 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 NTS mapsheets at a medium scale, joined NTS mapsheets, forest region, province of British Columbia at a small scale, or any geographically referenced area within British Columbia (small to large scale).

Figure 5 is an example of a medium-scale western spruce budworm defoliation map. The NTS mapsheet, 82ENW, displays the extent of defoliation shaded by severity rating (explained in the legend), the frequency and area statistics by individual severity and summed total, pest type (WSBW), map scale, map sheet, and reference name places.

Figure 6 illustrates a regional map of the 1992 budworm defoliation for the Vancouver Forest Region. This map shows similar information to the NTS map but for a greater area. At this small scale, the defoliation is shaded solid and is not distinguished by severity, while the tabular statistics are divided into individual severity classes and summed total.

In Figure 7, a province-wide, small-scale map of the 1992 western spruce budworm defoliation is illustrated. The defoliation is shown as solid shading and the statistical table includes the different severity classes. The six forest region boundaries are delineated.

6.2 Interactive Database Query

The western spruce budworm database can be queried interactively on the graphics screen of the Sun Workstation. The following three commands are examples of information that can be retrieved about the budworm 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 = 134600.340 (square metres)

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 = 4207789.500 (square metres)
perimeter = 0036.257 metres[RCP6]
bc92isw1992# = 60
bc92isw1992-id = 45
scode = 2
ha = 420.779

6.3 Cumulative Defoliation Analysis

ARC/INFO geometric intersection commands, such as union, identity, and intersection, can be applied to a user-selected set of defoliation coverages. Inclusive and exclusive areas for a specified period of historical defoliation can be derived. AML programs developed for FIDS will enable a user to perform multiple-year defoliation analysis for any number of years. The program unites a number of user-selected years of defoliation extent to produce a single coverage. The years chosen can be consecutive or nonconsecutive. The resultant polygons identify which years the delineated area 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.

This type of cumulative analysis can be used by managing foresters to indicate trends in pest outbreaks. Predictions concerning increase or decline of future budworm defoliation and severity can be made. Figures 8 and 9 are examples of multiple-year analysis performed on the Bridge River area and British Columbia, respectively.

The analyses were performed in 1992 and, as a result, 1993 data are limited to summary defoliation area and frequency tables in this report.

The Bridge River analysis map (Figure 8) shows the budworm defoliation history between 1985 and 1992. The map displays statistics of stand frequency and area by number of years of defoliation. The total number of years of defoliation for this period and region range from one to eight years. The total number of years is not necessarily consecutive. The Bridge River map indicates that most attacks occurred for one to three years total in any one area and within the single outbreak period, 1982–1993.

The British Columbia multiple-year analysis map (Figure 9) shows the western spruce budworm defoliation from 1909 to 1992. The "unioned"[1] area of defoliation for the whole period was just over two million hectares. The analysis covers an 84-year span during which stand attack was recorded for 54 years in British Columbia. The regions with the darkest shading indicate the most persistent areas of budworm attack.

Various statistical operations can be performed on the entire historical budworm data set and presented as tables, maps, and graphs. The total number of years of budworm defoliation (consecutive or nonconsecutive) can be plotted against area attacked over the 84-year period to produce a graph (Figure 10). This analysis indicates that 23% of the total area has been defoliated for 1–6 years, increasing to 75% of the total area defoliated for 7–13 years, while only 2% of the total area has been defoliated for 14–19 years. A similar trend for the stands defoliated indicates that 28% of the stands have been defoliated 1–6 years, 69% of the stands have been defoliated 7–13, years and 3% of the stands were defoliated between 14 and 19 years. This analysis shows that any given stand has a high probability of being defoliated for a total of 7–13 years.

The number of consecutive years of budworm attack in British Columbia is shown in graph form (Figure 11). The selection of only consecutive years in this case aids in distinguishing separate outbreak periods. The graph indicates four distinct groups of consecutive years of defoliation. Twenty percent of the total area has been defoliated for 1–3 years, sharply increasing to 58% at 4 years, 21% at 5–7 years, while less than 1% of the total area has been defoliated for 8–13 years. A similar trend for the stands defoliated indicates that 27% of the stands have been defoliated for 1–3 years, 54% of the stands have been

[1] Union is the name of the ARC/INFO command used in the overlay analysis. It means "to combine."

defoliated for 4 years, 18% for 5–7 years, and less than 1% for 8–13 years. This analysis shows that any given stand has a more than 50% chance of being defoliated for 4 consecutive years.

These same data are illustrated geographically in Figure 12. The historical budworm defoliation is mapped by number of consecutive years of defoliation. Clearly, most of the area has been defoliated for 4 consecutive years.

FIGURE 5. Western spruce budworm defoliation map for NTS mapsheet 82ENW (Kelowna) 1992[RCP7].

FIGURE 6. Western spruce budworm defoliation map for Vancouver Forest Region 1992.

FIGURE 7. Western spruce budworm defoliation map for British Columbia 1992.

FIGURE 8. Multiple-year analysis map for Bridge River 1985–1992.

FIGURE 9. British Columbia western spruce budworm multiple-year analysis 1909–1992.

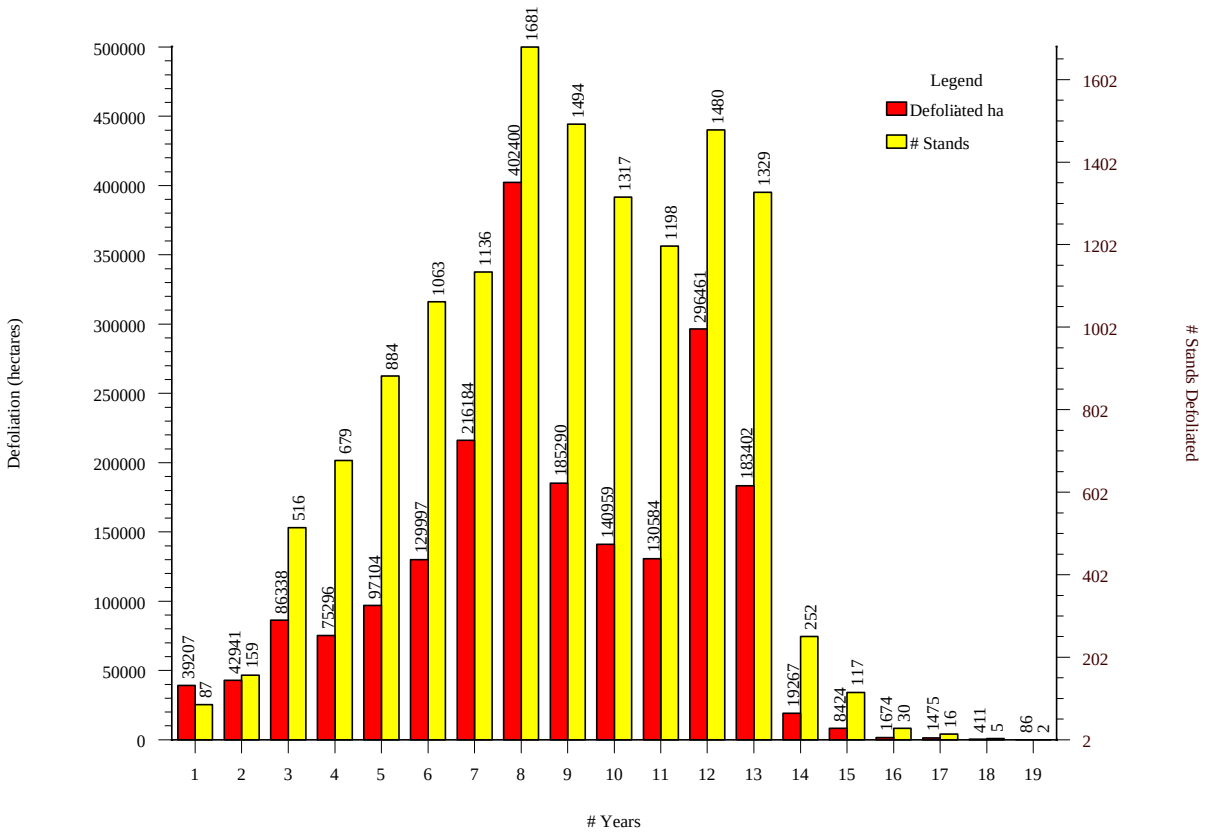

FIGURE 10. Multiple years of western spruce budworm attack in British Columbia 1909–1992.

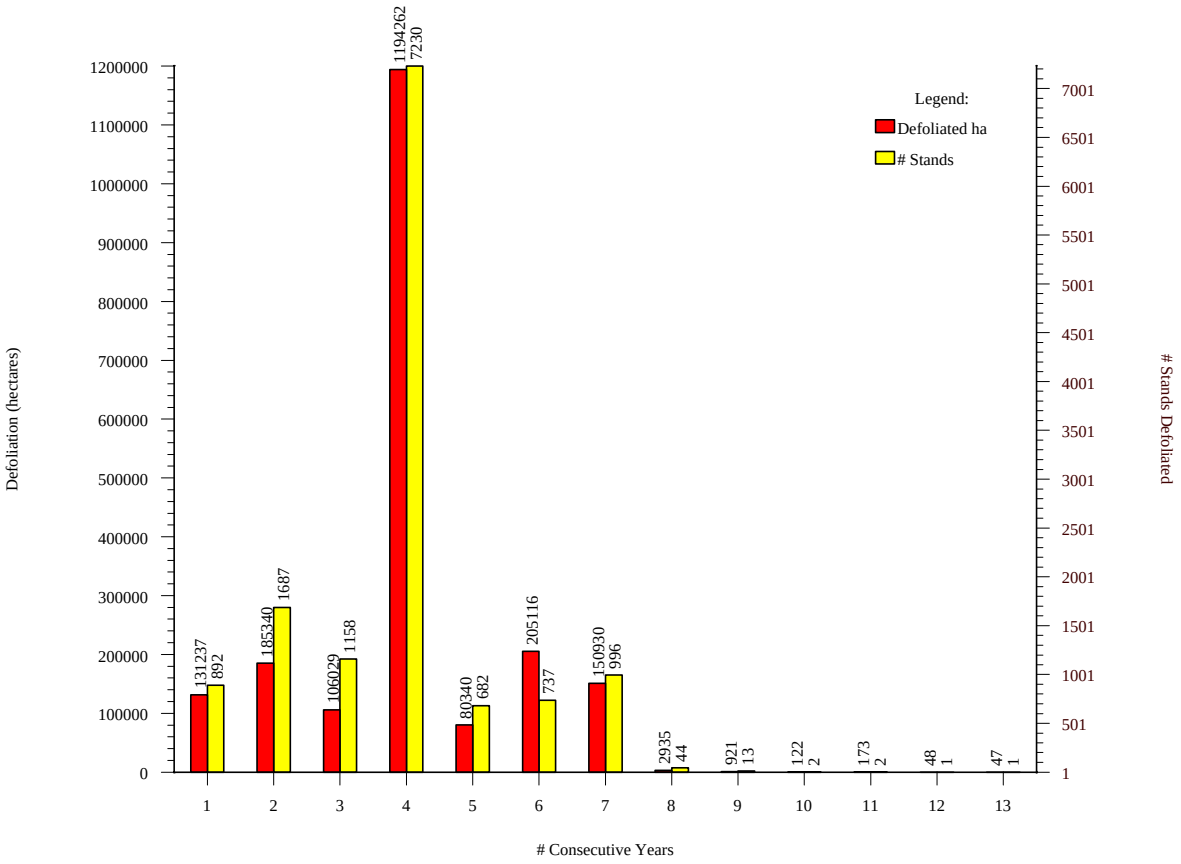

FIGURE 11. Consecutive years of western spruce budworm attack in British Columbia 1909–1992.

FIGURE 12. Location and patterns for consecutive years of western spruce budworm attack in British Columbia.

6.4 NTS Overlay Maps

To produce a hard-copy map that is particularly useful to the forest rangers when conducting annual aerial surveys, FIDS used a pen plotter to plot the defoliations directly onto NTS mapsheets. This method of mapping displays the extent of defoliation relative to the topographic features on the NTS mapsheets. While sketching the current areas of defoliation on the NTS maps, the polygons of the previous year's defoliation can be used as a reference.

6.5 Theme Overlay Analysis

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

FIDS transferred a digital 1:2 000 000 scale map of British Columbia, produced by the Surveys and Resource Mapping Branch of the Ministry of Environment, Lands and Parks into ARC/INFO format. This map is comprised of many layers of topographic information including boundaries, coastline, geographic grid, lakes, parks, rail lines, rivers, roads, spot elevations, and towns (B.C. Ministry of Environment, Lands and Parks 1992). Because this map was derived from a small-scale map (1:2 000 000), it is used at the regional- or provincial-scale. An example map illustrates how close western spruce budworm defoliation is to park boundaries (Figure 13). This digital map can also be used as a general topographic basemap.

Additional thematic maps from various sources have been digitally stored in the GIS. The data sets range in scale from 1:50 000 to 1:2 000 000, and included themes such as: Rowe's forest regions; Canada ecozones; biogeoclimatic zones; atmospheric pollution indicator data; climatic data; and forest region and district boundaries. These can be used in theme overlays with the budworm data.

6.6 Risk Analysis

Using FIDS western spruce budworm data records from 1909 to 1992, 54 years of spatially referenced defoliation data were unioned in the GIS to produce a multiple-year analysis. This product is a composite of all 54 defoliation years overlaid and merged into a single coverage. Each resultant polygon in the map contains information identifying which years the delineated area experienced defoliation, the total number of years defoliation occurred, and the maximum number of consecutive years of defoliation. The likelihood of an area being defoliated (risk) was then determined as a percentage value by dividing the total years of defoliation for a particular polygon by 84 (1909 to 1992 = 84 years). The maximum number of years of recorded defoliation in any one area is 19 years, producing a risk of 23%. Four classes of future risk were delineated and mapped from the resultant coverage information as follows:

1. 1–5% (1–4 years total defoliation)
2. 5–10% (5–8 years total defoliation)
3. 10–15% (9–12 years total defoliation)
4. 15–23% (13–19 years total defoliation)

The Pacific Forestry Centre (PFC) FIDS developed the western spruce budworm risk analysis map shown in Figure 14. The Cache Creek map displayed in Figure 15 is a zoomed-in section of Figure 14. It enables a more thorough examination of the defoliation information.

The analysis map discloses the following information. Based on all recorded areas of defoliation, from 1909 to 1992, 12% of the total area has a 1–5% frequency of defoliation, 41% of the area has a 5–10% frequency of defoliation, 37% has a 10–15% frequency of defoliation, while 10% of the area (more than 200 000 ha) is likely to be defoliated from 15 to

23% of the time. This report interprets the percentage frequency of defoliation as risk of future defoliation. Clearly, intensively managed stands in those areas of greatest budworm frequency should include management guidelines for budworm outbreaks. Such an analysis map can help to identify and focus forest health efforts where they are most needed.

FIGURE 13. Western spruce budworm defoliation proximity to parks 1992.

FIGURE 14. Western spruce budworm risk analysis map.

7 CONCLUSIONS

- During the years 1909–1993, budworm defoliation has been recorded more than 60% of the time (55 years).
- Annual defoliation ranged from relatively few hectares to as much as 838 120 hectares in 1987.
- Some 58% of the total area and 54% of the total number of stands were defoliated for 4 consecutive years.
- Some 75% of the total area and 69% of the total number of stands were defoliated for 7–13 years (non-consecutive).

8 SUMMARY

The western spruce budworm historical database was created using FIDS's GIS and this completed the first objective of the project. Defoliation information for western spruce budworm was either digitized or transferred to ARC/INFO for the period 1909–1993 with seven distinct infestation periods being noted. The report provided a brief history of the western spruce budworm and the aerial survey procedures conducted by FIDS, and discussed the development stages of the western spruce budworm GIS.

To meet the second objective, display and query operation programs were developed and applied to the western spruce budworm database. Statistical tables and maps of varying scales and media are now available. The completion of the sizeable database now makes ad hoc queries routine. Overall distribution and overlap of the western spruce budworm defoliations have been analyzed. Forest managers can use a risk analysis map to determine the likelihood of defoliation by western spruce budworm. Several application examples are included in the report to illustrate the capabilities of the western spruce budworm historical system.

9 FUTURE DEVELOPMENTS

The western spruce budworm historical GIS is the first major ARC/INFO GIS application created at FIDS. More GIS applications will be developed and much of the necessary ground work has already been accomplished through this project. Additional GIS analysis products are continually being developed by FIDS and, when complete, can be applied to the western spruce budworm historical system. In the near future, many different themes of data from other sources (e.g., forest inventory data) may be interfaced with the western spruce budworm system.

FIDS will continue to share data with other organizations such as the Petawawa National Forestry Institute, and the Ministry of Forests, and with private industry. In addition to the present electronic network, diskette, magnetic tape, or hard-copy options data could be distributed to clients through display and query media such as E.S.R.I.'s ARCVIEW. A client

FIGURE 15. Western spruce budworm risk analysis of the Cache Creek Region.

could then access the data at any area or scale. If clients use other GIS or mapping software such as Pamap GIS, Terrasoft, or Quickmap, the data could be used via data translation packages. FIDS is currently exploring these options. Scientists at Natural Resources Canada could use the geographical information base for research projects (e.g., modelling pest activity) and managing foresters can use the system to improve management decision-making.

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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:	– 26 00 00
latitude of projections origin:	48 00 00
false easting (metres):	1 000 000
false northing (metres):	0

APPENDIX 2. Western spruce budworm area statistics by forest region

Western Spruce Budworm Historical Defoliation Areas for Cariboo Region

Year	Defoliation area (hectares) (calculated by GIS)	Original data source
1974	3 749	Andrews 1987, aerial survey maps
1975	3 749	"
1976	3 749	"
1977	1 807	"
1978	590	"
1979	1 423	"
1980	14 280	"
1981	6 401	"
1982	3 193	"
1983	32 596	"
1984	15 475	FIDS digitized maps
1985	15 323	"
1986	178	"
1987	8 952	"
1988	7 664	"
1992	412	"

Western Spruce Budworm Historical Defoliation Areas for Kamloops Region

Year	Defoliation area (hectares) (calculated by GIS)	Original data source
1916	90	Erickson 1987
1917	90	"
1918	90	"
1919	90	"
1920	40	"
1943	6 352	Leech 1943
1944	3 776	Hopping 1944
1945	10 401	Hopping 1945
1946	4 476	Hopping and Farris 1946
1948	4 893	Sugden 1948
1949	1 416	Farris and Wood 1949
1950	2 396	Farris and Wood 1950
1956	22 454	Silver 1956[1]
1957	46 513	Silver 1957[2]
1958	43 066	Silver 1958[3]
1967	90	Geistlinger 1967
1968	90	Geistlinger 1968
1969	179	Wood *et al*. 1970
1970	1 682	FIDS aerial survey maps
1971	2 407	"
1972	10 158	"
1973	33 148	"
1974	31 877	"
1975	52 033	"
1976	168 303	"
1977	124 701	"
1978	5 626	"
1979	22 876	"
1980	36 770	"
1981	19 224	FIDS digitized maps
1982	22 760	"
1983	54 191	"
1984	48 452	"
1985	181 061	"
1986	408 520	"
1987	825 252	"
1988	346 554	"
1989	134 803	"
1990	164 883	"
1991	371 890	"
1992	319 843	"

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Western Spruce Budworm Historical Defoliation Areas for Nelson Region

Year	Defoliation area (hectares) (calculated by GIS)	Original data source
1923	1 256	Harris *et al*. 1985
1924	1 256	"
1925	1 256	"
1926	1 256	"
1927	1 256	"
1928	1 256	"
1978	353	Vallentgoed 1987, Aerial survey maps
1979	495	"
1980	125	"
1981	125	"
1982	125	"
1983	125	"
1984	125	"
1985	44	"
1986	3 703	FIDS digitized maps
1987	1 040	"
1988	3 277	"
1989	17 767	"
1990	1 152	"
1991	3 985	"

Western Spruce Budworm Historical Defoliation Areas for Vancouver Region

Year	Defoliation area (hectares) (calculated by GIS)	Original data source
1909	15 957	Harris *et al*. 1985, Humphreys 1986
1910	10 176	"
1926	8 098	"
1927	8 098	"
1928	10 321	"
1929	13 276	"
1930	3 741	"
1943	21 233	Leech 1943
1944	21 233	Hopping 1944
1953	6 805	Silver 1953[4]
1954	49 706	Silver 1954[5]
1955	76 215	Silver 1955[6]
1956	99 625	Silver 1956[7]
1957	89 340	Silver 1957[8]
1958	111 570	Silver 1958[9]
1969	188	FIDS aerial survey maps
1970	5 087	"
1971	7 754	"
1972	21 025	"
1973	61 831	"
1974	79 084	"
1975	86 189	"
1976	78 134	"
1977	119 060	"
1978	27 223	"
1979	18 371	"
1980	29198	"
1981	1 113	"
1986	1 259	FIDS digitized maps
1987	2 876	"
1988	3 649	"
1989	4 917	"
1990	3 846	"
1991	6 893	"
1992	21 133	"

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Page: 5
[RCP1] Abstract comes before Acknowledgements

Page: 6
[RCP2] All figure titles should be lower case

Page: 1
[RCP3] Biogeoclimatic zones might be more useful

Page: 3
[RCP4] Mapjoin?

Page: 3
[RCP5] What does this mean?

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[RCP6] Units?

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[RCP7] 1992 matches List of Figures

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[RCP9] Were these old FIDS references part of Can. For. Serv.?

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