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Historical pesticide applications for the treatment of eastern spruce budworm infestations in New Brunswick

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Open Research Statement: The complete data set is available as Supporting Information. The historical pesticide applications data set is also available for download directly from the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) in the forestry section as the "Digitized Pest Management Records".

Class I. Data set descriptors

A. Data set identity: Historical Pesticide Applications Database for the Treatment of Eastern Spruce Budworm (*Choristoneura fumiferana*) Infestations in New Brunswick

B. Data set identification code: DataS1.zip in supporting information and "Digitized Pest Management Records" in the forestry section on New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html).

C. Data set description:

1. **Originators:** Shane Heartz, David A. MacLean, Rob C. Johns, Drew Carleton, Luke Amos-Binks, Quinn Anderson, Yue Yu, Andrew D. Lewis, Dan Lavigne, Joseph B. Burant, Christopher B. Edge

2. **Abstract:** Pesticides have been used as part of large-scale aerial spray applications to control insect pests on forested lands in Canada since 1945. Some of the pesticides used historically were efficacious, non-selective, persistent, and lead to serious impacts on the environment. A well-known and extensively documented example are the large-scale aerial spray programs in New Brunswick, Canada. From 1952-1993, 97% of 6.2 million ha of the forested lands of New Brunswick were treated with at least one application of one insecticide, the majority of which were applied to control outbreaks of eastern spruce budworm (*Choristoneura fumiferana*). The most well known insecticide was dichlorodiphenyltrichloroethane (DDT), applied from 1952-1968, which persists in treated soils and adjacent water bodies, and caused individual and cumulative ecosystem effects that can still be measured today. The insecticides that replaced

DDT were non-persistent and unlikely to be found today. However, during the years of application some of the insecticides likely impacted local ecosystems to some degree. To aid future studies on the efficacy and environmental impact of these insecticides we created a digital spatial data set of known pesticide application in New Brunswick forestry from 1952-1993. The data set includes active ingredient, formulation, application rate, tank mix, aircraft type, and other ancillary information. The current version of the data is available on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page and in the supplemental material. Use of the data set for academic and educational purposes is encouraged, provided that both this data paper and the data source are properly cited; the Government of New Brunswick should be acknowledged as the data source (Open Government License http://www.snb.ca/e/2000/data-E.html).

D. **Key words/phrases:** aminocarb; *Bacillus thuringiensis kurstaki*; BT; *Choristoneura fumiferana*; DDT; eastern spruce budworm; fenitrothion; insecticide application; New Brunswick, Canada; phosphamidon; spray.

Class II. Research origin descriptors

A. **Overall project description:** Spatial data set of insecticides used for the control of insect pests in New Brunswick Canada from 1952-1993

   1. **Identity:** Historical Pesticide Applications Database for the Treatment of Eastern Spruce Budworm (*Choristoneura fumiferana*) Infestations in New Brunswick

2. **Originators:** Shane Heartz, David A. MacLean, Rob C. Johns, Drew Carleton, Luke Amos-Binks, Quinn Anderson, Yue Yu, Andrew D. Lewis, Dan Lavigne, Joseph B. Burant, Christopher B. Edge
3. **Period of study:** 1952-1993
4. **Objectives:** The present paper describes a large spatial data set of the application of insecticides between 1952 and 1993 to the forests of New Brunswick Canada. Following the 1993 treatment season the broad scale aerial spray program ended. We focus on describing the data set and its utility in future research and not the environmental impact of the insecticides applied or the decision-making process to use them. There have been several reviews that describe the environmental impact of insecticide use (for example, Elson 1967; MacDonald and Duffy 1968; Varty and Titus 1974; Kingsbury and Trail 1985; Ernst and Doe 1989; Kingsbury 1995; Holmes and MacQuarrie 2015) and annual reports published by Interdepartmental Committee on Forest Spraying Operations (ICFSO), (1958–1972) and the Annual Forest Pest Control Forum (FPCF), (1973-1993) detailing decision making for insecticides used, application areas, and treatment amounts. The Forum and Committee reports are available online via the Canadian Forest Service Publications website (https://cfs.nrcan.gc.ca/publications/search?q=test&format=citation, Table 1). In 1996 the Forest Pest Control Forum was renamed the Forest Pest Management Forum and continues to meet annually.

   Today, forests are an extremely important renewable natural resource and considerable effort is placed on ensuring their health and productivity. In 2020 forestry contributed $25.2 billion to Canada's nominal Gross Domestic Product, and forest products accounted for 6.9% of Canada's total exports (Natural Resources Canada 2022). The value of Canadian forests was proportionately greater in the recent past; in the early 1970s forestry was the dominant industry in parts of Canada, employed 220,000 people, and accounted for 19% of total value of Canada's exports (Prebble 1975). Pest management is an important component of maintaining a healthy and productive forest because insect pests defoliate large areas of forests every year (Natural Resources Canada 2022). In 2019, 14.5 million hectares of forest in Canada were affected by insects with eastern spruce budworm (*Choristoneura fumiferana*) accounting for 5.5 million hectares of moderate to severely defoliated forest (Natural Resources Canada 2022).

Eastern spruce budworm outbreaks occur throughout the North American boreal forest but have historically been most intense and widespread in its eastern range. For example, the previous large-scale outbreak peaked in the mid-1970s and caused ~52 million hectares of severe defoliation from Ontario to Newfoundland, as well as Maine, USA (Pureswaran et al 2016). Recent estimates predict economic impact of an uncontrolled outbreak could be as high as $4.7 billion in New Brunswick alone (Chang et al 2012). Comparatively, in the prairie provinces from Manitoba to Alberta aerial treatment operations were periodically (1973 to 1990) conducted to combat budworm outbreaks, alongside other pest species during similar time periods (Armstrong and Cook 1993). In British Columbia the western spruce budworm (*Choristoneura occidentalis*) can cause similar levels of defoliation and tree death to eastern spruce budworm (Axelson et al 2015). In

Manitoba, three widely scattered and short duration outbreaks of eastern spruce budworm have occurred since insect surveys began in 1938 (Hildahl and DeBoo 1975).

At the height of a large outbreak of eastern spruce budworm in 1949, the province of New Brunswick (Figure 1a) identified forest protection as a top issue and began investigating potential control methods (Miller and Kettela 1975; Holloway et al 2008). The timing of this major outbreak coincided with the release of the highly effective, broad spectrum, organochlorine insecticide dichlorodiphenyltrichloroethane (DDT) and a post-World War II surplus of military aircraft capable of delivering insecticide over large areas of forest (Miller and Kettela 1975; Dixon and Irving 1985). The first broad-scale aerial pesticide application program to control eastern spruce budworm began in 1952 and ended in 1993 (Miller and Kettela 1975; Holloway et al 2008). During this period other insects such as the Common House Mosquito (*Culex pipiens*), Spongy Moth (*Lymantria dispar dispar*), Eastern Hemlock Looper (*Lambdina fiscellaria fiscellaria*), Yellowheaded Spruce Sawfly (*Pikonema alaskensis*), Balsam Fir Sawfly (*Neodiprion abietis*), and Balsam Wooly Adelgid (*Adelges piceae*) were also targeted in New Brunswick, albeit over much smaller areas (Armstrong and Cook 1993).

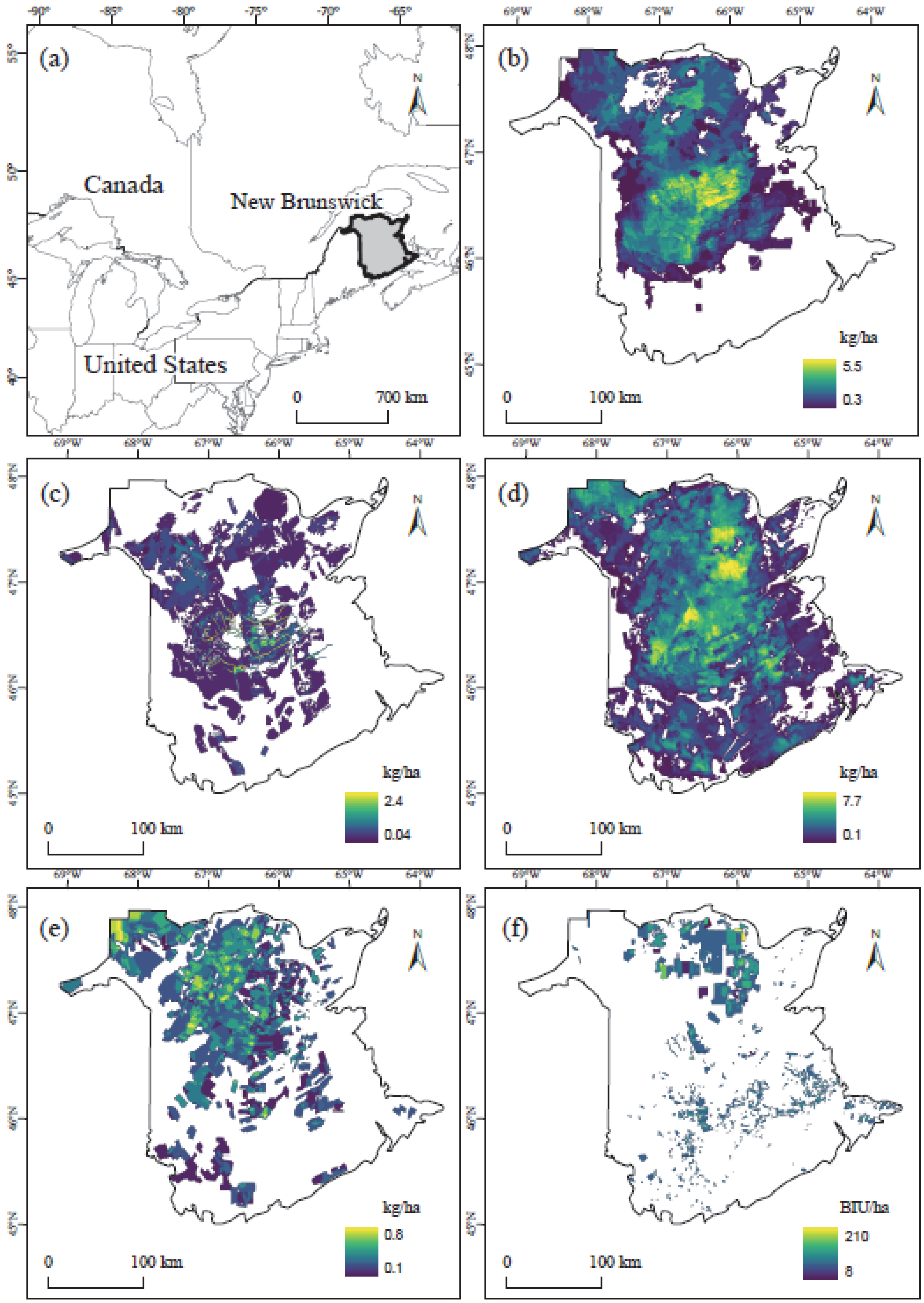

Figure 1: (a) Location of New Brunswick, Canada. Cumulative application rate of the four most commonly used insecticides in New Brunswick from 1952-1993: (b) Dichlorodiphenyltrichloroethane (DDT) 1952-1968 (kg/ha), (c) Phosphamidon 1963-1977 (kg/ha), (d) Fenitrothion 1966-1993 (kg/ha), and (e) Aminocarb 1970-1987 (kg/ha), and one insecticide which is currently used (f) *Bacillus thuringiensis kurstaki* (BTK) 1975-1993 (BIU/ha).

The historical aerial spray program in New Brunswick was the largest and longest of its kind in the world, making New Brunswick one of the most heavily sprayed regions in North America (Peakall and Bart 1983; Miller and Kettela 1975; Armstrong and Cook 1993). In contrast, current-day eastern spruce budworm control in New Brunswick involves the use of two narrow spectrum insecticides, tebufenozide and *Bacillus thuringiensis kurstaki* (BTK) and targeted application over small spatial extents (MacLean et al. 2019; Johns et al. 2019), and research has been conducted on the use of pheromones to disrupt mating (Régnière et al. 2019). Tebufenozide (Pest Management Regulatory Agency 2021) and BTK (Pest Management Regulatory Agency 2000) are relatively specific to feeding caterpillars and are broadly considered to be non-toxic to non-target species when applied at label application rates.

During the historical period (1952-1993) 12 insecticides (active ingredients) were applied over different time periods and areas of the province as part of the control program or research program (Table 2). Four of those insecticides were widely used and one is still used today. The first insecticide widely applied was DDT from 1952-1968 (Figure 1b), which was chosen largely because it was available, inexpensive, effective, and could be applied via aerial spray. The choice to use DDT was made before significant data and studies on toxicity and environmental effects were conducted (Miller and Kettela 1975; Shea and Nigam 1984). Subsequently insecticides were chosen after a more rigorous selection process that involved laboratory toxicity testing, small-scale field trials, and small-scale operational spray programs (Miller and Kettela 1975). The organophosphate

Phosphamidon was used in buffer zones along salmon streams instead of DDT from 1963-1967 (MacDonald 1966; Logie 1975) and remained in use to some degree until 1977 (Figure 1c). Fenitrothion replaced DDT across the province in 1968 and was used until 1993 (Figure 1d). Aminocarb was used from 1970-1987 (Figure 1e). Finally, the BTK insecticides were developed in the early 1970s, entered broad use in 1973 (Figure 1f), and are still used today because they are considered to be non-toxic to non-target species (Kreutzweiser et al. 1994; Richardson and Perrin 1994; Rubio-Infante and Moreno-Fierros 2016).

The immediate negative environmental consequences of using DDT on aquatic and terrestrial animals has been widely studied and is well known (e.g. Ide 1967; Elson 1967; Risebrough et al. 1967; Bitman et al. 1969). The use of DDT resulted in mortality of birds, mammals, salmon, and aquatic invertebrates (Elson 1967; Ide 1967; Finley 1965). Some of the subsequently used insecticides also had negative environmental effects. Phosphamidon is toxic to birds, mammals, fish, and aquatic and terrestrial insects (Finley 1965; Varty and Titus 1974; Mineau and Peakall 1987; Smith 1987). Fenitrothion is toxic to fish and invertebrates (Bull and McInerney 1974; Sundaram 1987; Ernst and Doe 1989; Fairchild and Eidt 1993; Ernst et al. 1994). Aminocarb is toxic to non-target insects (Bracher and Bider 1981) and was linked to negative effects on Atlantic salmon smolt (Fairchild et al 1999). Other insecticides were applied in smaller amounts and over shorter periods (Table 2). Except for DDT, most of the pesticides would be classified as non-persistent based on half-life (DT50) values in soils (Table 2). DDT has an extremely long half-life and despite being banned in Canada in 1985 and around the world by the Stockholm Convention on Persistent Organic Pollutants in 2001, it is found in soils (Boul 1995), lake sediments (Kurek et al. 2019; Satiroff 2021), and in the vast majority of all birds and fishes tested (Turusov et al. 2002) around the world today. In New Brunswick the environmental effects from historical DDT use can be measured in contemporary zooplankton communities (Kurek et al. 2019). It is possible that other insecticides altered terrestrial or aquatic invertebrate and vertebrate communities in the areas to which they were applied.

Here we describe a spatial data set detailing insecticide application to the province of New Brunswick for the control of insect pests, specifically eastern spruce budworm from 1952-1993. The data include the active ingredient, formulation, application rate, and ancillary information when available.

5. **Abstract:** Pesticides have been used as part of large-scale aerial spray applications to control insect pests on forested lands in Canada since 1945. Some of the pesticides used historically were efficacious, non-selective, persistent, and lead to serious impacts on the environment. A well-known and extensively documented example are the large-scale aerial spray programs in New Brunswick, Canada. From 1952-1993, 97% of 6.2 million ha of the forested lands of New Brunswick were treated with at least one application of one insecticide, the majority of which were applied to control outbreaks of eastern spruce budworm (*Choristoneura fumiferana*). The most well known insecticide was dichlorodiphenyltrichloroethane (DDT), applied from 1952-1968, which persists in treated soils and adjacent water bodies, and caused individual and cumulative

ecosystem effects that can still be measured today. The insecticides that replaced DDT were non-persistent and unlikely to be found today. However, during the years of application some of the insecticides likely impacted local ecosystems to some degree. To aid future studies on the efficacy and environmental impact of these insecticides we created a digital spatial data set of known pesticide application in New Brunswick forestry from 1952-1993. The data set includes active ingredient, formulation, application rate, tank mix, aircraft type, and other ancillary information. The current version of the data is available on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page and in the supplemental material. Use of the data set for academic and educational purposes is encouraged, provided that both this data paper and the data source are properly cited; the Government of New Brunswick should be acknowledged as the data source (Open Government License http://www.snb.ca/e/2000/data-E.html).

6. **Sources of funding:** The historical aerial spray operations in New Brunswick were funded by the forest industry, the provincial government, and the federal government. The decision to be involved in aerial control operations was made by individual forest industry companies, private land owners, or park boards (Prebble 1975). In 1952 Forest Protection Limited (FPL) was established as an Industry-Government cooperative (ICFSO 1958). Forest Protection Limited provided much of the logistical support for trial assessment during the early 1950s (ICFSO 1958) and the large-scale aerial spray programs that began later. From 1952 to 1973 federal funding decisions were made annually. In 1974 the first federal-provincial

Forest Subsidiary Agreement, that laid out specific guidelines for fundable forest activities, came into effect (Canadian Forestry Service 1985). The first agreement allocated $680,000 from the federal government to the province of New Brunswick specifically for resource protection (Regional Economic Expansion 1975) and New Brunswick treated 2.7 million ha of forested lands. Beginning in 1984 and continuing until 1989, a Forest Renewal Agreement was the standard for funding of the aerial control program. Insect control via the aerial application of pesticides was no longer the only aspect of forest protection covered and funding was shifted towards creating a more efficient protection program (Canadian Forestry Service 1985). For detailed funding aspects of each year see the annual subsidiary funding agreements for forestry operations, located at Library and Archives Canada (https://library-archives.canada.ca/eng, Table 1). Funding for the digital data compilation was provided by the Department of Natural Resources Canada – Canadian Forest Service and the New Brunswick Department of Natural Resources and Energy Development.

Work on data compilation was also supported by the Living Data Project as part of their data rescue initiative. The Living Data Project is an initiative of the Canadian Institute of Ecology and Evolution which is funded by a Collaborative Research and Training Experience grant from the Natural Sciences and Engineering Research Council of Canada.

B. Specific subproject description

1. Site description:

a. Site type: Acadian Temperate Forest

b. Geography: New Brunswick, Canada, 46.5653N, 66.4616W.

c. *Habitat:* New Brunswick is 72,908 km^2 in size of which 85% is forested. The Acadian Forest is a transitional forest between the coniferous dominant Boreal Forest to the north and the Temperate Deciduous Forest to the south. There are approximately 32 different tree species in the Acadian Forest, and dominant species include balsam fir (*Abies balsamea* L.), red spruce (*Picea rubens*), red maple *(Acer rubrum*), white birch (*Betula papyrifera*) and yellow birch (*Betula alleghaniensis*) (Rowe, 1972).

d. *Geology, landform:* New Brunswick bedrock types range from Mississippian to Pennsylvanian on top of a base of early Paleozoic (Ordovician to Devonian) and Precambrian rock types (Gussow 1953). The geomorphology is a variation of highlands, flat-topped lowlands and lowland plains composed of both sedimentary and igneous rocks (Colpitts et al. 1995). The landscape ranges in elevation from 0 meters (sea level) to 817 m at the top of a northern mountain, Mount Carleton. There are a total of 50 soil types, of which 48 are mineral, one is organic, and one is the result of mining debris being brought to the surface (Colpitts et al 1995).

e. *Watersheds, hydrology:* There are 15 primary river systems in New Brunswick that terminate in the Atlantic Ocean, the largest of which is the Wolastoq (Saint John) that drains 55,000km^2 of which half is in Canada. The primary rivers have been divided into 142 level two watersheds that range in size from 214 ha (South Patapedia River composite) to 776,969 ha (Southwest Miramichi River), (New Brunswick Hydrographic Network 2022). From 1952-1993 insecticides were applied to some portion of each of the level two watersheds. Table 3 identifies the catchment area for the watersheds larger than 100 000 ha in area and the percent of each sprayed at some point during the application period. Table 4 identifies the average cumulative totals for of the most common pesticide active ingredients for each of the watersheds larger than 100 000 ha.

f. *Site history:* The primary natural disturbance in the Acadian Forest is insect outbreak, in particular eastern spruce budworm. The eastern spruce budworm undergoes a cyclical population cycle with a periodicity of 25-40 years (Jardon et al 2003). Since the 1700s there have been at least eight major outbreak cycles, three of which occurred in the 20th century (Boulanger and Aresenault 2004). Forestry has always played an important role in land management for New Brunswick. Forest management in New Brunswick began in the 1800s when many shoreline communities were involved in harvesting for the shipbuilding industry. Currently 3,028,109 ha is under Crown forest license, 1,091,576 ha is industrial freehold, and 1,810,001 ha is private (New Brunswick Natural Resources and Energy Development, unpublished).

g. *Climate:* The climate in New Brunswick is largely determined by prevailing westerly winds and moderated by the Atlantic Ocean. In the southern coastal region (Saint John 45°19'N, 65°53'W) average daily temperature ranges from –7.9°C in January to 17.1°C in July, with 1295.5mm of precipitation annually. In the central region (Fredericton, 45°55'N, 66°37'W) average daily temperature ranges from -9.4°C in January to 19.4°C in July with 1094.7mm of precipitation annually. In the northern region (Charlo, 47°59'N, 66°20'W) average daily temperature ranges from -12.6°C in January to 17.2°C in August and 997.6mm of precipitation falls annually (Environment and Climate Change Canada 2022).

2. Experimental or sampling design

a. *Design characteristics:* A variety of fixed wing aircraft and helicopters, guidance systems, and application systems were used from 1952 to 1993 for spray operations (Armstrong and Cook 1993; Shea and Nigam 1984; Randall 1975; Dixon and Irving 1985). From 1952 to 1962 the main guidance for spray operations was visual large scale (1:50,000) map navigation from the cockpit. As the variety of available aircraft, navigation, and applications systems increased from 1958 to 1985, application was optimized to improve efficiency, limit waste, and minimize drift to non-target areas (Shea and Nigam 1984; Dixon and Irving 1985; Armstrong and Cook 1993). As smaller aircraft, digital navigation, and different boom types were developed and became available smaller application areas for research could be delineated at compact, easily accessible sites. Aircraft speed and height of application were calculated with droplet sized leaving the boom, as part of spray block planning (Armstrong 1975). Large droplets (400 microns in diameter) fall faster (0.3 minutes over 30.5 meters) than smaller droplets (50 microns, 5.7 minutes), making boom type and settings critical to achieve efficacy (Randall 1975; Armstrong 1975). The influence weather conditions have on deposition began to receive attention in the 1940s. The development of the 'HU' factor, 'H' being height of the aircraft from the ground and 'U' being crosswind speed (Gunn 1948; Hurtig et al. 1953), allowed for application drift calculation and management (Armstrong 1975). The use of detailed meteorological information such as ground temperature, wind speed, humidity and air inversions were well established in application management by 1984 to limit drift (Shea and Nigam 1984). Weather conditions also affected spray evaporation in the air, more volatile mixes showed lower average rates of fall (Armstrong 1975). Aircraft, application systems and guidance systems were enhanced with meteorological data to further improve application accuracy and efficiency (Armstrong 1975; Randall 1975; Shea and Nigam 1984). Advances in spray control and accuracy became more important as the program expanded closer to populated areas in the 1970s (Shea and Nigam 1984).

b. *Permanent plots:* Not Applicable

c. *Data collection period, frequency, etc.:* 1952-1993, Annual data collection.

3. Research methods

a. *Field:* During the application years spruce budworm egg mass counts, moth/egg surveys, and defoliation surveys were conducted annually to create hazard maps and delineate application areas the following year (Miller and Kettela 1975). Application areas were delineated annually on large scale, 1:500,000, paper maps by hand (Figure 2). Boundaries of individual application areas varied annually. Duplicates of the maps were created and maintained by Natural Resources Canada, Canadian Forest Service and the New Brunswick Department of Natural Resources. Prior to the field operations treatment adjustments were occasionally made to operational blocks or research (experimental) blocks were added. All changes applied were noted in subsequent summary reports to the ICFSO and later the FPCF. Following application annual summaries were produced and submitted to the ICFSO

(1958–1972) or the FPCF (1973–1993). At the meetings reports and additional information from other participating federal and provincial government departments were reviewed and used to modify the following years treatment areas. See Armstrong and Cook (1993) for a summary of treatments each year of aerial application.

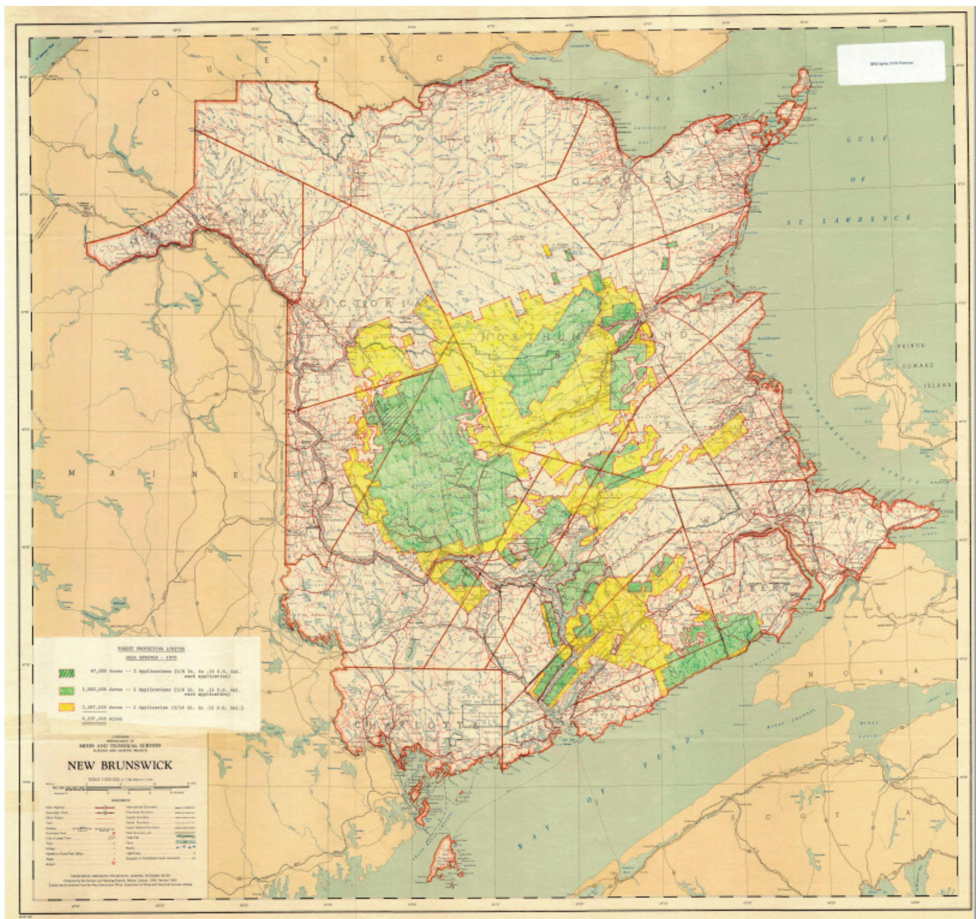

Figure 2: Example original treatment map for the New Brunswick, Canada aerial spray program for the year 1970.

A first attempt to compile the data was undertaken by the New Brunswick Department of Natural Resources circa 2010. The original hand drawn maps were gathered from FPL and Natural Resources Canada - Canadian forest Service and scanned for digital storage. The maps were freehand digitized on a large format digitization table, and the associated attributes from the maps compiled.

At the same time some supplemental information was compiled from reference material. A data model was developed to store the data, but there were some inconsistencies among years in how the data were compiled. Data were stored in Fredericton, New Brunswick, by the New Brunswick Department of Natural Resources and Energy Development, until they were made available to the Department of Natural Resources Canada - Canadian Forest Service for this project. The original database is referred to here as database 1.0.

To check accuracy and completeness of database 1.0, we independently digitized the original hand drawn maps for a six-year period (1970-75) to create database 2.0 in 2020. Physical maps for the six-year period were scanned into a Tagged Image File Format (TIFF) format using large scale flatbed scanner. After scanning, the maps were imported into GIS software (ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute), georeferenced, and individual polygons were digitally drawn for each application area. Ancillary data were collected from maps and reports (NRCan-CFS Original Aerial Application Maps 1970-1975; Kettela and Moran 1974; Armstrong and Cook 1993; Miller et al 1973; Varty and Titus 1974; Kettela 1969) and a consistent set of variables describing the application area and other ancillary information were defined (Table 5 and 6). The variables provide a consistent set of metadata for each application area in the data set.

The spatial extent of each application area and associated data were compared between the database 1.0 and database 2.0 to identify discrepancies or inaccuracies in database 1.0 in need of review. The number of application areas and spatial extent of application matched in database 1.0 and 2.0 in one of the six comparison years. In four of the years there were fewer application areas in database 1.0 than in database 2.0 because adjacent areas with the same insecticide and application rates where spatially merged in database 1.0 and the individual application area boundaries were maintained in database 2.0. Merging application areas only creates accuracy issues if areas with different insecticides or application rates were combined. We did not detect any cases of incorrect merging.

In one comparative year, 1970, database 1.0 contained more application areas than were in database 2.0. The discrepancy was due to additional application areas delineated in database 1.0 that were not found on the physical maps. These additional application areas and associated data could not be verified with available reference material. The additional application areas could have been created from reference material that is no longer available or by error.

To reduce the risk of errors associated with additional application areas with unsupported treatments being found in the data set, we compared annual summaries (Armstrong and Cook 1993) of insecticides used, application rates, and total area of applications to summaries generated from database 1.0. For each insecticide and application rate we calculated the total amount and area to which it was applied in each year and compared values with the summary data found in Armstrong and Cook (1993). Our expectation was the derived values in database 1.0 should be within 10% of that in the summary information. For all identified discrepancies we undertook a search of supporting documents for confirmation. Supporting documents were located by conducting a search of peer-reviewed literature, published reports, unpublished reports, and physical documentation. If supporting information could be found the records were included or changed appropriately. If no supporting information was found the records were removed or specific values identified as unknown (See section IV B 5, Data Anomalies).

Following review and revision, database 3.0 was created from database 1.0 and should be considered the best current day representation of pesticide application for the control of eastern spruce budworm in New Brunswick from 1952-1993. Database 3.0 consists of a shapefile delineating application areas (NBHistoricPesticideAreas.shp, Table 5) and table listing insecticide applications (NBHistoricPesticideApplications.csv, Table 6).

Each row in the annual applications attribute table (NBHistoricPesticideAreas.shp) represents an application area, which received the same treatment in a given year. Unique application areas are identified with the app_area field. Each individual application area may have received multiple, different pesticide applications which are listed in NBHistoricPesticideApplications.csv. Each row in NBHistoricPesticideApplications.csv corresponds to a unique pesticide application and is identified with the app_id field. A record in

NBHistoricPesticideApplications.csv can be linked to an individual application area found in NBHistoricPesticideAreas.shp using the app_area field.

b. *Instrumentation:* Not Applicable

c. *Taxonomy and systematics:* Not Applicable

d. *Permit history:* The New Brunswick Department of Environment did not issue aerial spray permits during the period covered by this data set, 1952 to 1993. Archive records from New Brunswick Department of Environment and Local Government showed records of pesticides used during this period and three permits were issued in 1992 for research to the Department of Natural Resources – Canadian Forest Service (NB DELG, 2022).

   A permit for research on Federal Lands (the Acadia Research Forest) using BTK was issued through the Control Products Section of the Department of Agriculture in 1979.

e. *Legal/organizational requirements:* Pesticide regulation in Canada began in 1927 and has matured over the last 100 years. In 1939 the Pest Control Products Act (currently SC 2002, c. 28) came into effect and was administered by the Department of Agriculture. Administration of The Pest Control Products Act shifted to Health Canada in 1995 when the Pest Management Regulatory Agency was created.

   Health Canada pesticide registration is a requirement for all pesticide use in Canada today. Beginning in the 1950s registration involved toxicity testing for human health and the environment. Regulations changed over the next half century in response to improved understanding of risk to human and environmental health. In the 1980s it was recognized that assessing and managing chemical substances in Canada required a systematic approach, leading to the creation of the Canadian Environmental Protection Act, which became law in 1988 and is currently Canadian Environmental Protection Act, SC 1999, c 33. This Act is under the responsibility of the Minister of Environment and Minister of Health with the responsibility of protecting human health and the environment.

In New Brunswick the New Brunswick Pesticide Control Act came into effect in 1973 (RSNB 1973, cP-8), since repealed to version RSNB 2011, c203. Under the Pesticide Control Act (1973) all pesticides to be applied in NB must apply for a Permit for application.

Finally, New Brunswick Regulation 90-80 of the Clean Water Act OC 90-532 cited today as the Watercourse and Wetland Alteration Regulation – Clean Water Act 2003-16, states a minimum of a 30m buffer must be maintained on any wetland or watercourse.

With respect to pesticide application for the control of eastern spruce budworm during the 1950s there was no permitting process for pesticide applications (Armstrong and Cook, 1993). The first New Brunswick aerial spray application in 1952 was a cooperative research project by various Federal and Provincial biologists and foresters assisted by Fraser Cos. Ltd, on Fraser leasehold lands (Miller and Kettela 1975). Subsequently, Fraser joined Bathurst Power and Paper Co Ltd, Irving Pulp and Paper Co Ltd and the New Brunswick Department of Lands and Mines to form FPL. Natural Resources Canada -

Canadian Forest Service provided technical information and advice in subsequent programs (Miller and Kettela 1975). The approval to proceed with chemical applications on a larger scale was sanctioned by the ICFSO starting in 1958, which provided a forum of representation of the three major natural resource management departments at the time: Fisheries through the Fisheries Board of Canada and the Department of Fisheries, Forestry through the Department of Agriculture's Forestry and Forest Biology Division, and the wildlife through the Canadian Wildlife Service (ICFSO minutes, 1958). Later Health and Wellness Canada and Northern Affairs joined the Committee. This oversight continued to sanction operations until 1972.

In 1973 the Forest Pest Control Forum was established and remains active today as the Forest Pest Management Forum, as the National format for discussions around pest management in Canada. Like the ICFSO the Forum functions based on the initiative of the Department of Natural Resources Canada - Canadian Forest Service (FPCF minutes 1973). Beginning in 1973 all provinces and operational companies were included in the forum.

4. **Project personnel:** Not Applicable

Class III. Data set status and accessibility

A. Status

1. Latest update: September 2022
2. Latest archive date: September 2022
3. Metadata status: September 2022
4. Data verification:

Data quality was assured by independently developing 6 years of data from existing paper maps and internal Federal reports to create database 2.0. Second, database 1.0 was reviewed, reorganized, and supplemented with information from various publications. See section II B 3a for description of methodology. See Section IV B 5 Data Anomalies for description of possible errors and omissions.

B. Accessibility

1. **Storage location and medium:** The most current data set at time of publication, is available on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) as the "Digitized Pest Management Records" in the forestry section. Updates to the data set will only be made there and it is strongly encouraged that the data be retrieved at this site.

2. **Contact persons:**

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   Shane Heartz, Atlantic Forestry Centre, 1350 Regent St, Fredericton, NB, E3B 5P7, Phone: 506-429-4236, e-mail: shane.heartz@nrcan-rncan.gc.ca

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3. **Copyright restrictions:** The data are available under the Open Government License (http://www.snb.ca/e/2000/data-E.html). Use of the data set for academic

or educational and non-commercial purposes is encouraged, provided the data source is properly cited and any adaptations are shared under the same terms.

4. **Proprietary restrictions:**

   a. *Release date:* Not Applicable

   b. *Citation:* When used for academic or educational purposes, this data set should be cited using the title of this Data Paper, the names of the authors, the year of publication, the journal name, and the article number. The Government of New Brunswick should be acknowledged as the data source.

   c. *Disclaimer(s):* While the digital map files may not be free from error or omission, care has been taken to ensure the best possible quality. The digital map files are a graphical representation of land related features which approximates the size, configuration and location of features. It is not a survey and is not intended to be used for legal descriptions or to calculate exact dimensions or areas.

      The New Brunswick Department of Natural Resources and Energy Development shall not be liable for any loss or damage of any kind including personal injury or death, or economic loss arising from the use of the digital map files or accompanying written materials or from errors, deficiencies, or faults therein, whether such damage is caused by negligence or otherwise.

5. **Costs:** None

Class IV. Data structural descriptors

A. Data set file

1. **Identity:** DataS1.zip contains the shapefile NBHistoricPesticideAreas.shp which delineates application areas and annual data (Table 5). The associated insecticide applications data is found in NBHistoricPesticideApplications.csv, which contains application rates and applied active ingredients (Table 6). Records in NBHistoricPesticideApplications.csv can be linked to the shapefile using the unique app_area ID field.

   Data can also be accessed on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) as the "Digitized Pest Management Records" in the forestry section.
2. **Size:** 10 files, 18Mb
3. **Format and storage mode:**

   Shapefile: NBHistoricPesticideAreas.shp is in

   Projected Coordinate System NAD_1983_CSRS_New_Brunswick_Stereographic plus a Comma Separated Values (csv) file: NBHistoricPesticideApplications.csv.
4. **Header information:** The shapefile NBHistoricPesticideAreas.shp attribute table's first row contains the column headers, see Table 5 for field definitions. The associated file NBHistoricPesticideApplications.csv table's first row contains column headers, see Table 6 for field definitions.
5. **Alphanumeric attributes:** None
6. **Special characters/fields:** None
7. **Authentication procedures:** None

B. Variable information

1. **Variable identity:** See Tables 5 and 6, Field Name, for the descriptor of each field of information in the data set.
2. **Variable definition:** See Tables 5 and 6, Identity, for the definition of each field name in the data set.
3. **Units of measurement:** See Tables 5 and 6, under Field Name, the units of measure for each field in the data set are stated. The definition under Identity describes the measurement units in more detail.
4. **Data type:**

   a. Storage type: Differs among variables, See Data Type in Tables 5 and 6, for field characterization.

   b. *List and definition of variable codes:* None

   c. *Range for numeric values:* See Table 7. Active Ingredient Application Ranges.

   d. *Missing value codes:* Null values in file NBHistoricPesticideAreas.shp do not occur in the software generated or mandatory fields FID, Shape, Shape_Leng and Shape_Area, or in specific fields associated with the existence of the polygon, app_area (unique ID), num_apps (number of applications for the designated area), year (application year), and reference (documents used to verify the record data). Null values can be found in the data fields block_ (including all the block fields). In the file NBHistoricPesticideApplications.csv, unknown values can be found in rate_kgha (application rate of the active ingredient), vol_lha (volume of active ingredient applied), form_type (mixed solution media) and brand (active ingredient brand name). Unknown values are identified as -9999 or “unknown” in numeric or character fields, respectively. If a value has been designated unknown, it could not be identified and/or verified in reference literature.

e. *Precision:* Precision on numeric fields is consistent with historical records, active ingredient application rates in kilograms per hectare (billion international units per hectare for BTK applications) or application volume in liters per hectare, two decimal places. Values were converted from pounds or acres applied to kilograms and hectares as needed. Calculated values, tank_mix, were maintained to five decimal places.

f. *Data format:* Shapefile and comma separated value (csv) file.

g. *Fixed, variable length:* Not Applicable

h. *Columns:* There are 18 columns (fields) and 4,545 rows (records) in the data file NBHistoricPesticideAreas.shp attribute table. The associated application data table, NBHistoricPesticideApplications.csv, contains 10 columns (fields) and 7205 rows (records).

i. *Data anomalies:* Overall, there is a consistent error associated with the drawing of application area boundaries that arise from the original drawing of the polygons and the digitization procedure. The physical maps were drawn by hand at a scale of 1:250,000 or 1:50,000 leading to error associated with accurately placing planned or actual application boundaries on a paper map. This practice also made showing buffer zones very difficult, especially smaller residential properties and water bodies. As a result, buffers were generally not shown on maps unless they are large, such as a lake or large municipal boundary (see Figure 2). The ‘drawing error’ is the largest source of error in application area, and in some cases can be significant.

Error in application area boundaries also occurred when the application area boundary polygons were traced from paper maps by hand using a large format digitizing table (see section II B 3 Research Methods). We compared the location of application area boundaries drawn in database 1.0 with those interpreted and drawn in database 2.0. Typically, the two digitally interpreted and drawn boundaries differed as little as 1 m and up to 800 m. Some varied to as much as 1.2 km. These differences were expected based on the map scale being interpreted for digitization.

Research trials on insecticides were tested at in-situ plots as new products became available. Often mixes, concentrations, and emulsifiers were investigated for effectiveness of controlling adult and larval populations and preventing defoliation. Most of the experimental data are listed in Armstrong and Cook (1993) and many are reflected in the database 3.0. However, we could not verify all the research or experimental applications with both mapping and reports. An unknown, but likely small, amount of the research applications are not found in database 3.0.

In all years, buffers during aerial treatments were placed on major waterbodies, residential areas, and dwellings. Most buffers have not been removed from the application areas in the data set. Application areas cross many streams, rivers, waterbodies, and include dwellings. Their inclusion as part of an application area does not mean the insecticide was applied to these features. Adhering to set buffers during aerial application was a function of aircraft guidance system, aircraft size, aircraft spray application height, and spray drift factors like weather and boom type. In addition, the number and location of individual dwellings changed over time making it impossible to track and include all used and recognized buffers in this data set. As stated in section II B 3 e, permitted buffer zones on NB recognized wetlands and watercourses were not regulated until 1990.

The following is a list of known data anomalies for each year of application contained in database 3.0.

1969

An internal federal report (Kettela, 1969) identifies that Zectran (Mexacarbate) and DDT applications occurred. The location of the application areas could not be found, and the data does not appear in database 3.0.

1980

Federal memos from 1980 identify treatments and application areas that are not included in the database, maps showing applications around Fredericton area, and memos indicating a Reldan (Chlorpyrifos) treatment near Chipman. We could not find complete data for these treatments and they are not included in database 3.0.

Class V. Supplemental descriptors

A. Data acquisition

1. **Data forms or acquisition methods:** Not applicable
2. **Location of completed data forms:** Not applicable

3. **Data entry verification procedures:** See section II B 3a for more information on data verification measures.

B. **Quality assurance/quality control procedures:** See section II B 3 for more information on data quality and control measures.

C. **Related materials:** Access to scanned copies of the original paper mapping (map_nam) can be provided by contacting the corresponding author or contact persons.

D. **Computer programs and data-processing algorithms:** Not applicable

E. **Archiving**

1. **Archival procedures:** The data set is permanently stored as supplemental material pertaining to this paper. Data are also permanently stored on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) as the “Digitized Pest Management Records” in the forestry section(Government of New Brunswick 2023). Updates to the data set will only be provided at the GIS Open Data Page. It is recommended that data be downloaded from the GIS Open Data Page to ensure the most up to data are used.

2. **Redundant archival sites:** That database was copied from one computer to another using standard procedures.

F. **Publications and results**: Not applicable.

G. **History of data set usage.**

1. **Data request history:**

No history to date.

2. **Data set update history:** All future updates will be posted on the New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) as the "Digitized Pest Management Records" in the forestry section (Government of New Brunswick 2023). It is recommended that data be downloaded from the GIS Open Data Page to ensure the most up to data are used.
3. **Review history:** The data set will undergo periodic revision as more information becomes available or errors are found. The current database will be maintained in New Brunswick Department of Natural Resources and Energy Development – GIS Open Data Page (https://www2.gnb.ca/content/gnb/en/departments/erd/open-data/data_download.html) as the "Digitized Pest Management Records" in the forestry section (Government of New Brunswick 2023).
4. **Questions and comments from secondary users:** None.

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Tables Section

Table 1: Database and search terms to retrieve annual forum and meeting minutes and agreements.

Item	Database and Website	Keywords	Search Settings
Interdepartmental Committee on Forest Spraying Operations (1958-1972)	Canadian Forest Service https://cfs.nrcan.gc.ca/publications/search?q=test&format=citation	"meeting of interdepartmental committee of forest spraying"	Enter keywords in keywords; check Boolean AND
Forest Pest Control Forum (1973-1993)	Canadian Forest Service https://cfs.nrcan.gc.ca/publications/search?q=test&format=citation	"forest pest control forum"	Enter keywords in keywords; check Boolean AND
Regional Economic Expansion Agreement 1975-1983	Library and archives Canada https://library-archives.canada.ca/eng	"Subsidiary Agreement Canada/New Brunswick Forestry"	Enter keywords in search box; choose year of interest
Canada/New Brunswick Forest renewal Agreement 1984-1989	Library and archives Canada https://library-archives.canada.ca/eng	"Subsidiary Agreement Canada/New Brunswick Forestry"	Enter keywords in search box; choose year of interest

Table 2: Insecticides applied to New Brunswick forests for the control of eastern spruce budworm from 1952-1993.

Active Ingredient	Class	Years Applied	Total Cumulative Area (ha)	Soil Half Life (days)	Water Solubility (mg/l)	Sorption Coefficient (Koc)	Octanol-water coefficient
Dichlorodiphenyl trichloroethane	Organo-chloride	1952-1968	11,811,103	2,000[ab]	0.0055[ab]	2,000,000[a]	8.13×10^{6}[b]
Phosphamidon	Organo-phosphate	1963-1977	3,362,620	9.2[b]	1,000,000[ab]	33[b]	6.24×10^{0}[b]
Dimethoate	Organo-phosphate	1965	6,958	7[a] 2.5[b]	39,800[a] 25,900[b]	20[a]	5.62×10^{0}[b]
Malathion	Organo-phosphate	1965	25,169	1[a] 0.17[b]	130[a] 148[b]	1,800[ab]	5.62×10^{0}[b]
Fenitrothion	Organo-phosphate	1966-1993	27,338,435	4[a] 2.7[b]	30[a] 19[b]	2,000[ab]	2.09×10^{3}[b]
Methomyl	Carbamate	1970	1,466	30[a] 7[b]	58,000[a] 55,000[b]	72[ab]	1.23×10^{0}[b]
Aminocarb	Carbamate	1970-1987	4.866,103	6[ab]	915[ab]	100[ab]	7.94×10^{1}[b]
Pyrethrin	Carbamate	1970, 1973	396	2[b]	0.3[b]	100,000	7.94×10^{5}[b]
Mexacarbate	Carbamate	1971	9,653	10[ab]	100[ab]	300[ab]	3.63×10^{2}[b]
Methoprene		1973	709	10[b]	0.52[b]	2535[b]	1.00×10^{5}[b]
Trichlorfon	Organo-phosphate	1973-1977	357,658	10[a] 18[b]	120,000[ab]	10[ab]	2.69×10^{0}[b]
Bacillus thuringiensis kurstaki	Biopesticide	1975-1993	1,095,086				

[a]National Pesticide Information Centre (Vogue et al. 1994)
[b]Pesticide Properties Database (Lewis et al. 2016)

Table 3: Catchment area and cumulative percent of the watershed treated with pesticides during the spray program from 1952 to 1993 in New Brunswick, Canada. Only watersheds greater than 100,000 hectares shown.

Watershed	Catchment Area (ha)	Percent Treated
Southwest Miramichi River	776,970	100
Tobique River	433,133	99
Jemseg River	394,993	91
Northwest Miramichi River	387,397	100
Upsalquitch River	235,819	99
Washademoak Creek	216,348	95
Kennebecasis River	214,566	77
Oromocto River	202,251	95
Magaguadavic River	187,116	85
Nashwaak River	170,599	100
Miramichi Bay	166,397	51
Little Main Restigouche River	158,226	91
Big Tracadie /Pokemouche	139,024	23
Richibucto River	134,828	82
Cape Tormentine Peninsula	132,840	34
Kedgwick River	127,387	100
Baie de Caraquet	117,968	49
Green River	107,450	95

Table 4: Average cumulative application rates of the seven pesticide active ingredients applied to more than one watershed as part of the aerial spray program from 1952 to 1993 in New Brunswick, Canada. Only watersheds greater than 100,000 hectares shown.

Watershed	Aminocarb (kg/ha)	BTK (BIU[a]/ha)	DDT (kg/ha)	Dimethoate (kg/ha)	Fenitrothion (kg/ha)	Phosphamidon (kg/ha)	Trichlorfon (kg/ha)
Southwest Miramichi River	0.1753	4.2649	2.3551	0.0004	2.3988	0.2503	0.0001
Tobique River	0.1772	3.0558	0.7830		0.7818	0.1327	
Jemseg River	0.0488	4.5627	0.4400	0.0051	0.7573	0.0516	0.0018
Northwest Miramichi River	0.1285	8.5771	0.6887	0.0095	1.3383	0.0602	
Upsalquitch River	0.1005	7.7504	0.4088		0.4952	0.0171	
Washademoak Creek	0.0225	2.6284	0.0488		0.3174	0.0190	0.0307
Kennebecasis River	0.0004	0.0407			0.1951	0.0075	0.0310
Oromocto River	0.0165	1.9295	0.0171		0.3099	0.0106	0.0024
Magaguadavic River	0.0151	0.9551	0.0076		0.2177	0.0106	0.1022
Nashwaak River	0.0259	2.9084	0.5790		0.5438	0.0553	0.0067
Miramichi Bay	0.0021	0.0644	0.0291		0.0644	0.0032	
Little Main Restigouche River	0.0296	0.9507	0.2685		0.1737	0.0218	
Big Tracadie /Pokemouche	0.0033	0.0397	0.0185		0.0272	0.0049	
Richibucto River	0.0021	1.6593	0.0564		0.1016	0.0005	
Cape Tormentine Peninsula	0.0028	1.3764			0.0437		
Kedgwick River	0.0533	0.2623	0.2324		0.4063	0.0013	
Baie de Caraquet	0.0082	0.0513	0.0479		0.0480	0.0095	
Green River	0.0484	0.2255	0.1021		0.1814	0.0030	

[a] BIU = Billion International Units.

Table 5: Definitions of fields included in the attribute table of “NBHistoricPesticideAreas.shp”.

Field Name	Definition	Data Type
FID	Software generated feature identifier number.	Numeric
Shape	Software generated feature shape – polygon.	Character
app_area	A unique identifier for each application area in each year in the format YYYY_AAA. YYYY is the year and AAA is a sequential number within the year.	Character
num_apps	Number of pesticide applications to the application area.	Integer
block_1	First block name (if assigned) assigned to the application area. Often block identification was for experimental reason.	Character
block_2	Second block name (if assigned) assigned to the application area. Often block identification was for experimental reason.	Character
block_3	Third block name (if assigned) assigned to the application area. Often block identification was for experimental reason.	Character
block_4	Fourth block name (if assigned) assigned to the application area. Often block identification was for experimental reason.	Character
year	Year of the application(s).	Numeric
province	Province of the applications	Character
map_nam	Paper map (now digital form) from which the application area was delineated.	Character
app_type	Indicates whether application area was part of operational treatments or experimental treatments.	Character
aircraft	A list of aircraft used to apply treatments to the application area during the identified year.	Character
guidance	The type of guidance system used by aircraft	Character
app_sys	The pesticide application system used on the aircraft	Character
reference	Reference numbers identifying sources used to populate database values. See “References Historic Pesticide Database.pdf”.	Character
Shape_Leng	Software generated feature length in meters.	Numeric
Shape_Area	Software generated feature area in square meters.	Numeric

Table 6: Definitions of fields included in "NBHistoricPesticideApplications.csv" which lists pesticide applications made to each of the application areas.

Field Name	Definition	Data Type
app_id	A unique identifier for each pesticide application in the format YYYY_AAA_B. YYYY is the year, AAA is a sequential number indicating the individual application area each year, and B is a sequential number indicating the application number to the application area	Character
app_area	A unique identifier for each application area in each year in the format YYYY_AAA. YYYY is the year and AAA is a sequential number indicating the individual application area each year	Character
year	The year the application occurred	Integer
insect	Abbreviated name of the insect being targeted with treatment.	Character
act_ing	Active ingredient of the insecticide applied.	Character
rate_kgha	The treatment rate in kilograms per hectare of the active ingredient. For BTK the units are billion international units per hectare. Value was often calculated or converted from source information.	Numeric
vol_lha	The volume in liters per hectare of the treatment applied to the application area. Value was calculated or converted from identified source information.	Numeric
form_type	The formation type or mix solution media.	Character
tank_mix	The treatment concentrated tank mix loaded into the aircraft for application. Calculated as rate_kgha / vol_lha	Numeric
brand	The commercial product or brand name of the pesticide applied.	Character

Table 7: Range in application rates for active ingredients applied as part of the aerial spray program from 1952 to 1993 in New Brunswick, Canada.

Active Ingredient	Minimum Application Rate (kg/ha)[a]	Maximum Application Rate (kg/ha)[a]	Minimum Volume (l/ha)	Maximum Volume (l/ha)
Aminocarb	0.04	0.11	0.44	1.46
BTK	0.21	45.00	0.44	9.35
DDT	0.11	1.12	1.87	9.34
Dimethoate	1.12	1.12	unknown	unknown
Fenitrothion	0.07	0.56	0.44	4.68
Malathion	1.12	1.12	0.75	0.75
Methoprene	0.07	0.14	4.68	4.68
Methomyl	0.06	0.06	1.40	1.41
Mexacarbate	0.04	0.02	1.40	1.40
Phosphamidon	0.04	0.56	0.73	7.48
Pyrethrin	0.02	0.02	1.40	1.40
Trichlorfon	0.14	1.12	1.17	4.67

[a] Units for BTK are BIU/ha.