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Biological Control of Forest Weeds: Canadian Research Efforts

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Abstract

This article presents a concise overview of Canadian research efforts towards biological control of forest weeds. It also includes information on Canada's forest resource and its management, common forest weeds and their occurrence, need for weed management and rationale for biological approach, and future strategies for biological control.

Introduction

Dorworth (personal communication, 1986) described "weeds" as plant species which are surplus to industrial (forestry), aesthetic, soil maintenance, wildlife or recreational interests in a particular situation. Watson (1977) described "weeds as plants growing where they are not wanted", and "biological control of weeds as a deliberate use of natural enemies to reduce the density of a particular weed to a tolerable level". I, however, define "biological control" as a "biological management" because in reality we are not aiming to eradicate weeds but to keep their populations to low levels so that they can co-exist with the crop species in the forest ecosystem without interfering in the development, growth and yield of the desired species.

This article contains an overview of the Canadian research program on the control of forest weeds through the use of fungal pathogens. It also includes some background of Canada's forest resource, forest weeds and need for weed management, and the objective and rationale for conducting research to develop biological control strategies.

The Canadian Forests (statistics from the Canadian Forest Industries Council 1986 Databook)

Canada is the second largest country in the world, covering an area of 9.9 million km^2. It has a forest cover of about 342 million ha, which represents 12% of the world's forest land and 44% of the country's land. Approximately 17% of which is considered unproductive and 27% (16 x 10^6 ha) as productive. This gives us a total of about 2.6 million km^2 capable of sustaining growth and allowable annual harvest of 276 million M^3/yr (Forest Industry Statistics for Canada 'CFS-HQs' 1982).

Except for the Alpine and Arctic tundra and the grasslands, the natural vegetation of Canada is forest. Eight forest regions are commonly recognized: Boreal, Subalpine, Montane, Coast, Columbia, Deciduous, Great Lakes-St. Lawrence, and Acadian (Rowe 1972) (Fig. 1). Each forest region "is conceived as a major geographic belt or zone, characterized vegetationally by a broad uniformity both in physiognomy and in the composition of the dominant tree species" (Rowe 1972). Literally the forest is considered as an interrelated assemblage of plants of various forms and animals living in a biotic association. A forest community exists in, and interacts with, a physical and biological environment. Together, a forest community and its habitat comprise an ecosystem. The resources of an ecosystem are limited and all

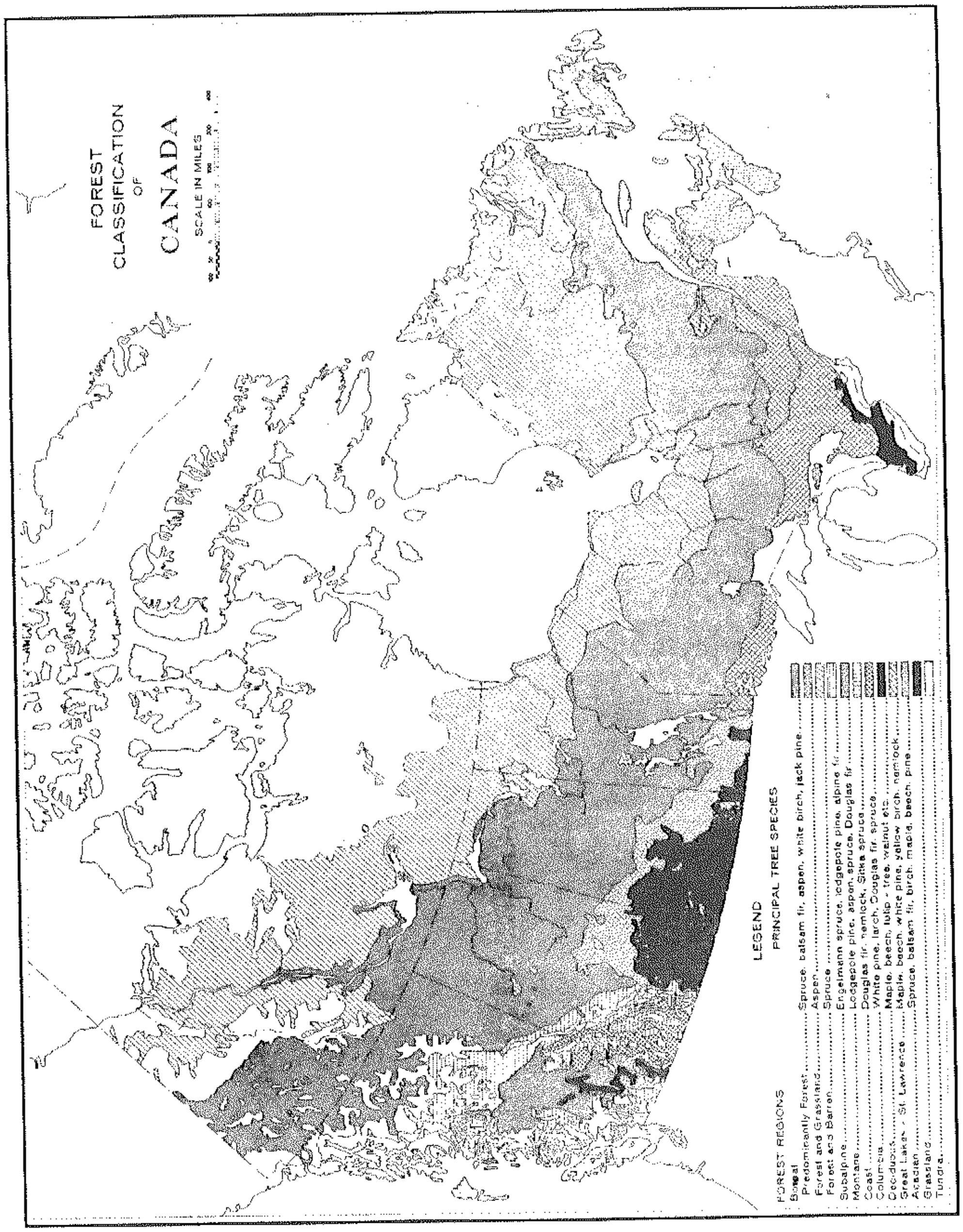

Figure 1. Map of Canada showing forest regions with principal tree species (after Rowe 1972).

organisms within an ecosystem must therefore compete for their survival, growth, and reproduction (Lawrence and Walstad 1978). Trees, particularly as seedlings, are not exempt from the competitive struggle.

Forest Management and Forest Resource

Stone (1975) viewed forest management as a spectrum of managerial purposes combined with the levels of skill and physical input, both increasing as we move from remote wildlands and protected wild forest through exploited forest and regulated forest to domesticated forest. In a regular forest, adequate regeneration is assured, the number of trees per unit area and the species composition are controlled to some degree, and the productivity of the site is considered as a fixed, inherent property. The exploited forest is, however, utilized with little or no investment of effort other than that needed to extract the forest yield, regeneration being left entirely to nature. The domesticated forest is exemplified by agroforestry as the silvicultural extension of agriculture (Zsuffa and Anderson 1981). Under this the potential for productivity of a site is not accepted as a fixed quantity but is regarded as a variable that can be increased by soil modification or by a combination of soil modification and genotype response to it. The Canadian forest industry is just approaching the threshold of regulated forestry but that exploitation remains the dominant characteristic.

The current reforestation effort in Canada is inadequate (Bonnor 1982). Morgenstern (1978), for instance, estimated that of the 251,000,000 ha of productive forest land in Canada, 750,000 ha are cut annually, and that nearly 200,000 ha of these do not regenerate adequately. The cumulative area of inadequately stocked forest land was estimated by Reed *et al.* (1978) to be 30,000,000 ha, more than the total forest land area of Japan (25,000,000 ha) (Forster 1978), and more than twice that of France (14,600,000 ha) (Anon. 1982).

As a major producer of manufactured forest products' Canada accounts for almost 22% of the total world production. Canadian exports are dominated by three products. Paper products (mainly newsprint), lumber and wood pulp contribute 42, 29 and 21%, respectively to the country's total forest products export of over $20.0 billion. Approximately 11% of total world production of lumber, 14% of all softwood timber resource, and just under 2% of the world's volume of hardwood fibre are produced in this country. Canadian forest products industry is vital to country's economic prosperity with about $30 billion worth of products in 1985. It employs about 300,000 persons; one out of every 10 Canadians is dependent on forest industry.

Although abundant forest resources have enabled a large industrial base to develop and contribute to the Canadian economy, "THE CHALLENGE" ahead is to ensure that the Canadian forests are renewed properly and that they remain productive. There are several means through which we can meet "THE CHALLENGE". One of these is to maintain or preferably increase the "Annual Allowable Cut" (AAC). Methods to accomplish this include proper renewal and management of forests to produce higher yields of desired species on shorter rotations (Reed *et al.* 1978). This will require numerous interventions during the life span of a forest stand, including preplanting site treatments, better planting methods, thinning and spacing, insect and disease control, and control of competing undesired vegetation. The last one may be one of the most important interventions because it will provide opportunity for the commercially important species to successfully compete with the naturally regenerating undesired plant species.

Need for Weed Management

The major requirement in forest renewal in Canada is the need to produce softwoods and on a short rotation. Most forests in this country develop as a mixture of softwoods and hardwoods, the latter predominating in the earlier years of stand development. The hardwood phase may vary from a few years as in Cape Breton Highlands (Wall 1983*b*) to more than five decades as in spruce aspen forests of Alberta (Lees 1966). Earlier hardwood stage as well as earlier herbaceous and shrub stage needs to be eliminated or reduced in duration.

Competition with undesired species in early stages of stand/plantation development is often intense, especially where the hardwood component of the previous stand was high.

Forest weeds present a major problem in the successful implementation of reforestation program on many sites in Canada. Most of the weeds affecting forest renewal are the early colonizers or pioneer plant species which normally invade a site after disturbance and which eventually give in to conifers and tolerant hardwoods. Although most weeds occur in non-crop areas of forests, equally undesirable densities of these plant species are also observed on productive sites which have been disturbed by logging operation or by fire.

Weeds interfere or have the potential to interfere with the following silvicultural and management activities (Cutler 1978, Witt 1978): (a) production of planting stock; (b) preparation of sites for the establishment of a plantation; (c) reduction of competition to crop trees during the establishment phase; (d) other silvicultural and managerial activities, including thinning, reduction of hazards, maintenance of rights-of-way, roadside brush control.

Objective of Weed Management

Vegetation management provides an opportunity to manage the undesired plant species so that they are least obstructive and least demanding part of the forest ecosystem. The main objective of management of forest weeds is not to eradicate them but to reduce their population and competition with the desired commercial tree species in the early stage of their development. Traditionally this has been achieved mostly thorough the use of chemical means; in some cases mechanical or silvicultural methods are used. However, there are only three chemicals which are registered for use in Canada. Although new herbicides are being produced, their registration is not easy (Benskin *et al.* 1985, Reynolds 1985, Sutton 1985). As a result there is tremendous pressure to develop alternate methods to control weeds. To slow down or halt the often explosive increase of their populations, natural enemies, such as insect pests, fungal pathogens or predators, are sought within the area or from elsewhere. Many of these pathogens cause several diseases and play a significant role in limiting the distribution, abundance, density and longevity of these pioneer plant species (Table 1), thus aiding in the release of the desired conifer species (Anderson 1964, Churchill *et al.* 1964, Schroeder 1983, Wall 1986). Indirectly they may also be reducing the rotation period by providing better opportunity for conifer growth. Introduced or genetically altered pathogen, or artificially increased population of the native pathogen may perform better, but they may also pose threat to related species which may have economic or amenity value.

Wilson (1969), Zettler and Freeman (1972), Templeton and TeBeest (1979), and Charudattan (1984) explained the need for and theorized on the potential of using plant pathogens for weed control. Charudattan (1984) also stated that biological control of weeds can be achieved by the use of specific biotic organisms or by manipulating the plants environment or resistance, the microbial imbalance, or by the combination of these factors.

Biological agents are being explored as an alternative to chemical herbicides or silvicultural methods. Although they are not expected to replace the presently available methods of weed control, they are expected to augment them or serve as substitute in some situations. Generally speaking the objective is to prevent complete occupation of a site by a dominant weed species, release the desired tree species from a dense cover of weeds, and reduce the longevity of the established weeds. Schroeder (1983) stated that "the objective of biological control of weeds is not the eradication of weeds but reduction and long term stabilization of weed density at a sub-economic level".

Common Forest Weeds in Canada

There are a large number of undesired plant species in Canadian forests. However, their distribution varies from region to region and from site to site. Brief notes on some of the most common Canadian forest weed species are given below:

(i) Mountain maple, *Acer spicatum* Lamb. (Aceraceae): Forms dense pure stands, reproducing largely by basal sprouting on coniferous or mixed wood sites, thus hindering the development of spruce and fir.

Table 1. Major forest weed species and some of their diseases problems.[1]

Species	Foliage diseases	Root diseases and wilts	Cankers and galls	Stem rots
Acer spicatum Lam.	8	1	6	2
A. rubrum L.	12	6	7	15
Alnus rugosa (DuRoi) Spreng.	8		3	3
A. rubra Bong.	12	3	2	4
Betula papyrifera Marsh.	10	3	2	13
Cornus stolonifera Michx.	8		1	
Corylus americana Marsh.	8	1	1	
Epilobium spp. 2	19	2		
Fagus grandifolia Ehrh.	6	2	6	10
Gaylussacia baccata (Wangh.) K. Koch	8		1	
Kalmia angustifolia L.	6			
Ledum groenlandicum Oeder[2]	6			
Populus tremuloides Michx.	15	1	5	5
Prunus pensylvanica L.f.	12	1	3	1
Pteridium aquilinum (L.) Kuhn	9	1		
Rhododendron canadense (L.) Torr.	2			
Rubrus strigosus Michx.[2]	16	6	7	
Solidago spp.[2]	32	2	3	
Vaccinium spp.[2]	24	1	6	
Viburnum spp.[2]	15	5	4	2

[1] Extracted from personal communications from Wall (1986-87).
[2] Important as alternate hosts of conifer rusts.

(ii) Red maple, *Acer rubrum* L. (Aceraceae): Can suppress softwood growth in young conifer plantations due to its tendency to form dense clumps of stems on recently cut stems.

(iii) Speckled alder, *Alnus rugosa* (Du Roi) Spreng. (Betulaceae): Considered as a weed species in the coastal forests of British Columbia with a tendency of profuse stump sprouting.

(iv) Hazel, *Corylus americana* Marsh (Betulaceae): A shrub which forms dense thickets in open mixed wood stands and partial cutovers, and suppresses conifer regeneration.

(v) Sheep laurel (Fire Weed or lambkill), *Epilobium angustifolium* L. (Onagraceae): An extremely common weed on black spruce cut-overs, barrens and blueberry fields.

(vi) Bracken fern, *Pteridium aquilinum* (L.) Kuhn. (Dennstaeditiaceae): Occurs on a variety of forest sites which have been disturbed by clearcutting, burning and forest opening.

(vii) Bramble or wild raspberry, *Rubus strigosus* Michx. (Rosaceae): Common on clearcuts on spruce-fir sites.

(viii) Pin cherry, *Prunus pennsylvanica* L.f. (Rosaceae): Common on cut- or burned over hardwood, mixed wood or spruce-fir sites.

(ix) Trembling aspen, *Populus tremuloides* Michx. (Salicaceae): A hardwood species occurring on a variety of medic sites.

(xi) American beech, *Fagus grandifolia* Ehrh. (Fagaceae): Common on rich hardwood sites, forming thickets of slow-growing unmerchantable stems because of beech bark disease.

(xii) Red alder, *Alnus rubra* Bong. (Betulaceae): Considered as a weed in coastal forests of British Columbia; characterized by profuse stump sprouting.

(xiii) Vine maple, *Acer circinatum* Pursh (Aceraceae).

(xiv) Broadleaf maple, *Acer macrophyllum* Pursh (Aceraceae).

(xv) Salmonberry, *Rubus spectabilis* Pursh (Rosaceae).

(xvi) Willows, *Salix* spp. (Salicaceae).

(xvii) White birch, *Betula papyrifera* Marsh. (Betulaceae).

(xviii) Yellow birch, *Betula alleghaniensis* Britton (Betulaceae).

(xix) Salal, *Gaultheria shallon* Pursh (Ericaceae): Common in coastal forests of British Columbia.

(xx) Grasses, sedges and rushes: Profusely common on some sites.

Canadian Program of Research on Biological Control of Forest Weeds

Past Research Work

Considerable research has been conducted on the biological control of agricultural weeds in Canada during the past few decades. However, very little has been attempted towards the control of forest weeds through the use of plant pathogens. The Canadian research efforts towards biological control/management of forest weeds started in early 1970s when Dr. R.E. Wall of Maritimes Forestry Centre (of Canadian Forestry Service) initiated investigations on the possibilities of controlling major weed species in plantations and young forest stands in Maritimes provinces (New Brunswick, Nova Scotia and Prince Edward Island). His target species included pin cherry, *Prunus pennsylvanica*, on cut- or burnt over sites; wild raspberry, *Rubus strigosus*, on cut-over sites, and sheep laurel, *Epilobium angustifolium* on burnt over sites. This study evolved from earlier investigations on the development of conifer regeneration and associated plants on clear-cut forest areas (Wall 1977, 1982, 1983*b*).

While investigating the role of black knot disease as a biological control agent for pin cherry, Wall (1981) reported that the causal organism, *Apiosporina morbosa* (Schw. ex Fr.) Arx, produces black knot type cankering on the main stem and branches of the host plant, thus effecting the terminal leader length and total height. Continuing his studies on the host-parasite relationship, Wall (1986) reported that infection of the main stem is critical and the pathogen invades the terminal meristem at the budbreak, thus damaging mostly the most dominant pin cherry trees and the most dominant branches. He recommended that early introduction of heavy inoculum of *A. morbosa*; i.e. within the first three years of stand development, particularly in a cut-over area and not in a burnt over site, is considered necessary for effective control of pin cherry, killing as many as 26% of the host trees. Infection of the main stem is considered a critical factor. He thus showed a regulatory role of black knot disease under existing forest management practices in that part of the country. However, production and delivery of inoculum were major constraints in development as a bioherbicide.

In 1977 Wall reported that his preliminary attempts to control sheep laurel, huckleberry and raspberry by mass inoculation with cultures of native pathogens did not show much promise. However, in 1983 (Wall 1983*a*,*b*) he suggested the possibility of using the fire blight organism, *Erwinia amylovora* Winslow *et al* f. sp. *rubi*, as a biological control agent against wild raspberry; the disease causes extensive blackening of juvenile stems and leaves of raspberry in localized patches.

Hunt *et al.* (1971) reported that fresh wounds and stump surfaces are susceptible to many pathogens not normally found in an undisturbed stand and treatment of these surfaces with wound colonizing is a promising practice in root rot control. Recently Wall (1980 - unpublished data) also investigated this approach towards the control and prevention of undesired sprouting and frill development in some hardwood weed species, such as yellow birch in certain sites through the use of *Chondrostereum purpureum* (Fr.) Pouz.

Current Research Program

In 1986 Dr. C.E. Dorworth (of Pacific Forestry Centre) initiated a program of research on mycoherbicides as a forest weed control possibility in the province of British Columbia. In 1987 Dr R.E. Wall got transferred to the Pacific Forestry Centre and joined Dr. Dorworth's research program.

Although there are two generally accepted biological control strategies: The CLASSICAL option and the INUNDATIVE option. The Pacific Forestry Centre has adopted ENHANCEMENT as a primary method, wherein the biological control agent is promoted in vigour and consequently in apparent virulence through nutritional and other reinforcement means. Simultaneously, attempts are made to precondition or PREDISPOSE the target plant to infection and colonization by the biological control agent through chemical or physical disturbance of plant tissues, or by any other environmentally-acceptable device that places the advantage on the side of the biological control agent in a pathogenic interaction between pathogen and host. The following protocols have been developed similar to that utilized in most biological control operations. The target species are *Alnus rubra*, *A. viridis* and *Gaultheria shallon* and the pathogens are *Melanconis* sp. and *Valdensia* sp.:

1. Identify the major forest weeds in British Columbia and the general mode of weed interference.

2. Identify the major diseases of these weeds, isolate and establish stable cultures of the causal organisms.

3. Inoculate stock with the candidate biological control agents and verify their pathogenicity. Thereafter, use the identified pathogens for graded inoculation series in order to quantify virulence.

4. Inoculate various crop- and non-crop plants to verify specificity of the candidate biological control agent as well as study their effects on other flora and fauna in the ecosystem.

5. Promising candidate biological control agents be applied to plants under field conditions to verify utility of the biological control agent at operational levels.

6. Appropriate biological control agents will be entered into final stages of patent procedures in cooperation with a potential marketing agency.

Future Directions for Biological Control of weeds in Canada

Currently more than 75,000 ha of forest land are treated with herbicides annually (Sutton 1985) and this figure will increase in spite of public opposition to the use of chemical herbicides. Availability of biological and other weed control/management alternatives, plus the pressure for more intensive forest management may result in much greater land areas receiving some kind of weed control or weed management treatment.

Although concerns about the side effects of pesticides have helped to improve the popular image of biological control, the impression that the biological control agents may themselves become pests is scary and somewhat frustrating. New concerns will also surface from the idea of introduction of exotic or alien organisms. The fear of introduced organisms becoming destructive pathogen on crop species does not hold well if one looks at the past history of biological control of weeds in agriculture. Debates and analysis of problems and procedures indicate that there is a need for new perspective and experimental approach. In Canada, our approach is certainly very systematic and careful.

Today we need to draw upon a great variety of fungal pathogens which we consider potential biological agents. Whether and how we use a particular pathogen depends on the following main attributes: virulence, persistence effectiveness, storage, and its delivery. Templeton and TeBeest (1979) and Charudattan (1985) stated that the future development of mycoherbicides is mainly dependent on investigations aimed to determine endemic pathogens of major weeds, particularly those which are highly pathogenic, developing methods for mass production of stable spores and propagules, and understanding the disease cycle and the weed patho-systems. Charudattan (1985) also suggested to obtain a better understanding of the genetics of the pathogen, which may eventually help to select and establish pathogens with greater virulence (what he calls "super pathogens") or may even assist to increase virulence through hybridization, parasexuality or genetic manipulation. Genetic engineering can introduce new properties into biological control agents, such as enhanced virulence, broader host specificity, and longer shelf life. He further, recommended the need to investigate host-parasite relationship, and host resistance. He believes that greatest hope is in the introduction of foreign highly specific pathogens to control the established weeds in an area. There is a risk of some hazard but it can be overcome with a high level international or inter-agency cooperation.

Canadian research, as already mentioned, is adopting 'middle of the road policy' and follow what Dr. Dorworth (1987) calls it "ENHANCEMENT" approach where in the potential biological control agents are being tested for their virulence on a variety of host and non-host plant species. Attempts will also made to promote the vigour/virulence of the select pathogen(s), and investigate the possibility of developing physically and economically viable biological control agent. Simultaneously investigations will also continue on predisposition of the host/target plant species. Genetic engineering and somaclonal lines may have excellent potential in these and related investigations.

Conclusion

The needs for weed control are expected to increase and as they do, prevailing conditions and attitudes are likely to dictate an increased emphasis on the use of technology alternate to chemical herbicide. Biological control is now a respected and valued pest management strategy in agriculture, but its wider acceptance in forestry depends on the confidence of foresters that it will work and that it is an economically viable option. However, there is a great need to educate foresters, forest and research managers at all levels within industry, provincial and federal governments concerning the need and implications of research on these and their use as an alternative to chemical control. Although no further proof is needed to show that pathogens can debilitate and kill plants, are host specific, have no toxicity problem, and leave no residue in soil or underground water, the challenge remains to demonstrate the concepts of biological efficacy and economic feasibility in natural forest ecosystems. It is not enough to determine that a pathogen is virulent and specific in greenhouse conditions or in small field tests; such success needs to be confirmed in general usage before it is recommended for commercialization.

Biological control application in Canada will continue to expand in future as the costs of other control methods increase and as public sensitivity and political pressure against chemical usage increases. There is an opportunity for participation/cooperation of fermentation and pesticide industries in the development, registration and commercialization of biological control agents. Modern biotechnology will hopefully assist in the selection or production of highly efficacious biological control agents.

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