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The emergence of research specialties in economic entomology in Canadian government laboratories after World War II

MISSION-ORIENTED GOVERNMENT laboratories employ an important share of a nation's scientific resources, human and material. Yet, their direct contribution to technoscientific development is rarely considered; the necessity to resolve pressing technical problems with certified knowledge does not appear conducive to innovative research. In the now widely discredited linear model of technological development,[1] research in government laboratories may be caricatured as the application of fundamental science from university laboratories. In the U.S. and in Canada, the federal government initially limited their support of scientific activities to data collection, surveys, and metrological activities.[2] The technical staffs of

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The following abbreviations are used: CFS, Canadian Forestry Service; CPPA, Canadian Pulp and Paper Association; *CJR, Canadian journal of research*, CSC, Civil Service Commission; CWSD, Directorate of Chemical Warfare and Smoke; DADM, Department of Agriculture, Deputy Minister's Office (Central Registry and indexes, 1918-1953); DAPM, Department of Agriculture, Prime Minister's Office (General Correspondence, 1936-1951); DAWB, Department of Agriculture. Production and Marketing Branch (War Boards and War Administrators, 1939-1952); DARB, Department of Agriculture, Research Branch; DDCWSD, Department of Defense; Chemical Warfare and Smoke Directorate; DDDRB, Department of Defense, Defense Research Board; FICB, Forest Insects Control Board; *FIIBPR*, *Forest insect investigations bi-monthly progress report*; NAC, National Archives of Canada; NRC, National Research Council of Canada.

1. Michael Gibbons, et al., *The new production of knowledge. The dynamics of science and research in contemporary societies* (Beverly Hills, 1994).
2. A. Hunter Dupree, *Science in the federal government. A history of policies and activities* (Baltimore, 1986); Vittorio M.G. de Vecchi, "Science and government in 19th-century Canada" (Ph.D. dissertation, University of Toronto, 1978).

HSPS, Volume 32, Part 1, pages 19-40. ISSN 0890-9997.

government laboratories, both state and federal, rarely extended their work beyond routine analysis and information gathering.[3] Patronage in the civil service led to the nomination of professionals valued for their partisanship rather than for their scientific qualifications.[4] For these reasons, governmental research appeared inferior to and dependent on university research. Nevertheless, government laboratories became an appropriate space for the production of fundamental knowledge and the training of researchers.

This paper examines the conditions underlying these two contributions of government laboratories in Canada in the field of economic entomology—the science of insect control in agriculture and forestry.[5] Between 1940 and 1960, the Entomology Division of the federal Department of Agriculture stopped assisting foresters and farmers in the field in order to devote itself more fully to research activities. Rather than seeking only to select appropriate control methods, entomologists investigated outbreak causes and the mode of action of control methods. They enjoyed enough autonomy to define a research agenda that met their interests as well as the demands of the Department of Agriculture and its patrons.[6]

Three case studies inform this paper. Each is organized around a research specialty—insect pathology, insect toxicology, and population ecology—and a corresponding control method. By introducing new approaches in insect physiology and ecology, Canadian entomologists shaped these research specialties and concurrently contributed to the application of microbial insecticides, the design of chemical insecticides, and the implementation of integrated pest management.

3. Charles E. Rosenberg, *No other God. On science and American social thought* (Baltimore, 1978); Allan I. Marcus, *Agricultural science and the quest for legitimacy. Farmers, agricultural colleges, and experiment stations, 1870-1890* (Ames, 1985); Margaret W. Rossiter, *The emergence of agricultural science: Justus Liebig and the Americans, 1840-1880* (New Haven, 1975).
4. Stephen Skowronek, *Building a new American state: The expansion of national administrative capacities 1877-1929* (Cambridge, 1982); Brian Balogh, "Reorganizing the organizational synthesis: Federal-professional relations in modern America," *Studies in American political development, 5* (1991), 177-172; John Edwin Hodgetts, et al., *The biography of an institution. The Civil Service Commission of Canada, 1908-1967* (Montreal, 1972); Vecchi (ref. 2).
5. Robert Glen, ed., "Entomology in Canada up to 1956. A review of developments and accomplishments," *Canadian entomologist, 88* (1956), 290-371; Paul W. Riegert, *From arsenic to DDT: A history of entomology in Western Canada* (Toronto, 1980); Paolo S. Palladino, *Entomology, ecology and agriculture. The making of scientific careers in North America, 1885-1985* (Amsterdam, 1996); Arthur Gibson, *Entomology in Canada, with special reference to development within the Department of Agriculture*, manuscript available at the Entomology Library of Canada Agriculture, in Ottawa.
6. Heather Johnston Nicholson, "Autonomy and accountability of basic research," *Minerva, 15* (1977), 32-61; John R. Sutton, "Organizational autonomy and professional norms in science: A case study of the Lawrence Livermore Laboratory," *Social studies of science, 14* (1984), 197-224; Bruce E. Seely, "The scientific mystique in engineering: Highway re-

1. INSECT PATHOLOGY

When the federal Department of Agriculture first launched a research project to control insect pests with pathogenic microorganisms, insect pathology was a research specialty that had not yet proved its worth.[7] Despite advances in understanding diseases of beneficial insects in apiculture and sericulture, microbial control trials in America and in Europe had proved useless. Difficulties involved in propagating pure cultures of pathogenic organisms and insufficient knowledge about the maintenance of disease pathogenicity in the field forced many entomologists to abandon this mode of insect control.[8]

At the end of the 1930s, the rapid decline of two important outbreaks reawakened the interest of American and Canadian entomologists in the microbial control method.[9] In the United States, the artificial spread of a bacterial disease caused a marked reduction of an outbreak that had lasted for more than twenty years. Entomologists from the U.S. Department of Agriculture identified, cultivated, and distributed a bacterium—*Bacillus popilliae*—responsible for the milky disease of the Japanese beetle (*Popillia japonica* Newm.).[10] The Division of Beneficial Insect Investigations of the University of California, Berkeley, soon added microbial control to its research agenda. Its director, H.S. Smith, recruited entomologist and bacteriologist Edward Steinhaus and asked him to set up and head the Laboratory of Insect Pathology in his division, one of the world's leading biological control centers.[11] There, Steinhaus gave the first regular course in insect pathology, trained many entomologists, and published *Principles of insect pathology*, a textbook that remained influential for the next three decades.[12]

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search at the Bureau of Public Roads, 1918-1940," *Technology and culture, 25* (1984), 309-342; Chandra Mukerji, *A fragile power. Scientists and the state* (Princeton, 1989), 85-104; Ronald Rainger, "Science at the crossroads: The Navy, Bikini Atoll, and American oceanography in the 1940s," *HSPS, 30:2* (2000), 349-371. Autonomy can also be explored in terms of a dual contribution of mission-oriented research to basic and applied sciences. See Donald E. Stokes, *Pasteur's quadrant. Basic science and technological innovation* (Washington, 1997).

7. Edward Arthur Steinhaus, "Insect pathology: The field concerned, training required, and opportunities defined," *Canadian entomologist, 81* (1949), 53-57; E.A. Steinhaus, "Microbial control. The emergence of an idea," *Hilgardia, 26* (1956), 107-160.

8. James William MacBain Cameron, "Insect pathology," in Ray F. Smith, Thomas E. Mittler, and Carroll N. Smith, eds., *History of entomology* (Palo Alto, 1973), 285-298.

9. Edward A. Steinhaus, "Insect pathology and biological control," *Journal of economic entomology, 38* (1945), 591-596.

10. R.T. White and P.J. McCabe, "Colonization of the organism causing milky disease of the Japanese beetle larvae, 1939-1949," *USDA-BEPQ, E- 819* (Washington, 1951); Edward A. Steinhaus, *Principles of insect pathology* (New York, 1949), 675.

11. Richard C. Sawyer, *To make a spotless orange. Biological control in California* (Ames, 1996), 165-166.

12. Alfred Briggs Baird, "Biological control of the spruce sawfly *Diprion polytomum* Hartig," *European Spruce Sawfly Conference*. Belleville, 20 Nov 1936; "Preliminary statement re

In Canada, a virus disease ended the outbreak of the European spruce sawfly (*Gilpinia hercyniae* Htg.), which had devastated the forests of Quebec and New Brunswick throughout the 1930s.[13] The outbreak inflicted severe losses to the Canadian pulp and paper industry which responded by supporting the biological control work of the federal entomological service. It financed the importation and multiplication of parasitic and predaceous insects and the hiring of field entomologists to release these natural enemies.[14] Impressed by the sharpness of the decline—it occurred in less than four years (1938-1941)—forest entomologists from the Canadian Department of Agriculture began studying the disease and its role in subduing the outbreak.[15]

Insect pathology in Canada took off just before the end of World War II when the Forest Insects Unit of the Entomology Division received resources to develop it. The availability of resources resulted from a combination of ecological, economic, and political factors stimulated by wartime conditions. During the war, the forest industry and the pulp and paper industry pressed the federal government to increase its financial contribution and its involvement in forest protection and conservation.[16] Besides the European spruce sawfly, which remained the principal target of the Forest Insects Unit, the spruce budworm (*Choristoneura fumiferana* Clem.) had initiated another destructive cycle in Manitoba and was moving eastward.[17] To appease the industry, the federal government created the Forest Insects Control Board in September 1945.

Composed of representatives from industry, federal and provincial governments, and the Federal Department of Agriculture, the Board coordinated and fi-

spruce sawfly parasite work. Season of 1937," A.B. Baird to James Malcolm Swaine, 29 Sep 1937, RG-17, DADM, vol. 3047, file 40-6(1), NAC; Blair Malcom McGugan and Harry Charles Coppel, "Biological control of forest insects, 1910-1958," Commonwealth Institute of Biological Control, *Technical communication, 2* (1962), 90-109.

13. Reginald Ernest Balch and Frederick Theodore Bird, "A disease of the European spruce sawfly, *Gilpinia hercyniae* (Htg.), and its place in natural control," *Scientific agriculture, 25* (1944), 65-80.

14. Stéphane Castonguay, "L'Institut de Belleville. Expansion et déclin de la recherche sur le contrôle biologique au Canada, 1909-1972," *Scientia canadensis, 22-23* (1999), 51-100.

15. *Division of entomology news letter, 22* (Aug-Sep 1941).

16. "Recommendations of the Executive Council of the Woodlands Section regarding the provision of funds for the collection of spruce sawfly cocoons," 26 Mar 1941; "Necessity for immediate action by Dominion Government," F.G. Robinson [President of the CPPA] to G.S.H. Barton [Deputy minister of Agriculture], 25 Apr 1941; F.G. Robinson to George Samuel Horace Barton, 26 June 1942, RG-39, CFS, vol. 462, file 49434, NAC.

17. "Preliminary report on the spruce budworm outbreak in Ontario, 1941," by Carl Edmund Atwood and David E. Gray, RG-39, CFS, vol. 261, file 3487-6, NAC. The CPPA established a committee dedicated to the spruce budworm in 1944. "Minutes of meeting of Spruce Budworm Committee, 21 Sep 1944," RG-39, CFS, vol. 203, file 50085, NAC. The last outbreak of the spruce budworm spread over the provinces of Ontario, Quebec, and New Brunswick between 1909 and 1923. James Malcolm Swaine, Frank Cooper Craighead, and Irving Widmer Bailey, "Studies on the spruce budworm, *Cacoecia fumiferana* Clem.," *En-*

nanced scientific and practical activities in the fight against the spruce budworm. Ready to devote as many resources as necessary to combat the outbreak, the board resolved at its first meeting that "we should leave no stone unturned to meet the situation no matter how costly it should be to turn that stone."[18] The forest industry had hoped to stop the outbreak with DDT, the new organic synthetic insecticide, but two years of experimentation by Canadian and American entomologists showed spraying it from the air could not control an outbreak over a large territory.[19] Pathogenic organisms became the next important stone to turn. Major General Kennedy, the chairman of the Board and president of the very influential Canadian Pulp and Paper Association, stated: "It is extremely important that any possibility of using diseases against the spruce budworm be thoroughly investigated and although no promise of success of any kind can be held out for this investigation, its possibilities are such as to command very special attention."[20]

John J. de Gryse, chief of the Forest Insects Unit, laid out a program of work for developing insect pathology in Canada. His program underscored the central role of fundamental research in the development of efficient control methods. At the first meeting of the Forest Insects Control Board, de Gryse declared his faith. "The use of unscientific methods cannot be justified in the present day and can only lead to a waste of time and money. This point is not sufficiently realized by the majority of people who are anxious to deal summarily with insect infestations by treating them in a haphazard manner, following principles which are entirely outmoded and utterly ineffective."[21]

The Forest Insects Control Board readily agreed to finance the program of work defined by De Gryse. First, it funded the construction of a laboratory entirely dedicated to the study and propagation of pathogenic organisms for insect control. Second, it authorized a search for an organism lethally specific to the spruce budworm insect. When domestic surveys failed to locate such an organism, two Canadian entomologists left for Europe where German and Czechoslovakian entomological services collaborated in the identification and collection of natural enemies of *Choristoneura murinana* and *C. histrionana*, two species closely related to the spruce budworm (*C. fumiferana*).[22] In the same year, 1946, the federal government provided the Department of Agriculture with $150,000 to construct an insect pathology laboratory at Sault Sainte Marie in Ontario.[23] The Entomology Division

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tomological branch bulletin, 25 (1924).

18. "Forest Insects Control Board. Minutes of the first meeting," 1 Nov 1945, RG-39, CFS, vol. 205, 50193A-1, NAC.

19. "Memorandum re: biological control," J.J. de Gryse, 15 Jan 1946, RG-17, DADM, vol. 3125, file 64-5-2, NAC.

20. Ref. 18.

21. Ibid.

22. "European insect disease investigations," Kenneth William Neatby to George Samuel Horace Barton, 6 Nov 1946, RG-17, DAMO, vol. 2876, file 12-6-10, NAC.

23. James Gardiner [Minister of Agriculture] to the secretary of the Treasury Board, 7 Mar

had recently established its headquarters there in its Forest Insects Laboratory.[24]

Among the entomologists transferred to Sault Sainte Marie, James Cameron and Kenneth Graham were responsible for the initial studies in insect pathology. Both had recently completed their doctoral degrees, respectively at Macdonald College and at the University of Toronto, in physical ecology and toxicology.[25] Cameron had spent the war years on a biological warfare project at the Bacteriology Department of Queen's University, using the housefly and Drosophila as insect carriers of human diseases (botulism, diphtheria).[26] Because of his knowledge of the physical requirements of experiments on the relationship between insects and microorganisms, he was asked to plan the construction of the laboratory and devise its scientific equipment.[27] Graham took charge of defining the research agenda in insect pathology. His multi-faceted program ranged from the discovery and isolation of pathogenic microorganisms to the dissemination of the most promising pathogens over large scale infestations.[28]

The lack of specialized workers hampered experimental studies on entomopathogenous viruses and forced Graham to limit his ambitious plan to the survey of microorganisms and the identification of pathogens most virulent to the budworm.[29] Facing these shortcomings, the Forest Insects Unit sought to rapidly assemble a research team in insect virology. It hired graduates in histopathology and in biochemistry to assist Graham, it brought Frederick Theodore Bird, who had worked on the virus responsible for the decline of the European spruce sawfly, and was completing a doctoral dissertation on the pathogenecity of the virus at McGill University;[30] it appointed Gernot Hildebrand Bergold, a German entomolo-

1946, RG-17, DAMO, vol. 3046, file 40-5-70, NAC.

24. Major General Kennedy to Roy Cameron [Coordinator, Resources Developments, Department of Reconstruction and Supply], 1 Oct 1946; Kennedy to J.J. de Gryse, 2 Apr 1947 and to Roy Cameron, 21 Jul 1948, RG-36, FICB, vol. 3, file 286-12-1, NAC.

25. James William MacBain Cameron, "The reaction of the housefly, *Musca domestica* (L.) to light of different wavelenght" (Ph.D. dissertation, McGill University, 1938); Kenneth Graham, "Respiratory mechanisms and inhibitor action in tissues of codling moth larvae" (Ph.D. dissertation, University of Toronto, 1945).

26. Alfred Briggs Baird to Henry Gordon Crawford, 23 Mar 1945, RG-17, DARB, vol. 335, file 170.1/250 pt. 1, NAC; John Bryden, *Deadly allies. Canada's secret war 1937-1947* (Toronto, 1989); Donald H. Avery, *The science of war: Canadian scientists and allied military technology during the Second World War* (Toronto, 1998).

27. Joseph John de Gryse to H. G. Crawford, 10 Mar. 1947, RG-32, CSC, vol. 1181, file 1910.10.15.

28. "Minutes of a special meeting of the Forest Insects Control Board and the principal members of the staff of the Forest Insects Laboratory, Sault Ste. Marie. Investigative projects in operation in 1946," 13 Sep 1946, RG-17, DAMO, vol. 3125, file 64-5-2, pt. 1, NAC.

29. Kenneth Graham, "Investigations in insect pathology," *Forest insect investigations bimonthly progress report, 2:3* (1946), 1.

30. "Minutes of the fifth meeting of the Joint Advisory Committee on Forest Entomology and Pathology. Projects proposed under the Forest Insects Laboratory for the season of

gist who participated in the European survey financed by the Board, and had worked on virus diseases of silkworm at the Kaiser Wilhelm Institute in Tübingen.[31]

The government laboratory offered enough flexibility to accommodate entomologists, histologists, biochemists and virologists and thus to accelerate the development of an emerging research specialty. The pulp and paper industry had already financed a university chair on the chemistry of cellulose and a laboratory to work on wood products and improve pulp production. However, these initiatives were directed by university professors whose spheres of influence and activity centered on their own scientific disciplines.[32] For members of the Board, the government laboratory possessed a decided advantage over academic departments and their rigid boundaries.

The laboratory achieved cohesion by focusing on a unique research object. The selection of insect viruses to organize the research in insect pathology also enabled the Forest Insects Unit to satisfy the expectations of the Forest Insects Control Board. After the European spruce sawfly, the decline of an outbreak of the hemlock looper in British Columbia further confirmed the potential of viruses as the most powerful tool for the microbial control of forest insects.[33] Studies on insect viruses then met the demands of the Board members eagerly awaiting for an end to the spruce budworm outbreak.

The Board's demands determined the type of microorganism investigated at the Sault Sainte Marie Laboratory, but not the type of research pursued. Researchers chose their way in studying the composition, physiology, and pathogenecity of viruses. Further, when certain industrial and governmental representatives pressed large-scale control projects, entomologists successfully defended the program of conducting fundamental studies in all aspects of insect pathology first. The chairman of the board endorsed the entomologists' position. During a Board meeting, Kennedy said that he was "entirely in sympathy with the necessity for fundamental work and that the staff of the laboratory need not feel that it would be compelled to undertake wide scale application prematurely."[34]

The Insect Pathology Laboratory further emphasized basic studies after its opening in April 1950. Although the Forest Insects Unit conducted field experi-

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1948," 15 Oct 1947, RG-39, CFS, vol. 657, file 1310.3 [1] , NAC; F.T. Bird, "A virus (Polyhedral) disease of the European spruce sawfly, *Gilpinia hercyniae* (Hartig)" (Ph.D. dissertation, McGill University, 1949).

31. "Visit to Forest Insects Laboratory Sault Ste. Marie, Feb 28-Mar 1, 1949," Robert Glen (coordinator of the Entomology Division) to Kenneth W. Neatby, RG-17, DAMO, vol. 3441, file 4121-11, NAC. For Bergold's background and arrival in Canada, see RG-32, CSC, vol. 1202, file 1911.06.19, NAC.

32. James P. Hull, "From the FPL to PAPRICAN: Science and the pulp and paper industry," History of science and technology in Canada, *Bulletin, 7* (1983), 3-13.

33. Kenneth Graham, "Pathological investigations," *FIIBPR, 3:2* (1947), 3.

34. "Forest Insects Control Board. Minutes of the twenty-seventh meeting," 23-25 Aug 1949, RG-39, CFS, vol. 205, file 50193-3, NAC; G.H. Bergold, "The polyhedral disease of the spruce budworm, *Choristoneura fumiferana* Clem.," *FIIBPR, 5:3* (1949), 2; F.T. Bird,

ments in which entomologists released pathogenic microorganisms in Southern Ontario to combat an outbreak of the European pine sawfly (*Neodiprion sertifer* Geoff.),[35] the principal activities of the laboratory remained the identification of pathogenic organisms and the determination of their mode of action. From the day the laboratory opened, the research agenda encompassed microorganisms other than the virus (bacteria, protozoa and fungi), and host organisms other than spruce budworm (pine sawfly, larch sawfly, Jackpine sawfly).[36]

Lack of researchers for the nacent specialty presented a serious obstacle to diversifying the agenda of the Insect Pathology Laboratory. Strategies to acquire the requisite staff differed according to the microorganism under study. Canadian and foreign universities trained scientists in the different biological sciences that comprised insect virology. Despite a high turnover of researchers in virological studies, the laboratory succeeded in hiring specialists to cover its research program: analyses of the nucleic acids of viruses and the composition of viruses; identification of sequences of viral development; and study of the reproduction cycle of viruses in the insect host and of virus development.[37] To strengthen its work on the characterization and development of viruses, the Insect Pathology Laboratory relied on investigators with research programs underway. For research on non-viral microorganisms, the laboratory modeled its staff and constituted endogenous research specialties. Between 1950 and 1959, researchers recruited at the Sault Sainte Marie Laboratory were enrolled in departments of bacteriology, parasitology, or botany at different Canadian universities to undertake advanced studies and conduct graduate projects.[38] The projects supported the scientific agenda

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"Histopathology and epidemiology," *FIIBPR, 5:3* (1949), 2-3.

35. Frederick Theodore Bird, "The dissemination and propagation of a virus disease affecting the European pine sawfly, *Neodiprion sertifer* (Geoff.)," *FIIBPR, 6:5* (1950), 2-3; F.T. Bird, "The use of a virus disease in the biological control of the European pine sawfly, *Neodiprion sertifer* (Geoff.)," *Canadian entomologist, 85* (1953), 437-446.

36. [James William MacBain Cameron], "The Laboratory of Insect Pathology Sault Ste. Marie, Ontario," *FIIBPR, 6:4* (1950), 2, 5.

37. James William MacBain Cameron, "A survey of investigations on the disease of insects," Entomological Society of Ontario, *Annual report, 82* (1952), 9-10.

38. Arthur MacLeod Heimpel, "The normal bacterial flora and pathogens of the Eastern tent caterpillar (*Malacosoma americanum* Fabr.)" (M.A. thesis, Queen's University, 1949); A.M. Heimpel, "Investigations of the mode of action of strains of *Bacillus cereus* Fr. and Fr. pathogenic for the larch sawfly *Pristiphora erichsonii* Htg." (Ph.D. dissertation, Queen's University, 1954); Thomas Anderson Angus, "The normal aerobic bacterial flora of the Eastern hemlock looper *Lambdina fiscellariaI* Gn." (M.S.A. thesis, Ontario Agricultural College, 1950); Thomas Anderson Angus, "Studies on the toxin of *Bacillus soto* Ishiwata and on its toxicity against certain insects" (Ph.D. dissertation, McGill University, 1955); Hugh MacIntosh Thomson, "Aerobic bacteria associated with the digestive tract of the spruce budworm, *Choristoneura fumiferana* Clem. (Lepidoptera: Tortricidae)" (M.Sc. thesis, McGill University, 1951); H.M. Thomson, "*Perrezia fumiferanae* Thom., a protozoan parasite of the spruce budworm, *Choristoneura fumiferana* (Clem.)" (Ph.D. thesis, McGill

of the laboratory and shaped the development of insect pathology in Canadian universities. If academic departments had taken up the various aspects of insect pathology, none of them individually could have offered the array of approaches related to the field. The Sault Sainte Marie Laboratory had the instruments and experimental data, as well as the collaborators, to tackle research problems and contribute to the development of the different branches of insect pathology.

In the mid-1950s, when the research agenda of the laboratory drifted toward the study of *Bacillus thuringiensis (B.t.)*, insect bacteriologists proved their work.[39] The commercial preparation of *B.t.* had nurtured the expectations of the Forest Insects Control Board. So far, viruses cultivated in the laboratory had been inefficient against the spruce budworm. On the other hand, field tests had shown the effectiveness of *B.t.* against several sorts of insects. *B.t.* reached a central position on the agenda at Sault Sainte Marie where researchers studied the nature of the bacteria and its infection mechanisms in silkworms.[40] They also investigated the mode of action of bacteria (including *B.t.*) on the spruce budworm. Practical concerns continued to guide the development of insect pathology and researchers illustrated their sensitivity to the concerns of the Forest Insects Control Board. When the Forest Insects Unit conducted field trials with *B. t.* against the spruce budworm in the 1960s.[41] The Insect Pathology Unit defined the modalities of the trials. Although insect mortality reached seventy percent, it remained well below the required rate for an effective control program.

During the 1960s, the laboratory achieved an important place in the development of insect pathology worldwide. From the late 1950s onwards, editorial committees of the *Journal of insect pathology* or the *Journal of invertebrate pathology*, as well as the contributors to collective volumes on insect pathology, invariably included Canadian entomologists who had completed their doctoral research at the Sault Sainte Marie Laboratory. Many of them joined foreign institutions—academic or governmental—during the 1960s when the research agencies of the

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University, 1957). Heimpel arrived at the laboratory in 1948, Angus in 1949, and Thomson in 1950.

39. Malcolm Lawrence Prebble, "Review of forest entomology, 1948-1953," Sixth Commonwealth Entomological Conference, *Report* (London, 1954), 207-208; Irvin M. Hall, "Microbial control," in Edward Arthur Steinhaus, ed., *Insect pathology. An advanced treatise* (2 vols., New York, 1963), *2*, 477-515; Thomas Anderson Angus and Arthur MacLeod Heimpel, "The bacteriological control of insects," Entomological Society of Ontario, *Annual report, 90* (1960), 13-21.

40. Arthur MacLeod Heimpel, "Investigations of the mode of action of strains of *Bacillus cereus* Fr. and Fr. pathogenic for the larch sawfly, *Pristiphora erichsonii* (Htg.)," *Canadian journal of zoology, 33* (1953), 311-326; Thomas Anderson Angus and Arthur MacLeod Heimpel, "Recent advances in the knowledge of some bacterial pathogens of insects," in Edward Coulton Becker, ed., Tenth International Congress of Entomology, *Proceedings* (4 vols., Ottawa, 1958), *4*, 711-722.

41. N. Morris, T.A. Angus, and W.A. Smirnoff, "Essais en forêt du *Bacillus thurgiensis*

Canadian government adopted a mission-oriented science policy and drastically discouraged research of a strictly fundamental nature.

2. INSECT TOXICOLOGY

The central role of the Sault Sainte Marie Laboratory in the development of insect pathology resulted from an institutional autonomy. Both the Forest Insects Control Board and the research agency of the Department of Agriculture (named the Science Service) encouraged the autonomy. In an attempt to compensate for the activities of its regional laboratories—oriented toward the resolution of local problems—the Science Service provided certain laboratories with a "national mandate." There, researchers were asked to work on the more "fundamental academic phases of agricultural research in specialized domains."[42]

Within its national laboratories, the Science Service attempted to recruit and retain highly qualified researchers as a means of guarding its sphere of competencies. Otherwise the National Research Council of Canada (NRC) or provincial universities would have acquired the researchers and developed an expertise within the mandates of the federal Department of Agriculture. The rivalry between the Department and other governmental and academic institutions dated back to the establishment of the Experimental Farms System in 1886.[43] It intensified during World War II.

The federal Department of Agriculture had always been responsible for insecticide research in Canada. During and after the war other institutions besides its Entomology Division focused their research on DDT after the discovery of the insecticidal properties of that organic compound.[44] In 1944, the Chemical Warfare and Smoke Directorate (CWSD) established an entomological section in its principal laboratory, the Suffield Experiment Station (Ralston, Alberta).[45] The CWSD hoped to apply its expertise on chemical gas warfare to the aerial spraying of insecticides. An entomologist formerly employed by the Department of Agriculture,

contre la tordeuse des bourgeons de l'épinette, 1960-1973," in Malcolm Lawrence Prebble, ed., *Traitements aériens pour combattre les insectes forestiers au Canada* (Ottawa, 1977), 144-148.

42. "Impressions gained in the course of visits to U. S. research laboratories, 17 Sep-30 Oct 1947," by K.W. Neatby to G.S.H. Barton [n.d.], RG-17, DAMO, vol. 2877, file 12-6-19, NAC.

43. Stéphane Castonguay, "Fédéralisme et centralisation de la recherche agricole au Canada. Dynamique scientifique et écologie institutionnelle," *Bulletin d'histoire politique, 7* (1999), 21-39.

44. John H. Perkins, *Insects, experts, and the insecticide crisis. The quest for new pest management strategies* (New York, 1982); Thomas R. Dunlap, *DDT. Scientists, citizens, and public policy* (Princeton, 1981).

45. E.Ll. Davies [superintendent, Suffield Experimental Station] to Otto Mass [director, CWSD], 20 Dec 1944, RG-24, DDCWSD, file 4354-29-13-2, NAC.

Major Anthony William Alridge Brown, directed the section.[46] Meanwhile, the NRC of Canada provided grants to researchers at McGill University to resolve problems linked to the development of compounds analogous to DDT.[47] For this project, the Department of Chemistry synthesized compounds,[48] the Department of Entomology tested their insecticidal efficiency, and the Department of Genetics conducted the statistical studies.[49] This project reproduced a traditional approach in gas warfare research: the establishment of a correlation between biological activity and the structure of organic molecules. Nevertheless, it represented an innovation in chemical control research, and exceeded the qualifications of the researchers of the Entomology Division, which stayed away from the project.[50]

After the war, the Entomology Division rapidly regained the lead in insecticide studies within military and academic institutions.[51] It sent some of its ento-

46. D.J. Goodspeed, *A history of the Defence Research Board of Canada* (Ottawa, 1958), 148; "Memorandum. Status of DCW & S research and development projects," 1 Sep 1945, RG-24, DDCWSD, file HQS. 4354-29-13, NAC; Experimental Station Suffield, Alberta. *Technical minute no. 111. Toxicity of selected organic compounds to insects*, 25 Nov. 1945, RG-24, DDCWSD, file HQS, 4354-29-4-1, NAC; "Report DDT spraying - Suffield No. 144," 29 Nov. 1945, RG-36, FICB, vol. 3, file 286-13-5 (1945-1946), NAC.
47. C. Leonard Huskins [chair, Department of Genetics, McGill University] to G.S. Peart, 5 Jul 1944, RG-17, DAWB, vol. 3519, file 5-2-19-35 [4] , NAC.
48. Scientists published results from this project in the NRC journal after the war. T.A. Eastwood, D.L. Garmaise, D.J. Morantz and C.A. Winkler, "Studies in the formation of DDT," *CJR, Section B, 25* (1947), 509-524; G.T. Barry and R. Boyer, "The synthesis and biological toxicities of some DDT homologues and related compounds," ibid., 511-517.
49. See the introduction in Maurice Desmond Proverbs, *Studies on the insecticidal action of DDT (1,1, bis (4,4' dichlorophenyl)2,2,2-trichloroethane)and related compounds, with a view to correlating this action with chemical structure* (M.Sc. thesis, McGill University, 1946); Maurice Desmond Proverbs and Frank O. Morrison, "The relative and insecticidal activities of DDT and related organic molecules," *CJR, Section D, 25* (1947), 12-44; H.C. Browning, F.C. Fraser, K. Shapiro, I. Glickman and M. Dubrûlé, "Biological activity of DDT and related compounds," ibid. (1948), 282-300; H.C. Browning, K. Shapiro, and M. Dubrûlé, "The insecticidal activity of DDT and related compounds against different insect species," ibid., 301-306; Frank O. Morrison [professor, Department of Entomology, McGill University] to William Harold Brittain [dean, Faculty of Agriculture, McGill University], 26 Oct 1944, McGill University Archives, RG-43, Dr. Morrison Archives, container 24, file 00911, NAC.
50. American entomologists were also kept away from these developments. The U.S. Office of Scientific Research and Development set up the Insect Control Committee to pursue military research on insecticides after the war. No entomologist participated in the Committee's activities until pressure from the Department of Agriculture and the American Association of Economic Entomologists forced the appointment of an entomologist on the Committee one year after the committee's creation. E.P. Russell, "War on insects: Warfare, insecticides, and environmental changes in the United States, 1870-1945" (Ph.D. dissertation, University of Michigan, 1993), 423-428.
51. Meanwhile, the NRC turned down a grant proposal refused from the Department of Genetics of McGill University to fund a laboratory for studies on the biological effects of insecticides. S.P. Eagleson [secretary-treasurer, NRC] to J.W. Boyes [chair, Department

mologists to the Suffield Experiment Station in 1946 to study the effects of aerial spraying of DDT against field-crop insects in the Prairies.[52] The Entomology Division also financed university researchers to study synthetic insecticides, a research area formerly supervised by the CWSD and the NRC. Projects concerned the relationship between chemical structure and the toxicity of compounds, the influence of the size of the particles on persistence and toxicity, and the synthesis of new compounds.[53] Furthermore, the Entomology Division actively participated in the Entomological Research Panel, an advisory body of the Defense Research Board established in 1947 to coordinate insect control research in universities and at the Suffield Experiment Station.[54] With five of the ten members of the panel originating from their ranks, the Science Service and the Entomology Division possessed an important tool to orient the development of insecticide research in military and academic laboratories.[55]

The Science Service built a laboratory entirely dedicated to research on synthetic pesticides on the campus of the University of Western Ontario. Its chief proponent, William A. Ross, Chief of the Fruit Insects Unit and coordinator of insecticide investigations in the Division, envisioned a laboratory to assess the mode of action and environmental impact of synthetic pesticides and to develop new organic compounds. Ross had supervised the work of regional laboratories on DDT. He deemed it important to go beyond field trials. According to him, too little was known about the toxicity of DDT and its impact on the natural enemies of

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of Genetics, McGill University], 12 Apr 1946; J.W. Boyes to S.P. Eagleson, 15 Apr 1946; S.P. Eagleson to J.W. Boyes, 29 Apr 1949, RG-77, NRC, acc. 1988-89/046, box 11, file 4-D1-9, NAC.

52. H.G. Crawford to K.W. Neatby, 5 Mar 1946, RG-17, DADM, vol. 3050, file 40-37, NAC; Alexander Ross [National Defense, Deputy Minister] to G.S.H. Barton, 17 Dec 1946, RG-17, DADM, vol. 3046, file 40-5-55; H.G. Crawford to G.S.H. Barton, 5 Mar 1947, NAC; H.G. Crawford to K.W. Neatby, 5 Mar 1947; R. Glen to H.G. Crawford, 8 Jul 1947, RG-17, DADM, vol. 3046, file 40-5-86, NAC; Henry Hurtig, "Entomology Section, Suffield Experimental Station, Ralston, Alta.," *Division of entomology news letter, 35* (Jan. 1957), 2-3.

53. Statement on cooperative research grants made to universities from Science Service appropriations for the years 1948-49 and 1949-1950, K.W. Neatby to G.S.H. Barton, 30 Sep 1949, RG-17, DADM, vol. 2877, file 12-6-17, NAC.

54. Memorandum by K.W. Neatby, 5 Mar 1947, RG-17, DADM, vol. 3046, file 40-5-86, NAC; W.E. van Steenburgh, "Entomological research programme," n.d.; K.W. Neatby to George Samuel Horace Barton, 15 Jan 1948, RG-17, DADM, vol. 3132, file 69-7-1. The Defense Research Board was the scientific arm of the Canadian Armed Forces; Goodspeed (ref. 46). The Department of Defense, concerned with biting flies and mosquitoes in the Canadian North, sought to maintain a level of expertise in entomology. Department of National Defence, "Memorandum. Mosquito and black fly control," 7 Jan 1948, RG-24, DDDRB, vol. 4134, file 4-9-35-43-2, pt. 1.

55. Entomological Research Panel. Minutes of the first meeting held on 27 Feb 1948, ANC, RG-24, DDDRB, vol. 4129, file 4-120-43-1, part 1, NAC.

insect pests.[56] Issues related to DDT also concerned fungicides and herbicides, two phytosanitary products that benefitted from developments in organic chemistry during World War II. In 1945, Ross recommended that the Entomology Division construct "a large laboratory well equipped for insecticide studies and in due course adequately staged with capable entomologists, chemists and at least one physicist. This laboratory should be made the headquarters of all our insecticide work and of the biological testing of insecticides. Furthermore, if the Division of Botany is interested, it could also be equipped for the biological testing of fungicides."[57]

Two officials from the Canadian Department of Agriculture, the Dominion Entomologist and the Director of the Science Service, submitted the project to the Minister of Agriculture.[58] Although impressed by the need to conduct research on organic pesticides, the minister could not provide the necessary funding. Meanwhile, Ross proposed to the Chair of the Zoology Department and the Dean of the Medical Faculty at the University of Western Ontario to establish a laboratory of the Department of Agriculture on their campus. In January 1948, the Deputy Minister presented to the Privy Council a petition for the construction of a laboratory of the Science Service on the campus of the University of Western Ontario, in London.[59] The government approved the project but budgetary constraints prevented its immediate fulfillment. While waiting for permission to build, the Science Service started organizing the working of the laboratory.[60]

Ross called before him the chiefs of the Divisions of the Science Service to plan the establishment of the Dominion Pesticide Laboratory.[61] They had to define a research program and select scientists to lead the different sections of the laboratory: entomology, phytopathology, chemistry, microbiology, and fumigation. In entomology, the research program initially remained within the realm of the regional laboratories. It studied "the toxicity of insecticides to a variety of species …; the most effective formulations and concentrations for different purposes;… influence of wetters, stickers, synergists and other adjuvants on toxicity, coverage and persistence."[62]

The director of the Science Service and its assistant showed little interest in this program. It merely reproduced the current agenda of the Entomology Divi-

56. Initially exposed in a report on the first field trials of DDT (W.A. Ross, *Summary of experiments with DDT at Vineland Station, Ontario* (Ottawa, 1944)), these concerns were latter published in the proceedings of the 1948 Commonwealth Entomological Conference of 1948. W.A. Ross, "Use and limitations of the new insecticides in the field," Fifth Commonwealth Entomological Conference, 22-30 Jul 1948, *Report* (London, 1948), 38-44.
57. [Elvin Yuill Spencer], *The beginnings of the London Lab* (London, ON, 1986), 2.
58. Ibid., 6.
59. K.W. Neatby to G.S.H. Barton, 7 Jan 1948, RG-17, DAODM, vol. 3134, file 73-4, NAC.
60. [Spencer] (ref. 57), 6.
61. W.A. Ross, "Letter sent to chiefs of divisions, Science Service," 30 Jan 1947, RG-17, DADM, vol. 2875, file 12-6, part 2, NAC.
62. Quoted in [Spencer] (ref. 57), 11.

sion. Spurred by the ambition to distinguish their organization and attract first-rate scientists, the Science Service representatives wanted to secure new knowledge about "the more basic chemical and physical interactions involved."[63] not "superficial laboratory and field testing." W.E. Steenburgh, assistant to the Science Service Director, emphasized this point when justifying the creation of twenty-two laboratory positions to the Deputy Minister. He stated that the Science Service designed the London Laboratory to establish new research specialties: "It might be pointed out that the research which will be undertaken at this new laboratory is not a consolidation of projects at present in progress in other laboratories but represents instead, fields of study which have been heretofore beyond the resources of Canadian science."[64]

The Division chiefs recognized the limitation of the traditional character of the program. They supported more innovative approaches, such as the investigations of technical and scientific problems raised by the introduction of organic insecticides. Among the topics covered were: "the mode of action of insecticides involving studies on the physiological effects of poisons…; the influence of particle size and shape on toxicity, coverage and persistence; the building up or segregation of resistant of [sic] virile strains of insects by exposure to insecticides;…and [the] relation of chemical structure to toxicity.[65]" The Division chiefs thus demonstrated their awareness of current issues in insect toxicology. Their program encompassed problems investigated by university researchers during the war supported by the Defense Research Board. It also rested on the redefinition of insecticide toxicity in physico-chemical terms. Neither program, however, would be pursued at the London laboratory after its opening in 1951.

The recruitment of a tight-fisted administrator with an international scientific reputation as director would be the key to shaping the London Laboratory. The representatives of the Science Service wanted a director who would have sole charge of hiring researchers and defining their research program. They selected British chemist Hubert Martin, one of the first agricultural scientists to propose a hypothesis on the mode of action of DDT.[66] Although Martin's co-workers at the Long Ashton Agricultural and Horticultural Research Station complained about Martin's authoritarian character, Robert Glen, coordinator of the Entomology Division, considered it an asset. After meeting with Martin, he wrote to van Steenburgh: "I imagined he is very tough minded but it is going to take a man of conviction to safeguard the pressure of industries, field labs, Unit Chief, and the testing and registration service."[67] Martin was given a free hand. He set up an advisory com-

63. Letter sent to chiefs of divisions, Science Service, W.A. Ross (ref. 61).

64. William Elgin van Steenburgh to J.G. Taggart [Deputy Minister of Agriculture], 19 Sep 1950, RG-17, DARB, acc. 1984-85/550, box 186, file 170.1, NAC.

65. [Spencer] (ref. 57), 12.

66. Hubert L. Martin and R.L. Wain, "Insecticidal action of D.D.T.," *Nature*, *154* (1944), 312-313.

67. Robert Glen to W. E. van Steenburgh, 19 Jul 1949, RG-32, CSC, vol. 623, file 1899-06-

mittee to supervise the evolution of the laboratory. No member of the agricultural community or of the Department of Agriculture besides the director of the Science Service had a seat on the committee, which otherwise comprised members of the academic community and the NRC.[68]

Martin made sure that the laboratory had an independent scientific management dependent only on the Science Service Director, but he gave the researchers complete latitude in defining their research projects.[69] The research program in insect toxicology rapidly coalesced around an approach that corresponded to the backgrounds of the researchers of the Entomology Section: Beverly Northcott Smallman, William Chefurka, E.H. Colhoun, and Leonhard Scott Wolfe. Except for the latter, these entomologists had worked in regional laboratories and obtained a doctoral degree in experimental biology abroad.[70] Their approach rested on a biochemical and neurophysiological interpretation of insect toxicology, rather than on a physico-chemical interpretation as proposed by the division chiefs.[71]

As developed at the London laboratory, research in insect toxicology went beyond the morphological stage to investigate vital mechanisms of insects, principally neural transmission and energy metabolism.[72] Human physiology and toxicology provided the principal working hypothesis for explaining the mode of action of organophosphorous insecticides.[73] Since nerve gas acted on the human nervous system by inhibiting the action of the cholinesterase enzyme, entomologists sought to demonstrate the existence of a similar enzymatic system in insects. Work by Smallman, Wolfe, and Colhoun identified acetylcholine and cholinesterase and the inhibition mechanisms of cholinesterase in insects. Studies of the enzymatic system of insects also formed the starting point of research on chlorinated hydro-

24, pt. 2, NAC.

68. Hubert Martin to Kenneth William Neatby, 12 Dec 1950; K.W. Neatby to J.G. Taggart, 13 Dec1950; K.W. Neatby to J. G. Taggart, 12 Apr 1951, RG-17, DARB, acc. 1983-84/064, box 266, file 24-7-19, NAC.

69. [Spencer] (ref. 57), 19.

70. B.N. Smallman, "Quantitative characters of the growth and development of a paurometabolous insect, *Dixippus*, *Carausius*, *Morosus* Br. et Redt." (Ph.D. dissertation, University of Edinburg, 1940); W. Chefurka, "Biochemical studies of the blood of the giant silkworm *Platysamia cecropia* L." (Ph.D. dissertation, Harvard University, 1953); L.S. Wolfe, "Investigations on the structure and deposition of the larval, pupal and imaginal cuticles of *Calliphora erythrocephala* Meigen" (Ph.D. dissertation, University of Cambridge, 1953). E.H. Colhoun, "Cold acclimatisation in insects with especial reference to the German cockroach *Blatella germanica* L." (Ph.D. dissertation, University of Cambridge, 1954).

71. "Science Service Laboratory, London, Ontario. Work in progress," Nov 1951, RG-17, DARB, acc. 1988-89/045, box 1, file 3-12-A.1-61, NAC.

72. Science Service Laboratory. London, Ontario, *Report, 1951-1956* (Ottawa, 1956), 14-16.

73. Robert Lee Metcalf, "The impact of the development of organophosphorus insecticides upon basic and applied science," Entomological Society of America, *Bulletin, 5* (1959), 3-15.

carbon compounds such as DDT.[74] Chefurka investigated the inhibition of glycolytic enzymes responsible for the degradation of carbohydrates and the production of energy in animal metabolism.[75]

By pursuing studies undertaken during their doctoral studies, researchers at the London Laboratory reoriented the development of insect toxicology in Canada. They also inspired graduate students from the University of Western Ontario with their concept of the field. The Board of Governors of the University granted faculty status (honorary professorship and lectureship) to officers of the London Laboratory who gave lectures, organized graduate seminars, and provided bench space to graduate students.[76] Researchers then had the means to recruit students to further the research agenda of the London Laboratory. For example, a graduate student R.D. O'Brien worked under Elvin Yuill Spencer, a former university professor appointed Chief of the Chemistry Section in 1951. At that time, one of his projects dealt with the biochemistry of Schradan—a selective organophosphorous insecticide that only killed aphids. Spencer attributed this specific action to physiological compounds produced by aphids that transformed Schradan into anticholinesterase. The selective toxicity of Schradan became the subject of O'Brien's doctoral dissertation.[77] When he completed his Ph.D., the Chemistry Section created a position in comparative toxicology for him. He began a research program on the synergistic action of organophosphorous compounds.[78]

Eight of the ten new researchers engaged in the 1950s by the London Laboratory were, like O'Brien, graduates of the University of Western Ontario. They received permanent positions in the sections of Chemistry, Entomology and Fumigation.[79] This mechanism of training and recruitment guaranteed researchers tailored to fit the needs of the London Laboratory. While the Science Service and the Defense Research Board financed university laboratories for research on the relationships between the molecular structure and the insecticidal properties of or-

74. This reorientation of research on DDT followed the discovery of the mode of action of organophosphorous compounds on the nervous system. Russell (ref. 50), 435.
75. W. Chefurka, "Oxidative metabolism of carbohydrates. I. Glycolysis in the housefly *Musca domestica*," *Enzymologia, 17* (1954), 73-89; W. Chefurka, "The occurrence of a direct oxidative pathway of carbohydrate metabolism in the fly *Musca domestica*," *Biochemica et biophysica acta*, *17* (1955), 295-296; Science Service Laboratory (ref. 72), 17.
76. "Science Service Laboratory. London, Ontario. Advisory Committee," 1 Dec 1952, RG-17, DARB, acc. 1988-89/045, box 1, file 3-12-A.1-61, NAC; Anthony William Alridge Brown, "Entomology at the University of Western Ontario," *Entomology newsletter, 38:4* (1960), 1-2.
77. Richard Desmond O'Brien, "The biochemistry of Schradan" (Ph.D. dissertation, University of Western Ontario, 1954).
78. Richard Desmond O'Brien and E.Y. Spencer, "Schradan metabolism related to tissue enzyme system," *Agricultural and food chemistry, 1* (1953), 946-953; [Spencer] (ref. 57), 20-21; Science Service Laboratory (ref. 72), 18-20.
79. Pesticide Research Institute, *Research report, 1957-1960* (Ottawa, 1961), 3.

ganic compounds, the London Laboratory served as an entry for an approach based on insect neurophysiology and biochemistry. Because of the laboratory's location on the campus of the University of Western Ontario, it possessed the facilities to create a pool of young scientists for a research agenda in the making.

3. INSECT ECOLOGY, ORCHARD PROTECTION, AND AGRICULTURAL PRACTICES

Research in insect toxicology and pathology took place in laboratories with a national mandate to foster basic research. The directorship of the Science Service considered that any direct links between its researchers and the patrons of the Department of Agriculture constrained scientific autonomy (although, as we have seen, insect pathologists benefitted from their close relationship with the forest industry). Consequently, the Science Service created national laboratories with a different mission from regional laboratories, which addressed problems of local relevance for local patrons. The Annapolis Royal Laboratory (located in Kentville after 1953) in Nova Scotia benefitted from this relationship. With the support of the Nova Scotia Fruit Growers' Association, entomologists there began a research program in insect ecology and in integrated pest management.[80]

After the introduction of synthetic insecticides, the multiplicity of problems related to orchard protection pointed at limitations to chemical control: insects developed resistance to insecticides; parasites and predators disappeared; and the population of insect pests after an initial decline sharply increased. Farmers resorted to an integrated control program whereby phytosanitary treatments avoided inhibiting the activities of the natural enemies of insect pests.

Rachel Carson's *Silent spring* popularized the idea of integrated pest management in environmental and agricultural circles in the 1960s.[81] By then, entomologists at the Kentville Laboratory had published some twenty articles on the ecology of the entomological fauna of orchards and the harmonization of biological and chemical control techniques. Allison D. Pickett, former Director of the Annapolis Royal laboratory, had set up this research program during World War II. Before his appointment in 1939, Pickett had served as provincial entomologist in Nova Scotia. From that experience grew his awareness of the economic hardships facing apple growers of the province during the Depression.[82] Their difficulties in penetrating foreign markets intensified during the war as entomological problems also increased. Multiplication of spraying had driven up production costs while

80. Ref. 5 and Sawyer (ref. 11).

81. Perkins (ref. 44); Paolo S. Palladino, "On 'environmentalism': The origins of the debates over policy for pest-control research in America, 1960-1975," in Michael Shortland, ed., *Science and nature. Essays in the history of the environmental sciences* (Stratford in the Vale, 1994), 181-212.

82. Margaret Conrad, "Apple blossom time in the Annapolis Valley, 1880-1957," *Acadiensis, 9* (1980), 14-36.

not achieving satisfactory control.[83] The Nova Scotia Fruit Growers' Association drew the Entomology Division's attention to these problems and the financial difficulties of its members.[84] In 1944, with the financial support of the Association, Pickett undertook a long-term study of the impact of insecticide spraying on the orchard entomological fauna.[85] Pickett identified several research problems that covered different ecological aspects of orchard protection. Each aspect constituted a separate project investigated by entomologists of the Annapolis Royal laboratory.

Pickett encouraged his entomologists to work in an academic setting as well as at Annapolis. Acting on this encouragement, Frank T. Lord, an entomologist engaged at the laboratory since 1935, undertook a project on the oyster-shell scale, an insect that had established itself as the worst orchard pest in Nova Scotia.[86] Like many of his colleagues, Lord applied the methods and data collected in the experimental orchards of the Annapolis Royal Laboratory to earn a graduate degree.[87] He also contributed to an important series of articles on the consequences of spraying for the fauna of apple orchards in Nova Scotia. These articles covered different aspects of research on integrated pest management—insect pests, parasites and predators, and entomopathogenous diseases.[88]

83. *Division of entomology newsletter, 25:12* (1944). On the beginning of the research program, see A.D. Pickett, "Integrated control," in W.H. Upshall, ed., *History of fruit growing and handling in the United States of America and Canada, 1860-1972* (Kelowna, 1976), 292-295, on 295.
84. J.M. Swaine to G.S.H. Barton, 23 Mar 1945, RG-17, DADM, 3300, file 649 (5), NAC.
85. A.D. Pickett, et al., "The influence of spray programs on the fauna of apple orchards in Nova Scotia: I. An appraisal of the problem and a method of approach," *Scientific agriculture, 26* (1946), 590-600.
86. Frank Tennant Lord, "The influence of spray programs on the fauna of apple orchards in Nova Scotia: II. Oystershell scale *Lepidosaphes ulmi* (L.)," *Canadian entomologist,* 79 (1947), 196-209.
87. Frank Tennant Lord, "The influence of the spray program on the natural control of oystershell scale, *Lepidosaphes ulmi* (L.)" (M Sc. thesis, McGill University, 1947); Harold Thorne Stultz, "Bionomics of the codling moth, *Carpocapsa pomenella* L., in the Annapolis Valley, Nova Scotia" (M.Sc. thesis, McGill University, 1946); Albert William MacPhee, "The morphology and bionomics of the predaceous thrips, *Haplothrips faurei* Hood" (M.Sc. thesis, McGill University, 1947); Albert William MacPhee, "Low temperature mortality of European red mite, *Panonychus ulmi* (Koch), winter eggs and its ecological significance" (Ph.D. dissertation, McGill University, 1960); Charles D. Dondale, "A preliminary study of spiders in apple orchards" (M.S. thesis, Ohio State University, 1955); Charles D. Dondale, "Revision of the genus Philodromus (Araneae: Thomisidae) in North America" (Ph.D. dissertation, McGill University, 1959); Charles Roger MacLellan, "The use of the precipitin test in evaluating codling moth predators" (M.A. thesis, Queen's University, 1954); K.H. Sanford, "The life history and habits of the predacious mirid *Hyaliodes harti* Knight" (M.Sc. thesis, McGill University, 1963). Lord arrived at the laboratory in 1935, Stultz in 1937, MacPhee in 1945, Dondale in 1948, Sanford in 1949, MacLellan in 1950.
88. Allison DeForest Pickett and N.A. Patterson "The influence of spray programs on the

Since these studies centered on projects within the overall research program of the laboratory, a new relationship took shape between Canadian universities and government laboratories. In the 1930s, when the Entomology Division sought to introduce new approaches in chemical control on the relative toxicity of insecticides, it sent its entomologists to Macdonald College where they learned about the work of British and American scientists on botanical insecticides.[89] With the implementation of integrated pest management, governmental entomologists imported into academic settings, research problems generated in their professional environment. Moreover, after Lord, Harold T. Stultz, and other entomologists had joined the graduate program in entomology at Macdonald College, the entomology professor, F.O. Morrison, expressed his desire to participate in the activities of the Annapolis Royal Laboratory.[90] The Dean of Macdonald College asked the Entomology Division to allow Morrison to conduct summer fieldwork at Annapolis Royal. Pickett readily approved of this opportunity for an external review of his scientific activities. For his part, the Dean valued such experiences for enabling professors "to improve their teaching of economic entomology."[91]

As problems related to chemical control spread over different fruit growing areas, the Entomology Division extended research on integrated pest management to other laboratories in Eastern Canada, such as Harrow and Vineland in Ontario, and Saint-Jean in Quebec. This extension benefitted from the availability of entomologists who had previously worked on similar problems in biological control, but it also resulted from the pressure of fruit growers' associations who requested that their regional laboratories follow research agendas of the Annapolis Royal laboratory.[92]

The spraying of chemical pesticides remained a necessary agricultural practice for the control of plant disease. Entomologists consequently retained insecticide

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fauna of apple orchards in Nova Scotia: IV. A review," *Canadian entomologist, 85* (1953), 472-478, and in J. Fred Hockey, *Agricultural research in the Annapolis Valley area, 1909-1960* (Ottawa, 1967).

89. Frederick Merriet Cannon, "The standardization of a method for utilizing *Drosophila melanogaster* as a test animal for toxicity experiments with nicotine" (M.Sc. thesis, McGill University, 1939); Charles Wilmot Brown Maxwell, "Studies of the toxicity of nicotine in combination with various adjuvants" (M.Sc. thesis, McGill University, 1939); Frank O. Morrison, "The standardizing of a laboratory method for comparing the toxicity of contact insecticides," *CJR, Section D, 21* (1943), 35-75.

90. Allison DeForest Pickett to H.G. Crawford [Apr 1947]; H.G. Crawford to K.W. Neatby, Apr 30 1947, RG-17, DADM, vol. 3040, file 40-5-3 (2), NAC.

91. Memorandum re Dr. Frank Morrison, Macdonald College [1947], RG-17, DADM, vol. 3040, file 40-5-3 (2), NAC.

92. L.F. Burrows [secretary-treasurer of the Canadian Horticultural Council] to James Gardiner, 26 Feb 1945; "Resolutions voted at the annual congress of the Canadian Horticultural Council on Feb 25 1945," RG-17, DAMO, vol. 3300, file 649 (5), NAC; J.M. Swaine to G.S.H. Barton, 23 Mar 1945; L.F. Burrows to James Gardiner, 9 Mar 1946, RG-17, DAPM, vol. 3568, file 1776, NAC.

spraying as a central experimental practice in fruit protection research. Their studies focused on rectifying this agricultural practice rather than subverting it totally. Because entomologists refused to increase the workload of fruit growers, biological techniques could not be the sole measure of control. Rather than a control program based on laboratory propagation and field release of parasites and predators, entomologists proposed a revised spraying program to increase the activities of indigenous natural enemies. However, experiments in fruit protection encompassed more diversified research practices than did field trials. Studies relied on the survey of arthropod populations and embraced a novel analytical method for understanding the interrelationships between insect species in the orchard under different spraying conditions.[93] This innovation resulted in large part from developments in the study of population dynamics in forest entomology and the arrival of population ecologists in agricultural entomology. Entomologists described the relationships between insect pests and their natural enemies as a means of identifying the causes of significant variations in insect populations and assessing the role of environmental factors on the density and efficiency of natural enemies.[94] Although this research included theoretical considerations and aimed at mathematical modeling of the dynamics of the orchard entomological fauna, entomologists continued to pursue the practical goals of predicting population tendencies and defining appropriate phytosanitary treatments.

Research in integrated pest management involved Canadian entomologists in larger debates on population ecology.[95] Farmers adopted the integrated pest management strategies that entomologists designed from their studies on the effects of insecticides without bothering about their bearing on ecological questions. Despite regional differences, fruit growers either provided entomologists with experimental plots or simply followed their spraying recommendations; close to eighty percent of the orchards in Nova Scotia were under integrated pest management treatment in 1964.[96] By maintaining chemical insecticides in their experimental design, entomologists guaranteed a relationship between their research and agricultural methods.[97]

93. A.L. Turnbull and Donald A. Chant, "The practice and theory of biological control of insects in Canada," *Canadian journal of zoology, 39* (1961), 697-753.
94. During its annual congress in 1961, the Entomological Society of Canada organized a symposium to present recent Canadian studies on insect ecology. "Population dynamics of agricultural and forest insect pests," in Edgard Joseph Leroux, ed., Entomological Society of Canada, *Memoirs, 32* (1963).
95. Palladino (ref. 5).
96. Allison DeForest Pickett and Albert William MacPhee, "Twenty years' experience with integrated control programs in Nova Scotia apple and pear orchards," Paul Freeman, ed., Twelfth International Congress of Entomology, *Proceedings* (London, 1965), 597.
97. Edgard Joseph Leroux, "The application of ecological principles to orchard entomology," *Canadian entomologist, 96* (1964), 348-356.

4. CONCLUSION

Albeit limited to Canada and economic entomology, this article demonstrates that government laboratories can play a central role in the shaping of research specialties. Their contribution revolves around two mechanisms: the capacity of applied scientists to undertake fundamental research related to practical problems and the training of young researchers. Central to these mechanisms is the autonomy of governmental scientists. This autonomy resulted from a convergence of interests in which field application informed basic studies. By selecting research objects with features that corresponded to their patrons' goals, entomologists legitimized the study of fundamental phenomena related to problems in insect physiology and ecology. The early selection of entomopathogenous viruses and the subsequent shift to *Bacillus thurigiensis* reflected the practical concerns of entomologists at the Sault Sainte Marie Laboratory. Similarly, the avoidance of a program that relied exclusively on biological control suggested that entomologists in Nova Scotia were reluctant to increase the workload of farmers and remove chemical insecticides from the spraying programs of fruit growers. Entomologists acknowledged the embeddedness of pesticide spraying in fruit growing practices geared toward the prevention and control of insect pests and plant diseases.

The reliance of the fruit growers and the pulp and paper industry upon government laboratories may be specific to Canada. Their intervention was instrumental in securing resources and the maneuvering room necessary to launch original research projects. Rather than drawing entomologists away from their scientific concerns, patrons of the Sault Sainte Marie and Kentville laboratories legitimated research on the fundamental aspects of insect control. In these two case studies, interaction with patrons determined the mission and activities of the laboratories. The autonomy of scientists at the London Laboratory resulted from a different institutional context. Here the Science Service explicitly kept scientists in relative isolation from the practical environment of the Department of Agriculture. In insect toxicology, the producers and users of knowledge were the scientists themselves. The autonomy of governmental scientific activity emerged as a result of a departmental policy aimed at pre-empting other organizations from defining the research priorities within its domain. In competition with academic and military institutions that had done research on synthetic insecticides, the Department of Agriculture instituted different measures to acquire and build from within its ranks the necessary expertise to promote its ascendancy in pesticide studies. For entomologists, these initiatives generated a sense of autonomy to investigate the mode of action of insecticides. Their link to a university facilitated the reproduction of their community and thereby strengthened their autonomy.

Overall, the emergence and shaping of research specialties benefited from access by government scientists to a flexible environment and to material resources beyond those of their academic colleagues. This last feature underscores another issue concerning the autonomy of government laboratories—the capacity of mission-oriented government laboratories to train researchers, an issue neglected in the literature on science policy and higher education. Initially, the introduction of new research methods in government laboratories resulted from the advanced training of governmental scientists in academic laboratories. The consolidation of government laboratories after the war reversed this trend. Young researchers found equipment, data, and research projects in these laboratories. Furthermore, they were trained to identify research problems, interpret results, and diffuse knowledge from within an international scientific community. During their graduate studies, they transported the scientific agenda of the Entomology Division from their governmental laboratory to their academic setting. Governmental scientists extended their research activities beyond the laboratories of the Entomology Division, and shaped the development of entomological specialties. Relationships between government laboratories and universities therefore appear to be far from unilateral. Distinctions between them cease to be decisive when the production of research and researchers is considered.