ABSTRACT

PETERSON JR., PAUL DAVID. The Common Barberry: The Past and Present Situation in Minnesota and the Risk of Wheat Stem Rust Epidemics. (Under the direction of Dr. Turner B. Sutton)

One of the classic host-pathogen relationships in plant pathology is between the common barberry, *Berberis vulgaris*, and *Puccinia graminis*, the cause of stem rust, a destructive disease of small grains. As the alternate host of *P. graminis*, the barberry is the key in the sexual stage of the pathogen's life cycle. The combination of extensive small grains production and widespread cultivation of the common barberry in the north central United States resulted in major stem rust epidemics by the late 1800s and early 1900s. In 1918, the Barberry Eradication Program was initiated by the U. S. Department of Agriculture in cooperation with important small grain producing states. Before the termination of the program in the late 1970s, more than 500 million barberry bushes were destroyed. Since the end of the program, however, scientists have voiced concerns about the potential for barberry to reemerge as a source of inoculum and of new genetic forms.

The objectives of this research were to examine the history of barberry eradication in Minnesota, to determine whether barberry has reemerged on sites in Minnesota and what effect this reemergence may have on future stem rust epidemics.

An evaluation of archival records revealed that the origin of the Barberry Eradication Program was in reaction to successive stem rust epidemics and concerns over production shortages during World War I. The program that developed after 1918 was an unprecedented

collaborative effort among federal-state agencies, land-grant colleges, and agricultural industry. Initial survey work was focused on the removal of barberry bushes in cities, towns, and rural planted sites; priorities shifted and procedures changed with the discovery of large numbers of escaped bushes, particularly in southeastern Minnesota. More than one million barberry bushes were destroyed in Minnesota between 1918-1990.

A field survey of 72 of the approximately 1200 active sites in Minnesota was conducted. Active sites were defined as those sites that remained to be inspected for barberry regrowth at the end of the eradication program in 1980. Barberry had reemerged on 32 of the 72 sites. More than 90% of the barberry bushes were found in counties with less than 400 ha of wheat per county, mostly in southeastern Minnesota, but one bush was found in a major wheat-producing county in northwestern Minnesota. Reemergence of barberry may play a role in future epidemics of stem rust, particularly with regard to sexual reproduction in the pathogen population.

Aecial isolates of *P. graminis* collected from common barberry in Minnesota between 1912 and 2002 were obtained and used to evaluate changes in *forma speciales* over time. Uredinial isolates collected in Minnesota during the same time period were compared to the aecial isolates to evaluate changes in race structure of *P. graminis* f.sp. *tritici*. *Forma speciales* in aecial populations changed over the 20$^{th}$ century and coincided with changes in barberry populations. *P. graminis* f. sp. *tritici* has become the predominant *forma speciales* identified in collections since 1990, resembling the pathogen population structure before eradication. Removal of barberry from areas around wheat fields contributed to a reduction in race diversity in uredinial populations; however, diversity in aecial populations was unchanged in relation to barberry removal. With the lessons learned historically during barberry eradication, the knowledge that barberry has reemerged on many sites and the recent changes in the *P. graminis* population, there is reason to be concerned over the possibility of increasing stem rust epidemics in Minnesota.

# THE COMMON BARBERRY: THE PAST AND PRESENT SITUATION IN MINNESOTA AND THE RISK OF WHEAT STEM RUST EPIDEMICS

by
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# The Establishment and Operations of the Barberry Eradication Campaign in Minnesota, 1918-1990

"For 2,500 years the barberry bush has been known to man. He has cared for it and protected it, planters have planted it in every continent, writers have written of it in nearly every language. For 2,500 years it has been bringing failure, destruction, and despair to the people who have cared for it . . . . Now man has turned on his enemy, but he must fight to the finish. We have made only a good start, the fight must go on until the common barberry is unknown" (31).

"Stem rust is one of the most destructive diseases of cereal crops. When it sweeps across a nation's cereal producing areas in epidemic quantity, the tragedy begins with the farmer, plagues processing and related industries, and ends to the detriment of consumers at national and international levels"(114).

## Introduction

In 1990, Robert J. Laudon, field supervisor with the Minnesota Department of Agriculture, retired after a career of thirty-five years with the Barberry Eradication Program. Laudon was among the last of the "old barberry men" who had participated in barberry eradication before the program began to dwindle, first with the pullout of the USDA in the late 1970s, and later, with the ending of state efforts by 1990. With the drawdown of the major participants and the retirement of personnel such as Laudon, the Barberry Eradication Program quickly faded from awareness. Today, few people recall the enormous efforts expended to exterminate the common barberry (*Berberis vulgaris* L.) from major small grain growing areas. Also poorly understood is the importance of the Barberry Eradication Program to plant pathology. From humble beginnings in the late nineteenth century, plant pathology aspired for national recognition in the early decades of the 1900s as a scientific discipline that could both solve practical problems for American agriculture and provide fundamental contributions to biology (10). Plant pathology's leading role in using science to manage agriculture through its establishment and operations of the eradication program brought this recognition and elevated the discipline to the forefront of American agricultural science. Largely unnoticed as well are both the state-federal cooperation, unparalleled in agriculture up to that period, and the unprecedented public support for a large-scale scientific management program, still a rarity in American society. These aspects alone make the Barberry Eradication Program an important event in America's scientific, agricultural, and social history and a worthy subject for historical examination.

Begun in 1918, the Barberry Eradication Program was a cooperative federal and state endeavor initiated in thirteen states to eradicate common barberry, the alternate host of stem rust (*Puccinia graminis*), from the major areas of small grains production in the U.S. In the early decades of the 1900s, stem rust epidemics were common in the north central states, thwarting successful production of small grain crops. The huge epidemic of 1916 and the resulting unprecedented losses of wheat at the height of World War I provided the impetus for action. Aware that the common barberry, once planted as an ornamental bush throughout the north central U.S., was responsible for initiating local, devastating stem rust epidemics of small grains, leaders of the eradication movement successfully argued for the total removal of the bush. What followed was one of the most massive undertakings to remove an invasive plant species from the United States. Before the eradication campaign was phased out in the 1970s and 1980s, eighteen states had participated in the program and over 500 million bushes had been destroyed (6, 9).

Most of the knowledge about barberry eradication remains scattered in historical archives in the form of internal annual reports, unpublished technical papers, correspondence between key individuals, and voluminous raw data. Apart from largely anecdotal information that has survived with retired participants, little is known, for example, of the establishment and operations of the eradication program. This study attempts to shed light on this important, but largely unexplored event in American science and agricultural history. It will examine the factors that led to the initiation of the Barberry Eradication Program and highlight key participants that fostered the movement for the massive enterprise. It will also, through a focus on Minnesota, provide a much better picture of the program's dynamics by investigating the geographic distribution and numbers of barberry bushes destroyed over time. Lastly, this study will explore the changing approaches and methods used to eradicate barberry throughout the duration of the program.

For various reasons, Minnesota is the archetype of the general Barberry Eradication Program as well as an excellent window from which to view the formation and execution of the campaign. It was among the first states to enter the program and the last to exit. Throughout the life of the program, Minnesota also remained a principle small grains producing state in the United States. Perhaps most important, however, was the central and guiding role that the state played in eradication activities. Its scientists were leaders in the organization and administration of the program as well as key participants in the development of major scientific concepts and methods involved in eradication.

**The Barberry Moves West**

By the seventeenth century, colonists had transported the common barberry to North America (46). One contemporary observer recorded that common barberry bushes were growing in abundance in the American colonies long before the Revolutionary War, both in places where they had been planted and also in pastures, in woodlands, in waste land, and among stone fences (15). Barberry owed its popularity to its apparent usefulness. By the seventeenth century, a list of the bushes' reported beneficial medical properties had grown substantially to include use against scurvy, bladder trouble, jaundice, constipation, loss of appetite, and fever. The barberry bush also had proven to be quite a useful plant in many other ways. The juice extracted from the barberry was used for making a "good-tasting, healthful English drink called 'punch'." Water in which the bark was boiled served as a mouthwash. Its red berries were used for making jellies, while the bark and roots, with their characteristic yellow pigment, were used as dye. The wood was used as teeth in rakes, in woodturning, and in the joiner's trade. Perhaps the major use of the barberry, however, was as a hedge and ornamental. Because of its thick growth, sharp thorns, and hardiness, the bush provided an excellent hedge as a windbreak and a natural deterrent to traffic by man and animals. Thus, with almost every part of the plant employed for household and farm use, with its conspicuous red berries and attractive fan-shaped branches, the barberry naturally became an ideal plant to have around (31).

The barberry bush, however, was not without its detractors. Both in Europe and in the American colonies during the seventeenth and eighteenth centuries, farmers often associated the appearance of rust on wheat stems with the presence of rust on barberry plants. Although the biological relationship was not understood, the perceived connection was strong. Common sense and repeated experience told many farmers that barberry rust must be related to wheat rust.  This practical "cause and effect" understanding influenced occasional legislative action to destroy barberry bushes, many years before the German scientist Anton de Bary demonstrated the connection between the barberry and the stem rust of grain in 1865 (14).  The first known legal action against the barberry occurred in Rouen, France in 1660. Laws to eradicate barberry also were passed in Connecticut in 1726, in Massachusetts in 1754, and in Rhode Island in 1766 (10).   How effective these laws were on the spread of stem rust is difficult to determine, but it is safe to assume from the increased reportage of epidemics and failure of grains that they were marginal.  The bush was also proving difficult to exterminate.  One contemporary observer remarked that the barberry is "the most pernicious bush that ever I knew grow upon the face of the earth, multiplying exceedingly fast though great pains are taken by many of our people to clear their lands of them, but to no purpose" (13).

Although an empirical connection had been made between the presence of barberry bushes and outbreaks of stem rust since the seventeenth century, a scientific explanation remained elusive until De Bary's discovery in 1865 that the "cluster cup fungus," *Aecidium berberidis*, on barberry was not an independent fungus but was in reality a very important stage in the life cycle of *Puccinia graminis* (14).  Proponents of barberry eradication were vindicated.

Still, one scientific paper could not easily change centuries of practice. Although the evidence mounted against it, barberry enjoyed continued popularity as a useful plant throughout the nineteenth century, especially in the U.S.  And, as settlers spread out into the nation’s midsection, seeds of the common barberry journeyed west and north with them. By the time of the American Civil War, barberries were growing in a number of north-central states. Records indicate that they were planted in Minnesota at least as early as 1880 (6).

Aiding this dissemination was their easy propagation by seed or cuttings, vigorous growth habits, and popularity in nursery catalogs. Nurserymen and horticulturists lauded the barberry as a useful and beautiful hedge on the prairie. Some nurseries even offered the common barberry bushes as special premiums with large orders for other plants. The effect was the wide distribution and firm establishment of the bush in the Great Plains by 1900-- on private property as well as in parks, in cemeteries, and along roadsides (6). Little did midwesterners realize, however, that with birds scattering the seeds of the bush, the common barberry had escaped the confines of the urban and farm home setting to thrive in pastures, along fence rows, and at the edge of woods.

**Wheat Stem Rust Epidemics in the Midwest**

By the second half of the nineteenth century, the midwestern spring-wheat regions of the United States and Canada were quickly becoming the world’s breadbasket. Improved transportation, better agricultural implements, fertile soils, and new markets in growing cities all promoted this rise to prominence, although the renowned bread-making quality of the hard-red wheats (*Triticum aestivum*) produced there held the key (37). Sown in the spring to escape the cold northern winters, wheat crops nevertheless faced constant uncertainty. With spring often arriving late and autumn early, frosts were an annual risk, while the dangers of drought, heat, and thunderstorms with violent winds, rain, and hail, as well as voracious grasshoppers were ever-present threats (4, 16, 36). And adding to the farmer's lists of insecurities was the likelihood of stem rust.

Wheat was described as the "king" of crops in the region when the disastrous stem rust epidemic of 1878 hit Minnesota, Iowa, and Wisconsin, slashing yields and shriveling quality. "To those unfortunate enough to own wheat fields in southeastern Minnesota and northern Iowa," wrote the editors of the *St. Paul Pioneer Press* of July 29, 1878, "it will not be necessary to speak of blight and rust and general failure . . . it has for some days been too apparent to need reiteration." Losses were estimated to have ranged from 17 to 27 % in the three states (32).

Stem rust of wheat was a formidable foe to the prairie farmer, and as production increased, epidemics expanded in number and size. Severe losses occurred in Minnesota, Iowa, Illinois, Indiana, and Ohio in 1892 and 1894 (11). The devastating effects of stem rust became all too apparent to midwesterners during the epidemic of 1904. More than any other region, it was particularly felt that year in the spring wheat belt of the northern Mississippi Valley. Losses to wheat farmers in Minnesota, North Dakota, and South Dakota alone were estimated to be over $10 million (25).

Even before the serious epidemics of 1904, controlling rusts was part of the USDA disease control program, directly or indirectly, through cooperation with land-grant college and agricultural experiment station scientists. The successful use of chemical fungicides against a number of plant diseases in the last two decades of the nineteenth century precipitated experiments with various potential chemical controls for stem rust (8, 33, 38, 81). In the early 1890s, B.T. Galloway, chief of the USDA's Division of Vegetable Pathology, placed a high priority on treatments that might check the damage from rusts that "have unquestionably played an important part in keeping the average yield down to a ridiculously low figure." But the results of experiments were far from encouraging. Soil and seed treatments showed little promise, and fungicide spraying provided inconclusive results while proving "exceedingly laborious and expensive" (29). Some plant pathologists viewed chemical control as impractical. As one plant pathologist remarked, "although this method is practical in an orchard, . . . the mechanical difficulties to be overcome in spraying a wheat-field are so great, that it is no longer regarded as of practical importance" (47).

There were some bright spots, however. Observations that early ripening wheat cultivars were often less damaged by rust than late maturing cultivars led plant pathologists to advise early planting with the early maturing varieties (7, 47). Another promising area of investigation was the apparent differences in the susceptibilities that different cultivars showed to rust. "No variety of wheat is known to be rust proof," H.L. Bolley remarked in 1889, "yet some possess greater powers of resistance than others" (7). Led by the research of W. Farrer in Australia with rust-resistant wheat, plant disease workers and other agricultural scientists, by the 1890s, began to pursue the acquisition of disease resistance as a goal (33).

The loss of millions of bushels of spring wheat in the United States prompted the U.S. Department of Agriculture to action in 1905. Immediately a cooperative federal-state program was begun on cereal rust control, with the primary objective of developing wheat cultivars resistant to stem rust, especially for the spring wheat region (82, 100). Scientists were optimistic that rust resistance held the key for the future success of the spring wheat industry. E.M. Freeman of the University of Minnesota and a USDA collaborator on the cereal rust control program, wrote in 1905: "Consequently something beneficial may be expected from the efforts of plant breeders in the production of rust-proof cereals. With intelligent care in the selection of cereal varieties and with a broader and better knowledge of the habits and life-history of the parasitic plants causing rusts, it is very probable that the ravages of this disease can be at least considerably checked" (21). Time would prove Freeman correct, but only slowly.

There were some early successes in obtaining disease-resistant cultivars by selection, but not against stem rust. W.A. Orton of the USDA had obtained several varieties of cotton resistant to cotton wilt, H.L. Bolley of North Dakota Agricultural College had obtained different flax cultivars resistant to flax wilt, while R. H. Biffen had reported success with a cultivar of wheat resistant to stripe rust (10, 93). Progress toward the development of satisfactory stem-rust resistant bread wheats was slow, however. The methods of selection used so successfully for cotton and flax wilt failed to work because of the inability to locate resistant cultivars of the common bread wheats. Moreover, when crosses were made between the best bread wheat cultivars and the most generally resistant varieties of durum wheat (***T. durum***), complete linkage between rust resistance and durum characteristics made it difficult to obtain bread wheat cultivars with good levels of resistance to stem rust (100). Adding another hurdle to the development of resistant cultivars was the presumed inescapable adaptive ability of the stem rust fungus, an idea originating with the bridging-host theory of the British plant pathologist H.M. Ward (40, 82, 100). If host or climatic factors easily altered the pathogenicity or virulence of biologic forms, as Ward and other suggested, then the feasibility of maintaining rust-resistant cultivars seemed doubtful. In reality, when the USDA embarked on its program of controlling stem rust in 1905, relatively little was known about the nature of cultivar resistance to plant disease. The science of genetics was in its infancy, as were the disciplines of plant pathology and plant breeding. As Stakman and

Harrar later recalled, “It soon became apparent that the development of bread wheats resistant to stem rust would not be easy” (102).

Despite slow progress in the breeding program and conceptual stumbling blocks about the nature of stem rust, the federal-state rust project made some headway over the next decade. A rust nursery was established, encircled by barberry bushes, where epidemics of stem rust could be created to furnish data both on resistant cultivars and the nature of rust resistance in wheat generally (100). Similar studies also focused on the nature and variability of biologic forms of stem rust. Attacking the bridging-host theory head on, Stakman and co-workers demonstrated between 1915 and 1918 that the biologic forms of *Puccinia graminis* were stable, unaltered by host or climatic influences. Removing the fear that resistant cultivars were rendered ineffectual by the ability of stem rust to adapt itself quickly to new hosts breathed life into the breeding program (40, 100). Meanwhile, a new spring-wheat cultivar, Marquis, produced in Canada and planted widely in the region by 1912, seemed to offer hope because of its early ripening and apparent stem rust resistance (100). But the rust epidemic of 1916 showed that Marquis was not the magic bullet, and that neither it nor any other known cultivars of bread wheat could withstand the onslaught of stem rust at its worst.

Cool, wet weather in the spring and early summer of 1916 favored the vigorous growth of wheat, promising a bumper crop. These same weather conditions also promoted the development of rust infections on barberry, threatening an epidemic of stem rust if the temperatures rose significantly later in the summer. This is just what happened. Beginning in early July, temperatures were high for three weeks, providing the perfect scenario for rapid disease development (85, 86). The result was the worst outbreak of stem rust on record in the spring wheat regions of the United States and Canada. In Minnesota, North Dakota, and

South Dakota, yields were reduced from 17, 18.2, and 17.1 bushels per acre in 1915 to 7.6, 5.5, and 6.8 bushels per acre in 1916 (Table 1). Stem rust destroyed approximately 61% of the wheat crop in Minnesota (101). On a larger scale, the loss from stem rust in the United States was estimated at 200 million bushels or about 40 % of the U.S. crop; losses were another 100 million bushels in Canada. It was later estimated that the 1916 epidemic cost the world $250 million (22). Far from a bumper yield, the 1916 crop was an unqualified disaster. The time had come to look for other solutions to the stem rust menace.

**Movement Toward Eradication**

In 1917 a new era began in the fight against stem rust. At a meeting of the Tristate Grain and Stockgrowers Convention at Fargo, North Dakota in January of that year, the question of stem rust and how to control it took center stage. Present at the meeting were a number of prominent plant pathologists including H.L. Bolley of North Dakota Agricultural College, M.A. Carleton of the USDA, A.H. R. Buller of the University of Manitoba, and E.C. Stakman of the University of Minnesota. All favored more aggressive action on stem rust and, prior to a scheduled talk on the matter by Stakman, they met to formulate a strategy. All four scientists agreed on three principal objectives: that more attention and funding should be placed on breeding for resistance; that an extensive epidemiology research program should begin, through cooperation between the USDA and different state agencies, to determine the factors affecting the development of rust outbreaks; and that the eradication of barberry be conducted in major grain-growing areas of the Upper Midwest. These were the major points that Stakman emphasized in his formal presentation, and he was obviously convincing. The Convention passed resolutions on all three goals and pledged to help find the support to carry them forward. And, as a direct result of the meeting, North Dakota passed its own barberry law shortly thereafter, becoming the first state in the United States to take compulsory action against the bush (12).

The North Dakota law actually had as much to do with the forceful tenacity of H.L. Bolley as any factor of scientific evidence. In reality, a consensus on barberry eradication had not emerged by the beginning of 1917, particularly on government mandated eradication. A few believed that eradication was unnecessary; others argued that if it were warranted, voluntary action was enough. As E.C. Stakman later disclosed, “nobody really knew how much a factor the barberry was in the development of rust” (100). Since De Bary’s scientific confirmation of the relationship between the rust on barberry and that on grain in the 1860s, scientists had debated the barberry’s role. Investigations already were beginning to reveal that aeciospores from barberry might be limited in the distance of spread from bushes to grain as well as in their germinating powers. Troubling scientists even more were stem rust epidemics that occurred in areas either a good distance away from barberry or where the bush did not exist (47). Still, most scientists by the turn of the century had developed the impression that the barberry was important at least as a local source of inoculum and, thus, eradication on some scale might be warranted in the United States. “While it is indeed impossible to expect if all the barberry … plants in the whole state were once destroyed wheat rust . . . would wholly disappear,” wrote E. W. Olive, botanist of the South Dakota Agricultural Experiment Station, “the experiment would nevertheless be worth trying, if only to try to decrease the local virulence of the disease” (80).

Adding even more credibility to the idea of eradication was a growing climate of acceptance to the increased role of science in the formulation of public policy during the first two decades of the twentieth century. Awareness of the dangers of introduced, foreign pathogens led to an expansion of federal regulatory powers, exemplified by the passage of the Plant Quarantine Act of 1912. Government had become a powerful vehicle for facilitating the control of plant diseases like stem rust (10). Influential, as well, was the recent anti-barberry legislation in Europe, particularly Denmark's law of 1904. Heralded as the first national legislation with "real teeth" because it ordered the complete destruction of barberries, except in botanical gardens and a few other restricted areas, the Danish law was considered a landmark success in a little over a decade (28). American plant pathologists F.L. Stevens and H.W. Anderson wrote just as eradication was on the table in the United States "that the black rust [in Denmark] has disappeared gradually, contemporary with the barberry bush" (104).

The entrance of the United States into World War I in the spring of 1917 had far reaching consequences on the movement for barberry eradication. With the memory of the 1916 stem rust epidemics very much alive, concerns arose over America's ability to feed both her people at home as well as armed forces overseas during wartime. Could the U.S. survive another epidemic year like 1916? This "war emergency" atmosphere drove organizational and financial support for projects designed to maximize food production, with wheat at the top of the priority list. Soon after America joined the war, the War Emergency Board of Plant Pathology was created from the top ranks of the American Phytopathological Society. This Board of eight commissioners set out to drum up support for plant disease control as a means of increasing food production. Stakman, as a commissioner, used this opportunity to convince the other members of the Board, as well as his plant pathology colleagues generally, that stem rust control was a priority, and that barberry eradication was an essential part of it (10).

H.L.Bolley of North Dakota also merged war spirit with the drive for barberry eradication. When cereal pathologists gathered for their Third Annual Field Conference in July 1917 at Madison, Wisconsin, Bolley strongly pushed his case. Not only was barberry eradication necessary, he insisted, but also it could be done quickly. Pointing to the North Dakota law as an example, he bragged that the "work of eradicating barberry bushes in North Dakota has almost been completed" (12).

For most plant pathologists, it was compulsory eradication that was the main sticking point. Stakman later recalled: "The obvious fear of rust really made it possible for the bolder people to push hard now for a national eradication campaign. Heretofore they'd been advocating voluntary eradication, but with the food shortage such as it were and the threat of a disaster from rust, the bold people got bolder and some of the more timid ones got a little less timid, perhaps. Many of them started a 'stop Bolley' movement because they were afraid that this agitation would come to their states and they weren't ready to advocate a law to compel the eradication of barberry. They hadn't objected particularly to voluntary eradication, but when it came to . . . an education or research institution advocating a compulsory law, that was a new precedent, going a bit too far" (12).

The vigorous campaigning by Bolley and Stakman provoked a special meeting of plant pathologists from the central and north-central wheat-growing states in Chicago during February of 1918. At the meeting Bolley continued to press his case for legislation against barberry, arguing that voluntary eradication "would prove, and had proved, ineffective." He also cited recent examples of where the USDA had assumed regulatory powers over agricultural matters insisting, “there was sufficient precedent for compulsory eradication in authority already granted to the Bureau of Animal Industry in controlling and eradicating animal pests” (96). Bolley’s arguments were persuasive. The plant pathologists at the Chicago meeting endorsed his proposal that a small delegation, including Bolley and Stakman, proceed to Washington to solicit federal aid for a regional eradication campaign (12).

The delegates met in Washington on February 21, 1918 where they found a receptive audience at the USDA. First meeting with Associate Chief of the Bureau of Plant Industry, K.F. Kellerman, and H.B. Humphrey of the Bureau’s Office of Cereal Investigations, the group learned that the Department was prepared to aid the effort “in every way possible” (97). Indeed, Secretary of Agriculture D.F. Houston already had shown that he favored action against the barberry. Just prior to their visit, Houston sent letters to various state governors “urging upon them the importance of barberry eradication.” Houston promised “almost to a certainty that the severity of stem rust epidemics can be reduced, even if they are not entirely prevented, by destroying all the common barberry plants.” He further suggested to the governors that “through your State Council of Defense and other appropriate agencies, you request farmers, gardeners, and all other residents of your State . . . to dig up and burn, or otherwise completely destroy, within the next few weeks, all plants of any variety or hybrid of the common barberry” (35). To no surprise, the delegates had a productive meeting with Houston on February 21st. He assured them that the USDA would support their objectives and was willing to “push the barberry eradication campaign as far and as rapidly as power and funds would permit.” Moreover, he shared their view that time was of the essence. The barberry eradication campaign would begin immediately under the auspices of a war measure for protecting and increasing food production (97).

### The Organization of Barberry Eradication

Following Secretary of Agriculture Houston's approval, a central barberry eradication unit was promptly organized within the USDA's Bureau of Plant Industry. E.C. Stakman accepted Houston's offer to lead the new program after the University of Minnesota granted his request for a temporary leave of absence. As a part-time collaborator with the BPI's Office of Cereal Investigations since 1914, where the new barberry initiative would be housed, Stakman had been rapidly building a reputation as one of the nation's leading authorities on cereal rust (12). His rising status combined with a dynamic, persuasive personality and a highly visible position as a member of the prestigious War Emergency Board of Plant Pathology gave Stakman a measurable amount of influence in his new position. Over his 15-month tenure as leader, Stakman would be the driving force behind the successful organization of the barberry eradication project.

The first task confronting the new leader was soliciting the participation of the states in the regional plan. The USDA held the position that the federal government lacked the authority to mandate eradication within the individual states; each state needed to outlaw its own barberries (98). The North Dakota legislature had set a precedent in 1917. In other states, however, skepticism and some outright opposition stood in the way, and Stakman realized that he had some selling to do. Immediately, an office staff was quickly assembled, including a professional writer to prepare articles for newspapers as well as farm and agriculture magazines. Contacts were made in different states and within the first several months of the project, a state headquarters was established in each of the 13-targeted states, usually at the state agricultural college, and a state leader was appointed. In most cases, the state leader was a plant pathologist. In addition, an assistant state leader was named, to be paid from federal funds. Stakman coordinated all these efforts, and he traveled far and wide making speeches as well as writing articles (12).

Certainly the reality of staggering losses in wheat due to recent epidemics of stem rust, particularly in 1916, played a major role in the development of the campaign. But war sentiment and appeals to patriotism provided critical momentum as well. States were advised that Secretary of Agriculture Houston requested action as “a war measure of utmost importance” (109). Quickly, the barberry bush became more than just a source of inoculum for stem rust disease: it became a foreign enemy. Thus, the failure to eradicate could be branded as anti-American. A press release from the South Dakota State College of Agriculture, for example, described the bush as “pro-German,” and warned that “it is decidedly disloyal to allow the common barberry bush to live -- it must be treated as a dangerous enemy alien” (41). From the University of Minnesota, Stakman’s mentor E.M. Freeman pronounced that failure to remove the common barberry was an “aid and comfort to the enemy” (23). Posters, already an important part of wartime propaganda, were designed to convey such sentiments (Fig.1). All of these efforts were quite persuasive.

While coordinating the patriotic appeals, Stakman also attempted to cement new alliances outside of science and government. He immediately began to harness leaders in the grain milling and merchandising industries, the railroads, and other agricultural-related businesses to the eradication project. In his view, scientists were unable to carry the load alone; he needed influence, financial resources, and administrative expertise of industry. As he later recalled, “Obviously it seemed that if this campaign was to succeed, you had to have influential people to push it, and insofar as scientists, shall we say, are usually poor lobbyists, and are suspected by money-granting institutions of just wanting to build their institutions for their own satisfaction, it seemed best to have the people who were really affected by rust, to have them help assume their responsibility for carrying things through” (12). Stakman obviously made a convincing pitch for rust control and barberry eradication. Key industry men like the vice president of General Mills, the president of the Northern Pacific Railroad, and the president of Deere-Weber Farm Machinery Company all pledged their support. The industry base would prove to be a vital resource to the eradication effort throughout its history, particularly in terms of lobbying state and federal legislators as well as agricultural organizations. Most immediately, it led to the organization of the Rust Prevention Association, centered in Minnesota, which became formally organized as the Conference for the Prevention of Grain Rust in 1922 (and even later, the Crop Quality Council) (12).

Largely as a result of Stakman’s aggressive leadership, the twelve additional states whose participation in the regional effort was desired soon took the necessary measures to join the campaign. By 1919 the original eradication area included thirteen states (Colorado, Illinois, Indiana, Iowa, Michigan, Minnesota, Montana, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, Wyoming), extending from the northern boundary of the country to latitude 37° and from longitude 80° to 110-115°, an area comprising about 960,000 square miles (Fig. 2). All state legislatures declared the rust-susceptible barberry harmful, outlawed its sale and distribution, and required property owners to destroy bushes on their premises (28). With the thirteen states in place, federal funds were allotted and personnel assigned. The active eradication program was begun.

## **Barberry Eradication in Minnesota**

### The Early Years and the Original Survey: 1918-1925

Minnesota was among the first spring wheat states to inaugurate a campaign to exterminate common barberry for the purpose of reducing the ravages of stem rust on grain crops. In Minnesota, the first volley in the war against barberry occurred on March 19, 1918, when the Commission of Public Safety issued Order No. 28, condemning the bush and calling for its destruction (Fig. 3 A&B). Created as an emergency war board by the state's legislature, the Commission of Public Safety was charged with, among other things, protecting the food supply against shortages (42). The Order declared, "All barberry (*Berberis* sp.) bushes except the species known as Japanese barberry (*Berberis thunbergii*) . . . a public nuisance and a menace to the public welfare," and prohibited "their maintenance, propagation, sale or introduction into the state" (77).

With the legal authority temporarily secured by the emergency declaration, efforts quickly got underway to organize the federal-state campaign in Minnesota. Immediately, the USDA, the University of Minnesota, the Minnesota Department of Agriculture, and other agencies all participated in the new campaign. Order No. 28 gave the State Entomologist the responsibility for the regulatory functions of eradication, but planning and directing the campaign came from a new organizational framework (77). Directed and financed by the USDA Bureau of Plant Industry Office of Cereal Investigations in Washington, D.C., the state headquarters were located at the University Farm in St. Paul. Customarily, the state offices were located at the agricultural colleges in each of the thirteen participating states. At each of these offices, a state leader was assigned an advisory role to plan and direct the campaign in that state and to work closely with the USDA as well as various state agricultural agencies. Federal leader Stakman named E.M. Freeman as the State Leader in Minnesota for 1918. Prominent plant pathologists in each of the participating states were tapped for this position in the initial stages of the program. In addition, a federal employee was assigned as assistant state leader. In Minnesota much of the early responsibility of the assistant state leader involved the direction of the actual fieldwork in terms of eradication and surveys as well as pubic relations (6).

Publicity was critical because of the voluntary nature of the early campaign. Although federal field workers would play a leading role in locating barberry, the assistance of the public was needed. If fact, the greater part of the removal of bushes was intended to come from property owners and occupants as well as nurserymen (77). Purposely, "a very small sum" of money had been allocated for eradication. The Commission of Public Safety insisted that "if proper publicity was given to the order and the digging out put on the ground of loyalty and patriotism very little need be done" by state authorities (90).

In 1918, eradication authorities stressed the patriotic duty of all citizens to destroy barberries. State Leader Freeman incited the public to action by insisting that "the common barberry is an 'aid and comfort to the enemy.'" Informational circulars, posters and plant specimens went out to various public institutions of the state, county agents, local associations and clubs, as well as newspapers (5). Even school-age children would be a vital asset to the location of bushes in towns and cities. The Minnesota Public School system and local scout troops served as the primary vehicles for getting the message out during the spring of 1918 (24).

At the beginning of the Barberry Eradication Program, authorities assumed that most existing bushes were strictly ornamental, that they had been planted in cities and towns (Fig. 4). Minnesota State Entomologist A.G. Ruggles expressed the widely held opinion that “the towns and cities contain more than 95 per cent of the plants while there were “comparatively few barberries” to be “found in the country districts.” With the “biggest problem . . . the eradication of these plants in the larger cities,” efforts during 1918 were directed toward these areas (91).

All in all, Minnesotans made significant progress in locating and eradicating urban barberry bushes in 1918 – approximately 661,000 were found and destroyed. They were removed from nurseries, from parks, and from other public and private properties (roughly 600,000 from nurseries; 61,000 on private and public grounds) (95). One particular standout was the location of hedge of barberry 1210 feet in length at Crystal Bay, Lake Minnetonka (30). During the first phase of the barberry program, bushes were removed primarily by hand digging and pulling. In some cases, bushes were so large they required pulling by teams of mules or tractors (Fig. 5). Evidence also suggests that in the earliest phase of the program, in haste to remove the source of rust infection, bushes were sometimes simply cut off at ground level (6, 49).

Authorities realized that any hope of eradicating the barberry required putting a stop to further plantings. One of their first actions was to halt the sale of rust susceptible barberries from state nurseries and to thwart the new shipment of plants from nurseries outside the state. As soon as Order No. 28 went into effect, a quarantine was placed on all the nurseries of the state (78). The State Entomologist’s Office sent notices to all Minnesota nurserymen that “if any of these orders were shipped from Minnesota nurseries, it must be that they were sent before the order for the eradication of the barberry went into effect . . .. Any billing for barberry sent after that time would be done at the nurserymen's risk." Notices were also sent to all railroads and express companies doing business in the state as well as to all nursery inspectors in other parts of the country (92). Although evidence indicates that eradication was unpopular among some nursery operators (27, 83, 111), "patriotic nurserymen of Minnesota destroyed nearly 600,000 barberry bushes in the spring of 1918" (99).

When the Commission of Public Safety put Order No. 28 into effect during the spring of 1918, it was intended to serve only as a temporary war emergency measure. State barberry authorities, aware of this, promptly began to push for more formal and lasting legislation from the state government. With apparently little political opposition, eradication proponents chose a low profile publicity campaign, mainly through newspapers and the agricultural press. Their strategy worked. On March 21, 1919, the Minnesota Legislature passed a law declaring "all species of the barberry, excepting only the Japanese barberry, and all species of Mahonia . . . a nuisance and menace to the public welfare" and mandating their eradication (Fig. 6 A&B). This law replaced the earlier Order No. 28 and placed barberry eradication on a stronger and more lasting foundation (79).

With the focus on planted bushes in towns and cities, most authorities appeared to have assumed that the eradication effort would be fairly brief, lasting only a year or two. In 1918 sights were set initially on that year's wheat crop and the removal of bushes before rust infections could occur, estimated to be around May 15$^{th}$ (90). Yet the continual location of barberry plantings expanded the field season throughout the summer. In 1919, eradication authorities estimated that the field season would last until mid-summer. Indeed, from April to July, fieldwork took place as planned in many of Minnesota's towns and cities. Survey of towns and cities was accomplished by foot scouting. In smaller towns, men worked alone; in larger towns and cities they often scouted in pairs. Their transportation from town to town was by train (49). Up to July 20, 1919, 542 towns in 78 of Minnesota's 87 counties were included in the search for barberry (50).

It quickly became apparent, however, that large numbers of bushes had been planted as ornamentals around farmsteads and other rural sites (Fig. 7). Eradication authorities were surprised when field crews and property owners increasingly reported bushes in rural areas widely distributed over the southern, central and western parts of the state. Although Minnesota officials reported good progress in removing bushes, they clearly realized that the barberry population had been underestimated and that the single focus on towns and cities was flawed. In 1919 State Barberry Leader L.W. Melander, E.M. Freeman's successor, insisted that "barberry eradication in Minnesota is showing real progress," but he warned "it is still far from completion." Melander estimated that work in the towns and cities could be completed in "another three to five years," but "the rural districts of Minnesota are a larger problem"(49). Minnesotans were told that locating remaining bushes would be a much tougher job than anticipated and the barberry eradication campaign more protracted.

With the realization that there existed a much larger barberry population than expected, the focus of the eradication campaign changed in 1919 from a strict town and city concentration to a search for common barberry in rural territory. Eradication authorities referred to this phase of the campaign as the original farm-to-farm survey. From July to December 1919, field workers began to focus on farmsteads and other rural sites, covering three Minnesota counties by the end of the year (49). In 1920, the original farm-to-farm survey became the main line of attack in the barberry campaign, although the inspection of towns and cities in those counties was conducted simultaneously. The work concentrated in the main grain-growing districts of the state, where every farm in every township in the designated counties was to be examined. At the beginning of 1920, eradication authorities decided to survey contiguous territory starting with the southwestern corner of the state, bordering on northwestern Iowa and eastern South Dakota. These two states also began a simultaneous survey in their adjacent regions. After the completion of the survey of southwestern Minnesota, the plan was to move northward through the Red River Valley. Once all the western counties were completed, field workers would gradually work eastward across the state (49, 50).

The earlier expectation that public participation would limit state involvement significantly appeared less and less realistic by 1920. The change to the original farm-to-farm survey also coincided with the transition from a voluntary program which relied largely on residents to locate and destroy bushes to an increasing reliance on the use of hired field crews backed with the legal authority to locate and remove bushes on private property. State eradication leaders complained that the volunteer program had serious flaws. Landowners and residents, threatened with fines if they failed to remove bushes, simply stopped reporting them. In a number of cases improper identification had led to the wrongful destruction of other shrubs resembling barberry like spirea and firebush (6).

For the original farm-to-farm survey, fieldwork began with four- two men crews working together on a seasonal basis. In the early years of the program, most of the barberry field scouts were students in plant pathology at the University of Minnesota. Their training in plant disease work was considered an important asset to the eradication effort. The crews traveled to rural sites by automobile. They talked to residents, if possible, to learn of any other plantings known or suspected to be barberries. Literature was passed out and specimen barberries were carried frequently to aid in teaching all residents how to identify the common barberry (50).

For the first three years of the campaign, funding had come strictly from the USDA. In 1921, the Minnesota State Legislature appropriated $20,000 a year for two years. Eradication authorities allocated these additional funds to fieldwork and hired extra crewmen. Crew numbers went from 12 in 1920 to 48 in 1922. As a result, 36 counties were completed in 1921, compared with nine in 1920. By the following year, 72 counties had been completed in the original farm-to-farm survey, or "approx. 85% of the territory" to be covered" (52). Moreover, authorities were able to announce that increased appropriations and the subsequent hiring of additional personnel had provided the opportunity to complete the survey in southeastern Minnesota in 1922, the region of the state already regarded as the most difficult to work because of rough terrain (52).

Although the eradication program had begun to rely much more on hired field labor by 1920, authorities still viewed property owners and residents as well as school children as valuable assets in locating and destroying bushes. Eradication officials also realized that general public cooperation was necessary for the program to move quickly. As a result, state forces continued their efforts to distribute newspaper and magazine articles, posters; plus they conducted radio addresses, demonstration fairs, and public lectures (Fig. 8). But meager funding and the lack of a specific publicity agency hampered these efforts (51). The situation changed in 1922, however, with the formation of the Conference for the Prevention of Grain Rust. This organization consisted of four representatives from each of the thirteen north-central states: the governor, commissioner of agriculture, a representative of the experiment station, and the president of the state Farm Bureau Federation or corresponding farmers' organization. Funds to support the activities of the Conference were provided by the railroads, banks, mills, elevators, grain dealers, and farm implement dealers. The organization aided the campaign for barberry eradication by providing personnel, by establishing links with commercial concerns and organizations, by acting as a lobbying group, and by providing publicity (2, 3).

In the nine months after its founding, the Conference for the Prevention of Grain Rust distributed nearly half a million copies of publications. Posters and educational leaflets were sent to "every county agent, railway station agent, bank, mill, elevator, lumber yard, creamery and county auditor" in the state. Also, dried samples of barberry leaves and other educational materials were sent to county agents, local farm bureaus, and schools. The Conference had one full-time person responsible for writing stories for newspapers and magazines, and another full-time person developing exhibits. As a result, barberry displays were presented at county fairs throughout Minnesota in 1922 (2).

Another novel effort to raise the level of public awareness to barberry eradication in the early phase of the program involved organizing "barberry bees," beginning in 1922 (Fig. 9). To remove bushes from large farm sites, farmers in the surrounding areas were invited to assist the field crews in removing the barberry menace. In 1922 for example, more than 200 farmers with their teams of horses and mules joined with state dignitaries such as Lieutenant Governor Louis L. Collins to destroy 4,300 bushes in Red Wing, Minnesota in one day. The idea caught on and was copied by other states in the Barberry Eradication Program beginning the next year (52).

At the same time that Minnesota's barberry authorities were working to garner more public support for eradication, they found themselves perplexed over troubling reports from the field. One startling realization involved the discovery that even with cutting, digging, and pulling bushes viable roots often remained in the soil and sprouted abundantly. Over the next two years, reports of regrowth reached a level where eradication officials suggested that annual inspections or resurveys of all former properties were necessary to locate possible sprouts and seedlings (50). By 1921, resurvey had become a routine part of the annual eradication effort (51).

Regrowth remained "the main problem of the Barberry Eradication Campaign," however, but authorities insisted that resurvey alone was not the solution. Some change in eradication methods was necessary (1, 52). One potential answer was a suitable chemical substitute for mechanical eradication (1). Under the direction of the USDA's Office of Cereal Crops and Diseases, N.F. Thompson and W.W. Robbins conducted experiments with 37 chemicals between 1921 and 1925. By the end of these studies, eradication methods had been altered to include the use of crushed rock salt, kerosene, and sodium arsenite. Sodium arsenite was effective in killing bushes, but it also proved quite attractive to livestock and other animals, and thus its use was discontinued rather quickly. Kerosene would be used on occasion, but its mode of action proved relatively slow (39, 110, 112). Salt, on the other hand, became the method of choice by the mid-1920s and would be used extensively in the eradication campaign over the next two and a half decades (Fig. 10).

To meet demand, large amounts of salt were transported by rail to local depots where it was then distributed by trucks. In the mid-1920s, field crews continued to pull bushes before pouring salt into the hole to prevent the development of sprouts. Sometime later, the decision was made to dig a trench around the condemned bush and to pour salt around the standing bush rather than removing it (Fig. 11). In theory, the standing bush would absorb the salt and be killed. About 20 pounds of salt or gallon of kerosene was applied to kill a medium-size bush, although up to 100 pounds were commonly used on large bushes.

In 1923, the eradication campaign was directed toward the northeastern region of Minnesota for the first time. The survey comprised the major part of what is known as the "cutover section" of the state, where lumbermen and forest fires had previously stripped the region of all timber of economic value. Roughly ten northeastern counties were surveyed in the farm-to-farm survey during that year. Field crews, however, located "very few bushes . . . in this section of the State." They found only 106 bushes on 27 properties in the original farm-to-farm survey in 1923. Eradication authorities concluded from this evidence that "we have sufficient data on this section to prove that our most important problems lie in other sections" (53). Indeed, the northeastern region of Minnesota would never again be considered a priority during the entire history of the Barberry Eradication Program.

At the end of 1925, Minnesota eradication authorities declared the original farm-to-farm survey completed (Figs. 12-14). So far, the entire area of Minnesota had received an inspection consisting of a check of each rural and city property for planted barberry bushes. Since the beginning of the campaign, field crews had inspected sites in 87 counties and 779,502 bushes had been located and destroyed on 4,650 city, town, and rural properties (Fig. 15). After the initial 661,000 bushes were destroyed in the first year of the campaign (1918), an additional 115,502 bushes were removed between 1919 and 1925 (Fig. 15). Since resurveys had begun in 1919, nearly 80,000 new sprouts and seedlings had been found on roughly 4,000 sites where bushes had been previously removed (55). Sixty-six percent of the properties where crews located bushes were in towns and cities (Fig. 16). The remaining bushes were found on rural properties, either as planted bushes or escapes.

With the close of the 1925 field season, the barberry eradication campaign in Minnesota finished its eighth year. A number of changes, particularly in methods used, had occurred over the course of this period. In 1918, for example, searching for planted bushes in city and towns was the main line of attack, whereas, by the 1920s, the focus had shifted to rural plantings. Also, where the campaign had begun as a volunteer effort in 1918, the eradication program came to rely heavily on hired field personnel by the beginning of the 1920s. The actual methods of eradication had been altered significantly as well over the eight years. Where the original methods used for eradication were digging, pulling, and cutting, by 1925 most of the bushes were killed with salt. Other changes also were evident. When the campaign began, most eradication experts assumed that the effort would be fairly brief, lasting only a couple of years until planted bushes were removed from towns and cities. It did not take long for the awareness of rural plantings to extend this estimation, however. Still, when the original farm-to-farm survey got underway, authorities continued to predict the complete removal of barberry within a relatively short number of years. But new information on the barberry population in Minnesota changed the picture significantly. With the realization that barberry bushes had escaped cultivation and were growing wild in many areas along fence rows, in pastures, and in woodlands, new survey strategies were necessary. Eradication authorities might still have proclaimed that their "goal was the last bush," but they were painfully aware that the war against barberry was no short-term endeavor (52).

**The Second Survey: 1922-1932**

When the Barberry Eradication Program began, most if not all scientists assumed that common barberry were confined to planted sites. It was known that the barberry had escaped from cultivation in the New England States, but it was not generally believed that barberry had escaped from cultivation to any great extent in the grain-growing regions of the Great Plains (6, 48, 91, 94). But as the field crews scouted around farmsteads during the early days of the original farm-to-farm survey, they continually located bushes that had obviously escaped from cultivation. To the surprise of most eradication officials, common barberry bushes were found growing wild in many areas -- along fencerows, in pastures, and within woodlands (Fig. 17). Even worse, many instances began to arise where crews found barberries in places not even associated with existing houses or farms.

As early as 1920, eradication authorities in Minnesota considered escapes a threat to the success of the program, especially with the apparently large populations being uncovered in the southeastern corner of the state. In Fillmore County alone, for example, 5,500 bushes were located on 39 properties in 1920 (51). Eradication workers surmised that the southeast "presents as difficult problems of eradication as can be found anywhere in the Barberry Eradication area." They based these conclusions on the topography of southeastern Minnesota, which "presents an ideal environment for common barberry seeds to germinate and grow almost any place they happen to fall." Authorities made a direct association between the large populations and "the limestone hills" that "seem to be conducive to escaped barberry bushes." In Goodhue County, field crews surveyed an area near Red Wing in 1922 where escaped bushes were found in 43 contiguous square miles (51) (Fig. 18).

With nearly 54,000 escaped bushes found in 29 counties during the first four years of the program, eradication officials realized that the classification of counties as "completed" under the original farm-to-farm survey reflected more of an exercise in semantics than the reality of barberry populations. As a direct result, they decided to conduct a small second farm-to-farm survey of two counties in the southeast region of the state, Nicollet and Freeborn, in 1922. Over 1000 bushes were found in these two counties during the year, but no decision was made to alter fundamentally the general direction of the survey (55).

The situation changed the next year, however. In August 1923, eradication authorities decided to shift field crews quickly from northeastern Minnesota, where relatively few bushes had been found, to the Red River Valley area to conduct a second farm-to-farm survey. A major stem rust epidemic in this region that year led officials to conclude that significant sources of inoculum from barberry remained in the principal grain-growing districts of the state. In the background uncertainty regarding the thoroughness of the original survey was growing (53). Ample evidence indicated that escaped bushes, particularly in the southeast, posed an incalculable problem. Barberry authorities acknowledged, "Some years will elapse before the supply of stem rust inoculum is cut down to a negligible degree from this section" (53).

The second farm-to-farm survey activities in 1923 and 1924 yielded "a significant number of missed plantings" in the counties covered. Eradication officials felt compelled to acknowledge, "It has always been the opinion of this office that no matter how thorough and conscientious a barberry field man may be, there is always a possibility of missing bushes" (53). Indeed, by 1924 they had come to the conclusion that just this possibility had occurred.

With the discovery of significant numbers of escaped and missed bushes in the selected counties, the second farm-to-farm survey became the focus of the program's statewide field efforts during and after 1924. The overall goals of the program remained essentially the same, if altered somewhat by the vastly expanding picture of escapes. These goals centered on the repetition of the surveys until all properties were cleared of barberries and placed on a maintenance basis. At that time, reinspections for re-growth or resurveys would be the only requirement of the eradication effort. Barberry officials even hoped that state weed inspectors would conduct this future resurvey work rather than regular barberry scouts (53). But eradication authorities realized that resurvey could only truly be effective when no new sites were located. Escapes continued to confound these goals (64). The slogan for 1924 read, "Get the stragglers, of which the last bush is a member" (54).

The decision was made to focus first on the counties along the western wheat belt of the state and gradually move east through the central counties before concentrating on the southeast. Plans called for a slower, more "systematic" procedure than occurred with the original farm-to-farm survey. Much of the reason behind the incomplete original survey, barberry authorities insisted, lay in the inexperience of early field crews as well as the public generally. Better training and publicity gave officials reason to assert that the second survey would be more meticulous (53, 54).

Eradication authorities also maintained that inexperience alone probably failed to explain the ineffectiveness of the original farm-to-farm survey. Instead, the current methods of locating bushes were far from perfect. Field crews basically inspected sites of likely planted bushes and then searched areas of close proximity for escapes. Finding missed plantings might not pose an intractable difficulty under these relatively constricted inspections, but locating escapes, especially on sites remote from existing houses and farms, was another story. Authorities rested their hopes on the development of better survey methods over time, just has salt had replaced digging and pulling by the early 1920s. They told Minnesotans that "to correct fallacies in the working machine of the barberry eradication campaign" required a natural evolution of knowledge. "Some mistakes have been made," eradication officials admitted, "but better methods can only be evolved through failure of former methods" (55).

Although when the second farm-to-farm survey began scouting strategies remained quite similar to those used previously during the original survey, there were adjustments made to accommodate the need to locate escaped bushes. These represented the first of a series of efforts to improve survey methods. Scouting procedures were altered to include an enlarged search of the environs near farmsteads where bushes might grow and crew size was increased by a couple of men. Known as farmstead survey, it began with a visit to the rural property, a short discussion with the residents, and an attempt to inform the residents of the appearance of the barberry and the rust to which it served as host. At the visit, the men made a thorough inspection of the planted shrubbery in the lawn, garden, and orchard. If barberries were found at these sites, then the men made a close inspection of adjacent fence rows, pastures and woodland, if any. Scouts also were on the lookout for abandoned home sites and cemeteries. Farmstead scouting required careful organization in order to make it effective. The use of reliable county maps was imperative. County maps served as a guide for the scout and also as a record of the roads traveled and the inspection accomplished (6).

In addition to subtle adjustments in scouting methods and slightly larger crews, there were fresh ideas as well. In 1923, E.M. Freeman and L.W. Melander proposed that escaped barberry bushes might be located in conjunction with "simultaneous surveys" for stem rust (26). The principle was that escaped barberries in close proximity to fields of small grains could be located through the local epidemics they produced. Cases existed where barberries had been located in Minnesota by this approach (Fig. 19) (53, 103). The question was whether simultaneous surveys could be "applied in those large regions . . . where the whole area has been completely surveyed and resurveyed." If so, a potentially more directed and less expensive method than the repeated surveys might provide "complete eradication in the immediate future" (26).

The procedure involved rust surveys over certain fairly uniform areas during the time of year (late spring, early summer) when local epidemics were most possible and detectable before epidemics became more general. The survey required the collection of as many typical samples of rusted small grains and grass hosts as possible over the area. Sample locations were recorded and mapped and estimates made of the percentages of infection. The average mean percentage of stem rust from the field estimates was then calculated and divided into three categories of infection: light, moderate, and heavy. These classes were used to plot the relative degrees of infection on a map. The location of barberries might explain differences in rust infections (26, 53). Scientists were aware that aesciospore infection was heaviest in fields nearer the source of inoculum and progressively declined with distance. Areas with heavy infection would indicate the most likely location of existing barberry bushes (26, 103).

Beginning in 1924, epidemiology studies became a part of the Barberry Eradication Program in Minnesota. A major impetus behind this decision was the hope of locating escaped bushes, but the desire for basic knowledge on epidemiology of stem rust provided momentum as well (54). To the disappointment of barberry officials, simultaneous surveys never really functioned well as an alternative method for locating escaped bushes. Over the next few years, scouts did occasionally locate small numbers of escapes, but not on a level to manage effectively large escaped populations, particularly in the southeast. Barberry officials found that several biological problems thwarted their efforts. Barberry, for example, failed to become infected every year, as did crops growing nearby. Hence, during conditions unfavorable for rust development, locating barberries was impossible by this method. Also, the period when local rust spread could be observed was limited because within a short time local infection centers were apt to be obscured by a general spread of disease from secondary urediniospore inoculum. Quickly, eradication authorities perceived that any system capable of managing these biological phenomena "would be more costly than the system of organized barberry surveys" (94).

By the end of the 1925 field season, the second farm-to-farm survey had covered a sizable amount of territory. All counties along the western border of the state had been completed and field crews had extended their scouting into a number of counties in the central and southern regions of Minnesota. Since the second survey began in 1922, 6,564 bushes and seedlings had been found and destroyed on 419 properties. The majority of these bushes were missed plantings (2685 compared to 1198 escapes). With significantly fewer escapes than missed plantings found in the western counties, eradication officials deduced that barberry populations in that region were nearly reduced to a manageable level (55). This was not the situation further east, however. As the survey pushed east from the western border in 1926, field crews located an appreciable number of escaped bushes. Escapes were found on 42% of the rural properties surveyed that year and comprised about 62% of the total bushes found, percentages that eradication officials considered alarmingly high. On another level, 95% of the 22,485 bushes found in Goodhue County and 17,356 of the 21,112 bushes located in Fillmore County since the beginning of the campaign were escapes (103). That most of the southeastern counties remained to be scouted in the second survey; an area already considered the most difficult because of escapes and seedlings, further elevated the level of concern (56).

In addition to the problem of escapes, the issue of re-growth on previously eradicated sites continued to trouble barberry officials. The use of salt appeared to have checked the earlier sprouting predicament that had come with digging and pulling bushes, but field crews throughout the middle and late 1920s found plenty of evidence to suggest a lurking crisis from the production of scores of seedlings on sites where fruiting bushes had been previously destroyed (Fig. 20). With regard to missed plantings and escapes, barberry authorities had modified scouting methods. But new scouting methods were short of a solution to the mounting seedling problem. It was obvious to eradication officials that all sites of previous activity would need to be checked periodically for re-growth. But how often and at what distance from the original seed sources were unknown.

In the early days of the eradication campaign when barberry populations were considered to be all cultivated bushes, officials insisted upon annual re-inspections on town, city and farm sites. The rapid awareness of significant numbers of wild barberries, however, nullified any plan of yearly resurveys. Eradication authorities realized that annual visits to vast numbers of active sites were unfeasible. But if they perceived that annual inspections were impractical, eradication officials lacked a clear estimation of how often sites required revisiting to prevent re-growth. Moreover, the knowledge of escaped bushes concomitantly brought out the awareness that barberry seeds could be dispersed over some appreciable distances. Birds already had been implicated as the possible main source of seed spread (51). This raised the additional question of what distances from the original seed source would need to be checked for seedlings. These questions would pester the program for years to come.

Gradually, barberry officials decided that one possible solution to the seedling problem lay in understanding the life cycle of barberry. In the early years of the campaign, little was known about germination rates, seedling mortality, time to reproductive development, seed dispersal, or habitat. These basic aspects of barberry biology and ecology were considered largely irrelevant to locating and destroying bushes. Perhaps as much as any factor, the ever-increasing size of the seedling problem became an impetus for an in-depth study of the biology and ecology of *B. vulgaris*. Begun on a small scale in the late 1920s, studies on barberry biology and ecology would play a key auxiliary role in the Barberry Eradication Program over the next decade or so.

The issue over seedlings and resurvey already had fundamentally altered the program. Where officials initially had predicted a relatively short campaign lasting only a few years, they were declaring by the late 1920s that, with the problem of re-growth, some type of eradication effort would be necessary indefinitely. "Resurveys will always be necessary regardless of the intensity of the preceding survey," eradication officials asserted in 1928. "Young bushes are constantly developing in the vicinity of former locations of common barberry. All of these cannot be found and eradicated by . . . survey. In the first place, many of them are so small at the time the work is done that it is impossible to detect them…. It is our opinion that resurveys can never be eliminated" (57).

At the end of its first full decade the eradication campaign had become mired in southeastern Minnesota. One indication of the loss of momentum was the proportional drop off of the amount of territory covered as field crews found large numbers of escaped bushes in the southeastern counties. Another was in the general mood of eradication officials, who complained that escaped barberry bushes appeared to be everywhere (Fig. 21). Eradication officials pessimistically concluded in 1929 "that the whole southeastern Minnesota should be considered as one area of escaped barberries." In Fillmore County, to give just one example, "bushes were found growing in almost every conceivable place" (65). The realization of swelling numbers of difficult-to-locate bushes in the southeast caused eradication officials to back off from predictions of when the second survey might be completed. It was evident that "cleaning up" this portion of the state would take many more years than earlier forecasted.

Compounding this uncertainty was a decrease in federal funding for the eradication effort (66). A concern that the cost of locating the additional bushes was becoming prohibitive precipitated a major shift in the program. Beginning in 1929, a new emphasis was placed on informational activities. The new emphasis was on providing appropriate and timely information to farmers and their children as well as other landowners, so that they could recognize barberry, and landowners could remove barberry on their land. In areas where many bushes were present in pastures and timberland, campaign officials also were turning to employment of temporary local labor to remove such bushes. Thus, although earlier emphasis had been on survey and removal of bushes by state crews paid with federal funds, the new emphasis shifted from funding the actual search for bushes to a program that relied increasingly on a more systematic effort to disseminate information among farmers. As Minnesota's eradication officials explained, "We are attempting to lay a ground work to put the barberry campaign on a basis that will make it live in the minds of the people to the extent that . . . can be relied upon to carry on the work indefinitely” (67).

The informational phase of the program was elevated in status even further as federal funding fell sharply in 1932. Barberry officials found themselves with budgets half of their usual amounts. One of the first casualties was a significant reduction in personnel. As a result, eradication authorities decided to suspend survey efforts “indefinitely” and to focus on the information program. The main informational activity was centered in schools. Promotional materials, lesson plans, and materials for students to take home and complete were sent to all public schools throughout Minnesota. “Rustbuster” clubs also provided recognition medals for rural children who reported the locations of barberry bushes (68) (Figs. 22-23).

A total of 89,143 barberry bushes and seedlings had been found and destroyed on 1,195 properties during the entire period of the second farm-to-farm survey between 1922 and 1931 (Figs. 24-25). Of the 26,137 bushes destroyed, 79% were escapes (Fig. 26). Seedlings and the problem of regrowth were increasingly important during this period (Fig. 27).

By the early 1930s, plant pathologists in charge of the state program pointed to a reduction in wheat losses to make the case that eradication had been effective. According to their estimates, in the years from 1923 to 1930, the average annual loss from stem rust was 10.2 %, down 5.4 % annually from the previous eight-year period (66). Nevertheless, eradication officials fretted over the large number of escapes in the southeast as well as the simmering problem of re-growth throughout the state generally. They insisted that both surveys to locate new sites and the reinspections of old ones must be maintained or “our original efforts to get rid of the barberries will have been wasted" (65). Eradication leaders continued to insist that their mission was "to find and destroy the last common barberry bush . . . in Minnesota" (66). In 1932, however, it was obvious that they had serious doubts that this would occur.

**The New Deal Era and the Initial Intensive Survey: 1933-1942**

At the beginning of the 1933 field season the prospects for extensive barberry eradication field operations in Minnesota were meager. America's mounting economic problems in the midst of the Great Depression seemed to offer few bright prospects for the eradication effort. Accordingly, eradication officials decided to attempt a localized clean-up of escaped bushes reported in counties where the assistance of school children had been enlisted. Between June and August, field crews worked in Pope, Stearns, Goodhue, and Wabasha counties on this clean-up operation (69). But circumstances radically altered the picture by August. Ironically, America's unprecedented financial troubles would breathe new life into the eradication campaign.

A major change in the Barberry Eradication Program occurred with President Franklin D. Roosevelt's initiation of the New Deal soon after he took office in 1933. That spring and summer, Roosevelt held Congress in session to deal not only with the national banking crisis, but with employment and farm relief as well. This congressional session, later know as the "Hundred Days," enacted a comprehensive body of legislation affecting banking, industry, agriculture, labor, and unemployment. It also had a direct affect on the future of barberry eradication. Created under the National Industrial Recovery Act of June 1933, the National Recovery Administration (NRA) and the Public Works Administration

(PWA) were designed, among other purposes, to reduce unemployment (113). Through these agencies, funds were quickly made available to the Barberry Eradication Program for the purpose of hiring laborers.

The Black Stem Rust Control Project was the first PWA program inaugurated in Minnesota. The PWA made 79 laborers available to the Barberry Eradication Program in 1933, bringing the barberry eradication field force to a total of 91 men. Immediately, the decision was made in August to deploy all field crews to the problem region of the southeast (69).

For several years, the most difficult barberry eradication problems in Minnesota were believed to lie in the southeastern corner of the state. As far back as 1922,when the first barberry survey was made in the region, many escaped barberries were found. Yet since that time, field crews had made only sporadic attempts to resurvey and clean up localized areas of escaped bushes. Eradication officials maintained that an “intensive search” for escaped bushes “would necessitate going over the whole southeastern corner of the State” (69). Until the summer of 1933, the lack of personnel had prevented such a thorough barberry survey. The influx of laborers from the PWA, however, revitalized efforts to survey the southeast (Fig. 28). It also allowed for the deployment of refined scouting methods that had been under consideration since the late 1920s.

In the late 1920s, as stated above, eradication officials had hoped to replace the existing inspection routine with a more intensive survey method of scouting. They insisted that in certain areas of the state, especially the southeast, every possible site of living barberries required a new systematic searching to effectively reduce the population. Limited amount of personnel had barred this goal, however, in the late 1920s. With significant increases in field labor in 1933, new scouting methods became a reality and were incorporated into the field program under the new name, initial intensive survey.

Fundamentally, the new scouting methods involved a much more careful examination of wooded areas where barberries could be growing in conjunction with and partially concealed by undergrowth, weeds, and other shrubs. Not only was more time required that on previous surveys, but more people as well. Large crews of several men working together under a "squad leader" were found to be most effective. A major change in the scouting routine was the initiation of advance work in planned areas. Before the laborers were assigned to scouting certain territory, the squad leaders reconnoitered and laid out the territory to be worked. This was particularly necessary in areas of rough terrain, such as was common in the counties in the southeast.

Once the crews entered the field, a system of "strip scouting" was inaugurated whereby the crew of men working abreast would inspect the territory one strip at a time. Each man would examine a strip of land three to ten yards wide on either side as he progressed across an area. Parallel strips were examined as the crew proceeded together across the woodland or block of territory. The first man in the crew on the first trip would follow a fence or boundary of the areas to be worked. The next man would guide on him and keep abreast, and so on. "Checkers" worked behind the line, each one covering not more than four laborers in the line. "Checkers" were necessary to maintain the proper interval between crew members to make sure that nothing was missed. Not surprisingly, they were chosen on the basis of their ability to locate barberries.

In order to keep lines consistent and to prevent overlap through the woods, the last man in the group needed to make some type of mark on trees, bushes or stones. At the end of each segment the last man would become the leader and follow back close to his line of marks, and the others would take their places in new territory abreast of him. In 1933, State Leader L.W. Melander and G.D. George designed a paddle-shaped device with a handle on one end and a piece of perforated inner tube on the other for the purpose of marking lines (Fig. 29). Powdered lime was put in the tube, and every time it was swung against a tree, stone, or other object, a plain white mark was made. These marks through the woods were found to be “very easy to follow” (69). This flexible system permitted the scouting of irregularly shaped areas in lines that could be adjusted to follow contours. It was also adapted to working the varying densities of undergrowth without overlooking any of the area needing inspection (6).

These new scouting methods were well established as the Barberry Eradication Program entered its second year of operation under the national emergency funding in 1934. For the first time in the program’s history, field activities began with the start of the year. Additional funding from the Civil Works Administration (CWA), which had been created specifically to cushion economic distress over the winter of 1933-1934, allowed for the early launching of activities (113). The CWA funding evaporated in March, but PWA support allowed the field program to run throughout the remainder of the year. Just as it had been during the previous year, the entire focus during 1934 was on the southeast. In addition, field crews concentrated all of their efforts on the five counties considered the most difficult to survey -- Fillmore, Goodhue, Olmsted, Wabasha, and Winona. During these two years, nearly 24,000 barberry bushes and seedlings were found on approximately 700 properties in these five counties, practically all of which were escapes. In addition to these figures, almost

11,000 bushes were located in various parts of the state over these two years through reports by school children as part of the intensive school campaign that had begun in 1929 (69, 62).

With the beginning of 1935, the prospects for an extensive field campaign were not bright. Only a small amount of NRA funding was available during the first half of the year. Consequently, limited survey work was conducted while most efforts were placed on the intensive school campaign up until July (63). Much like two years previously, however, the situation changed abruptly during midsummer. This time it came in the form of an even larger-scale national works program for the jobless -- the Emergency Relief Appropriation Act of April 1935 and the creation of the Works Progress Administration (WPA), a works program of unprecedented proportions. By March 1936, the WPA rolls reached a total of more than 3,400,000 persons. By the time that it was terminated in June 1943, the WPA had employed more than 8,500,000 different persons on 1,410,000 individual projects, and had spent about $11 billion (113). For the first time in the history of the eradication campaign, the program had the funds to hire as many laborers as could be absorbed, trained, and supervised (19). Nearly $2.8 million in emergency funds from the Works Progress Administration were made available for the Barberry Eradication Program between July 1935 and December 1936. This translated into 41,399 man-months of relief employment or an average of 2,764 men per month in the program (20).

When Minnesota eradication officials first began to receive WPA funds in August of 1935, they quickly moved to get back into the field with the intensive survey. That fall, 300 men were added to the program from the “relief rolls,” which allowed for a significant expansion in both the numbers and size of crews in the field. Crew size, for example, swelled to 10 men working under a supervisor who often was in charge of several crews. In

1935, the increase in labor allowed for 1200 square miles of territory to be surveyed in 14 counties. The survey focus continued to be on the southeast (63).

WPA funding in 1936 allowed for field crews to survey throughout the year, a rare occasion in the program's history. At one point in the year, 341 relief workers were employed in the Minnesota campaign and crew size was increased to 20 men. Much of this additional labor became available in the fall, the time of year already considered by eradication experts as the best for bush identification. Eradication officials also decided to shift the survey work west, from the southeastern counties to the south-central district. Although they realized that difficult counties like Goodhue, Wabasha, Winona, and Olmsted were far from bush free, barberry authorities insisted that previous, less intensive surveys and the inability to conduct resurveys had left the potential for large barberry populations in the counties further west. While WPA funding remained strong, eradication officials planned to cover as much of the grain-growing area of the state as possible. "Eventually, we hope to survey the whole grain growing area of Minnesota," eradication leaders declared (71).

Over the next couple of years, the main thrust of the initial intensive survey pushed further west, although some scouting continued in the southeast. By 1937, field crews were scouting throughout the southwest corner of the state, and the next year, began to move northward into the west-central region. To the delight of Minnesota's eradication officials, field crews appeared to be making excellent progress. During 1936 and 1937 alone, field crews covered well over 11,000 square miles in over 30 counties as well as conducting city surveys in St. Paul and Minneapolis (72). This was in marked contrast to approximately 3000 square miles covered in the southeast between 1933 and 1935 (63). The main reason behind the significant increase in square miles related directly to the differences in terrain as field crews moved west.  In contrast to the rough, wooded hillsides of the southeast that made surveys so laborious, the rolling, open terrain with comparatively little timber that crews came upon in the western counties made their job much easier.

Eradication officials also attempted to accelerate survey progress by making adjustments to the scouting methods in response to the changes in topography.  Smaller crews were believed to be just as effective in prairie-type counties in comparison to the southeast region where larger crews were considered requisite.  Thus, crews were split in half in the western counties, allowing squads to cover more territory. Also, in the open prairie terrain, crews were positioned to work in one direction checking fencerows, ditch and creek banks, and small woodlots instead of the intensive switchback system that characterized scouting in the densely forested southeast.  Both the larger numbers of crews and the single direction approach worked to increase the amount of territory scouts could cover.

By the end of 1938, eradication officials reported significant progress -- approximately 29 counties had been completed in the initial intensive survey since this phase had begun in 1933.  A total of 37,766 bushes, 20,216 seedlings, and 55,195 sprouts were located and destroyed on 2,350 properties.  The majority of the bushes found were escapes (90%) located on rural properties (Figs. 30, 31).

Whereas WPA funding had declined and laborers were somewhat fewer in number, eradication officials maintained that the easier terrain of the western counties allowed smaller crews to be just as effective as larger units of previous years (74).  While the amount of territory surveyed continued to increase significantly as field crews pushed west, there was a corresponding decrease in the number of bushes found.  Between 1936 and 1938, roughly 19,756 bushes and seedlings were located as compared to approximately 34,350 in the previous three-year period. Also, there was a marked drop in the average number of bushes found per property as the survey marched west. Between 1936 and 1938, field crews were locating approximately 17 bushes per property compared to an average of 28 per property between 1933-1935 when the intensive survey was confined to the southeast. Eradication officials viewed this lower ratio of the total bushes to the total number of properties optimistically, leading them to predict in 1938 "the intensive survey would be completed in the entire grain-growing portion of the State within 10 years at present rate of funding" (74). On a more somber note, however, many of the bushes were located on old properties. So obviously many bushes had emerged since previous survey efforts, leaving ample room for concern.

This anxiety was manifested in a couple of ways in the late 1930s. One was the revision of future survey plans in 1939 and the other was a renewed concentration on resurvey. In the mid-1930s, Minnesota eradication officials had believed that it would be possible to use several different survey approaches with varying levels of intensity, based on the numbers of previous bushes located in various regions, diverse types of topography, and the recognition of limited resources. Since the inception of the initial intensive survey in 1933, it had become standard procedure during the focus on the southeastern counties to inspect for a minimum of two miles beyond the last located bush. In other words, whenever a bush was located, an area of at least two miles surrounding this location was intensively inspected; and, if more escaped bushes were found, additional territory was scouted until a two-mile barberry free area had been completed. Eradication officials, in their haste to cover more territory in the mid-to-late 1930s insisted that this procedure was too thorough and time-consuming for all counties, particularly for future work in the northeastern, central, and west-central districts. By 1938, they maintained that area surveys (minus the two-mile rule) could work effectively for approximately 26 of the 83 counties remaining to be worked (74). But the continual location of many bushes on old properties during the intensive survey as well as the ever-present anxiety over re-growth in counties already completed led eradication officials to a more cautious approach in 1939. For future surveys, the two-mile rule was readopted in all counties (73).

Concern over re-growth led barberry officials to focus once again on resurvey, beginning in 1939. The assumption at the time was that old properties had to be checked within a five to six year period to prevent the development of new escapes from seed and to catch new bushes before fruit production occurred. In southeastern Minnesota, several years had passed since the intensive survey work in this region between 1933-1935. Eradication authorities maintained in 1939, "The problem of preventing barberry fruit and seed production in old areas of escaped bushes now has to be faced" (73, 75). Consequently, field crews moved back into the southeast and the square mileage covered on survey dropped precipitously. Some of the historically most difficult counties, such as Dodge, Fillmore, Goodhue, Hennepin, Houston, Olmsted, Wabasha, and Winona, were again considered priorities.

Both the initial intensive survey and resurvey work continued in Minnesota over the next three years. By the close of 1942, another 22 counties had been completed in the initial intensive survey, while resurvey was conducted in six southeastern counties. Since 1939, crews had located a total of 12,768 bushes, seedlings and sprouts on 927 properties. For the first time during the program, eradication officials began to differentiate between bushes found on previously inspected properties ("Old") and bushes found on newly located properties ("New") in their progress reports (73). Ten thousand one hundred and ten (79%) of the bushes and seedlings located during this period were on New properties and the majority (97%) were escapes (Fig. 32). Of the 2,658 bushes found on Old properties, 20% were seedlings. Another addition to their progress reports was the inclusion of the total number of Old properties inspected where eradication crews found no bushes. Data on New properties were only recorded when bushes were located (73). Of the total 2,280 Old and New properties inspected, crews found bushes on 337 (15%) Old properties and 597 (26%) New properties (Fig. 33). On the remaining 1,353 Old properties, field crews found no bushes during this period. On average, survey crews located approximately eight bushes per site on Old properties during the period, while they found 17 bushes per site on New properties.

Circumstances changed drastically halfway through the 1942 field season. The cessation of WPA funding, as the New Deal program drew to a close, caused eradication officials to dismiss most of their labor in the field. Subsequently, the initial intensive survey slowed to crawl during the second half of 1942, while resurvey efforts were jettisoned altogether. At the end of the year, eradication officials seriously questioned the future of the Barberry Eradication Program.

On the positive side, eradication officials could point to evidence of genuine progress in 1942. Over the ten-year period since work began under emergency funds, field crews had scouted over 37,000 square miles in the state, the greater proportion under the intensive survey method. Their efforts had yielded nearly 63,000 bushes and seedlings, the vast majority of these escapes growing on some of the most difficult terrain in the state (Fig. 34). They also had covered the principal grain-growing areas of the southern half of Minnesota.

The State Program Leader pointed directly to a comparison of average annual losses over a period of years to demonstrate progress in stem rust control. L.W. Melander wrote (60):

> From 1915 to 1928 the average annual loss to wheat, oats, barley, and rye from stem rust in Minnesota was 11.6 million bushels. For the next 14-year period, this loss was reduced to 5.7 million bushels a year, which represents an annual saving of approximately six million bushels. This reduction in stem rust losses can be attributed to the elimination of more than 990,000 rust-susceptible barberry bushes and to the use of rust-resistant varieties of grain.

Yet, eradication officials were also quick to point out that much work remained to be done and that barberry eradication was far from completed. In fact, much of the southern territory that had been covered in the initial intensive survey effort over the last ten years required repeated, rigorous rework. In spite of the fact that the initial intensive survey had been completed in the southern half of the state, barberry authorities asserted, "we have many counties that cannot be put on an ordinary maintenance basis. There is a tremendous amount of subsequent resurvey that has to be done and will require a large amount of labor in the future" (76). And beyond rework in the southern counties, barberry officials acknowledged that a large amount of initial intensive survey work remained to be done in the northern two-thirds of Minnesota that had received less thorough attention. Although they were becoming less and less concerned about the northeast, the extreme western edge of the north and other important grain-growing areas to the east of the Red River Valley were priorities. At the close of 1942, as WPA funds disappeared, eradication officials warned, "it is essential that some other type of aid be available to supplant WPA. If this is not done, progress costing thousands of dollars in many important agricultural communities will have been naught because if the barberries are not kept from developing, many of these communities will be infested again, and will become a dangerous source of rust for this part of the country" (70). Whether or not their admonitions would be heeded was uncertain.

Historically, the end of the calendar year 1942 marked the end of one of the most profitable eras in the progress of the barberry eradication campaign in Minnesota. When the government agencies were asked to put unemployed men to work in 1933 as part of Roosevelt's New Deal program, the barberry eradication organization was in a fortunate position to utilize a large number of these men and the opportunity was immediately taken to make a systematic and intensive survey of Minnesota. Prior to 1933, it was apparent that the campaign was losing ground with only small amounts of regular funds available. The availability of emergency funds had enabled the program to survey large, rough areas in the southeast and then to spread west. It is doubtful that this would have been possible had it not been for the ironic circumstances of the Great Depression.

**The Completion of the Initial Intensive Survey: 1943-1954**

America's entrance into World War II on December 8, 1941 brought major changes to the barberry eradication campaign in Minnesota. Whereas New Deal resources had provided plentiful labor to survey vast amounts of territory during the previous period, the discontinuance of WPA support, together with general loss of manpower to the war, decimated the labor supply for field crews. During the fall of 1943, for example, only two six-men crews were operating in the field (59). With only meager federal and state funding available and unmanageable shortages of labor, the initial or intensive survey abruptly came to a halt. In its place arose comparatively small rework efforts over the next couple of years designed to check re-growth in some of the most difficult and troubling areas.

Under such circumstances, eradication officials attempted to find alternatives to counterbalance their limitations in the field. One strategy was to work more closely with cooperators, particularly the State Entomologist's Office, the University Extension departments, and the Grain Rust Prevention Association. Eradication officials looked directly to Minnesota's weed inspection service administered through the Entomologist's Office to locate and remove bushes (58). Barberry authorities had hoped that state weed inspectors would remove significant pressure from rework, but this failed to occur. Officials continued to report poor and unreliable results in the field from weed inspectors.

A more novel approach was the inauguration of a "bounty system" around 1943 to excite interest among the public to locate bushes (Fig. 35). Where efforts to get the community involved had waned during the flush years of WPA funding, during World War II barberry officials renewed attempts to involve the public in the location of bushes. "It also was obvious that something had to be done to stimulate public interest in barberry eradication to aid in augmenting our survey program," barberry officials conceded. All across the state, county boards passed resolutions offering bounties for reporting properties having barberries (61). The bounty system drew a measure of attention throughout the war years and would be a part of the program for a number of years afterwards. Although state officials loudly proclaimed its success in stirring public involvement, they never considered the bounty system effective enough to substitute for an organized field program. As it turned out, the bounty system represented the last major initiative to elicit public cooperation in the eradication effort in Minnesota.

In 1943, when eradication officials made the decision to focus on rework instead of the initial intensive survey, the preliminary hope was that intensive survey procedures could be continued, but on a much smaller scale (Fig. 36). Quickly, however, authorities found that field crews were reduced to such levels by the next year that intensive methods were impossible to maintain. Instead, they opted for more limited rework, much closer in practice to the reconnaissance or inspection methods that had been conducted during the original and early second survey phases of the campaign. This new modified program of rework consisted principally of a re-inspection of old properties with a limited inspection of immediate adjacent territory. With the limited amount of personnel available, authorities insisted, “it is impossible to follow through a program of conducting a desirable full-scale rework program that would consist of surveying intensively all territory covering a distance of two miles from old locations” (61). Consequently, the two-mile rule was abandoned for the time being. Since they were concerned primarily with new bushes emerging on old sites, eradication leaders asserted “this type of program was designed to allow maximum coverage of infestation centers with the limited labor available” (105).

Over the next couple of years, as the readjustment from the large survey program with federal emergency funds to a limited-type financed by regular federal and state appropriations occurred, field work consisted primarily of the re-inspection of old properties in more than 23 counties. Much of this limited rework took place in the “prairie type of territory” in the south central and central counties of the state. Eradication authorities argued this was the best decision because it would not only allow for some coverage of important grain-growing areas, but made the most practical sense “with the present limited manpower and funds.” In the meantime, with regard to the troubling southeast, they also insisted, “we will do everything we can with our limited means to get all the fruiting bushes possible" (105).

Barberry eradication officials reported mixed results. On the one hand, considering both the total number of counties visited and the numbers of old properties inspected compared to bushes found, officials maintained that the findings under this limited rework were relatively small. For example, between 1943 and 1945, field crews had inspected nearly 2,600 old properties and had located 3,290 bushes on only 229 of them. Eradication authorities were quick to claim that these data indicated that previous survey efforts had been effective in many counties, particularly in the southwest (61). This led them to conclude for the first time that many square miles of territory could be placed on a "maintenance" basis, and thus would need no further survey work.

The number of bushes and seedlings that crews located on new properties as they conducted rework was a sobering reminder of an underlying problem, however. Of the 94 new properties located between 1943 -1945, nearly all in the southeast, field crews found 2,462 bushes and seedlings. The average of 27 bushes per new site stood in marked contrast to 15 bushes, seedlings, and sprouts found per site on the old properties during the same period. Eradication officials considered "the development of bushes on new properties . . . the most perplexing problem" for the barberry campaign. And most of the problem remained situated in the southeast. "At present," authorities reported in 1944, "we are faced with the problem of the badly infested areas of southeastern Minnesota producing fruiting bushes more rapidly than we are able to rework them. This makes it impossible for us to make real cleanup progress in most of the difficult areas" (61, 105). As a direct result, eradication officials decided to restore the two-mile rule. Nevertheless, the lack of resources and labor severely limited progress during the war years.

With the termination of the Second World War in May of 1945, Minnesota's barberry eradication leaders began to consider the future of the program. First, they took stock of the overall accomplishments in the field. So far, the entire area of Minnesota, 80,883 square miles, had received an inspection consisting of a check of each town, city and rural property for planted barberry bushes with the completion of the original survey in 1925. The discovery of significant numbers of escaped bushes as well as sprouts and seedlings, however, had led eradication authorities to conduct additional surveys and rework efforts since 1922. Unlike the original survey, however, these supplementary surveys and rework campaigns had not fulfilled their attended goals. Eradication leaders insisted that "the lack of continuity of sufficient" resource had prevented "the cleanup of the barberry infestation in Minnesota" (105).

By the close of 1945, 32,458 square miles had received initial intensive survey and 7,681 had been reworked. On the completion of initial work or rework in each county, the area of the county had been classified as to the type of work required in the future. At the close of 1945, it had been possible to eliminate 36%, or 29,258 square miles, of the area of the state as requiring no further work in the future. Over a million barberries had been eradicated from well over 8,000 properties (Figs. 37-38). In addition, as each property was reinspected, the property records were analyzed and those which required no further inspections were classified as inactive. By the end of 1945, 4,399 properties, or roughly 50% of the total, had been classified as inactive (105).

Still, eradication officials insisted that much work remained to be done (Fig. 39). Forty-six percent of the area of Minnesota, consisting of 37,324 square miles in the northern half of the state, where "it has been impossible to maintain a schedule . . . in recent years," required rework. State eradication leaders maintained, however, that knowledge of this area "indicating that barberries are not numerous," meant that this work could be conducted under the farmstead procedures. As had been the practice for decades, the farmstead approach was a limited inspection around the environs near farmsteads as compared to the intensive method where all property was systematically searched. In addition to these square miles needing farmstead rework, another 1,841 square miles in the northern half of the state, where no survey work of any kind had occurred since the 1921-1926 period, required initial intensive survey. In southern Minnesota, an additional 12,459 square miles needed intensive rework. Eradication officials insisted that farmstead methods were ineffective in the southern counties and that the intensive approach had to be used in rework to locate barberries. Eradication officials also warned that "large labor crews will be necessary to accomplish satisfactory progress" in the southeastern region (105).

After the war, the Minnesota barberry eradication campaign continued to operate solely with funds supplied by federal and state appropriations as it had since 1943. Overall funding for the program improved slightly in the years after 1945, as did the availability of labor, but never again reached the numbers seen during the New Deal era. The total numbers of men in the field averaged around 11-12 full-time employees during the next several years with occasional infusions of part-time labor. Thus the numbers of crews in the field, usually two or three, obviously was much smaller than during the 1930s and early 1940s. Another change occurred in leadership. In 1945, L.W. Melander, state leader of barberry eradication in Minnesota since 1920, was transferred to a position with the Federal Program Office. T.H. Stewart was assigned as the new state leader (105).

For the next several years, the fieldwork fell into three main categories: i. initial intensive survey; ii. intensive rework; and, iii. farmstead rework. The basic procedures involved with these various categories remained essentially the same as they had since the 1920s and 1930s. Just as they had during the war, eradication officials continued to adjust the field project to the reality of fewer personnel. One adjustment was the use of "reconnaissance" forays into certain old areas to determine the need for crew work, particularly in the northern half of the state. This method eventually became coupled with the use of barberry biological and ecological data and the history of re-infestation and spread on specific sites to determine work priorities.

The other major change in survey procedure occurred during 1947 when the decision was made, once again, to reduce the amount of territory reworked around old properties from a two-mile radius to a one-mile radius beyond the last bush. During the previous three years intensive rework had been conducted to a full two-mile limit around active barberry locations. In 1947, results of the findings in sixteen counties were studied and analyzed with reference to the distance of re-infestation from the nearest old location. The most important conclusion drawn from this study was that 99.5% of the cases of rework to a one-mile limit would have eliminated all re-infestation, and the remaining 0.5% would have been found by extending rework limits to 1.25 miles. Thus, an intensive rework of 425 square miles (under the one-mile limit) instead of the 1,701 square miles actually worked, would have found and destroyed 99.5% of all re-infestation with only 25% of the outlay of time and funds. Eradication officials were quick to remark, "as rework progressed, it appeared that the use of an arbitrary two-mile limit was involving the coverage of a good deal of territory in excess of that actually required." They also added, 'While it is not intended that the two-mile limit be arbitrarily dropped in favor of a one-mile limit, it does appear that by a careful study of individual properties and areas, we can reduce the time and funds expended without materially decreasing the efficiency of the rework program" (106).

With these adjustments in place, eradication leaders attempted to cover as much of the territory needing initial intensive survey as well as farmstead and intensive rework as possible over the next several years. Their general strategy was to work northward from the south while concurrently moving west and south from the northeastern counties. When significant progress had been made in these regions, field crews would return to the difficult southeast. Beginning in 1946, survey work occurred predominately both in the southwestern and northeastern regions of the state. Over the next couple of years, it shifted to central and north-central counties before moving into the important grain-growing region of the northwest. Survey work was centered in the northern half of Minnesota until 1952 when efforts shifted into eastern central counties and back into southern part of the state.

The year 1954 turned out to be a major milestone in Minnesota's Barberry Eradication Program. At the close of that year, eradication leaders proclaimed that, with the conclusion of work in 12 additional counties, all of the required initial intensive work as well as farmstead rework had been completed. Their pronouncement brought to an end roughly a quarter century of efforts to cover the state with the initial survey. Barberry officials in 1954 indicated that 95.5% of the area of the state was considered on maintenance, while only 4.5% required intensive rework (107) (Figs. 40-41).

Eradication authorities arrived at these calculations in 1954 by a combination of adjusted survey strategies and the reclassification of territory. Since 1946, the amount of territory required for work had dropped off sharply. For example, of the 37,324 square miles estimated for farmstead rework in 1945, 23,624 had actually been completed by 1954. The remaining 13,700 or 37% of the total square miles estimated for farmstead work in 1945, were reclassified during the intervening nine years. The same was true for initial intensive work and intensive rework. In 1945, eradication officials indicated that 1,841 square miles required initial intensive work. By the close of 1954, however, only 493 square miles or approximately 27% of the total estimated in 1945 were completed by this method.

In terms of numbers of bushes found and destroyed as well as properties visited, field crews had located 10,380 bushes, seedlings and sprouts on 4,508 Old and New sites in the intervening eight years between 1946 and 1954. Most bushes were found on Old properties (Fig. 42). Three thousand eight hundred seventy-six (37%) bushes and seedlings located during this period were on New properties and the majority (78%) were escapes. Of the 6,504 bushes, seedlings, and sprouts found on Old properties, 41% were seedlings. Of the 4,191 old sites inspected, 679, or 16% of the total inspected, contained bushes, whereas field crews found barberries on 317 New sites (Fig. 43). The rate at which barberry was reemerging on Old properties appeared to have remained constant (approximately 16% of properties with reemerging bushes) since 1939. On average, survey crews located approximately 9.5 bushes per site on Old properties during the period, while they found 12 bushes per site on New properties.

The completion and elimination of all initial intensive survey work and farmstead rework requirements fundamentally shifted the nature of the Barberry Eradication Program in

Minnesota after 1954. With "the pattern of distribution of barberry . . . established for all areas of the state," eradication officials insisted that future field requirements could be confined to maintenance involving periodic intensive rework of known areas of infestation to prevent re-infestation or spread. In addition, the use of reconnaissance would be continued based on ecological factors and history of re-infestation and spread on specific sites. This strategy, eradication leaders promised, would allow for a reduction in intensive crew work (107).

**Rework: 1955-1990**

After the completion of the initial intensive survey and farmstead rework in 1954, the barberry eradication campaign in Minnesota shifted almost entirely to a focus on rework, the final phase of the program (Fig. 44). Program service activities were limited to small levels of cooperative work conducted through the Cooperative Extension Service and State Department of Agriculture channels. Federal and state personnel continued to offer talks, show films, conduct radio interviews, present exhibits at fairs and distribute bulletins and circulars, but nowhere close to the scale of previous years. The primary route for public participation continued to be the bounty system, with from $2 to $10 paid for each infested property reported. Since the Barberry Plan was adopted, 94 bounty claims had been paid, resulting in the eradication of 1,705 bushes by the end of 1955 (108).

Rework consisted of looking for new growth on old properties where bushes had been found previously. In addition to the likelihood that all bushes had not been destroyed earlier and that not all asexual sprouts had been killed, plenty of evidence had demonstrated that barberry seed could remain viable in the soil for years. Areas infested with bushes were scheduled for the first rework five to seven years following the initial work (R.J. Laudon, personal communication).  Sites were considered “active” for 15 years and checked one or two times during this period of time until there was no evidence of re-growth.  Infested areas were placed on an “inactive” or “maintenance” basis after sufficient rework had been done (119).

The size of the area to be reworked and the way the work was to be done were determined by the nature of a site’s history.  During the rework phase, small crews worked strictly from the use of Property Locator Forms, or L-Forms as they were called, which gave a history of the number of bushes found and destroyed on each site as well as meticulously hand-drawn maps that had been carefully produced during the earlier phases of the program (Fig. 45).  The determination of the work area and procedures used were made on the basis of the probable distance of spread of barberry seed.  If the bushes had never produced seed, only the site of the original bushes was re-inspected.  On the other hand, if fruiting bushes had been found previously, inspection of one-half mile from the “active” site was considered standard procedure, whereas in some cases up to one mile was checked.  Eradication authorities, from their analyses of records, insisted “that the majority of escaped bushes are within a half-mile radius of the fruiting bushes and that fewer bushes are found and the number decreases directly as the distance is increased.”  Before a property could be declared inactive, however, all territory within one mile of the seed sources had to be considered on the final inspection (118).

At about the same time that the program shifted to rework, a major change occurred in the method of barberry eradication. The use of salt had proven quite effective over the past 30 or so years, but not without problems.  By the mid-1930s, many barberry bushes were found in out-of-the way places where salt would have to be carried long distances over rough terrain. With from 10 to 100 pounds of salt used on individual bushes, the need arose for an alternative chemical that could be effective in smaller quantities. This came with ammonium sulfamate (sold under the trade name, Ammate) herbicide (Fig. 46). By decapitating a barberry at the ground level and applying a few ounces of ammate to the cut surface of the crown, penetration took place and a complete kill of the root system followed. Only small quantities were needed for each bush and only a saw or clipper was required to cut the bush, thus reducing the labor of carrying materials to a minimum. Ammate would be used exclusively during the remainder of the Barberry Eradication Program.

Ammate was used particularly in cases where single bushes of a relatively small number were to be eradicated. When treating bushes in ornamental plantings where there was a danger of injury to other vegetation, a concentrated solution or oil-water emulsion of Ammate was painted on cut barberry canes. When large numbers of barberries or large bushes were to be eradicated, however, a 2 to 1 mixture of 2,4-D and 2,4,5-T was recommended. This mixture was applied to the lower 12 inches of the canes and crown while the soil was drenched to a distance of 6 inches outside the area covered by the canes with a knapsack sprayer (120-122).

Over the next 20 years barberry crews continued rework, as they attempted to inactivate as many properties as possible in order to place them on a maintenance basis. From the 2,514 square miles considered to need rework in 1955, this number was reduced by 1,743 to a total of 771 square miles needing rework in 1974 (Table 2). Subsequently, the total square miles needing no additional rework climbed from 78,369 in 1955 to 80,112 in 1974. Barberry crews located and destroyed 15,516 bushes, seedlings, and sprouts on 359 properties between 1955 and 1974 (Table 3). The rate at which barberry reemerged on properties where bushes had been previously removed remained constant, as it had since 1939. The number of properties requiring re-inspections fell by 1,366, from 2,872 in 1955 to 1,506 in 1974. Subsequently, the total number of properties considered completed rose from 6,355 in 1955 to 8,054 in 1974 (Table 3). Although most efforts were focused on rework and Old properties, there were a small number of New properties discovered throughout the period, particularly those reported from public (R.J. Laudon, unpublished).

By 1974, the future of the barberry eradication campaign appeared about as dim as it had at any time before. State assistance had been sharply reduced and federal personnel split between other regulatory activities such as insect and nematode control work. Since 1970, the work force had decreased to four state men and two federal technicians. As a direct result, the rework schedule increasingly had fallen behind. Stearns County, for example, had not been reworked since 1967. Eradication officials warned, “It now appears that the seven-year rework schedule will not be accomplished” (114). Moreover, the last appreciable reconnaissance work on inactivated properties had not been done for ten years.

Concerns about the future of the program heightened considerably in 1975 when eradication leaders announced that federal participation would be phased out and eventually terminated by the end of the decade. Just prior to the decision, federal authorities interviewed state eradication leaders and field personnel as well as small grain breeders and plant pathologists regarding their opinions on the effectiveness and future direction of the program. Plant breeders and plant pathologists said that the program had helped stabilize the stem rust race situation, but they added that “if the program were completely dropped, it would only be a matter of time before forms of stem rust would appear to break resistance in current resistant varieties of small grains." "When this would happen," they insisted, "depends upon how soon barberries reappear in cultivated areas." They estimated there could be a problem within 5 years after barberries were reestablished in grain-growing areas (115).

State and federal field workers also voiced concerns about the potential termination of the eradication program. Field workers, with the most practical experience with barberry, maintained that with the number of active sites remaining in 1975, it was "totally unrealistic, unfeasible, even impossible to predict what properties will have bushes and would therefore have to stay on the active list." Even "if the men could find <u>all</u> bushes," they argued, "the possibility exists that this work" could not be completed until 1995 (34).

Not all of the solicited opinions reflected this pessimism, however. Some prominent USDA scientists and administrators argued that the time had come to consider different approaches to barberry control in light of apparent success in the eradication efforts. "We are ready to move into a new phase of barberry control because the main objective to eliminate these plants as a source of stem rust inoculum has been achieved," one USDA Research Leader declared. To back his claims, J.B. Rowell insisted that there had not been "a single reported incident of spread of stem rust from barberry to a commercial field of small grain" in Minnesota over the last 25 years. Moreover, he added, the physiologic forms of stem rust recently identified from aecia found on barberry rarely turned out to pathogenic on small grains; they normally were forms specifically pathogenic to various wild grasses. Thus, Rowell concluded, "barberry has been effectively removed at the present time as a factor in stem rust epidemics" (89).

This optimistic assessment led to a much different opinion about future plans for the Barberry Eradication Program from those who desired that it continue under existing operations until the last bush was located and destroyed. On the premise that it was "probably impossible to eradicate every existing barberry," Rowell and others maintained the only areas of the state that should receive future rework were those threatened by "a risk" from stem rust. "Clearly barberries cannot be tolerated in the vicinity of small grain crops," Rowell and others insisted (87). Yet for areas where limited small grain production occurred, organized rework efforts were largely unnecessary and could be discontinued. Rowell argued that every effort should be made to complete the rework in those areas of Minnesota where barberries might exist near grain fields, but not through the current single organized effort, which had proven too "formidable and expensive." Instead, some type of "surveillance system" using extension personnel, county agents, and farmers was needed "to detect reestablishment of barberries near cultivated fields so that these plants could be eradicated before they cause a significant rust problem" (89). Ironically eradication leaders, in favor of a continuation of the existing program until the last bush was removed, envisioned a similar system, but only after the entire state had been placed on a maintenance status.

How much these assessments influenced federal barberry directors is unclear, but major program changes soon occurred. In anticipation of the phase out, federal eradication authorities issued new survey guidelines in 1975. Among the specific changes was the period for property inactivation, reduced from the long-held standard of 15 years to a maximum of 10 years after the last fruiting bush had been destroyed. Although theoretically a couple of inspections would occur over this 10 year period on sites where fruiting bushes had been located previously, for those sites where just non-fruiting bushes had been found, only one negative survey was required for property inactivation. Officials also altered the extent of coverage for rechecking properties. The standard procedure of inspecting one-half mile from the specific locations of previous bushes was shortened to rework at 0.1 to 0.2 mile from fruiting barberry and 100 yards from non-fruiting bushes (116). In addition, federal eradication authorities decided to alter the overall rework priority based on the amount of small grain grown per county. To redirect diminishing efforts "to control areas where grain production and danger of disease is most evident," counties with over 30 acres of small grain per square mile were given rework priority in order to place them on a maintenance basis as soon as possible (117).

These changes had a profound effect on barberry eradication in Minnesota after 1975. On a large scale, the decision to prioritize properties based on small grain acreage redirected rework to high production counties, particularly those in the Red River Valley. Counties in southeast and east-central Minnesota for the first time in the history of the eradication campaign were given a low priority, although they contained about 75% of the active barberry area remaining in the state. R.J. Laudon maintained that the reprioritization meant, in affect, that these active properties in the southeast and east-central Minnesota "were for all practical purposes declared inactivated through this change" (R.J. Laudon, personal communication).

On another level, the reduction in the period of time for property inactivation, from 15 to 10 years, resulted in the de facto inactivation of many properties scheduled for rework under the earlier guidelines. Eradication authorities inactivated properties simply by meeting the new criteria. For example, in Dodge County 21 active properties were to be reworked by 1978 under the old 15-year guideline. Yet under the 10-year procedure 18 of these properties were automatically inactivated. As one barberry worker explained, "the new guidelines allowed for review of property L-Forms before they went to the field; inactivation could occur from the office" (84). Indeed when data is compared to previous years, the rate at which properties were inactivated increased significantly after 1974. Between 1955 and 1975, the average rate of inactivation was approximately 90 properties per year, compared with roughly 140 properties per year between 1975 and 1978 (R.J. Laudon, unpublished).

During the fall of 1979, the USDA withdrew from the cooperative Barberry Eradication Program in Minnesota. Responsibility for barberry control was transferred to state regulatory agencies. For the next 10 years, Minnesota furnished monetary support to do some limited barberry eradication work. One to three men were employed for rework intermittently during these years. Public activities, which had been suspended even before the federal phase out, were not revived, however.

When the federal government pulled out of barberry eradication in Minnesota, state authorities decided to reevaluate guidelines for rework, based largely on the recommendations of R.J. Laudon and other field personnel. In an attempt to "place territory on maintenance status as rapidly as it qualifies," areas requiring rework were divided into high and low priority counties. High priority counties were those with an average of 25 acres or more of small grain per square mile rather than the 30 acres specified under the earlier federal guidelines. State officials also amended the schedule of inactivation from 10 years under the prior federal guidelines to 15-20 years after the last fruit production, depending on the particular site location and history. In addition, Minnesota authorities returned to the one half mile rule for rework coverage on sites with fruiting bushes and a quarter mile for sites with isolated non-fruiting bushes (43).

With these new guidelines in place, Minnesota's small barberry force covered as much of the high priority territory as resources allowed for over the next decade. Field personnel conducted rework in approximately 16 counties where an additional 2,736 bushes, seedlings, and sprouts were located and destroyed. For the first time, however, as a direct result of the reevaluation effort, the square miles requiring rework and the number of properties needing re-inspection actually increased over the period (Tables 2-3).

The last barberry eradication work occurred in southeastern Minnesota in the spring of 1990. It was also the last known barberry eradication work in the United States. By that date, approximately 1,030,471 barberries had been destroyed on 9,581 properties in the state (Tables 3-4; Fig. 48). More than 95% of all bushes were destroyed during the first three decades of the program (Fig. 49). These properties were not randomly distributed over Minnesota. They were somewhat concentrated in the southeastern one-third where early settlement and excellent growing conditions had allowed the bush to thrive and escape cultivation. Of the 87 Minnesota counties, 48 had been cleared and were considered barberry free. The properties infested in these counties had been rechecked, normally at 15 year intervals, found negative on the last rework and considered inactive, with no further organized survey work planned. Yet, when the state efforts ended in 1990, active properties remained in Minnesota, although in less than 1% of the 80,883 square miles of the state. In 39 counties, approximately 1200 active sites required rework (Fig. 47).

Even before R.J. Laudon contemplated retirement in 1990, he and others voiced concern over the possible premature termination of the program in Minnesota (17, 18, 44, 45, 88). With many years of experience in the field, Laudon and others insisted that the barberry had the biological capacity to reemerge as a threat to small grains in some areas of the Upper Midwest. Throughout the history of the Barberry Eradication Program, barberry had demonstrated the capacity for reemerging from seed and sprouts on sites previously infested with bushes for a period of years.  The failure to complete the required rework before the termination of the program led Laudon and others to warn of impending reemergence, and, in the process, to cast a cloud over the overall Barberry Eradication Program.

## Literature Cited

1. Anonymous. 1922. Memorandum on Barberry Eradication Campaign, March 27, 1922. Barberry Eradication Records, University of Minnesota Archives.

2. Anonymous. 1922. Proceedings : Second Annual Conference for the Prevention of Grain Rust, November 14, 1922, University Farm, St. Paul. Topical Files, Barberry Eradication. USDA ARS Systematic Botany and Mycological Laboratory, Beltsville, MD.

3. Anonymous. 1926. Barberry eradication reviewed at meetings. USDA, *The Official Record*, Vol. 5, No. 52:1&5. Washington, D.C.: GPO.

4. Atkins, A. 1984. *Harvest of Grief: Grasshopper Plagues and Public Assistance in Minnesota, 1873-78.* St. Paul: Minnesota Historical Society Press.

5. Balmer, J.E., to County Agents, May 1, 1918. Barberry Eradication Records, University of Minnesota Archives.

6. Bills, R.W. 1968. One half century of service: The first 50 Years of barberry eradication. Unpublished Report. USDA ARS Cereal Disease Laboratory, St. Paul, MN.

7. Bolley, H.L. 1889. *Wheat Rust.* Indiana Agricultural Experiment Station Bulletin 26. Lafayette.

8. Bolley, H.L. 1891. Wheat rust: is the infection local or general in origin. *Agricultural Science* 5:259-264.

9. Campbell, C.L., and Long, D.L. 2001. The campaign to eradicate the common barberry in the United States. In *Stem Rust of Wheat: From Ancient Enemy to Modern Foe*, ed. By P.D. Peterson, 16-51. St. Paul, MN: APS Press.

10. Campbell, C.L., Peterson, P.D., and Griffith, C.S. 1999. *The Formative Years of Plant Pathology in the United States*. St. Paul, MN: APS Press.

11. Carleton, M.A. 1899. *Cereal Rusts of the United States: A Physiological Investigation.* USDA Division of Vegetable Physiology and Pathology Bulletin 16. Washington, D.C.: GPO.

12. Christensen, C.M. 1984. *E.C. Stakman: Statesman of Science.* St. Paul, MN: APS Press.

13. Colonial Society of Massachusetts. 1907. January Meeting, 1907. Transactions, 1906-1907, 72-97. Boston: The Society.

14. De Bary, A. 1865-1866. Neue Untersuchungen über Uredineen, inbesondere die Entwicklung der *Puccinia graminis* und den Zusammenhang derselbe mit *Aecidium berberidis*. In two parts, 15-49, 205-215. Berlin: Monatsberichte der Berlinder.

15. Dwight, T. 1821. *Travels in New England and New York*. New Haven.

16. Ebeling, W. 1979. *The Fruited Plain: The Story of American Agriculture*. Berkeley: University of California Press.

17. Fitchett, D.J., to Seetin, M., September 12, 1981. R.J. Laudon Personal Papers, St. Charles, Minnesota.

18. Fitchett, D.J, to Stowell W., December 9, 1981. R.J. Laudon Personal Papers, St. Charles, Minnesota.

19. Fracker, S.B. 1938. Present status of barberry eradication and white pine blister rust control. *Journal of Economic Entomology*. 31:591-594.

20. Fracker, S.B., Popham, W.L., and Bulger, R.O. 1937. A report on the progress made in barberry eradication during the year 1936 including summarized results for the period 1918-1936. U.S. Dep. Agric. Bureau of Plant Quarantine, Washington, DC.

21. Freeman, E.M. 1905. *Minnesota Plant Diseases*. St. Paul: University of Minnesota.

22. Freeman, E.M. 1917. “Rust - Is it a scare? Great danger seen.” *Minnesota Farm Review*.

23. Freeman, E.M. 1918. *The Common Barberry: An Enemy of Wheat.* The University of Minnesota, College of Agriculture, Extension Division Special Bulletin 26. St. Paul.

24. Freeman, E.M., to County Superintendent, April 4, 1918. Barberry Eradication Records, University of Minnesota Archives.

25. Freeman, E.M., and Johnson, E.C. 1911. *The Rusts of Grains in the United States*. USDA Bureau of Plant Industry Bulletin 216. Washington, D.C.: GPO.

26. Freeman, E.M., and Melander, L.W. 1924. Simultaneous surveys for stem rust: A method of locating sources of inoculum. *Phytopathology* 14:359-362.

27. Freeman, E.M., to Tighe, A., March 25, 1918. Barberry Eradication Records, University of Minnesota Archives.

28. Fulling, E.H. 1943. Plant life and the law of man. IV. Barberry, currant and gooseberry, and cedar control. *The Botanical Review* 9:483-592.

29. Galloway, B.T. 1893. Report of the chief of the Division of Vegetable Pathology for 1892. In *Report of the Secretary of Agriculture, 1892*. 215-46. Washington, D.C.: GPO.

30. George, G.D., to Freeman, E.M., May 16, 1918. Barberry Eradication Records, University of Minnesota Archives.

31. Gregerson, R.O. 1932. History of barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

32. Hamilton, L.M. 1939. Stem rust in spring wheat area in 1878. *Minnesota History* 20:156-164.

33. Hitchcock, A.S., and Carleton, M.A. 1893. *Preliminary Report on Rusts of Grain*. Experiment Station of the Kansas State Agricultural College Bulletin 38. Manhattan, Kansas.

34. Hoger, H., to Flaskerd, R., October 15, 1975. Office memorandum. Minnesota Department of Agriculture, St. Paul, Minnesota.

35. Houston, D.F, to Philipp, E.L., February 4, 1918. Topical Files, Barberry Eradication. USDA ARS Systematic Botany and Mycological Laboratory, Beltsville, MD.

36. Hunt, T.F. 1909. *The Cereals in America*. New York: Orange Judd Company.

37. Hurt, R.D. 1994. *American Agriculture: A Brief History*. Ames: Iowa State University Press.

38. Kellerman, W.A. 1891. *Spraying to Prevent Wheat Rust.* Experiment Station of the Kansas State Agricultural College Bulletin 22. Manhattan, Kansas.

39. Kempton, F.F., and Thompson, N.F. 1925. *The Common Barberry and How to Kill It*. USDA Department Circular 356. Washington, D.C.: GPO.

40. Kolmer, J.A. 2001. Early research on the genetics of *Puccinia graminis* and stem rust resistance in wheat in Canada and the United States. In *Stem Rust of Wheat: From Ancient Enemy to Modern Foe*, ed. By P.D. Peterson, 51-82. St. Paul, MN: APS Press.

41. Larsen, C. 1918. April 22, 1918. Cooperative agricultural extension work. South Dakota State College of Agriculture Press Release 901. Brookings, SD. Topical Files, Barberry Eradication. U.S. Dep. Agric. Systematic Botany and Mycological Laboratory, Beltsville, MD.

42. Lass, W.E. 1998. *Minnesota: A History*. New York: W.W. Norton.

43. Laudon, R.J. 1980. Guidelines for Barberry Control. Unpublished document. Minnesota Department of Agriculture, St. Paul, Minnesota.

44. Laudon, R.J., to Flaskerd, R., September 30, 1975. R.J. Laudon Personal Papers, St. Charles, Minnesota.

45. Laudon, R.J., to Stowell, W., December 13, 1981. R.J. Laudon Personal Papers, St. Charles, Minnesota.

46. Lind, J. 1915. *Berberisbusken og Berberislovan* (The Barberry Bush and Its Law). Kobenhaven: Tryke Hos Nielson & Lydiche.

47. McAlpine, D. 1906. *The Rusts of Australia. Their Structure, Nature, and Classification*. Melbourne: Government Printer.

48. Meier, F.C. 1933. The stem rust control program. *Journal of Economic Entomology* 26:653-659.

49. Melander, L.W. 1920. Resume of the Barberry Eradication Campaign in Minnesota, 1919. Barberry Eradication Records, University of Minnesota Archives.

50. Melander, L.W. 1921. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1920. Barberry Eradication Records, University of Minnesota Archives.

51. Melander, L.W. 1922. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1921. Barberry Eradication Records, University of Minnesota Archives.

52. Melander, L.W. 1923. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1922. Barberry Eradication Records, University of Minnesota Archives.

53. Melander, L.W. 1924. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1923. Barberry Eradication Records, University of Minnesota Archives.

54. Melander, L.W. 1925. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1924. Barberry Eradication Records, University of Minnesota Archives.

55. Melander, L.W. 1926. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1925. Barberry Eradication Records, University of Minnesota Archives.

56. Melander, L.W. 1927. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1926. Barberry Eradication Records, University of Minnesota Archives.

57. Melander, L.W. 1929. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1928. Barberry Eradication Records, University of Minnesota Archives.

58. Melander, L.W. 1942. The importance, progress, and future needs of the Barberry Eradication Campaign in the State of Minnesota. Unpublished report. Barberry Eradication Records, University of Minnesota Archives.

59. Melander, L.W. 1944. Status of Barberry Eradication in Minnesota with a report of progress in 1943. Barberry Eradication Records, University of Minnesota Archives.

60. Melander, L.W. 1945. *Barberry Eradication in Relation to Stem Rust of Wheat, Oats, Barley, and Rye.* University of Minnesota. Agricultural Extension Service Extension Folder 127. St. Paul.

61. Melander, L.W. 1945. Status of Barberry Eradication in Minnesota with a report of progress in 1944. Barberry Eradication Records, University of Minnesota Archives.

62. Melander, L.W, and Brueggeman, E. 1935. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1934. Barberry Eradication Records, University of Minnesota Archives.

63. Melander, L.W, and Brueggeman, E. 1936. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1935. Barberry Eradication Records, University of Minnesota Archives.

64. Melander, L.W., and Holmberg, N.J. 1925. *Report of Barberry Eradication to December 1, 1924.* State of Minnesota Department of Agriculture Bulletin No. 40. St. Paul.

65. Melander, L.W, and Thompson, H.B. 1930. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1929. Barberry Eradication Records, University of Minnesota Archives.

66. Melander, L.W., and Thompson, H.B. 1931. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1930. Barberry Eradication Records, University of Minnesota Archives.

67. Melander, L.W, and Thompson, H.B. 1932. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1931. Barberry Eradication Records, University of Minnesota Archives.

68. Melander, L.W, and Thompson, H.B. 1933. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1932. Barberry Eradication Records, University of Minnesota Archives.

69. Melander, L.W, and Thompson, H.B. 1934. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1933. Barberry Eradication Records, University of Minnesota Archives.

70. Melander, L.W, Marshall, W.H., Roberts, W.B., and Fast, I.M. 1943. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1942. Barberry Eradication Records, University of Minnesota Archives.

71. Melander, L.W, Marshall, W.H., Stewart, T.H., and Brueggeman, E. 1937. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1936. Barberry Eradication Records, University of Minnesota Archives.

72. Melander, L.W, Marshall, W.H., Stewart, T.H., and Brueggeman, E.. 1938. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1937. Barberry Eradication Records, University of Minnesota Archives.

73. Melander, L.W, Marshall, W.H, Stewart, T.H., and Rohrs, L. 1940. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1939. Barberry Eradication Records, University of Minnesota Archives.

74. Melander, L.W, Marshall, W.H., Stewart, T.H., and Stewart, E. 1939. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1938. Barberry Eradication Records, University of Minnesota Archives.

75. Melander, L.W, Marshall, W.H., Powers, F.B., Rohrs, L., and Lien, M.K. 1941. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1940. Barberry Eradication Records, University of Minnesota Archives.

76. Melander, L.W, Marshall, W.H., Powers, F.B., Ludwig, C.E., Bannister, Z.M., and Fast, I.M. 1942. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1941. Barberry Eradication Records, University of Minnesota Archives.

77. Minnesota Commission of Public Safety. Order No. 28. March 19, 1918.

78. Minnesota Department of Agriculture. Entomologist's Office. Quarantine Notice No. 3. April 1, 1918.

79. Minnesota, General Laws. 1919. Chap. 81, S.F. 120.

80. Olive, E.W. 1908. *Rust of Cereals and Other Plants*. South Dakota Agricultural Experiment Station Bulletin 109. Huronite Printers.

81. Pammel, L.H. 1892. *Experiments with Fungicides: Experiments in Preventing Rust of Wheat*. Iowa Agricultural Experiment Station Bulletin 16. Ames, Iowa.

82. Peterson, P.D. 2001. E.M. Freeman: Early research on cereal diseases and the rise of plant pathology at the University of Minnesota. *Annual Review of Phytopathology* 39:13-26.

83. Reid, E.W. (Holm & Olson Nurseries, St. Paul, MN), to Freeman, E.M., March 19, 21, 1918. Barberry Eradication Records, University of Minnesota Archives.

84. Ring, W.M., to District Directors, September 12, 1975. R.J. Laudon Personal Papers, St. Charles, Minnesota.

85. Roelfs, A.P. 1985. Epidemiology in North America. In *The Cereal Rusts*, ed. By W.R. Bushnell and A.P. Roelfs, vol. 2, 403-434. Orlando, Florida: Academic Press, Inc.

86. Roelfs, A.P. 1985. Wheat and rye stem rust. In *The Cereal Rusts*, ed. By W.R. Bushnell and A.P. Roelfs, vol. 2, 3-37. Orlando, Florida: Academic Press, Inc.

87. Roelfs, A.P., to Flaskerd, R., December 9, 1975. Minnesota Department of Agriculture. St. Paul, Minnesota.

88. Roelfs, A.P, to Seetin, M., October 9, 1981. R.J. Laudon Personal Papers, St. Charles, Minnesota.

89. Rowell, J.B., to Flaskerd, R., December 2, 1975. Minnesota Department of Agriculture. St. Paul, Minnesota.

90. Ruggles, A.G., to County Director of The Minnesota Commission of Public Safety, April 8, 1918. Barberry Eradication Records, University of Minnesota Archives.

91. Ruggles, A.G., to Minnesota Commission of Public Safety, June 13, 1918. Barberry Eradication Records, University of Minnesota Archives.

92. Ruggles, A.G., to Minnesota Nurserymen, May 18, 1918. Barberry Eradication Records, University of Minnesota Archives.

93. Schafer, J.F., Roelfs, A.P., and Bushnell, W.R. 1984. Contributions of early scientists to knowledge of cereal rusts. In *The Cereal Rusts*, ed. By W.R. Bushnell and A.P. Roelfs, vol. 1, 3-38. Orlando, Florida: Academic Press, Inc.

94. Shepherd, D.R. n.d. The barberry eradication program. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives

95. Stakman, E.C. 1918. Annual report of The Barberry Eradication Campaign of 1918. Barberry Eradication Records, University of Minnesota Archives.

96. Stakman, E.C. 1918. Minutes of Barberry Eradication Conference, held on February 18, 1918, Chicago, Illinois. Topical Files, Barberry Eradication. USDA ARS Systematic Botany and Mycological Laboratory, Beltsville, MD.

97. Stakman, E.C. 1918. Minutes of the Conference with officials of Department of Agriculture held on February 21, 1918. Topical Files, Barberry Eradication. USDA ARS Systematic Botany and Mycological Laboratory, Beltsville, MD.

98. Stakman, E.C. 1918. Notes on the Conference meeting of the War Emergency Board, American Plant Pathologists, held at LaFayette, Indiana, March 15$^{th}$. Herbert Hice Whetzel Papers, Department of Manuscript and University Archives, Cornell University Libraries, Ithaca, NY.

99. Stakman, E.C. 1919. *Destroy the Common Barberry*. USDA Farmers' Bulletin No. 1058. Washington, D.C.:GPO.

100. Stakman, E.C. n.d. The war of attrition against wheat stem rust in North America. Unpublished paper. American Phytopathological Society Records, Iowa State University Special Collections, Ames.

101. Stakman, E.C., and Fletcher, D.G. 1930. *The Common Barberry and Black Stem Rust*. USDA Farmers' Bulletin 1544. Washington, D.C.:GPO.

102. Stakman, E.C., and Harrar, J.G. 1957. *Principles of Plant Pathology*. New York: The Ronald Press Company.

103. Stakman, E.C., Melander, L.W., and Fletcher, D.G. 1927. *Barberry Eradication Pays.* Minnesota State Department of Agriculture Bulletin 55. St. Paul.

104. Stevens, F.L., and Anderson, H.W. 1918. *Protect the Wheat Crop: Eradicate the Common Barberry from Illinois*. The University of Illinois, Agricultural College and Experiment Station Extension Circular 22. Urbana.

105. Stewart, T.H. 1946. Barberry Eradication: progress in 1945 with a resume of present status and future requirements, Minnesota. Barberry Eradication Records, University of Minnesota Archives.

106. Stewart, T.H. 1948. Barberry Eradication: Progress in 1947 with a resume of present status and future requirements, Minnesota. Barberry Eradication Records, University of Minnesota Archives.

107. Stewart, T.H. 1955. Annual Report: Barberry Eradication progress report in 1954, Minnesota. Barberry Eradication Records, University of Minnesota Archives.

108. Stewart, T.H. 1956. Annual Report: Barberry Eradication progress report in 1955, Minnesota. Barberry Eradication Records, University of Minnesota Archives.

109. Taft, L.R. and Coons, G.H. 1918. *Michigan Nursery and Orchard Inspection: Kill the Barberry*. USDA Bureau of Plant Industry, Office of Cereal Pathology Bulletin 5. Washington, D.C.:GPO.

110. Thompson, N.F. 1924. *Chemical Eradication of the Common Barberry*. USDA Department Circular 332. Washington, D.C.:GPO.

111. Thompson, N.F., and Robbins, W.W. 1926. *Methods of Eradicating the Common Barberry (Berberis vulgaris L.)*. 1926. USDA Department Bulletin 1451. Washington, D.C.: GPO.

112. Tighe, A., to Freeman, E.M. March 28, 1918. Barberry Eradication Records, University of Minnesota Archives.

113. Tindall, G.B. 1984. *America: A Narrative History*. New York: W.W. Norton and Company, Inc.

114. USDA. 1975. Review of Minnesota Barberry Eradication Program. ORS report. R.J. Laudon Personal Papers, St. Charles, Minnesota.

115. USDA, APHIS, PPQ. June 10, 1975. Barberry Eradication Program. Report. Minnesota Department of Agriculture, St. Paul, Minnesota.

116. USDA, APHIS, PPQ. June 26, 1975. Revision of Barberry Eradication Survey Manual. Memorandum. R.J. Laudon Personal Papers, St. Charles, Minnesota.

117. USDA. APHIS, PPQ. November 21, 1975. Survey-Barberry Eradication. Memorandum. R.J. Laudon Personal Papers, St. Charles, Minnesota.

118. USDA. ARS. Plant Pest Control Division. 1963. *Extent of Coverage. Barberry Eradication Survey Manual: 803-01.3400*. Washington, D.C.: GPO.

119. USDA. ARS. Plant Pest Control Division. 1963. *Rework Interval. Barberry Eradication Survey Manual: 803-01.3500.* Washington, D.C.: GPO.

120. USDA. ARS. Plant Pest Control Division. 1972. *A Large Number. Barberry Eradication Control Manual: 807-01.2300*. Washington, D.C.: GPO.

121. USDA. ARS. Plant Pest Control Division. 1972. *Ornamental Plantings. Barberry Eradication Control Manual: 807-01.2200*. Washington, D.C.: GPO.

122. USDA. ARS. Plant Pest Control Division. 1972. *Single Bushes. Barberry Eradication Control Manual: 807-01.2100*. Washington, D.C.: GPO.

Table 1. Average wheat yields in three states in 1915 and 1916.

| State | 1915 bu/acre | 1916 bu/acre |
|---|---|---|
| Minnesota | 17.0 | 7.6 |
| North Dakota | 18.2 | 5.5 |
| South Dakota | 17.1 | 6.8 |

Data from Freeman (22)

Table 2. Numbers of square miles requiring re-work and requiring no re-work during the re-work phase of the barberry eradication campaign in Minnesota, 1955-1990.

| Year | Total square miles requiring re-work | Total square miles requiring no re-work |
|---|---|---|
| 1955 | 2514[a] | 78369 |
| 1961 | 1215 | 79668 |
| 1974 | 771 | 80112 |
| 1978 | 335 | 80548 |
| 1990 | 648 | 80235 |

[a] Data from Bob Laudon (unpublished).

Table 3. Number of bushes, total number of properties needing re-work, total number of properties completed to date and total number of properties where barberry bushes found during the re-work phase of the barberry eradication campaign in Minnesota, 1955-1990.

| Year | Total number of bushes/seedlings/ sprouts found to date | Total number properties needing re-work to date | Total number properties completed to date | Total number properties where bushes found to date |
|---|---|---|---|---|
| 1955 | 1010722[a] | 2872 | | 6355 |
| | 9201 | | | |
| 1961 | 1015044 | 2256 | | 7108 |
| | 9364 | | | |
| 1974 | 1026238 | 1506 | | 8054 |
| | 9560 | | | |
| 1978 | 1027735 | 963 | | 8613 |
| | 9576 | | | |
| 1990 | 1030471 | 1184 | | 8396 |
| | 9581 | | | |

[a] Data from Bob Laudon (unpublished)

Table 4. Minnesota barberry eradication program totals.

| County | Year Last Work Was Completed | SQUARE MILES | | | | PROPERTIES | | | Barberries Destroyed Total To Date |
|---|---|---|---|---|---|---|---|---|---|
| | | Total In County To Be Worked | Number Covered - Rework | Requiring Rework<br>Rework | Number Requiring No Future Work | Total Found to Date | Number Needing One or More Reinspections | Number Completed | |
| Aitkin | 1951 | 1,830 | 1,830 | - | 1,830 | 2 | - | 2 | 713 |
| Anoka | 1973 | 459 | 598 | 9 | 450 | 139 | 11 | 128 | 12,487 |
| Becker | 1988 | 1,349 | 1,367 | 1 | 1,348 | 16 | 1 | 15 | 283 |
| Beltrami | 1973 | 2,496 | 154 | - | 2,496 | 9 | - | 9 | 98 |
| Big Stone | 1946 | 491 | 503 | - | 491 | 21 | - | 21 | 410 |
| Benton | 1957 | 405 | 422 | - | 405 | 12 | - | 12 | 133 |
| Blue Earth | 1976 | 762 | 881 | 7 | 755 | 165 | 14 | 151 | 8,107 |
| Brown | 1975 | 612 | 702 | 3 | 609 | 76 | 4 | 72 | 3,101 |
| Carlton | 1973 | 869 | 869 | - | 869 | 13 | - | 13 | 79 |
| Carver | 1979 | 376 | 590 | 2 | 374 | 113 | 2 | 111 | 5,755 |
| Cass | 1968 | 2,104 | 404 | 1 | 2,103 | 8 | 1 | 7 | 90 |
| Chippewa | 1971 | 591 | 706 | - | 591 | 46 | - | 46 | 689 |
| Chisago | 1971 | 427 | 452 | 4 | 423 | 44 | 7 | 37 | 1,266 |
| Clay | 1984 | 1,043 | 1,018 | - | 1,043 | 84 | - | 84 | 1,253 |
| Clearwater | 1967 | 1,019 | 827 | - | 1,019 | 4 | - | 4 | 85 |
| Cook | 1946 | 1,498 | - | - | 1,498 | - | - | - | - |
| Cottonwood | 1952 | 640 | 684 | - | 640 | 40 | - | 40 | 658 |

| | | SQUARE MILES | | | | PROPERTIES | | | |
|---|---|---|---|---|---|---|---|---|---|
| County | Year Last Work Was Completed | Total In County To Be Worked | Number Covered - Rework | Requiring Rework | Number Requiring No Future Work | Total Found to Date | Number Needing One or More Reinspections | Number Completed | Barberries Destroyed Total To Date |
| Crow Wing | 1967 | 1,057 | 634 | - | 1,057 | 21 | - | 21 | 757 |
| Dakota | 1978 | 602 | 847 | 10 | 592 | 216 | 11 | 205 | 6,096 |
| Dodge | 1976 | 440 | 710 | 4 | 436 | 193 | 5 | 188 | 2,278 |
| Douglas | 1971 | 648 | 684 | - | 648 | 54 | - | 54 | 915 |
| Faribault | 1980 | 719 | 804 | - | 719 | 110 | - | 110 | 9,125 |
| Fillmore | 1972 | 868 | 1,629 | 127 | 741 | 637 | 11 | 426 | 56,690 |
| Freeborn | 1980 | 735 | 876 | 1 | 734 | 134 | 1 | 133 | 5,505 |
| Goodhue | 1975 | 767 | 1,321 | 73 | 694 | 602 | 166 | 436 | 63,611 |
| Grant | 1971 | 554 | 605 | - | 554 | 24 | - | 24 | 358 |
| Hennepin | 1976 | 565 | 734 | 40 | 525 | 1,699 | 117 | 1,582 | 73,250 |
| Houston | 1977 | 570 | 748 | 58 | 512 | 286 | 85 | 201 | 8,434 |
| Hubbard | 1952 | 958 | 958 | - | 958 | 8 | - | 8 | 33 |
| Isanti | 1971 | 442 | 461 | 5 | 437 | 32 | 10 | 22 | 886 |
| Itasca | 1973 | 2,730 | 124 | - | 2,730 | 4 | - | 4 | 11 |
| Jackson | 1980 | 702 | 800 | - | 702 | 35 | - | 35 | 4,043 |
| Kanabec | 1953 | 534 | 534 | - | 534 | 7 | - | 7 | 59 |
| Kandiyohi | 1986 | 801 | 866 | - | 801 | 85 | - | 85 | 1,723 |
| Kittson | 1949 | 1,111 | 1,111 | - | 1,111 | 17 | - | 17 | 914 |

| County | Year Last Work Was Completed | SQUARE MILES | | | | PROPERTIES | | | Barberries Destroyed Total To Date |
|---|---|---|---|---|---|---|---|---|---|
| | | Total In County To Be Worked | Number Covered - Rework | Requiring Rework | Number Requiring No Future Work | Total Found to Date | Number Needing One or More Reinspections | Number Completed | |
| Koochiching | 1946 | 3,141 | 61 | - | 3,141 | 2 | - | 2 | 43 |
| Lac Qui Parle | 1961 | 790 | 867 | - | 790 | 29 | - | 29 | 232 |
| Lake | 1946 | 2,099 | 4 | - | 2,099 | 1 | - | 1 | 1 |
| Lake of the Woods | 1948 | 1,346 | 59 | - | 1,346 | 2 | - | 2 | 42 |
| Le Sueur | 1979 | 466 | 549 | 1 | 465 | 53 | 1 | 52 | 654 |
| Lincoln | 1985 | 535 | 721 | 1 | 534 | 50 | 1 | 49 | 978 |
| Lyon | 1985 | 708 | 922 | 2 | 706 | 56 | 2 | 54 | 6,890 |
| Mahnomen | 1951 | 572 | 572 | - | 572 | 4 | - | 4 | 14 |
| Marshall | 1967 | 1,788 | 1,792 | - | 1,788 | 19 | - | 19 | 130 |
| Martin | 1980 | 719 | 873 | - | 719 | 63 | - | 63 | 3,148 |
| McLeod | 1971 | 496 | 711 | - | 496 | 66 | - | 66 | 806 |
| Meeker | 1971 | 621 | 756 | - | 621 | 86 | - | 86 | 3,277 |
| Mille Lacs | 1971 | 583 | 598 | 5 | 578 | 19 | 12 | 7 | 695 |
| Morrison | 1977 | 1,143 | 1,191 | 5 | 1,138 | 38 | 7 | 31 | 2,288 |
| Mower | 1975 | 711 | 970 | 3 | 708 | 150 | 3 | 147 | 3,011 |
| Murray | 1969 | 704 | 761 | - | 704 | 36 | - | 36 | 631 |
| Nicollet | 1975 | 443 | 597 | 6 | 437 | 88 | 9 | 79 | 7,762 |
| Nobles | 1969 | 722 | 905 | - | 722 | 77 | - | 77 | 1,462 |

| County | Year Last Work Was Completed | SQUARE MILES | | | | PROPERTIES | | | Barberries Destroyed Total To Date |
|---|---|---|---|---|---|---|---|---|---|
| | | Total In County To Be Worked | Number Covered - Rework | Requiring Rework<br>Rework | Number Requiring No Future Work | Total Found to Date | Number Needing One or More Reinspections | Number Completed | |
| Norman | 1971 | 860 | 877 | - | 860 | 17 | - | 17 | 1,387 |
| Olmsted | 1964 | 666 | 1,654 | 69 | 597 | 502 | 104 | 398 | 29,246 |
| Ottertail | 1977 | 2,039 | 2,141 | 7 | 2,032 | 96 | 8 | 88 | 3,025 |
| Pennington | 1985 | 607 | 609 | 0 | 607 | 8 | - | 8 | 80 |
| Pine | 1953 | 1,413 | 1,413 | - | 1,413 | 14 | - | 14 | 112 |
| Pipestone | 1960 | 469 | 541 | - | 469 | 39 | - | 39 | 1,144 |
| Polk | 1975 | 1,979 | 1,993 | 2 | 1,977 | 39 | 2 | 37 | 1,362 |
| Pope | 1986 | 693 | 817 | - | 693 | 71 | - | 71 | 1,314 |
| Ramsey | 1970 | 161 | 187 | 12 | 149 | 614 | 31 | 583 | 15,894 |
| Red Lake | 1950 | 432 | 432 | - | 432 | 2 | - | 2 | 38 |
| Redwood | 1071 | 881 | 1,032 | - | 881 | 46 | - | 46 | 730 |
| Renville | 1989 | 978 | 1,416 | 1 | 977 | 125 | 1 | 124 | 16,061 |
| Rice | 1979 | 495 | 739 | 7 | 488 | 187 | 8 | 179 | 19,759 |
| Rock | 1960 | 492 | 667 | - | 492 | 57 | - | 57 | 1,602 |
| Roseau | 1950 | 1,670 | 1,670 | - | 1,670 | 4 | - | 4 | 29 |
| St. Louis | 1962 | 6,503 | 2,673 | 0 | 6,503 | 230 | 61 | 169 | 5,031 |
| Scott | 1979 | 365 | 495 | 4 | 361 | 84 | 4 | 80 | 1,290 |
| Sherburne | 1974 | 448 | 504 | - | 448 | 57 | - | 57 | 648 |

| County | Year Last Work Was Completed | SQUARE MILES | | | | PROPERTIES | | | Barberries Destroyed Total To Date |
|---|---|---|---|---|---|---|---|---|---|
| | | Total In County To Be Worked | Number Covered - Rework | Requiring Rework<br>Rework | Number Requiring No Future Work | Total Found to Date | Number Needing One or More Reinspections | Number Completed | |
| Sibley | 1971 | 585 | 712 | - | 585 | 52 | - | 52 | 1,328 |
| Stearns | 1986 | 1,362 | 1,529 | 3 | 1,359 | 144 | 4 | 140 | 4,210 |
| Steele | 1975 | 431 | 494 | 5 | 426 | 100 | 6 | 94 | 10,621 |
| Stevens | 1964 | 564 | 605 | - | 564 | 25 | - | 25 | 978 |
| Swift | 1962 | 741 | 872 | - | 741 | 45 | - | 45 | 5,158 |
| Todd | 1977 | 957 | 1,021 | 4 | 953 | 42 | 6 | 36 | 3,444 |
| Traverse | 1971 | 568 | 608 | - | 568 | 26 | - | 26 | 251 |
| Wabasha | 1978 | 541 | 804 | 58 | 483 | 230 | 86 | 144 | 554,918 |
| Wadena | 1985 | 538 | 538 | 0 | 538 | 16 | 1 | 15 | 501 |
| Waseca | 1975 | 431 | 537 | 2 | 429 | 92 | 2 | 90 | 2,465 |
| Washington | 1978 | 397 | 542 | 30 | 367 | 250 | 69 | 181 | 12,009 |
| Watonwan | 1968 | 434 | 499 | - | 434 | 32 | - | 32 | 476 |
| Wilkin | 1984 | 745 | 765 | - | 745 | 15 | - | 15 | 388 |
| Winona | 1976 | 637 | 637 | 70 | 567 | 340 | 103 | 237 | 17,792 |
| Wright | 1977 | 691 | 691 | 5 | 686 | 139 | 6 | 133 | 11,625 |
| Yellow Medicine | 1988 | 749 | 749 | 1 | 748 | 46 | 2 | 44 | 3,326 |
| Total | | 80,883 | 71,463 | 648 | 80,235 | 9,581 | 1,184 | 8,396 | 1,030,471 |

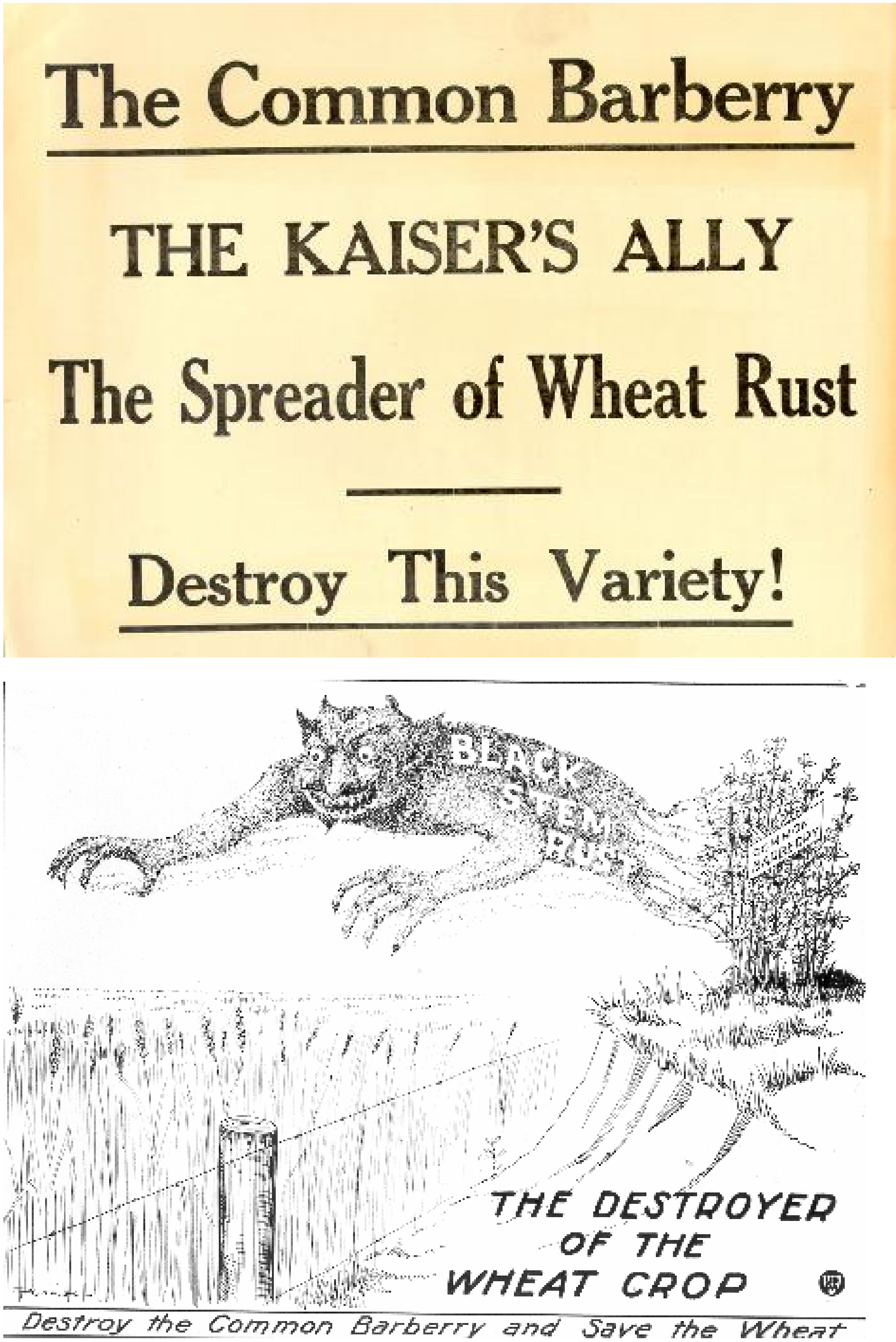



Figure 1. Posters illustrating WW1 propaganda used to stimulate interest in eradicating barberry (Courtesy of the University of Minnesota Archives).

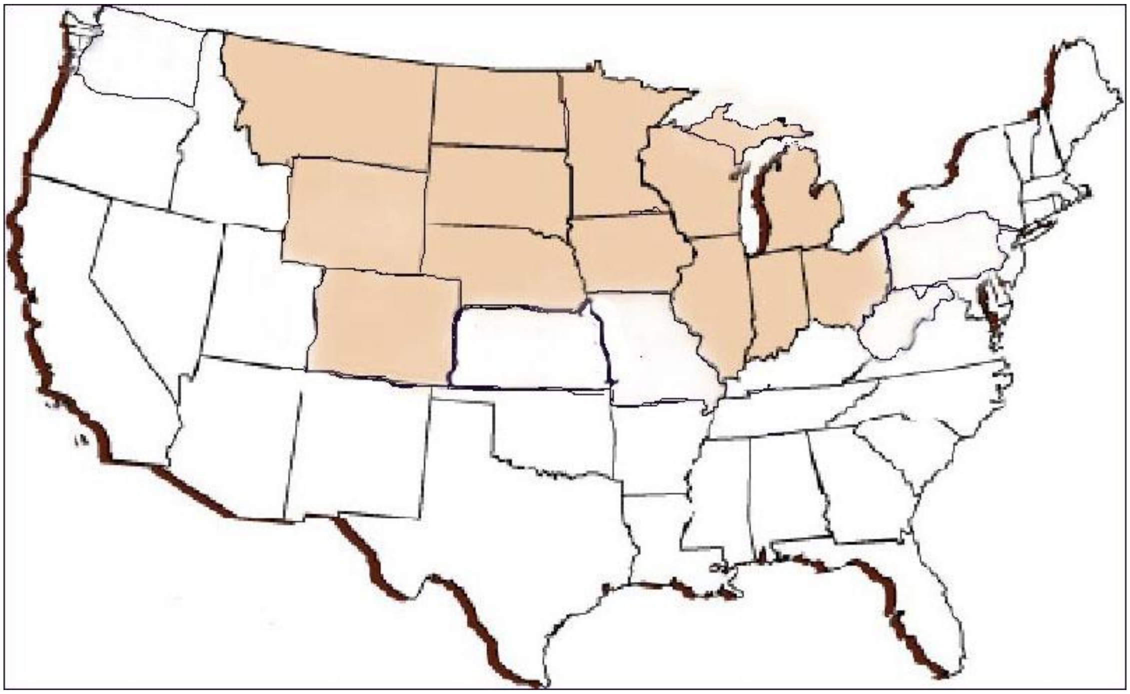
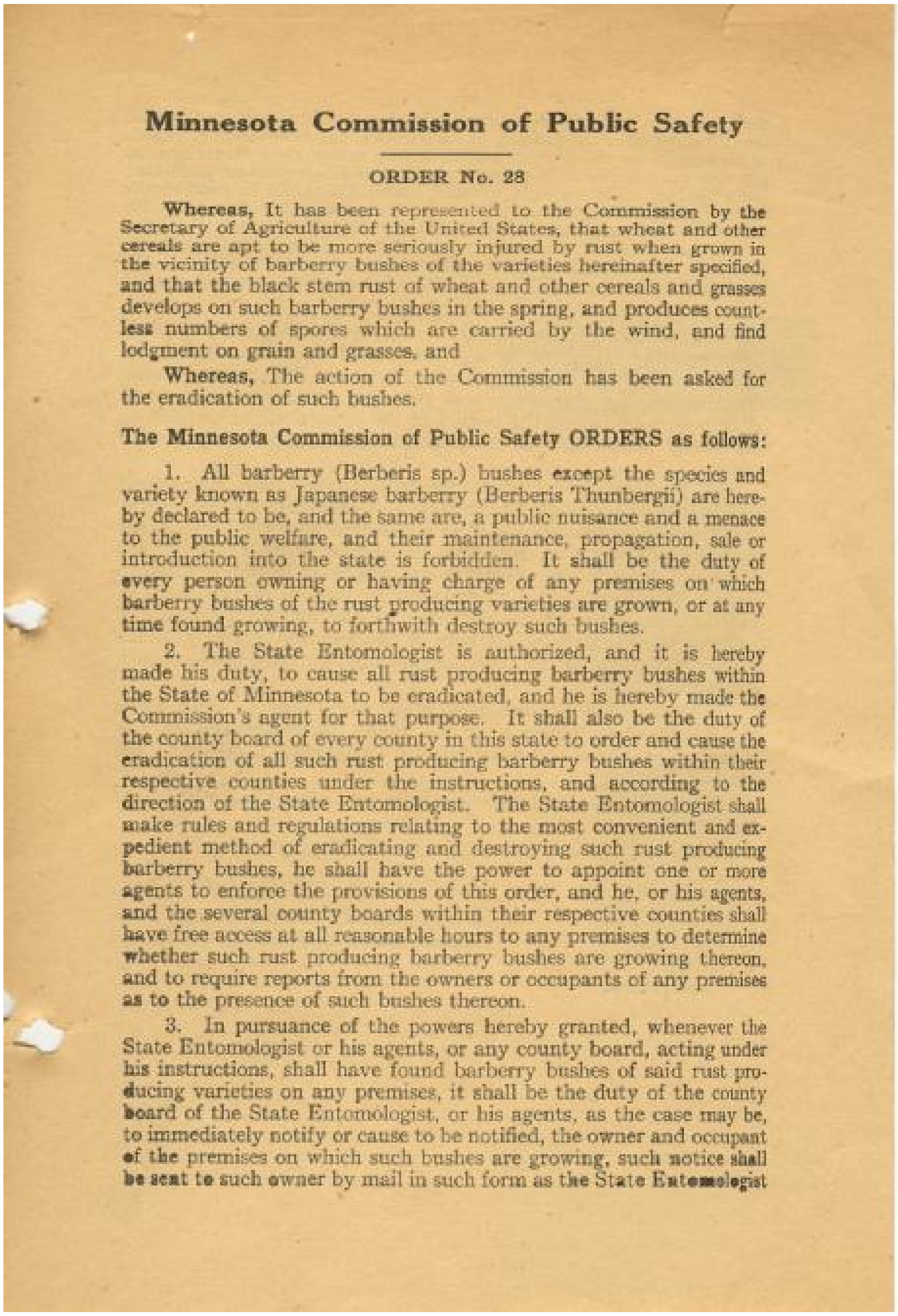


Figure 2. Thirteen original states participating in the Barberry Eradication Program.



## Minnesota Commission of Public Safety

ORDER No. 28

**Whereas,** It has been represented to the Commission by the Secretary of Agriculture of the United States, that wheat and other cereals are apt to be more seriously injured by rust when grown in the vicinity of barberry bushes of the varieties hereinafter specified, and that the black stem rust of wheat and other cereals and grasses develops on such barberry bushes in the spring, and produces countless numbers of spores which are carried by the wind, and find lodgment on grain and grasses, and

**Whereas,** The action of the Commission has been asked for the eradication of such bushes.

**The Minnesota Commission of Public Safety ORDERS as follows:**

1. All barberry (Berberis sp.) bushes except the species and variety known as Japanese barberry (Berberis Thunbergii) are hereby declared to be, and the same are, a public nuisance and a menace to the public welfare, and their maintenance, propagation, sale or introduction into the state is forbidden. It shall be the duty of every person owning or having charge of any premises on which barberry bushes of the rust producing varieties are grown, or at any time found growing, to forthwith destroy such bushes.

2. The State Entomologist is authorized, and it is hereby made his duty, to cause all rust producing barberry bushes within the State of Minnesota to be eradicated, and he is hereby made the Commission's agent for that purpose. It shall also be the duty of the county board of every county in this state to order and cause the eradication of all such rust producing barberry bushes within their respective counties under the instructions, and according to the direction of the State Entomologist. The State Entomologist shall make rules and regulations relating to the most convenient and expedient method of eradicating and destroying such rust producing barberry bushes, he shall have the power to appoint one or more agents to enforce the provisions of this order, and he, or his agents, and the several county boards within their respective counties shall have free access at all reasonable hours to any premises to determine whether such rust producing barberry bushes are growing thereon, and to require reports from the owners or occupants of any premises as to the presence of such bushes thereon.

3. In pursuance of the powers hereby granted, whenever the State Entomologist or his agents, or any county board, acting under his instructions, shall have found barberry bushes of said rust producing varieties on any premises, it shall be the duty of the county board of the State Entomologist, or his agents, as the case may be, to immediately notify or cause to be notified, the owner and occupant of the premises on which such bushes are growing, such notice shall be sent to such owner by mail in such form as the State Entomologist

A

Figure 3 A&B. Minnesota Commission of Public Safety. 1918. Order No.28. BarberryEradication Records, University of Minnesota Archives shall prescribe, and if such barberry bushes are not destroyed within ten (10) days after the mailing of such notice, the State Entomologist, or his agents, or the county board, acting under his instructions, as the case may be, shall destroy or cause to be destroyed such barberry bushes. The expense of such destruction shall be paid to the State Entomologist by the owner of the premises within ten (10) days after the rendition of a bill therefor, and if such cost shall not be paid within said time the bill shall be reported to the county attorney, who shall forthwith collect the same in the name of the state and shall turn the amount collected over to the State Treasurer to be credited to the appropriate fund.

4. The State Entomologist, or his agent, whenever requested by any county board, or by any resident of the state, shall determine, or cause to be determined, whether or not the barberry bushes grown on certain premises are of the rust producing variety, and after such examination the results of the same shall be certified to the county board, and his determination so certified shall be conclusive.

5. No expenses or outlays chargeable to the Commission's fund shall be incurred or made by the State Entomologist, or by any agent of his, or by any county board in connection with the enforcement of this order, except in the actual destruction of such bushes. On or before the tenth day of each month, the State Entomologist shall report to the Commission all expenses incurred or outlays made in such destruction during the preceding month, and until the further orders of the Commission the sum of two hundred and fifty dollars is appropriated out of the Commission's fund for the purpose of such destruction.

6. The State Entomologist shall, from time to time, make reports to the Commission of his doings hereunder, and of any violations or breaches hereof for the Commission's action in the premises.

This order shall be effective from and after the 19th day of March, 1918.

Dated at St. Paul, Minnesota, March 19, 1918.

J. A. A. BURNQUIST,
Governor and Ex-officio Chairman of the
Minnesota Commission of Public Safety.

H. W. LIBBY,
Secretary.

B

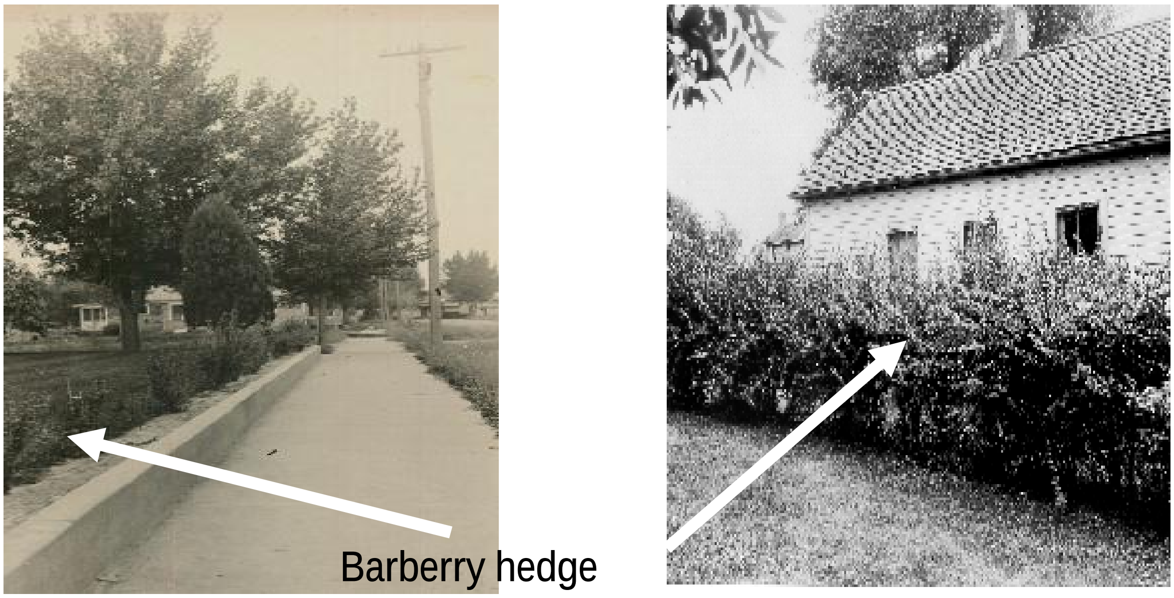



Figure 4. Planted barberries located in cities and towns in Minnesota, 1918 (Courtesy of University of Minnesota Archives).

A

B

C

Figure 5. Removing barberry bushes by A) hand digging and pulling; B) with teams of mules and C) with tractors (Courtesy of University of Minnesota Archives).

## MINNESOTA BARBERRY ERADICATION LAW

General Laws of Minnesota for 1919

Chapter 81—S. F. No. 120

*An act requiring the owner or occupant of premises within this state, on which Mahonia bushes and Barberry bushes of the rust producing varieties may be grown, to destroy the same, declaring the same to be a public nuisance; imposing certain powers and duties with reference to the same on the state entomologist; and providing penalties for the violation thereof.*

Be it enacted by the Legislature of the State of Minnesota:

Section 1. All Barberry (*Berberis sp.*) bushes and all Mahonia (*Mahonia sp.*) bushes except the species and variety known as Japanese barberry (*Berberis thunbergii*) are rust producing species and are hereby declared to be, and the same are, a public nuisance and a menace to the public welfare, and their maintenance, propagation, sale or introduction into the state is forbidden. It shall be the duty of every person owning, occupying or having charge of any premises on which such bushes of the rust producing varieties are grown, or at any time found growing, to forthwith destroy such bushes.

Section 2. The state entomologist is authorized, and it is hereby made his duty to cause all such rust producing Mahonia bushes or Barberry bushes within the State of Minnesota to be eradicated. The state entomologist shall make rules and regulations relating to the most convenient and expedient method of eradicating and destroying such rust producing Mahonia bushes or Barberry bushes; he shall have the power to appoint one or more agents to enforce the provisions of this act, and he, or his agents, shall have free access at all reasonable hours to any premises to determine whether such rust producing Mahonia bushes or Barberry bushes are growing thereon, and to require reports from the owners or occupants of any premises as to the presence of such bushes thereon.

Section 3. In pursuance of his powers hereby granted, whenever the state entomologist, or his agents, shall have found Mahonia bushes or Barberry bushes of such rust producing varieties on any premises, it shall be the duty of the state entomologist, or his agents, as the case may be, to immediately notify or cause to be notified, the owner or occupant of the premises on which such bushes are growing; such notice shall be sent to such owner or occupant in such form as the state entomologist shall prescribe, and if such Mahonia bushes or Barberry

A

Figure 6 A&B. Minnesota barberry eradication law, 1919 (From Melander, 52) bushes are not destroyed within ten (10) days after the mailing of such notice, if sent by registered mail, or within eight days after the delivery of such notice, if delivered by messenger, the state entomologist, or his agents, shall destroy or cause to be destroyed such Mahonia bushes or Barberry bushes. The expense of such destruction shall be paid to the state entomologist by the owner of the premises within ten (10) days after the rendition of a bill therefor, and if such cost shall not be paid within said time the bill shall be reported to the county attorney, who shall forthwith collect the same in the name of the state and shall turn the amount collected over to the state treasurer to be credited to the road and bridge fund of the county.

Section 4. The state entomologist, or his agent, may, or whenever requested by any resident of the state, shall determine, or cause to be determined, whether or not the Mahonia bushes or Barberry bushes grown on certain premises are of the rust producing varieties. The said entomologist shall make a certificate of his findings and determination in the premises, which certificate shall be prima facie evidence of the facts therein recited. Such certificate may be received in evidence in any civil action arising under the provisions of this act.

Section 5. Any person violating any of the provisions of this act shall be guilty of a misdemeanor.

Section 6. This act shall take effect and be in force from and after its passage.

Approved March 21, 1919.

B

Figure7. Planted barberries located around farmsteads in Minnesota, 1920 (Courtesy of University of Minnesota Archives).

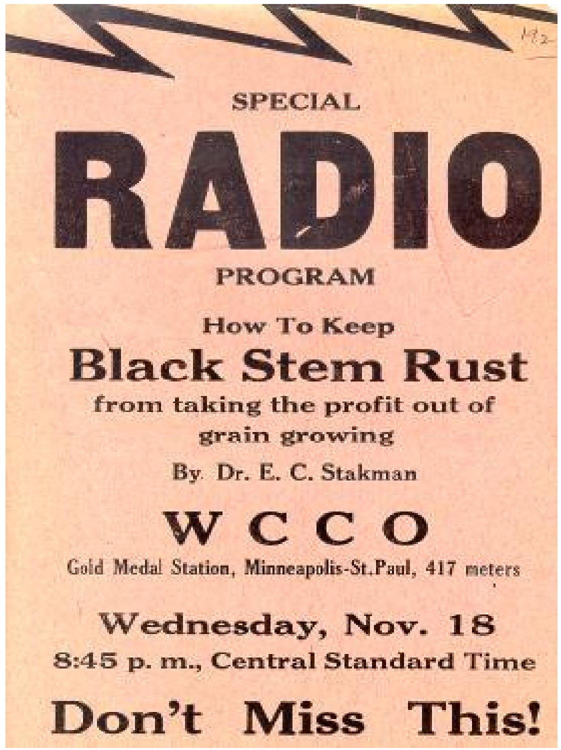




Figure 8. Barberry publicity and education, A) Advertisement for radio show hosted by E.C. Stakman and B) exhibit at county fair in Minnesota in 1922 (Courtesy of University of Minnesota Archives).

Figure 9. Barberry bee in Red Wing, Minnesota, 1922 (From Melander, 52).


Figure10. Salt being used to kill barberry bushes in Minnesota, ca.1925 (Courtesy of University of Minnesota Archives).

Figure 11. Barberry field crew at work, ca. 1925 (Courtesy of University of Minnesota Archives).

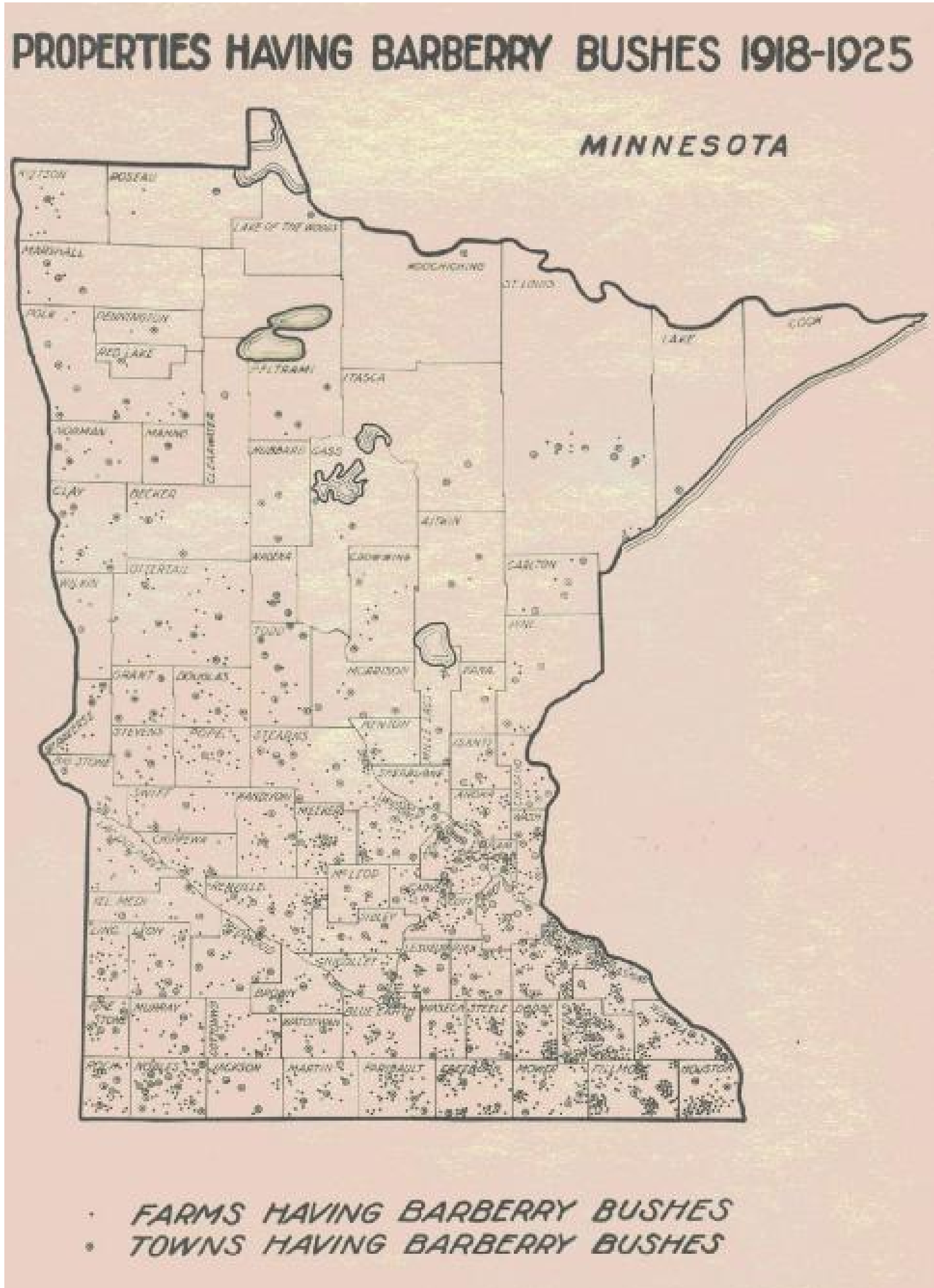



Figure 12. Map showing properties where barberry bushes were found and destroyed in Minnesota, 1918-1925 (From Melander, 55).

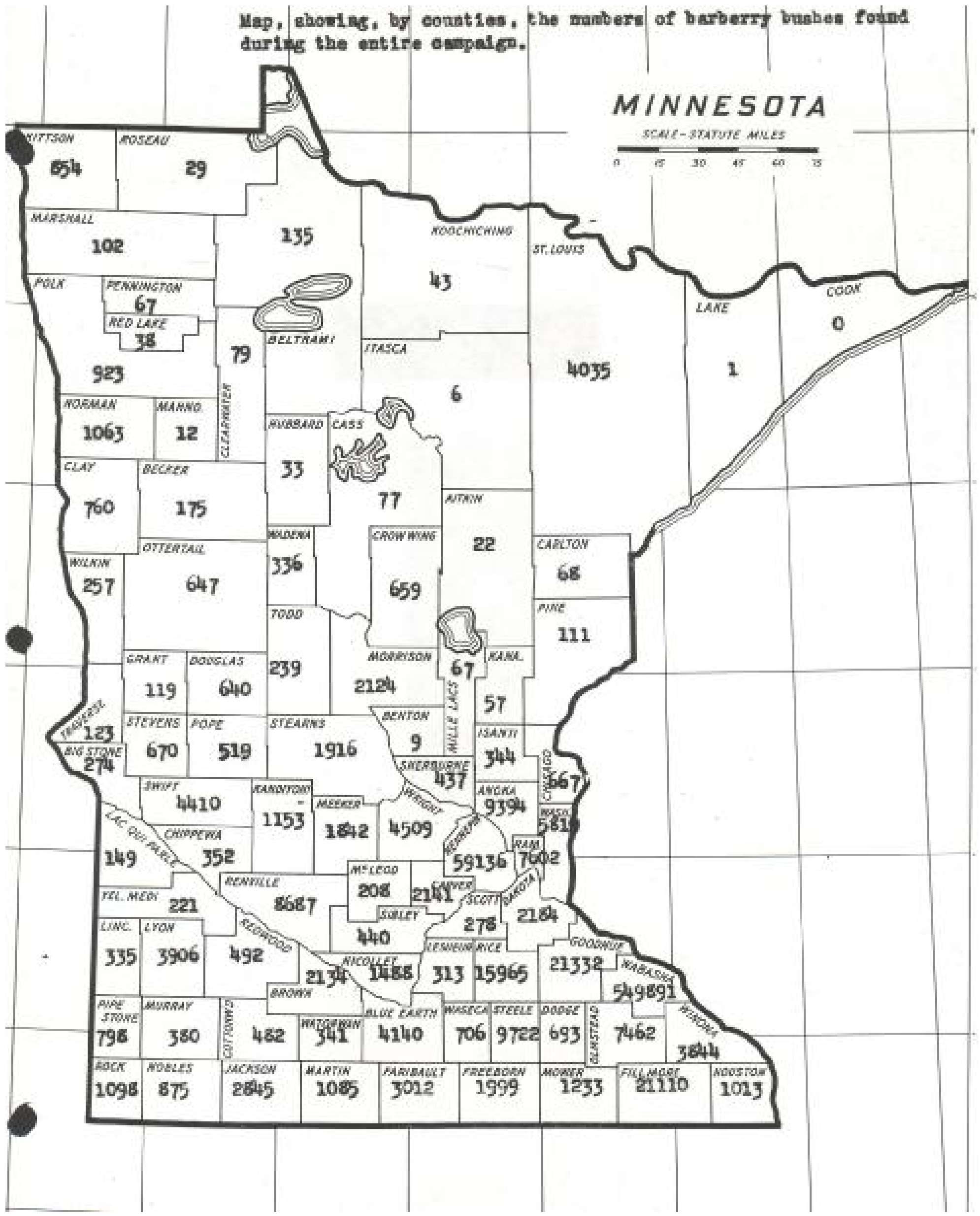



Figure 13. Map showing, by counties, numbers of barberry bushes located and destroyed in Minnesota, 1918-1925 (From Melander, 55).

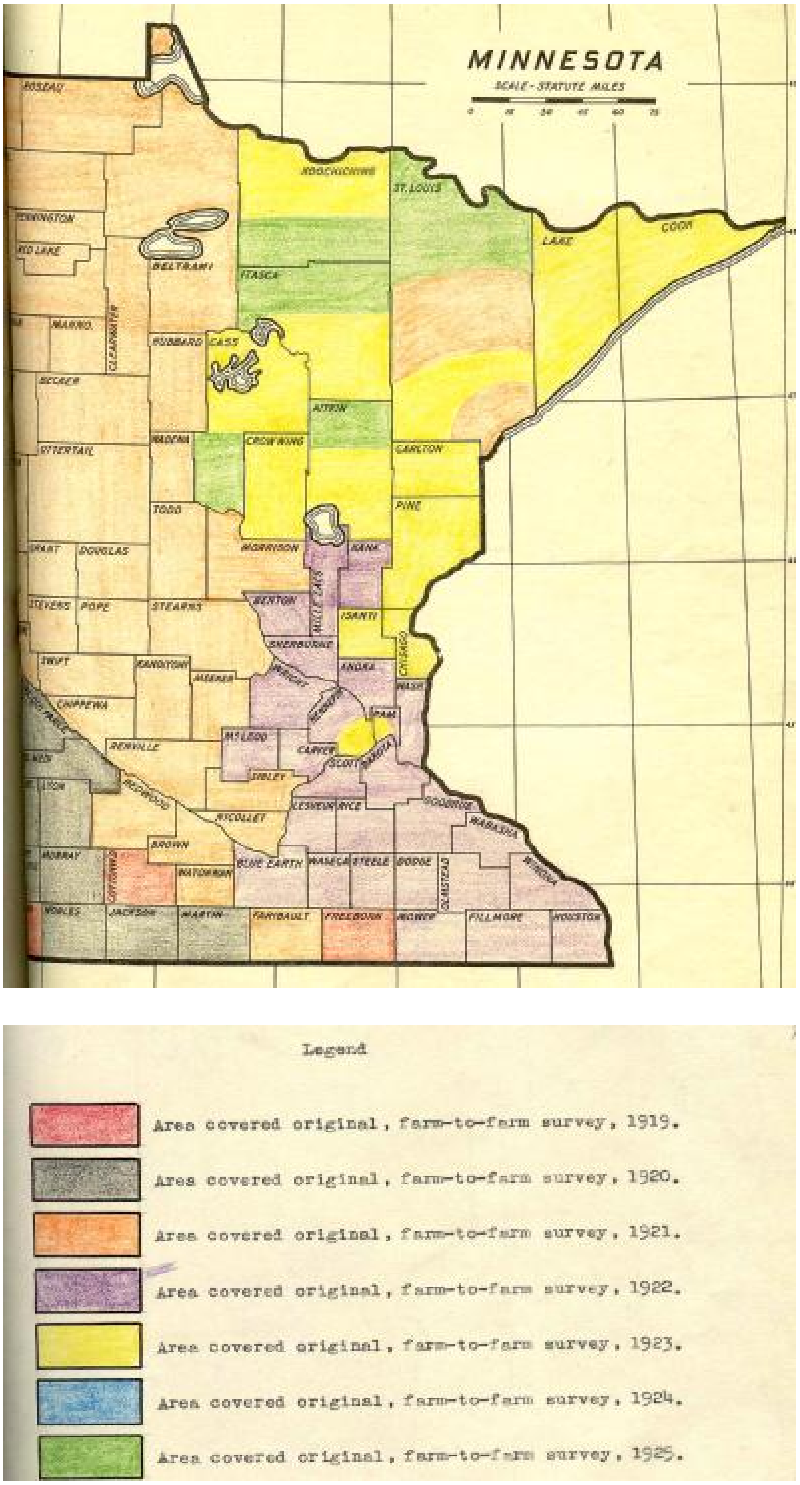



Figure 14. Map with legend showing progress of original survey in Minnesota, 1918-1925 (From Melander, 55).

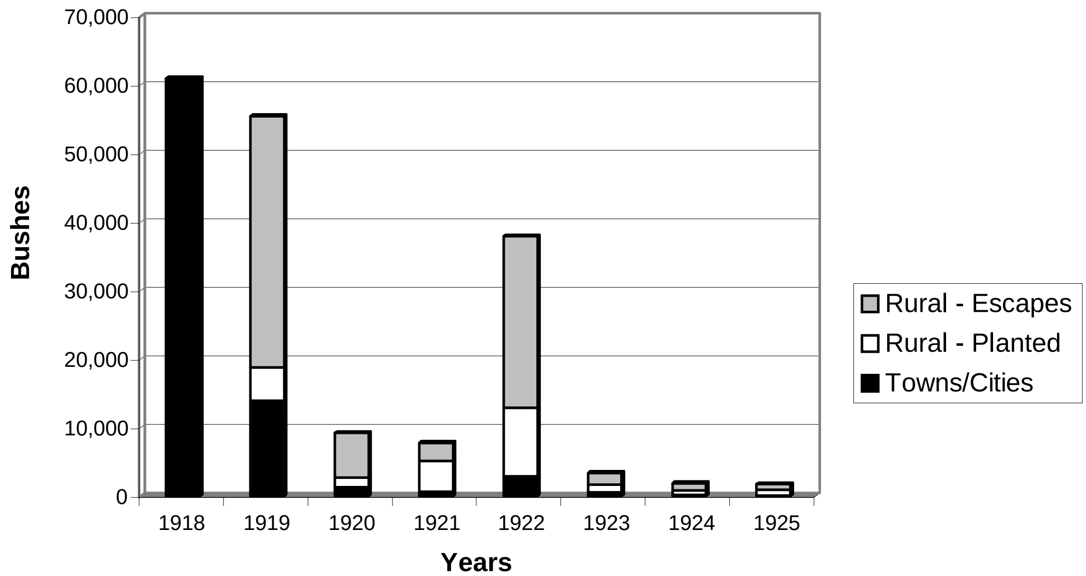



Figure 15. Bushes found on properties inspected during Original Survey, 1918-1925. Numbers of bushes for 1918 do not include the approximate 600,000 barberry bushes found in nurseries (Data from Melander, 55).

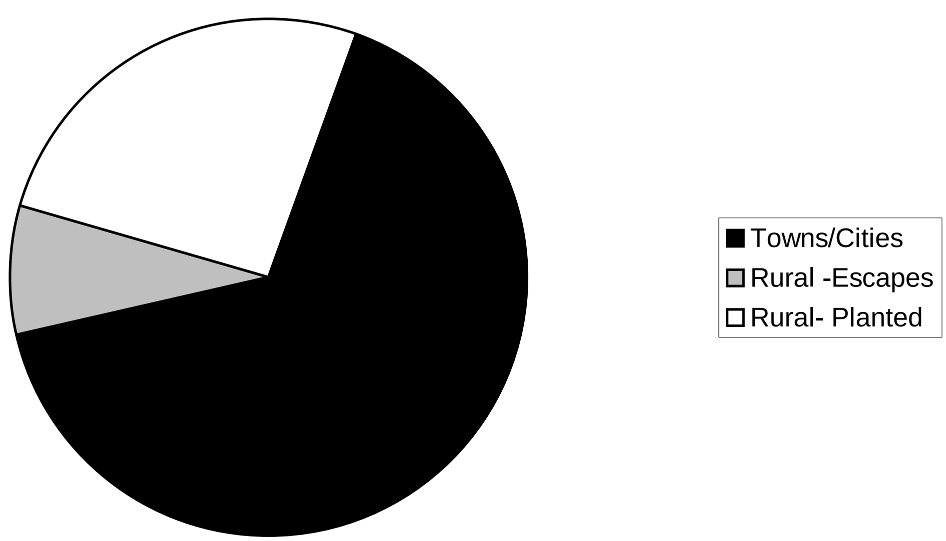



Figure 16. Proportion of properties on which bushes were located in Original Survey, 1918-1925 (Data from Melander, 55).

A

B

Figure 17. Escaped barberry bushes A) on a wooded property and B) covering a hillside (Courtesy of University of Minnesota Archives).

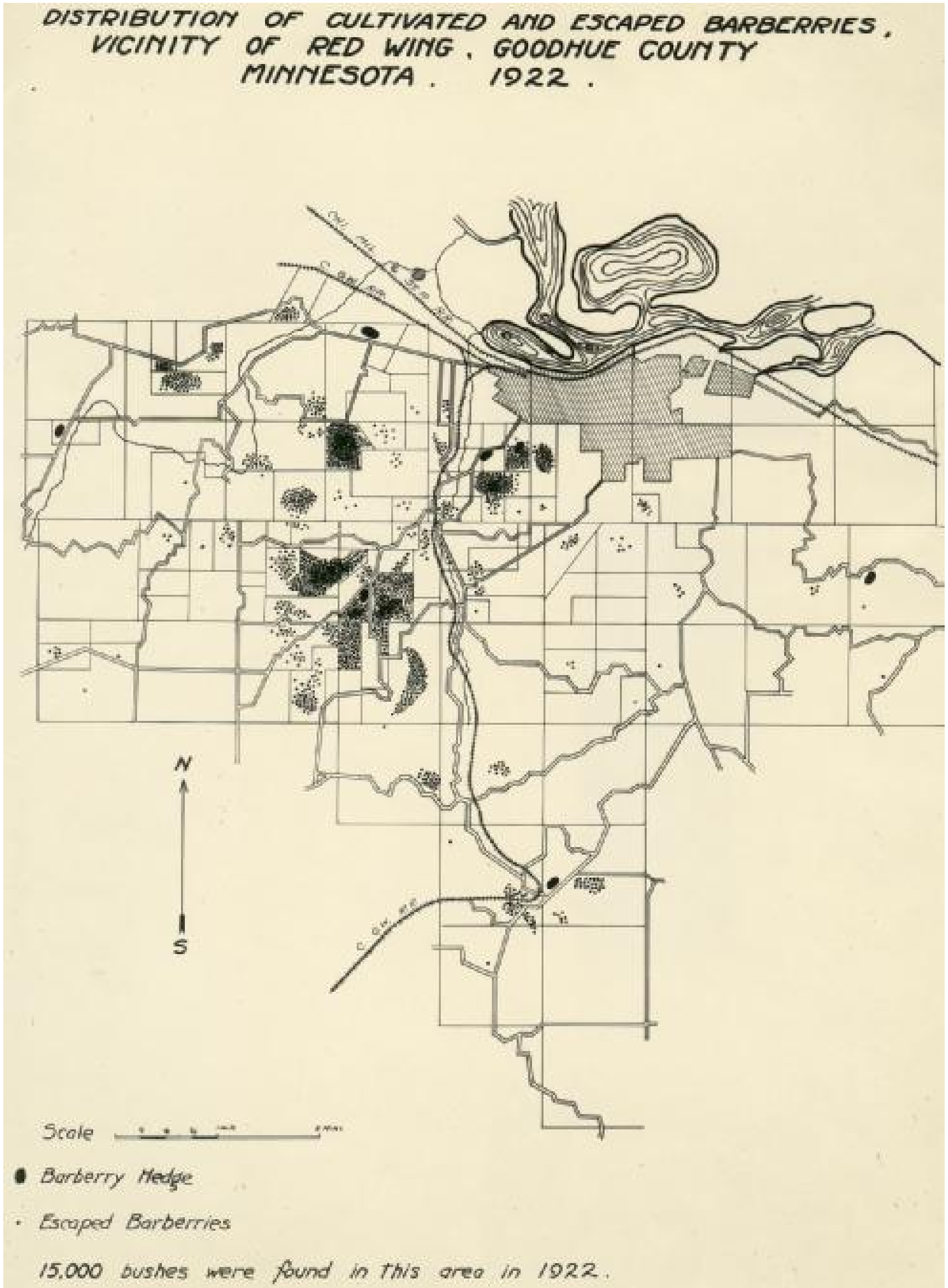



Figure 18. Distribution of planted and escaped barberries near Red Wing, Minnesota, 1922 (From Melander, 52).

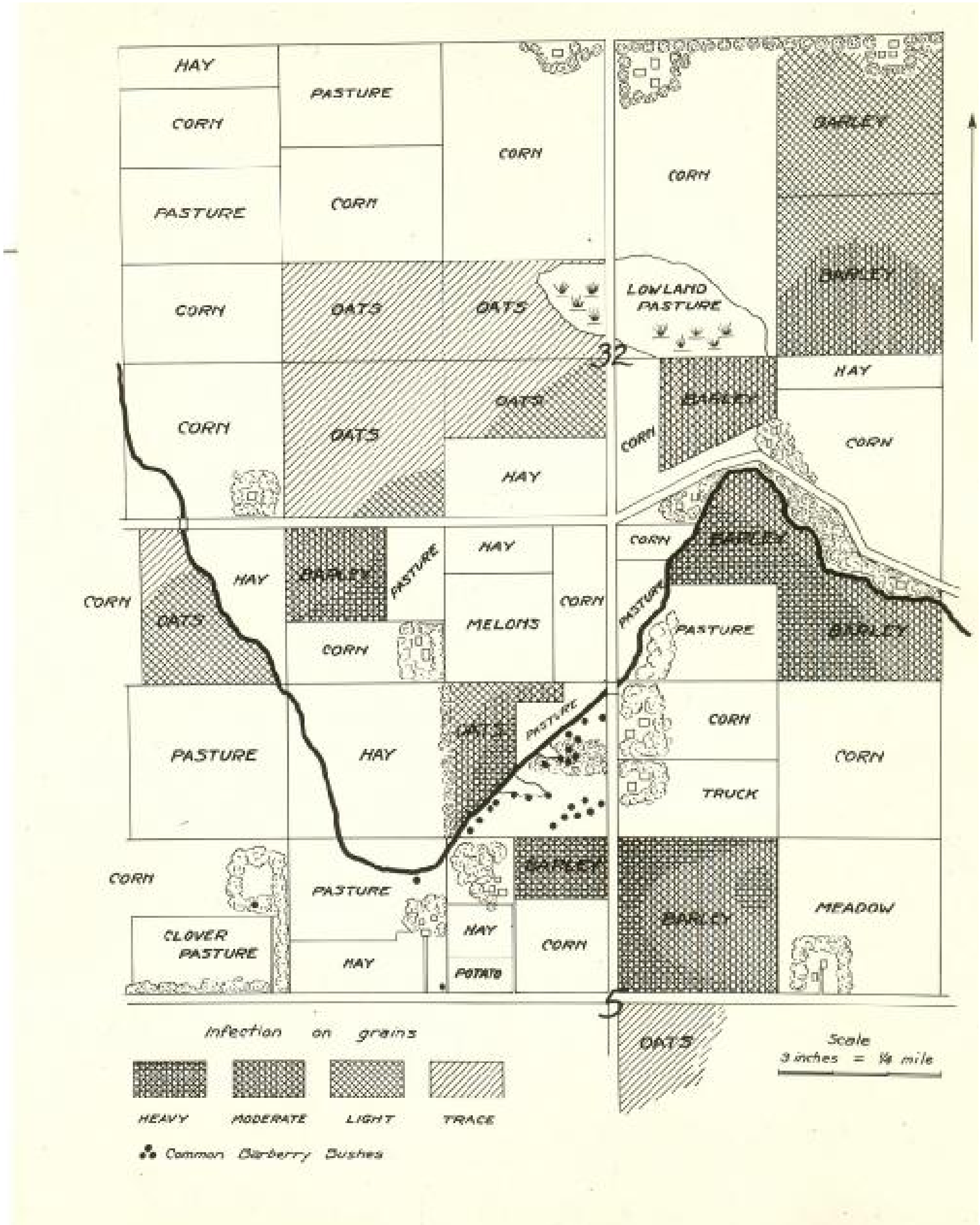



Figure 19. Map showing stem rust spread from barberry, Mower county, Minnesota, July 16th, 1923 (From Melander, 53).

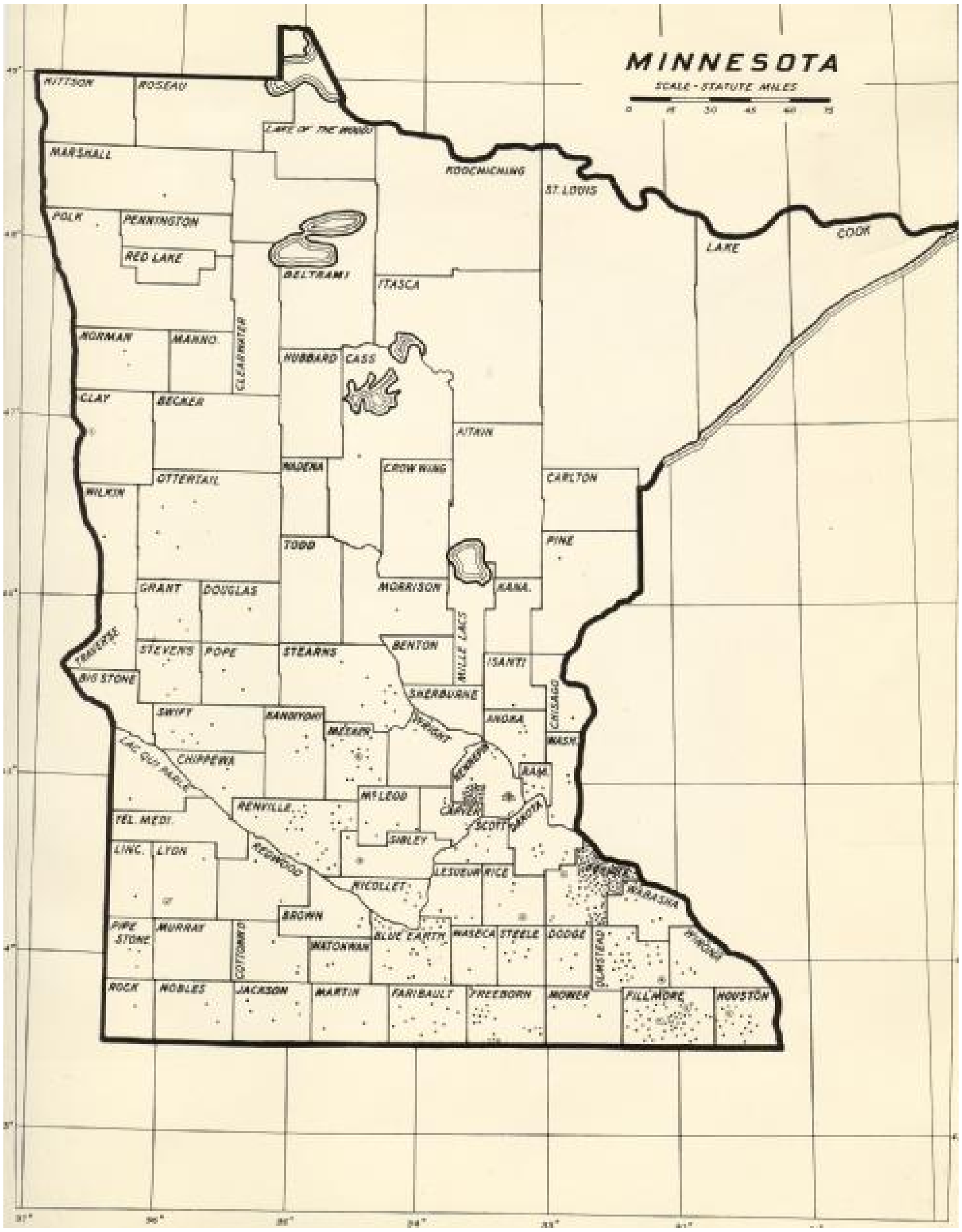



Figure 20. Properties in Minnesota on which seedlings were found through 1929 (From Melander and Thompson, 65).

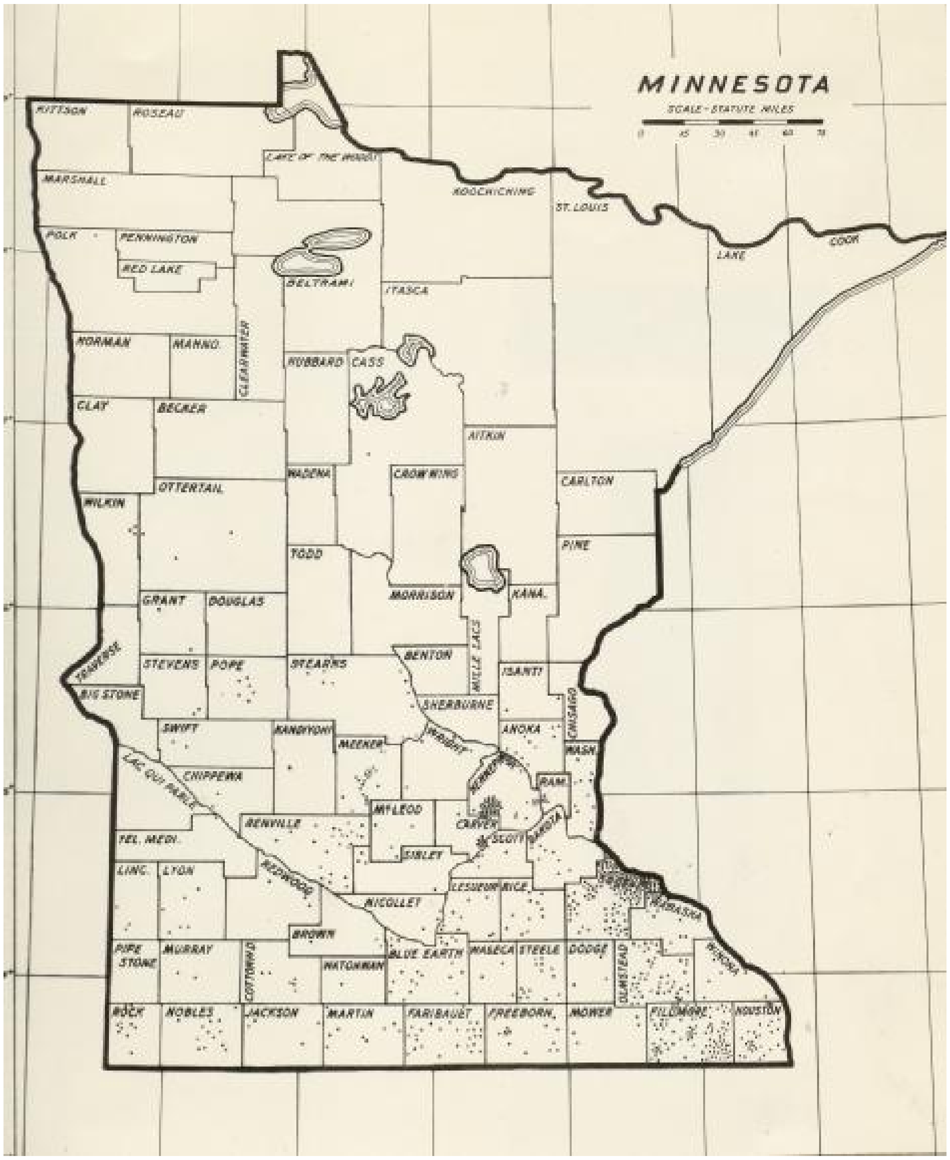
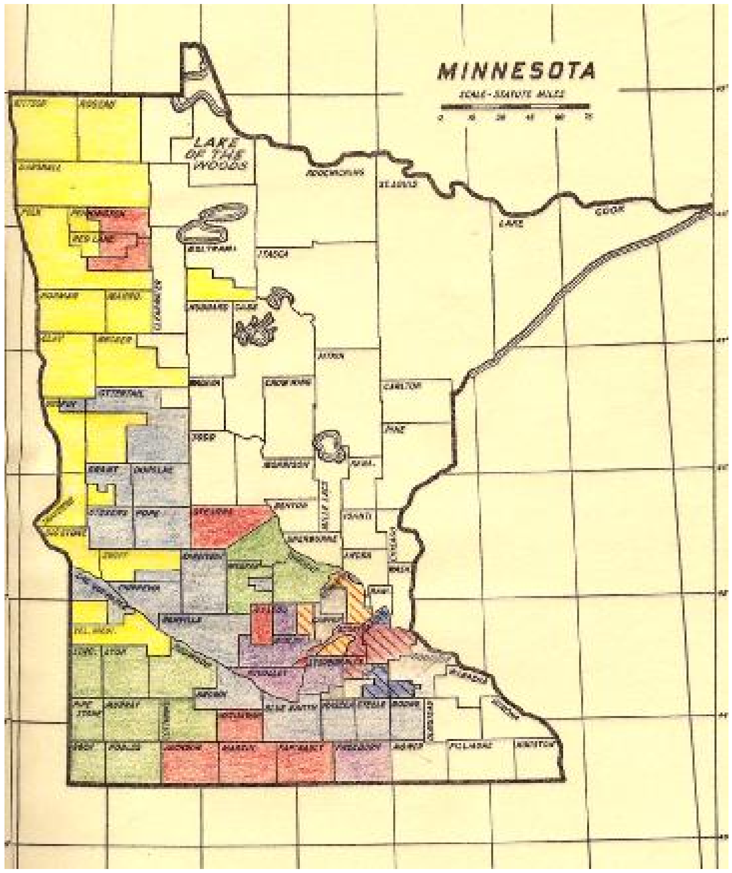



Figure 21. Map showing location of all properties with escaped bushes in Minnesota, 1918-1928 (From Melander, 57).

Figure 22. Boys who earned a National Rust Busters Club medal by finding a location of barberry, Waseca County, Minnesota, 1931 (Courtesy of the University of Minnesota Archives).


Figure 23. Minnesota State Fair demonstration, 1931(Courtesy of the University of Minnesota Archives).



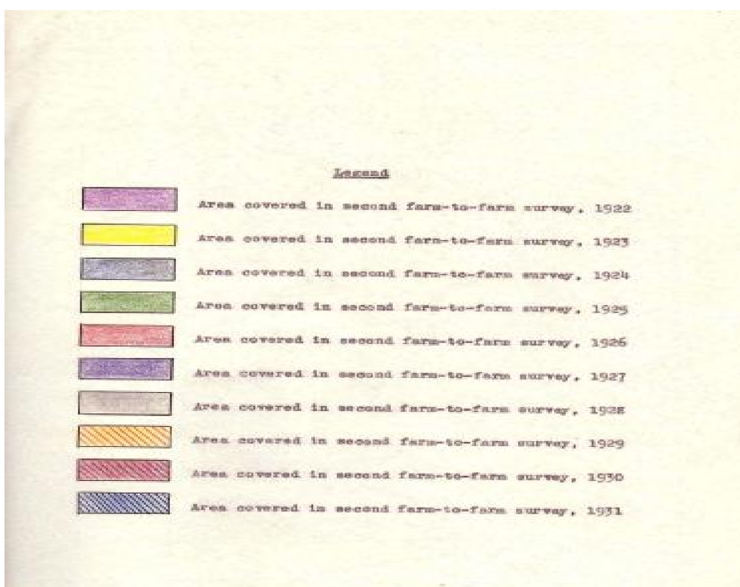




Figure 24. Map with legend showing progress of second survey in Minnesota, 1922-1931 (From Melander and Thompson, 67).

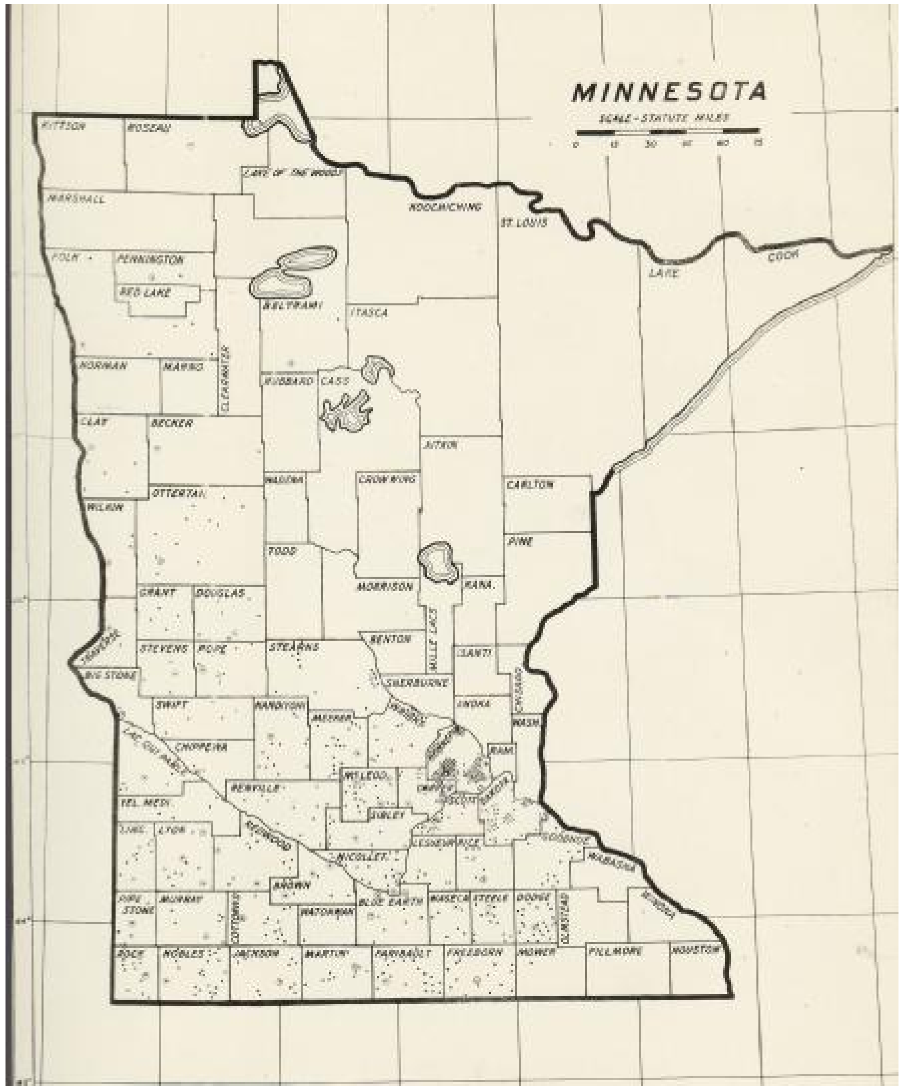



Figure 25. Map showing properties where barberry bushes were located and destroyed in Minnesota, second survey through 1930 (From Melander and Thompson, 66).

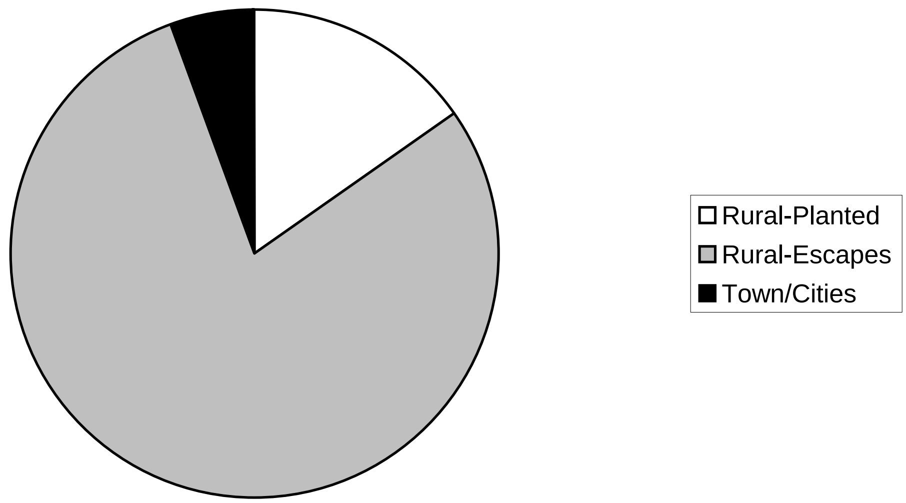



Figure 26. Properties with bushes in Second Survey. (Data from Melander and Thompson, 67).

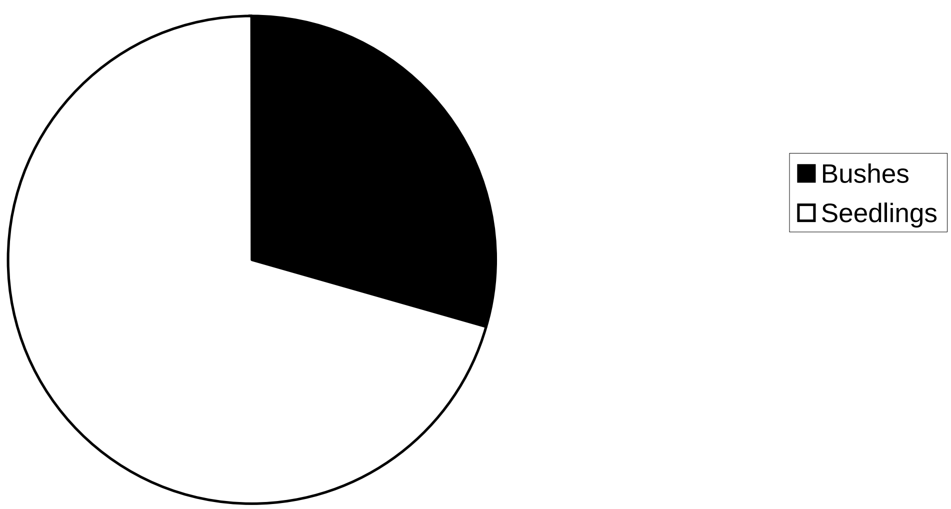



Figure 27. Proportions of bushes and seedlings found during the Second Survey, 1922-1931 (Data from Melander and Thompson, 67).

Figure 28. A nine-men barberry eradication crew, ca. 1930s (Courtesy of University of Minnesota Archives).

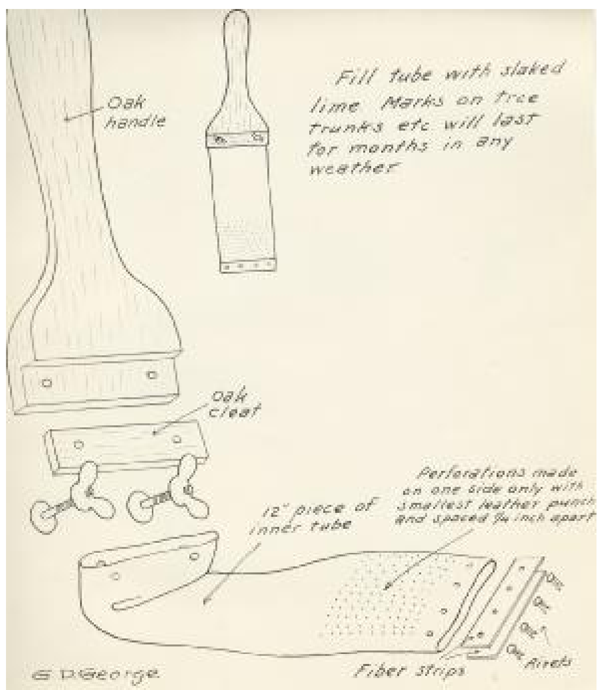



Figure 29. Survey line marker designed by Minnesota State Leader L. W. Melander and G. D. George (From Melander and Thompson, 69).

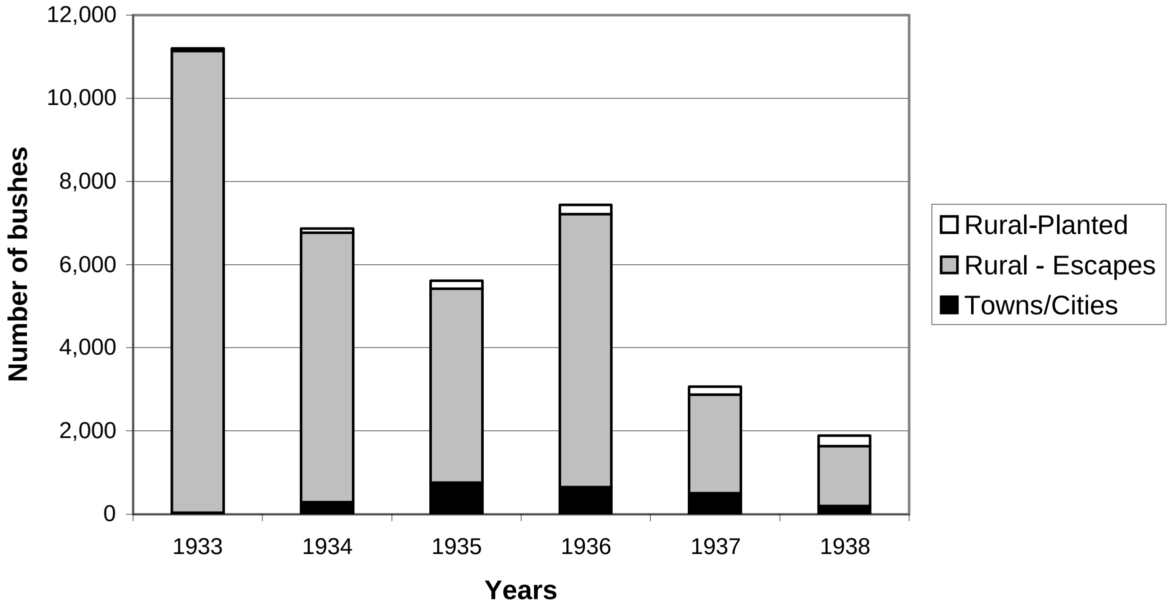



Figure 30. Number of bushes found in Intensive Survey, 1933-1938 (Data from Melander et al., 74).

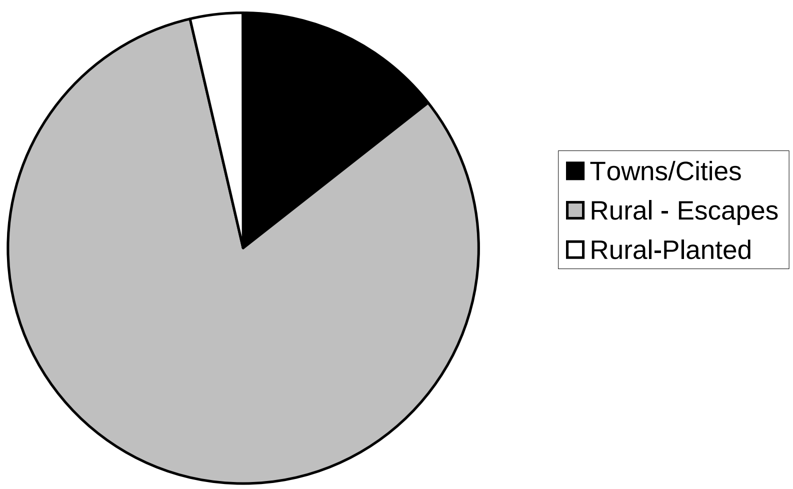



Figure 31. Properties with bushes in Intensive Survey, 1933-1938 (Data from Melander et al., 74).

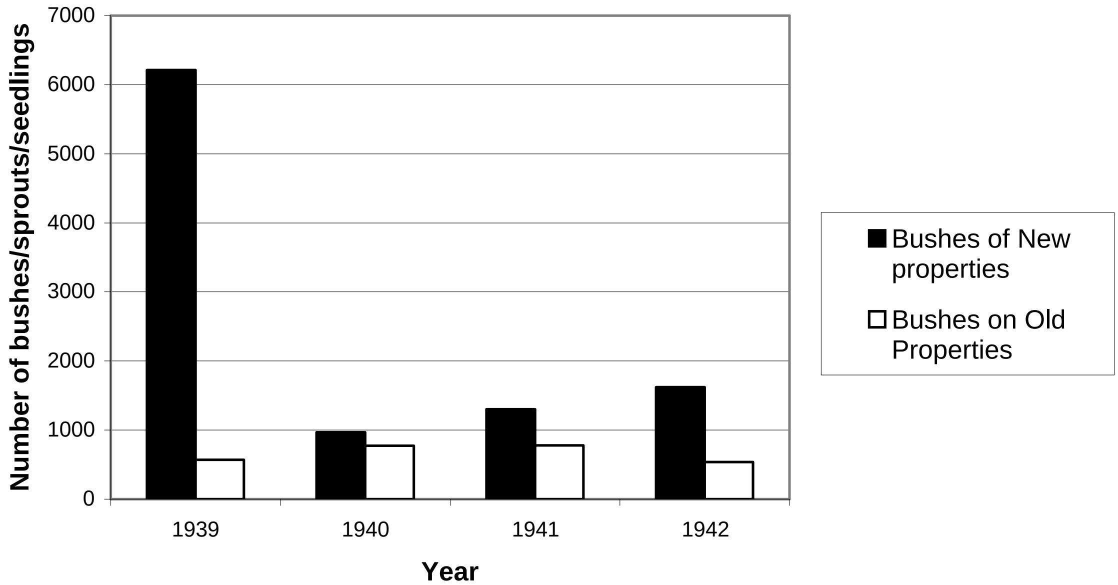



Figure 32. Bushes found on previously inspected properties (“Old”) and on newly located properties (“New”) in the Intensive Survey, 1939-1942 (Data from Melander et al., 70).

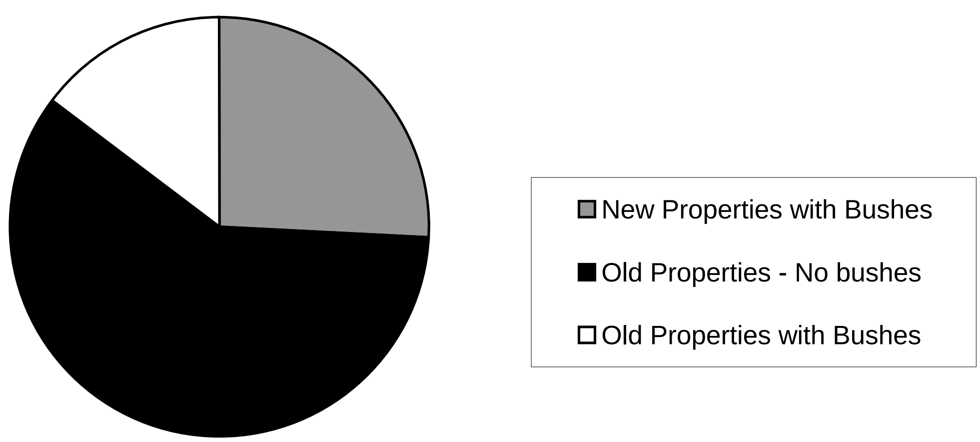



Figure 33. New and Old properties where bushes were found or bushes were not found in the Intensive Survey, 1939-1942 (Data from Melander et al., 70).

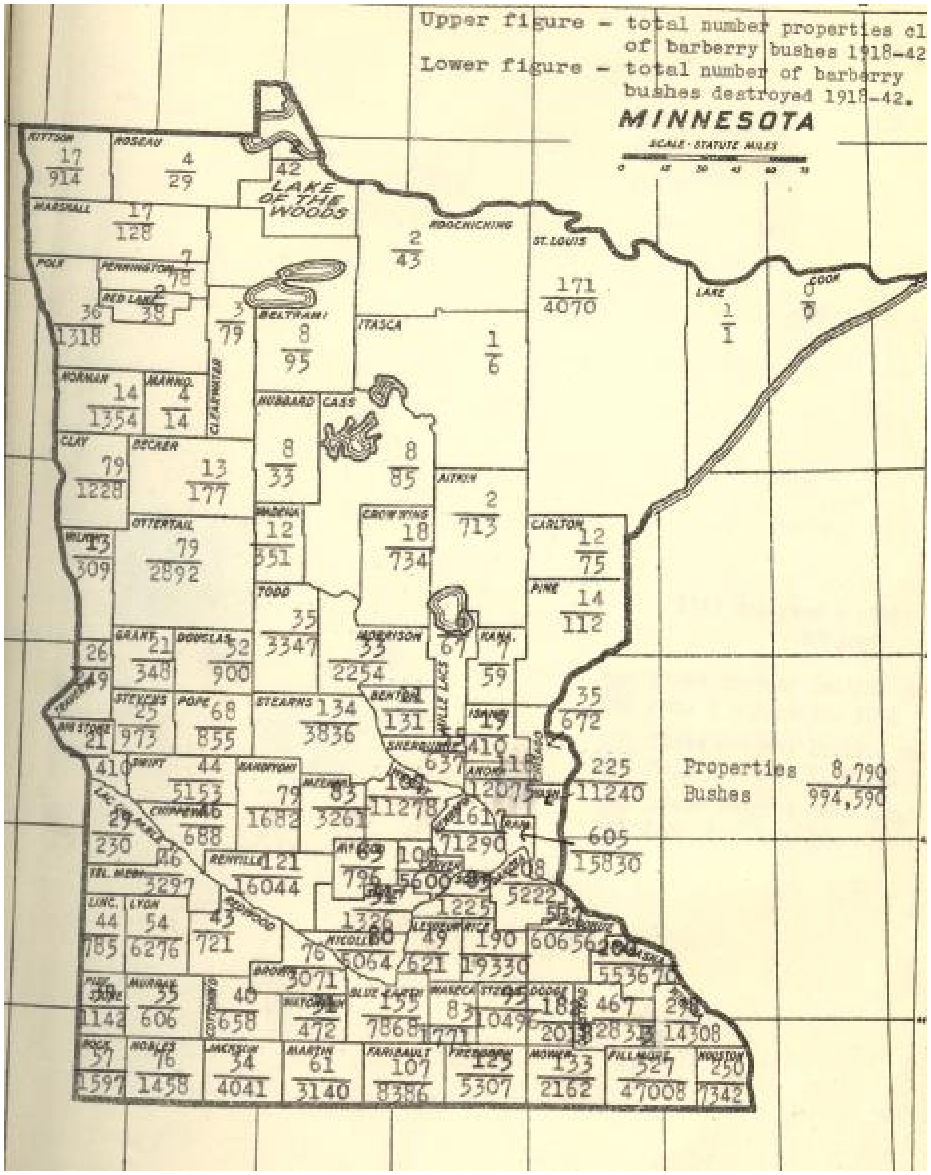



Figure 34. Map showing, by counties, numbers of properties cleared of barberry bushes (upper figure) and numbers of barberry bushes destroyed in Minnesota, 1918-1942 (From Melander et al, 70).

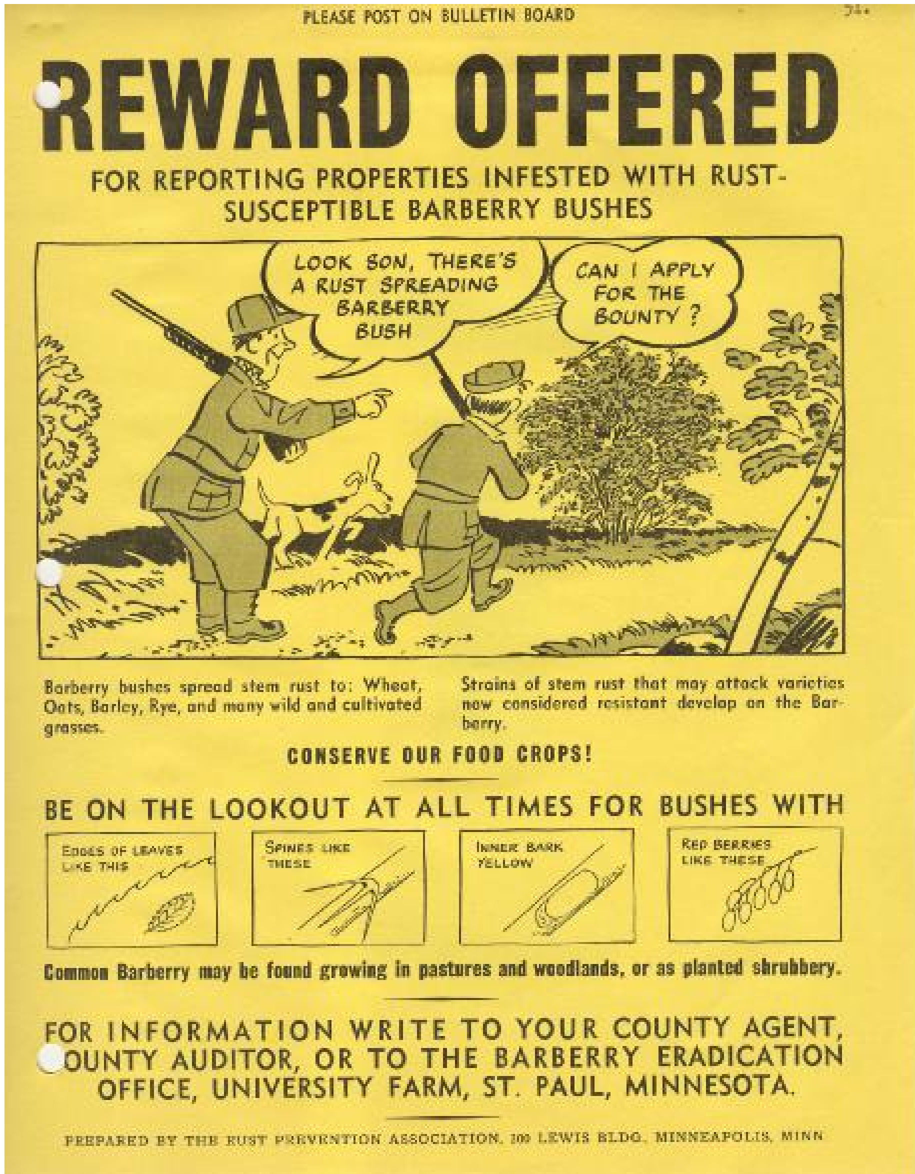



Figure 35. Bounty system poster, 1943 (Courtesy of the University of Minnesota Archives).

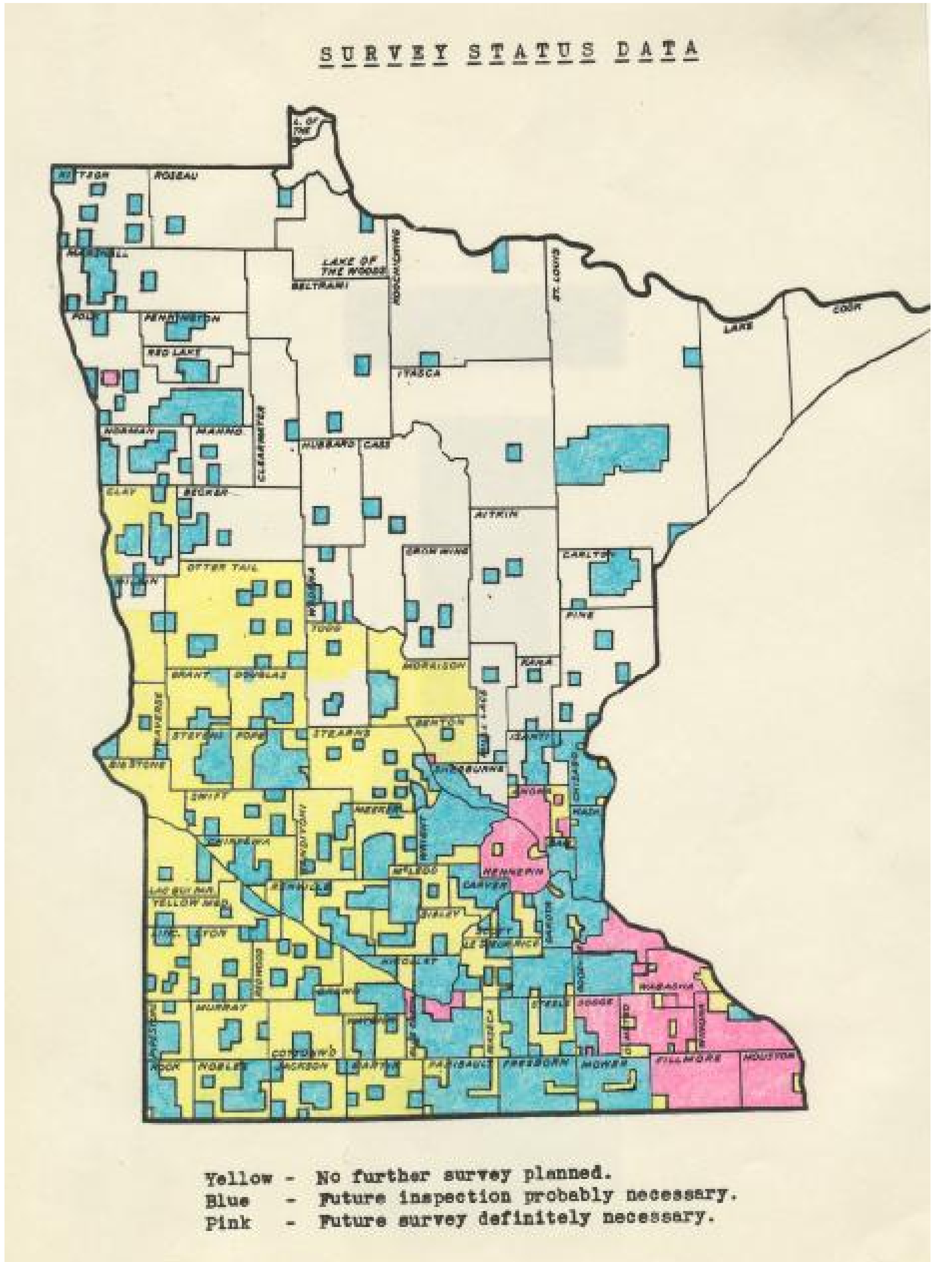



Figure 36. Map showing the status of barberry eradication in Minnesota, December 31st, 1943 (From Melander, 59).

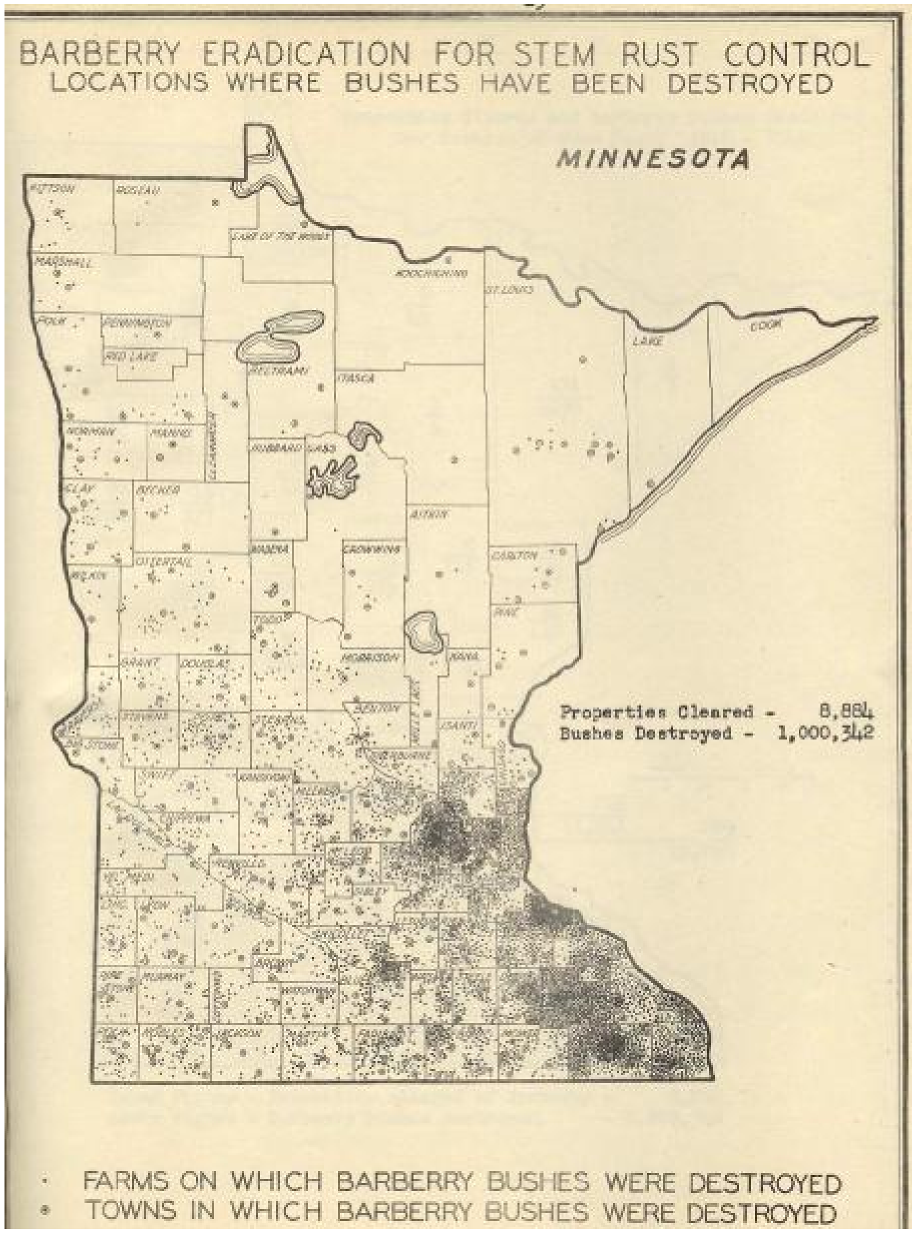



Figure 37. Map showing properties where barberry bushes were located and destroyed in Minnesota, through 1945 (From Stewart, 105)

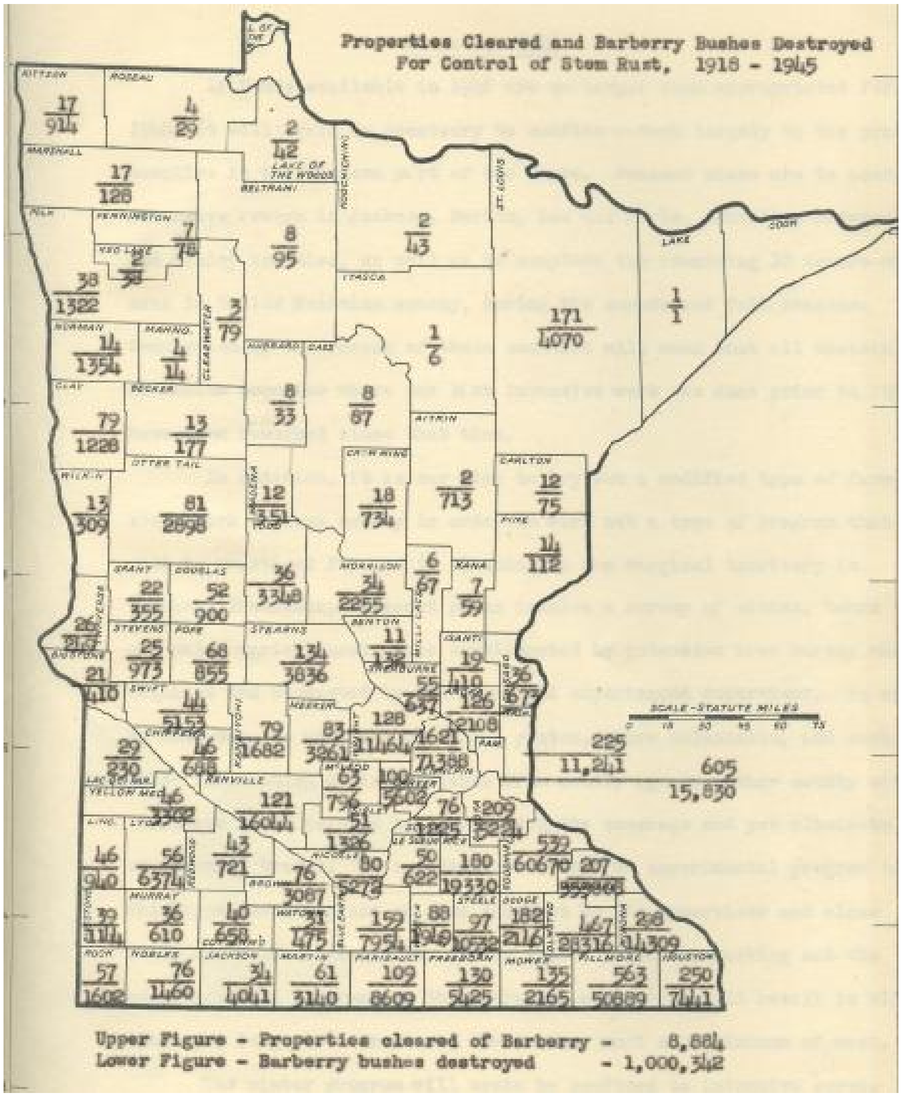



Figure 38. Map showing, by counties, numbers of properties cleared of barberry bushes (upper figure) and numbers of barberry bushes destroyed in Minnesota, 1918-1945 (From Stewart, 105).

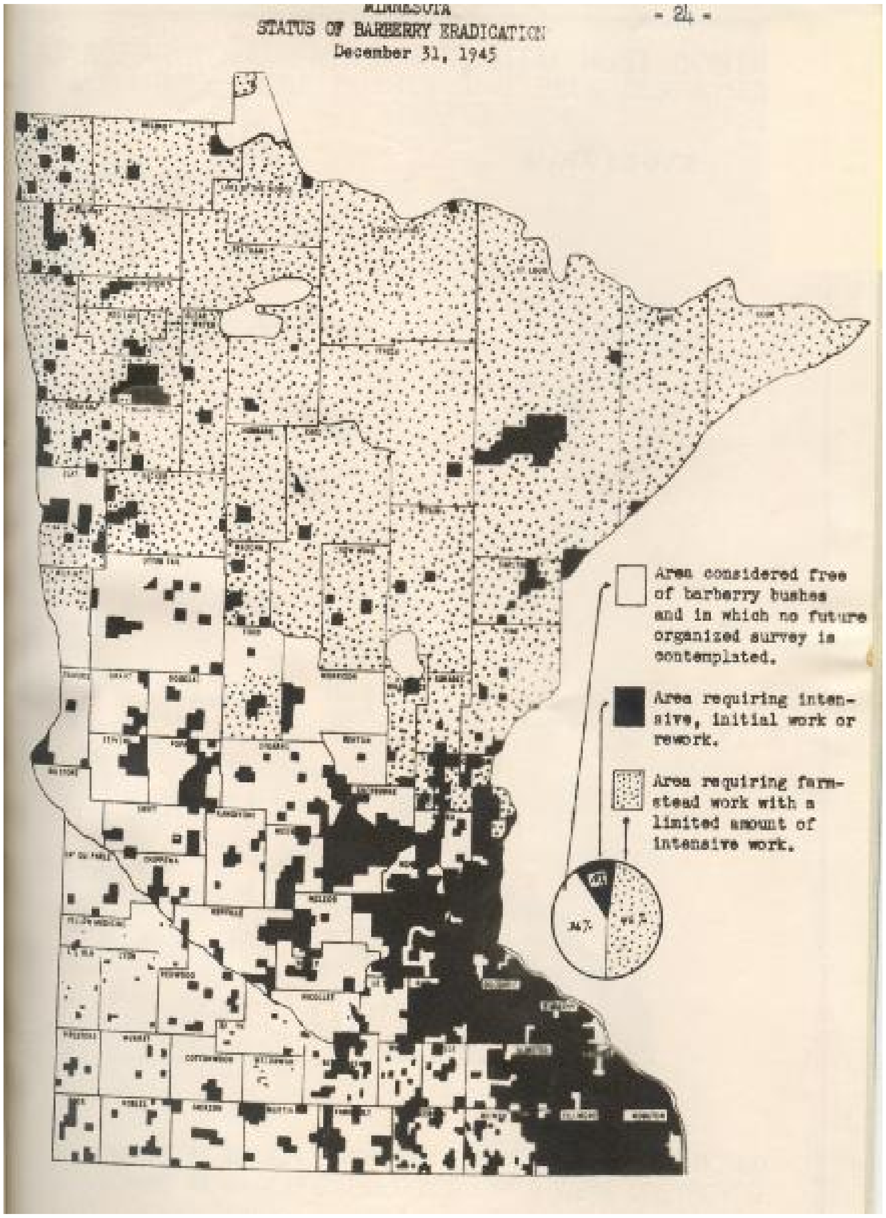



Figure 39. Map showing the status of barberry eradication in Minnesota, December 31st, 1945 (From Stewart, 105).

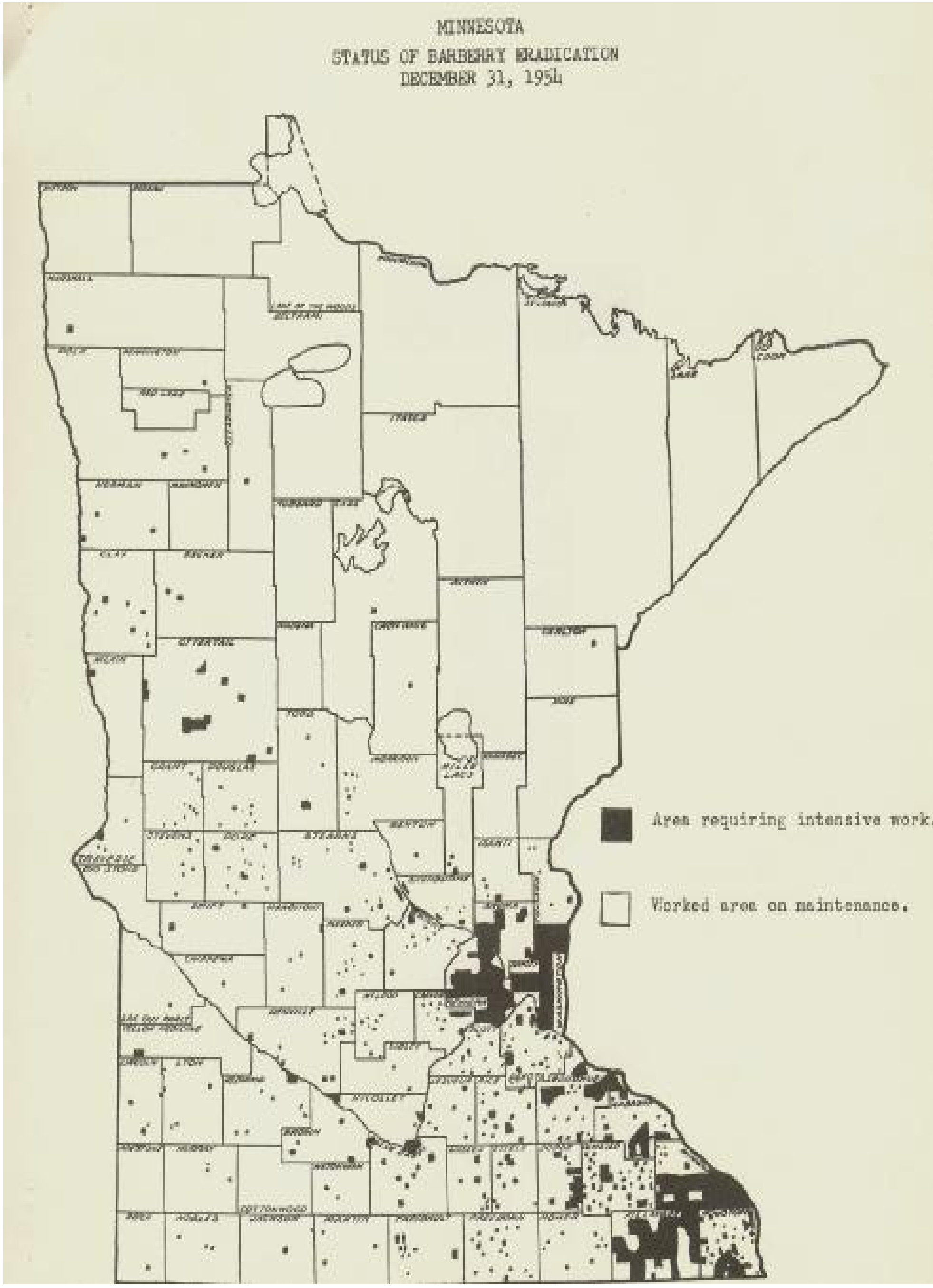



Figure 40. Map showing the status of barberry eradication in Minnesota, December 31st, 1954 (From Stewart, 107).

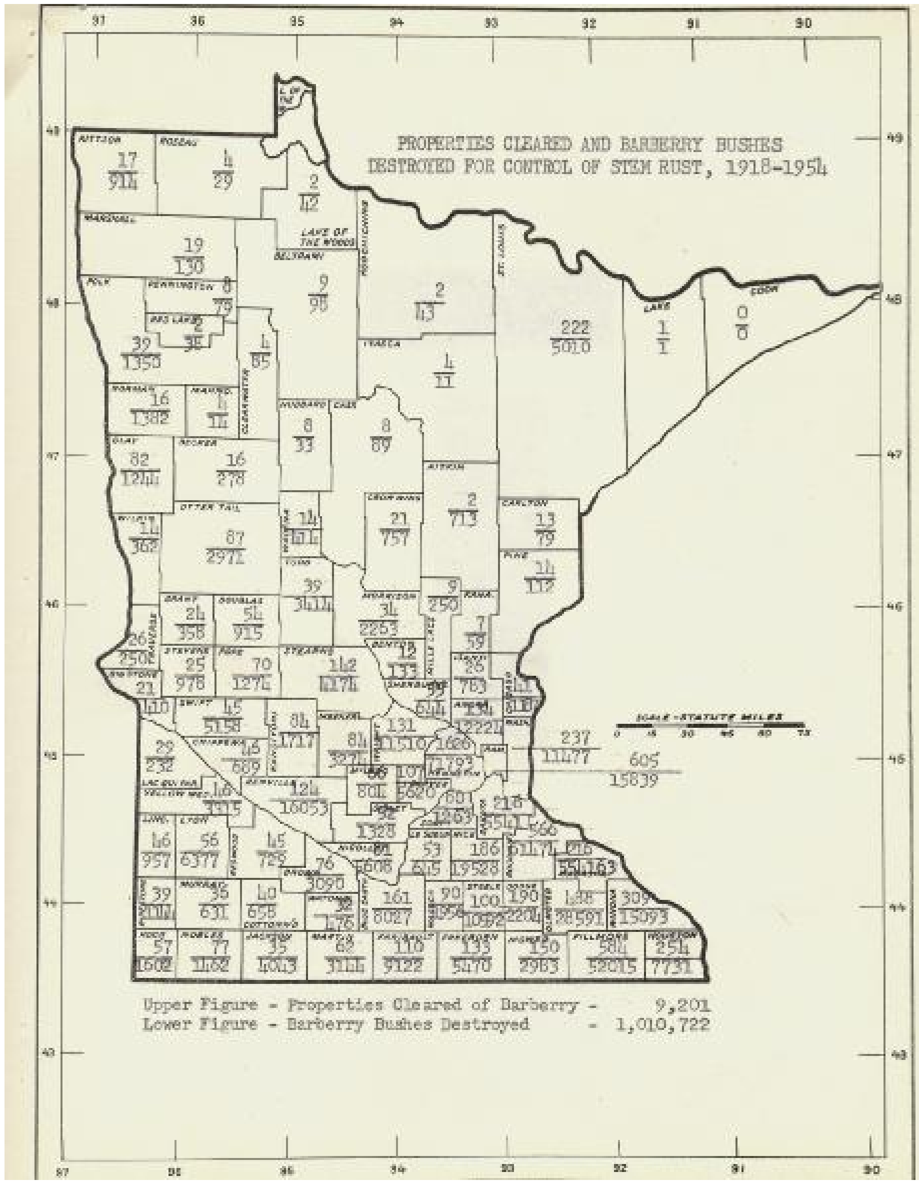



Figure 41. Map showing, by counties, numbers of properties cleared of barberry bushes (upper figure) and numbers of barberry bushes destroyed in Minnesota, 1918-1954 (From Stewart, 107).

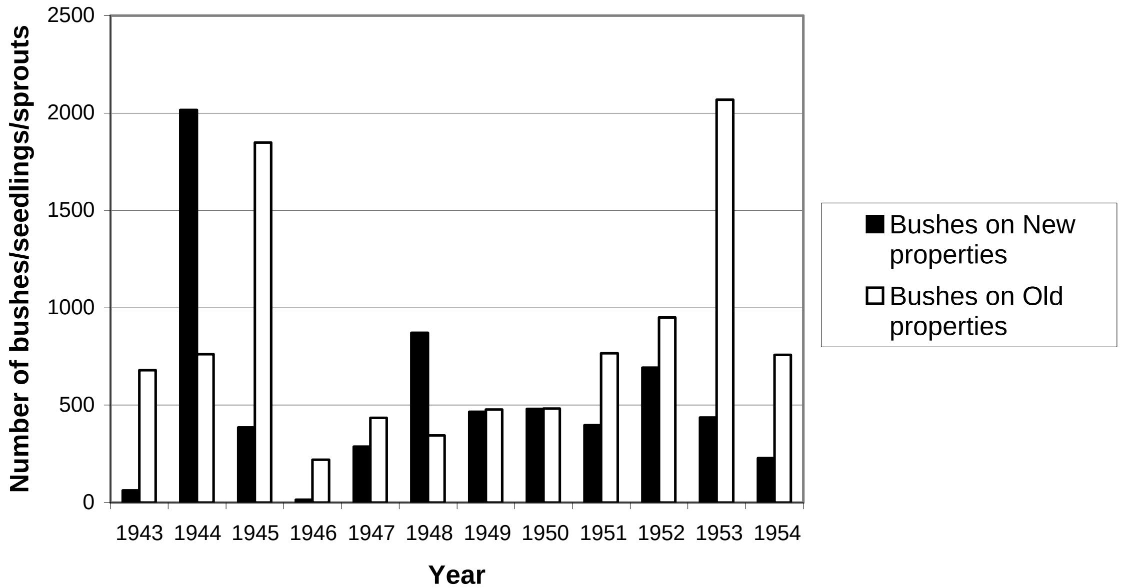



Figure 42. Bushes found on previously inspected properties ("Old") and on newly located properties ("New") in the Initial Intensive Survey, 1943-54 (Data from Stewart, 108).

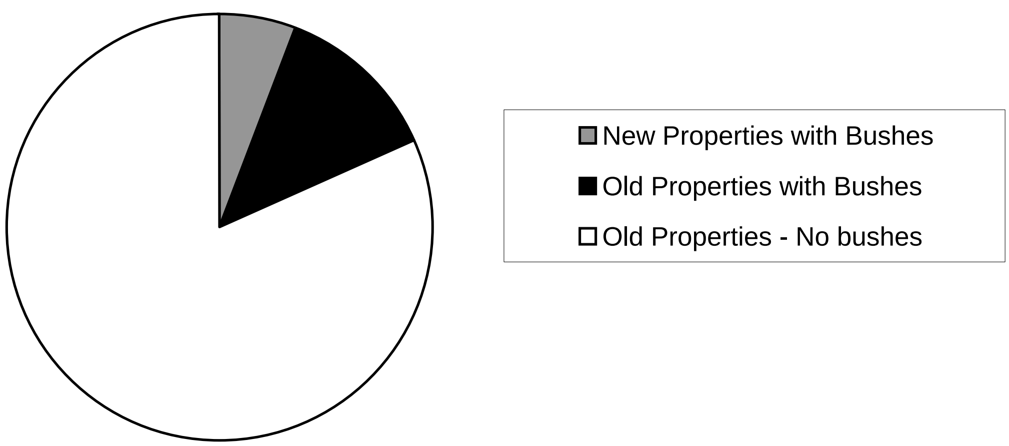



Figure 43. New and Old properties where bushes were found or bushes were not found in the Initial Intensive Survey, 1943-1954 (Data from Stewart, 108).

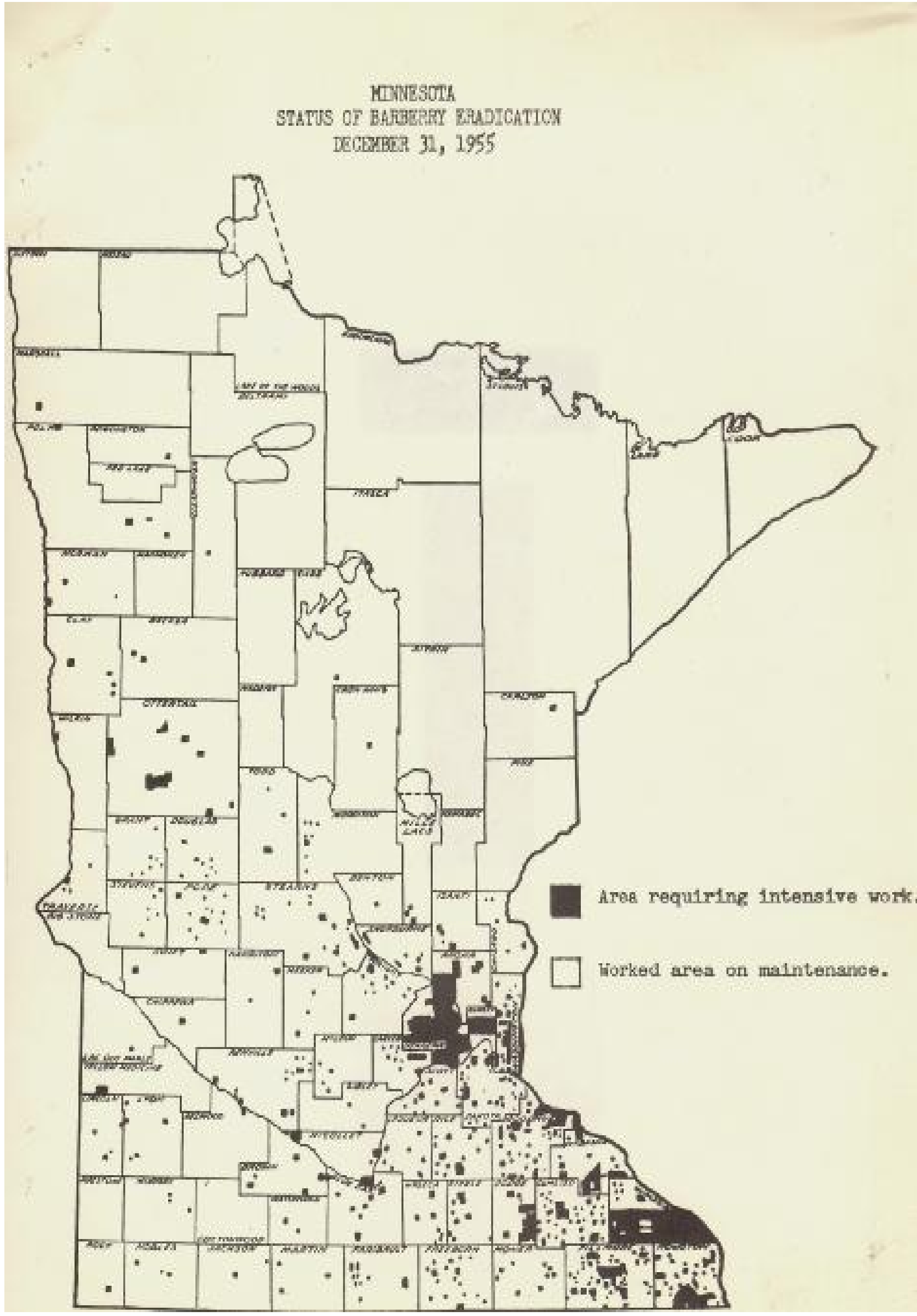



Figure 44. Map showing the status of barberry eradication in Minnesota, December 31st, 1955 (From Stewart, 108).

FINDS ON RESURVEY OR SUBSEQUENT INSPECTIONS

| Year* | New Owner | Year* | New Occupant** |
|---|---|---|---|
| 1954 | Heitman, A.H. | 1954 | A.H. Heitman |
| 1971 | Alvin Luhmann | | |

| Date | Supervisor | Number of Barberries Found & Destroyed | | | | | | Chemicals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Escaped | ~~Sprouting~~ N.E. | Seedlings | Fruiting | Treated | Kind | By USDA lbs. | By lbs. | Total lbs. |
| 12-3-54 | G | 7 | 7 | 4 | 1 | 2 | 7 | amate | | | 2 lbs. |
| 2-4-71 | Laudon | 605 | 605 | | 13 | 39 | 605 | A. | 65# | | 65# |

*Year of reinspection. **Insert name if changed since last check of property.

ORIGINAL REPORT OF BARBERRY LOCATION

County GOODHUE City or Township S.E. 1/4 of Sec. 36, Florence Twp. (Section, Quarter, Township)

Occupant Alvin Luhmann LakeCity (Mail Address of Property)

Owner Heitman, A. H. LAKE CITY (Address)

(Formerly H.C.Heitman)

| Maturity of Barberries | Kind or Species | No. of Barberries Found & Destroyed | | | | | Chemicals | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Planted | Escaped | Fruiting | Treated | Kind | By USDA lbs. | By lbs. | Total lbs. |
| Bushes | | 2 | | 2 | | 2 | D | | | |
| Seedlings | | | | | | | | | | |
| Total | | | | | | | | | | |

Attitude of Owner or occupant:

Aug. 8, 1920
(Supervisor Reporting)
W. S. Lund
(Date)

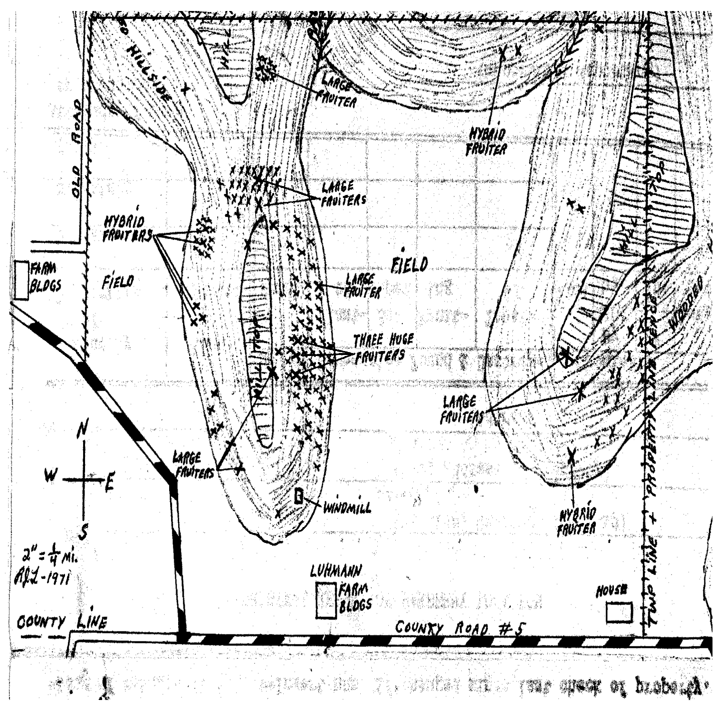



Figure 45. A) Barberry property locator form (L-form) and B) hand-drawn map

Figure 46. Ammonium sulfamate (Ammate) applied to cut stubs of barberry canes (Courtesy of University of Minnesota Archives).

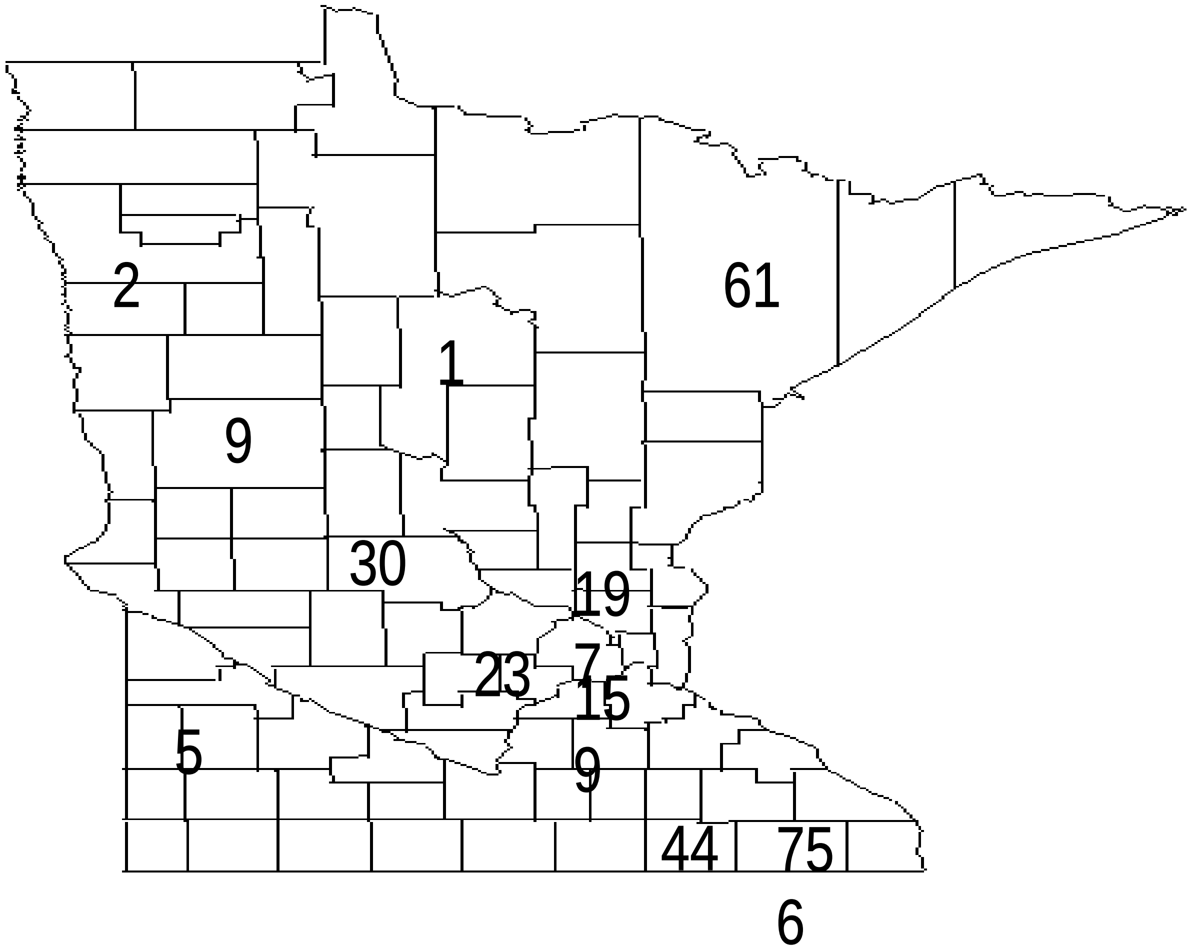



Figure 47. Number of active barberry sites and their distribution in Minnesota, 1986. (Data from Laudon, unpublished).

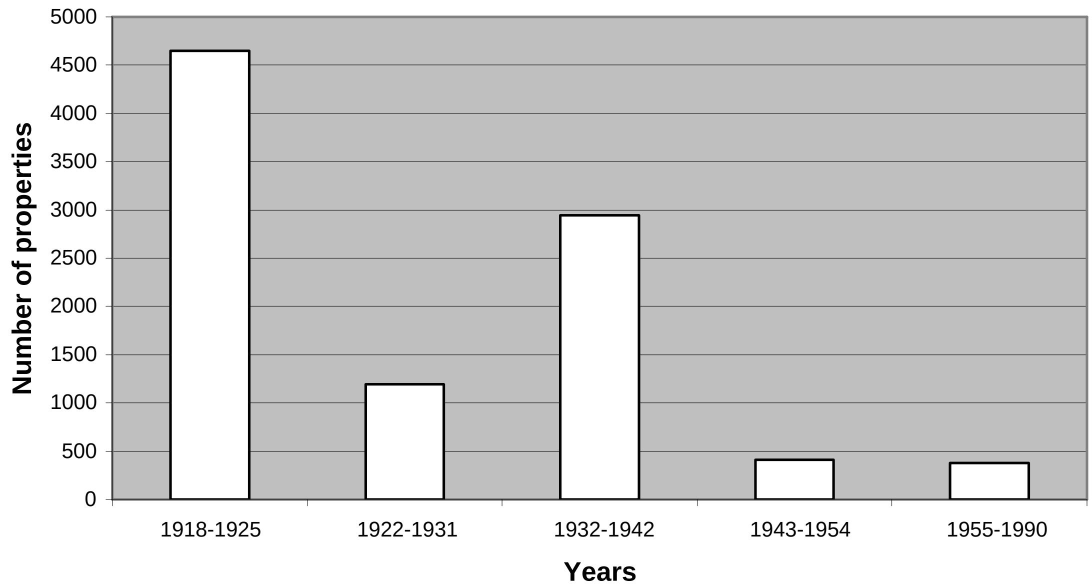



Figure 48. Number of properties where barberries were found during different phases of the barberry eradication campaign, 1918-1990.

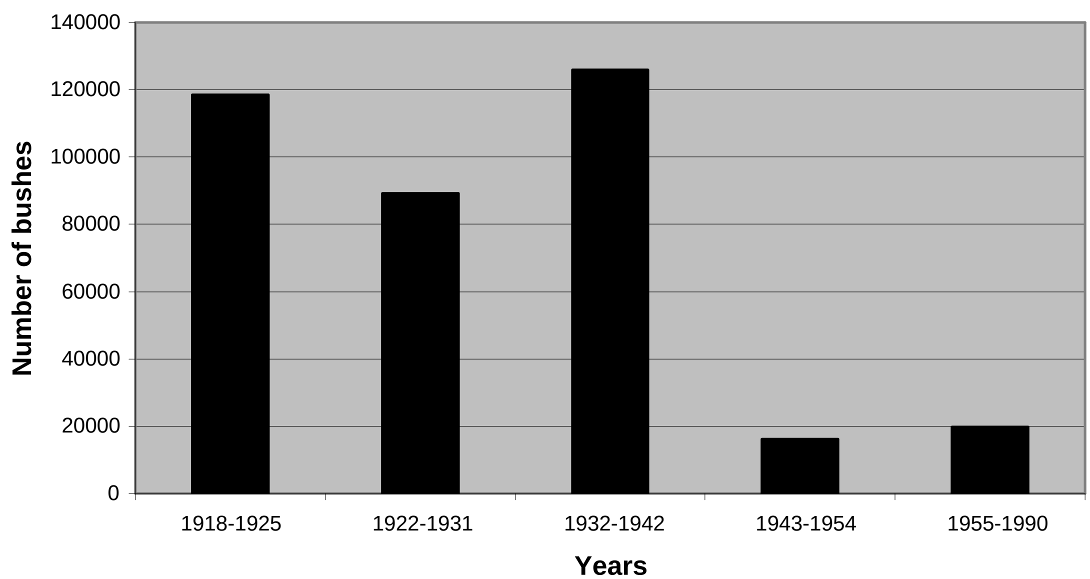



Figure 49. Total number of barberry bushes destroyed in each phase of the Barberry Eradication Program, 1918-1990. Numbers from 1918-1925 do not reflect the 600,000 bushes destroyed in nurseries in 1918

# The Origin, Spread, Biology and Ecology of *Berberis vulgaris*

## Introduction

The importance of barberry as the alternate host for the stem rust pathogen, *Puccinia graminis* L. has been known for more than a century, but little has been documented, in the public domain, on the biology and ecology of this bush. Countless studies on the biology and ecology of *Berberis vulgaris* Pers. were conducted during the course of the barberry eradication program; however, much of this information remains unpublished or inaccessible.

## Origins of Barberry and Distribution in the United States

The barberry has Asian origins, most likely deriving from the middle and western Asiatic mountains. It spread first in the Arab world, where Babylonians described its medicinal properties as early as 650 B.C. By the 7$^{th}$ century A.D., Arabians were using the berries as therapeutics. Barberries were introduced into Europe by the 13$^{th}$ century and gained popularity due to their reference as a medical plant by the Danish botanist, Henrik Harpestraeng (15). By the 17$^{th}$ century numerous reports place barberries in southern and northern Europe, England, and even North America, where they had been transported by early colonists and had become a common plant around farmsteads (9, 11).

As settlers spread out into the midsection of the United States in the mid-1800s, seeds of the barberry journeyed west and north with them. By the time of the American Civil War, barberries were growing in a number of north central states. Aiding this dissemination was their easy propagation by seed or cuttings, vigorous growth habits, and listings in nursery catalogs (11). Before extensive eradication efforts, *Berberis vulgaris* L. was distributed across many northern and mid-western states as well as in a few western states (Fig. 1). It is still known to occur in Massachusetts, New York, Wisconsin, and Washington and it still occurs in several other states of its former range (30).

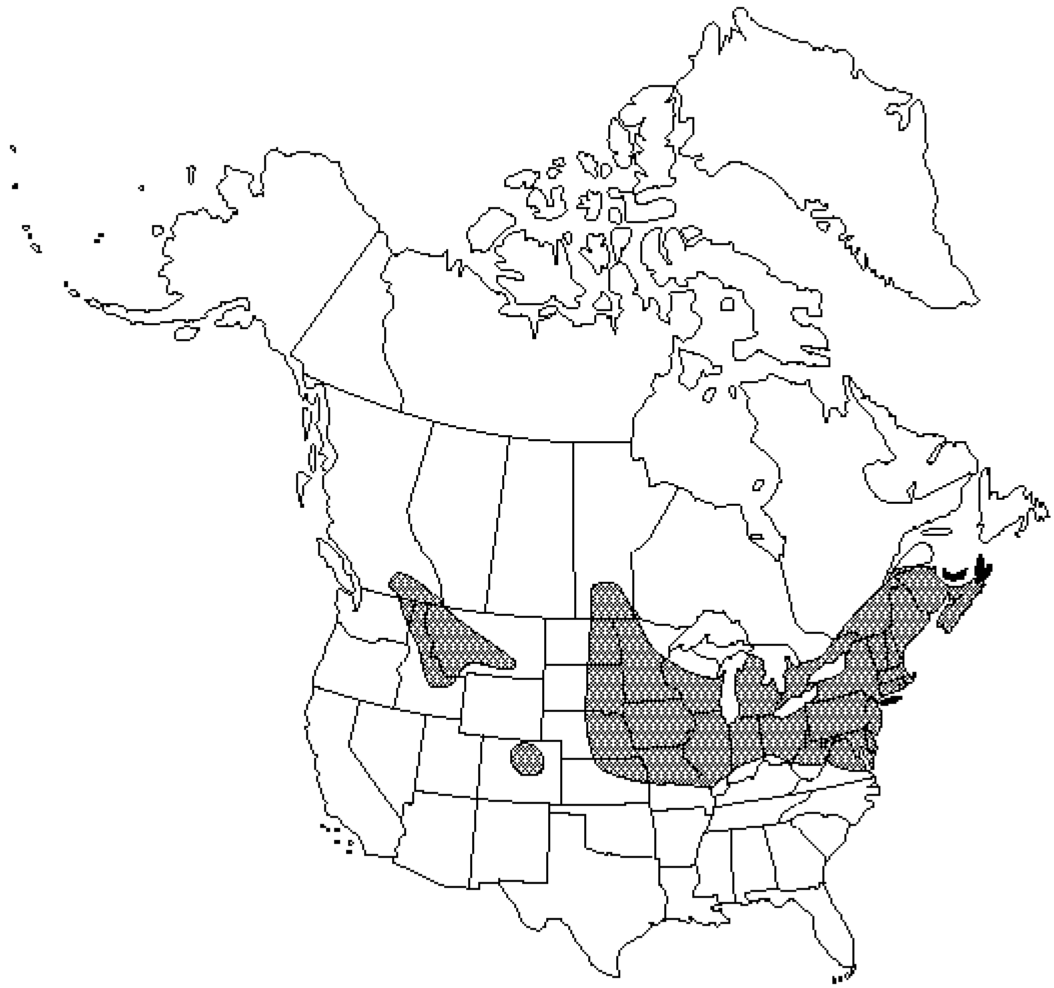


Figure 1. Distribution of *Berberis vulgaris* in the United States prior to the eradication program; from Flora of North America, Vol. 3 (30)

**Systematic Relationships**

*Berberis vulgaris* (Berberidaceae), the Common or European Barberry, is the type species of a widespread and diverse genus. Several species share some common characteristics, as do species within the genus *Mahonia* (Berberidaceae). Morphological similarities have resulted in an intricate synonymy, particularly with the inclusion of *Mahonia* spp. within *Berberis* (6,19). The most recent revision separated the genera (1). Plants within both genera typically possess bright yellow roots and inner bark and bright red berries on a raceme, and can be confused. Leaf shapes and the presence or absence of spines are typically diagnostic. *Berberis* spp. have smooth pinnate leaves, spines grouped along branches, and small yellow flowers borne on a raceme (1).

Figure 2. Yellow inner bark diagnostic of *Berberis vulgaris*

At the time of the initiation of the Barberry Eradication Project, the species then usually referred to as Trailing Mahonia was placed by different taxonomists in the genus *Odostemon*

(6) or *Berberis* (17, 19), with the species epithets *aquifolium* and *repens* both in use. Ahrendt's revision places it in *Mahonia* and distinguishes *M. aquifolium*, the Holly-leaved Barberry, and *M. repens*, Creeping Barberry (1). Although not usually listed as occurring in Minnesota, *M. aquifolium* is a widespread mid-western and western species of the open woodlands, and thus was found in some of the states, such as Nebraska, of the Barberry Eradication Project. Considered to be a barberry species, it was of some concern in states other than Minnesota.

Three species of *Berberis* are found in Minnesota – *B. vulgaris, B. canadensis* (American Barberry), and *B. thunbergii* (Japanese Barberry). Among *Berberis* species, *B. vulgaris* is distinguished by its entire leaf, by its tall erect growth habit, and by its deciduous nature (29). All three have been considered susceptible to *Puccinia graminis*. *B. vulgaris* is the most susceptible. The other main susceptible species in the U.S. is *B. fendleri*, which occurs in Colorado, New Mexico, and Utah.

Although *B. thunbergii* is listed by some authorities as not transmitting stem rust (21) or not particularly susceptible (25), some isolates of *P. graminis* from Canada were able to produce some infection on *B. thunbergii* (30). The main concern with this species is its ability to hybridize with *B. vulgaris*, resulting in a range of progeny with intermediate morphological and pathological characteristics (25). Some of these hybrids are difficult to distinguish from non-susceptible types and consequently could perpetuate a source of inoculum if left growing unchecked. Also, even hybrids which are resistant to *P. graminis* may produce seed through self-pollination that give rise to seedlings that are susceptible to *P. graminis*.

## Form and Habit of Growth

Barberry growth and development from seed follows a very orderly pattern. A single, primary, shoot is sent up from the germinating seed. This primary shoot does not grow to be very large and is typically slender and drooping (26). A mature bush of common barberry is typically composed of 20 to 30 individual stalks, with few branches (Fig. 3) (26).

Figure 3. A typical mature fruiting bush of *Berberis vulgaris*

In addition to these main stalks, there are also many slender unbranched shoots arising from underground lateral rhizomes. The rhizomes are usually devoid of roots until after aerial shoots have formed, then a mass of fibrous roots form around the base of each shoot. Continuous production of lateral roots, rhizomes, shoots (also known as sprouts), and fibrous roots allows the parent bush to increase its size.

The formation of shoots complete with their own set of roots provides a means of very effective long-term survival and reproduction in barberry. Even if the new shoots are severed from the parent plant, they have the capacity to live and reproduce once their root system is established. Hence, these reproductive characteristics make eradication of barberry a difficult process with continual problems of re-growth from disturbed sites (26).

**The Shoot System**

*Berberis vulgaris* is a tall erect shrub, approximately 1-3 m in height, with elliptic-obovate leaves with blunt tips (Fig 4.). The leaves with their characteristic spiny edges, are approximately 4 cm long and are attached to the stem by a 2 cm long petiole.

Figure 4. Diagnostic spiny edged leaves of barberry

The leaves are attached along the main branch in clusters or lateral spurs (Fig. 5).

Figure 5. Spiral arrangement of leaf clusters along barberry stem

The leaves are prominently net-veined, and grayish green on the adaxial side. *B. vulgaris* has spines approximately two to three centimeters long, grouped in threes or fives. Red, elliptical shaped berries are borne in bunches on a pendulous raceme or stalk (Fig.7). Berries typically contain between one and three seeds. Branches of the bushes are typically straight, strongly grooved and gray to yellowish gray in color (29), with short, sharp slender, three-branched spines at nearly every node (16). Flowers are small, pale yellow in color and arranged on pendulous racemes towards the ends of the branches (Fig. 6). *Berberis vulgaris* flowers in May or June with the yellow sepals and petals falling soon afterwards and berries forming in mid-late summer. Berries typically remain throughout winter.

Figure 6.  Flowers of barberry borne on a raceme

Figure 7. Characteristic bright red berries of barberry borne on a raceme

**The Root System**

The root system of *B. vulgaris* is characterized by a network of fibrous roots surrounding the base of the crown (20).  This network of roots is responsible for procuring any nutrients and water for the developing barberry (26).  Rhizomes produced from the crown grow underground and form lateral supporting roots (24). These lateral roots can grow 3.1 to 5.0 meters long. Typically they grow approximately 1.0 m from the base of the crown before turning upwards and breaking the ground surface to produce aerial shoots (Fig. 8). Barberry may have many lateral roots just below the soil surface (24). In addition to playing a supporting role for the plant, it is mainly these superficial laterals from which sprouts originate. Disturbance of the soil is necessary for them to form aerial shoots (Fig. 9). Emergence of these shoots through the soil surface promotes further root growth resulting in a fibrous root mass around the base of each shoot. Shoots may also form from these laterals in response to the cutting or removal of the aerial portions of the plant.

Shoots develop rapidly from stems or roots cut back intentionally or damaged by grazing. Different soil conditions result in different root patterns in *B. vulgaris*. The gently sloping hillside or deep loamy pastureland, typical habitat of *B. vulgaris*, does not encourage growth of a deep tap root and sandy or loose textured soils tend to promote the growth of long supporting lateral roots.

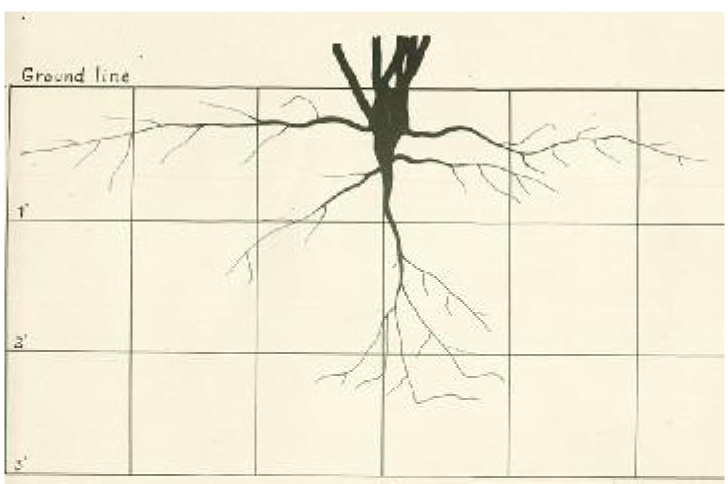



Figure 8. Schematic of the root development of *Berberis vulgaris*

Figure 9. Barberry root growth showing shoot development (sprouts) from rhizomes

**Sexual Reproduction in *Berberis vulgaris***

Reproduction in *B. vulgaris* can either occur by sexual means with the production of seed, or asexually by underground stems (rhizomes) or root fragments. Both sexual and asexual reproduction play important roles in the barberry life cycle and attribute to the ability of the plants to survive in harsh conditions and in situations where intentional or unintentional damage is inflicted.

Barberry's distinctive small yellow flowers are borne in clusters and hang downwards from the stem. The reproductive organs of the flower are protected from rain by three inner concave sepals (2) as well as six petals that completely enclose the stamens and anthers. Bees, wasps, ants, flies and beetles are the most common pollinators. The nectaries at the base of each petal attract insects, resulting in the insects moving the filaments and causing the pollen to dehisce on the insect's body.

**Pollination in *Berberis vulgaris***

Typically, pollination is facilitated by an insect moving among flowers, touching the receptive stigmas with the pollen on the surface of its body (2). *Berberis vulgaris* is adapted to cross-pollination but can self-pollinate if no insects facilitate the process. Isolated fruiting bushes with berries containing seeds indicate that self-pollination does occur or that barberry may be able to reproduce parthenogenetically (2).

**Reproduction by Vegetative Structures**

Shoots (vegetative structures) that develop from underground rhizomes play an important part in the barberry's life cycle as well as its long-term survival. Shoots can arise from the ends of lateral roots or from rhizomes arising from the root crown (26). Barberry shoots are especially abundant in areas where barberry roots are damaged by grazing or cut back intentionally. The lateral roots and rhizomes respond to such damage by sending up shoots.

**Bush Maturity and Seed Production**

Barberry bushes are capable of producing berries in many different environments. Light, temperature, rainfall and soil conditions all influence the development of barberry and the age at which berries are produced. In greenhouse conditions Shepherd (25) reported that flowers and fruit were observed on barberry bushes less than one year after seed germination. However, he (25) also stated this was unusual and certainly not typical of barberry growth in natural environments. Generally, barberry bushes grown from seed begin producing fruit from the 4th to the 7th year of growth (24, 25). Bushes from sprouts may produce fruit any time after one season's growth (25).

## Germination of Seed

Barberry bushes have been found in abundance in areas with limestone outcrops, which may indicate that seeds of *B. vulgaris* germinate best in alkaline soils (22); however, barberries have also been found growing in neutral and slightly acidic soils (2).

In controlled environments with adequate soil moisture, a constant soil temperature of $5^{o}C$ is optimum for barberry seed germination (7). Under field conditions, soil temperatures of $10^{o}C$ for 18 hours followed by a period of 6 hours at $22^{o}C$ provides optimum conditions for seed germination (2, 13, 14, 18, 22). Low and delayed germination occurs at temperatures less than $10^{o}C$ and no germination occurs at temperatures $> 35^{o}C$ (equivalent to germination in full sunlight). Conditions found in shaded areas at the edges of woodland are ideal for germination of barberry seeds. In addition to this, alkaline, sandy-loam soils under a canopy of trees are most favorable for the growth and survival of seedlings (4, 7, 8, 27, 28).

Requirements for germination include water, moderately high soil temperatures and oxygen. Cultivation loosens the soil and increases exposure to sunlight, which increases the oxygen flow to the seed and promotes germination (23). Excessive soil moisture is the most important limiting factor to seed germination (2, 25). Other factors that limit seed germination include direct sunlight and seed dormancy requirements and depth of seed burial. Seed germination is optimum at planting depths of 1.5 cm and is completely inhibited at a depth of 8 cm (13).

Even under optimum conditions, levels of seed germination may not be very high. Extensive seed germination experiments were conducted in Lucas County, Ohio in 1936. In these studies, Atwood and Stover (4) found that the average germination across all of the plots was 12.7% with 52.5% germination in plots under optimum soil temperature and moisture conditions. No germination was observed in conditions of full sunlight (25). In growth chamber tests, the percentage of seeds germinating in pots planted with seeds separated and extracted from the berries was much higher than for those planted with the seeds still within the berries. Denton concluded that the presence of the berry tissue was inhibitory to seed germination (8).

**Barberry Seedlings**

Seedling mortality in barberry is very high. Out of the vast numbers of seeds produced, only a small percentage germinate and produce seedlings which survive to maturity (2). Robbins (24) reported that most seedlings die within the first year primarily because of insufficient root growth. He also indicated that this provides an important means of controlling these plants if the seedlings could be eliminated within the first year of growth. Subsequent years of growth provide the plant with extensive root growth (crown and laterals) and consequently a means to recover from any intentional or unintentional above ground damage. In one study, Shepherd (25), demonstrated that 86% of new seedlings produced in August of one year, perished by the August of the following year. Atwood and Stover (4) demonstrated that of the small percentage of seedlings surviving through their first year, 21.6% survived to the sixth year or beyond.

The main factors influencing seedling survival are similar to those influencing seed germination i.e. protection from direct sunlight, soil drainage, preference for alkaline sandy-loam soils (25). Denton (8) attributed the high mortality rate among seedlings growing in full sun to the indirect drying effect of the sun on the soil.

**Dormancy and Seed Longevity**

Robbins (24) reported that seed dormancy in *B. vulgaris* could not be simply attributed to the physical and chemical composition of the seed coat inhibiting water intake. Barberry seeds require a ‘resting period’ or a period of cold temperature treatment (vernalization) between seed production and germination. Seeds may germinate as early as the spring after they are produced, but they have the capacity to lie dormant for many years before germinating. Germination can occur in either the spring or the fall (7). Reddy (22) reported that seeds germinated and seedlings were produced from seeds gathered in 1918, each year up to 11 years after they were first collected. Similarly, in studies in North Dakota and Minnesota, seeds were found viable after lying dormant in soil for nine years and seven years, respectively. Longevity of seeds buried in the soil results from them having a hard seed coat (testa) and little exposure to the air, freedom from wetting/drying cycles and uniformly low soil temperatures (23).

In addition to this, seeds from barberry are very resistant to chemical and physical treatments. Scarification, salt and kerosene treatments have no effect on the viability of seed (5). Atwood (3) reported that if a barberry bush was removed from an area after producing seed, most of the seeds from that bush would germinate and produce seedlings within 3 to 4 years. However, some of the seeds remain dormant and would still be viable after several more years. In addition to this, if bushes were cut down but not removed from an area, berries on these bushes containing seeds could be mature enough to produce seedlings. Atwood (3) also demonstrated that seeds produced from bushes growing in the shade in well-drained soil, were much more viable than seeds produced from bushes growing in full sun (11.22% compared with 0.55%).

**Dissemination of Barberry Seeds**

Many species of birds are attracted to the bright red fruit of the barberry bushes and consequently birds are the main agents of dissemination of barberry seeds. Birds known to consume barberries as a portion of their diets include: Lesser Scaup (*Aythya affinis*), Ruddy Duck (*Oxyura jamaicensis*), Ruffed Grouse (*Bonasa umbellus*), Ring-necked Pheasant (*Phasianus colchicus*), Hairy Woodpecker (*Picoides villosus*), Northern Flicker (*Colaptes auratus*), American Crow (*Corvus brachyrhynchos*), American Robin (*Turdus migratorius*), Swainson's Thrush (*Catharus ustulatus*), Hermit Thrush (*Catharus guttatus*), Gray Catbird (*Dumetella carolinensis*), Northern Mockingbird (*Mimus polyglottos*), European Starling (*Sturnus vulgaris*), Cedar Waxwing (*Bombycilla cedrorum*), White-throated Sparrow (*Zonotrichia albicollis*) (24). Barberry seeds have a high malic acid content and are not the primary choice of many birds, but in the winter when food is scarce, they are consumed by a number of bird species. In some cases, especially in smaller birds, the barberry seeds move undigested through the birds' digestive tract (24). Other evidence suggests that smaller birds such as thrushes eat the pulp of the fleshy berries but do not consume the seeds. In such cases, the seeds are dropped in the area where the birds encounter and consume the berries.

Most barberry seeds and sprouts from these seeds tend to be found at the edges of wooded areas. Not only is this a more favorable environment for seed germination and seedling survival, but is also more commonly the favored habitat of many bird species, including most of the species listed above. The edges of wooded areas are much preferred by these birds over the dense inner areas of the forest canopy (24).

Whether or not the seeds are actually ingested when the berries are consumed or are simply deposited on the ground around the original source depends on the species of bird. Some birds carry barberry seeds in the beaks and deposit them over a short distance, up to 1/4 mile radius from the original source. Circumstantial evidence exists that supports the idea that seed may travel through the birds' digestive system and still maintain its viability. Bushes found several miles from the original source suggest that seed was ingested and regurgitated or dropped after passing undigested through the digestive tract (10). There is also a possibility of seed being transported over even greater distances by migratory birds (24). One example given by Flake (10) suggested that a single barberry bush that had appeared on an island in Lake Erie might have been the result of seed passing through the digestive tract of a migratory bird.

Cattle may also play a role in the dispersal of barberry seeds over a limited area (2). Man may also have unintentionally been responsible for distribution of barberry seeds. Sprigs of barberry-laden berries were used for decorative purposes and bushes were planted as garden ornamentals and the seeds or berries disposed of indiscriminately (2). A small number of seeds are distributed by movement in water.

## Rate of Growth of Barberry

There is considerable variation in the rate of growth and development of barberry (12). Depending on environmental conditions, bushes of the same age can range from small shrubs to tall erect bushes. In one experiment conducted in Iowa, seven barberry bushes of the same age and in similar growing environments were kept under observation from 1939 to 1947 (12). Bush height and width and photographs of each bush were recorded annually. Three of the bushes were no larger in 1947 than they had been in 1939, while four of the bushes had increased in height by 0.6 to 1.0 m during the same period. Although several bushes were cut back to ground level deliberately or by animals grazing during the study, all had re-grown to be fruiting bushes of 1.3 m or more in height in 1947 (12).

These results indicate the plasticity of barberry growth and its ability to respond to intentional or unintentional damage. Shepherd (25) also reported that the width of annual rings in barberry stems does not correlate well with the age of barberry stems. Shepherd (25) suggested that environmental factors such as the amount of sunlight and rainfall, may exert a strong influence on the number and width of annual rings and therefore these would not function well as an indicator of plant age.

Other morphological structures such as leaf thickness and number of spines seem to be strongly correlated with the environmental conditions surrounding a bush. Bushes growing in continuously moist conditions tend to have weak spines or suppressed spine growth (25).

**Characteristics of Barberry and Problems for Eradication**

There are numerous characteristics of the barberry that make eradication of the bush problematic. Reproduction by both sexual and asexual means enables the bush to thrive in many different environments. In addition to the prolific production of seed, vegetative growth through the production of shoots (sprouts) that develop from rhizomes enhances the barberries survival, particularly when damaged during digging or cutting. Shoots severed from the parent plant have the ability to survive independently.

Barberry seeds are dispersed by birds over short and long distances, greatly influencing the spread and distribution of the bush. The period between seed germination and fruit production is relatively short, resulting in a high rate of reproductive. In addition, barberry seeds can remain viable for a number of years and bushes can survive in many different environments.

**Literature Cited**


1. Ahrendt, L. W. A. 1961. *Berberis* and *Mahonia* a Taxonomic Revision. *J. Linn. Soc. Bot.*, 57, 188.
2. Anonymous. 1945. Handbook of Operations: Barberry Eradication. Barberry Eradication Records, University of Minnesota Archives.
3. Atwood, H. 1930. Experimental Studies on Common Barberry Seeds and Seedlings, 1926-1930. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.
4. Atwood, H. and Stover, W. G. 1936. The Maumee Seed Germination and Seedling Survival Experiments 1930 – 1936. Barberry Eradication Records, University of Minnesota Archives.
5. Atwood, H., Stover, W. G. and Horton, C. W. 1931. Experimental Studies on Common Barberry Seeds and Seedlings Conducted in Geauga, Ashtabula, and Lorain Counties, Ohio, 1926 – 1931. Barberry Eradication Records, University of Minnesota Archives.
6. Britton, N. L. and Brown, A. 1913 (2nd ed.). *An Illustrated Flora of the Northern United States and Canada*. NY: Charles Scribner's Sons.
7. Cotter, R.U., 1942. Ecology of *Berberis vulgaris*. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.
8. Denton, R. R. 1952. Germination and Establishment of the Common Barberry (*Berberis vulgaris* L.). Master of Science Thesis. Iowa State College.
9. Dwight, T. 1823. Travels in New England and New York in 1796 and 1797. London.

10. Flake, M G. 1945. Birds and Barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

11. Gregerson, R. O. 1932. History of Barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

12. Hagge, A. H. 1948. Observations of Rate of Growth of Barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

13. Kempton, F.E.1922. Report of Progress in Barberry Eradication. Barberry Annual Report for 1922. Barberry Eradication Records, University of Minnesota Archives.

14. Kempton, F.E., and Hutton, L.D. 1924. Report of Progress in Barberry Eradication to December 31, 1924. Barberry Annual Report for 1924. Barberry Eradication Records, University of Minnesota Archives.

15. Lind, J. 1915. *Berberisbusken og Berberislovan* (The Barberry Bush and Its Law). Kobenhaven: Tryke Hos Nielson & Lydiche.

16. Lindsay, D. R. 1951. Survey of Common Barberry (*Berberis vulgaris* L.) in Southwestern Ontario. Science Service. Division of Botany and Plant Pathology. Department of Agriculture, Canada.

17. Mathews, F. S. 1915. *Field Book of American Trees and Shrubs*. NY: G.P. Putnam's Sons.

18. Morinaga, T. 1926. Effect of Alternating Temperatures upon the Growth of Seeds. *Am. J. Bot.*13: 141-158

19. Muenscher, W. C. 1922. *Keys to Woody Plants*. Ithaca, NY: Cornell University Press.

20. Offord, H.R., and Draper, G.E. 1933. Field Investigations in the Chemical Destruction of Common Barberry, 1919 to 1930. USDA Report (unpublished). Barberry Eradication Records, University of Minnesota Archives.

21. Petrides, G. A. 1958. *A Field Guide to Trees and Shrubs*. Boston: Houghton Mifflin Co.

22. Reddy, W.F. 1924. Experimental Studies with Common Barberry Seed and Seedlings. Michigan Annual Report on Barberry. Barberry Eradication Records, University of Minnesota Archives.

23. Reddy, W.F. 1929. Distribution and Habits of the Common Barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

24. Robbins, W. W. 1921. Notes on Ecology of the Common Barberry and Methods of Eradication. Barberry Eradication Records, University of Minnesota Archives.

25. Shepherd, D. R. 1944. Summary of Ecological, Morphological, and Chemical Eradication Studies of Importance to the Barberry Eradication Project. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

26. Thompson, N. F. and Robbins, W.W. 1926. *Methods of Eradicating the Common Barberry (Berberis vulgaris L.).* 1926. USDA Department Bulletin 1451. Washington, D.C.: GPO.

27. USDA ARS, Forest Service. 1948. *Seed Manual.* Pub. 654: 97-98.

28 USDA ARS, Bureau of Entomology and Plant Quarantine. Barberry Eradication Office, Columbus, Ohio. 1931. Unpublished report. Barberry Eradication Records, University of Minnesota Archives.

29. USDA ARS, Bureau of Entomology and Plant Quarantine, Division of Plant Disease Control. 1958. *Nursery Inspection Manual*. Washington, D.C.: GPO.

30. Whetston, R. D., Atkinson, T. A., and Spaulding, D. D. 2002. Flora of North America, Vol. 3. Online (http://flora.huh.harvard.edu/FloraData/12395/Taxon/Map/03m/m233500244.gif)

# Prevalence and Distribution of Common Barberry, the Alternate Host of *Puccinia graminis*, in Minnesota


## Abstract

A Federal and state program operated from 1918 until the 1980s to eradicate common barberry (*Berberis vulgaris*), the alternate host of *Puccinia graminis*, from the major areas of cereal production in the U.S. Over 500 million bushes were destroyed nationally during the program; approximately 1 million barberry bushes in Minnesota. Some sites in Minnesota where barberry bushes were destroyed remained in the 'active' class when eradication was phased out in the 1980s. Active sites were defined as those on which there was still a possibility of emergence of barberry seedlings or sprouts arising from the parent bush.

In the present study, from 1998 to 2002, 72 of the approximately 1200 active sites in Minnesota were surveyed. At each site, a 90-meter radius around the area where bushes were previously found was checked for the presence of bushes. Reproductive status of any bushes found and the GPS coordinates of each site were recorded. Barberry plants reemerged on 32 of the 72 sites. More than 90% of the barberry bushes were found in counties with less than 400 ha of wheat per county, mostly in southeastern Minnesota, but one bush was found in a major wheat-producing county in northwestern Minnesota. Reemergence of barberry may play a role in future epidemics of stem rust, particularly with regard to sexual reproduction in the pathogen population.

## Introduction

The Common Barberry (*Berberis vulgaris* L.), once planted as a popular ornamental shrub throughout the north-central United States, has been responsible for initiating local, devastating epidemics of stem rust of small grains (3, 11). As the alternate host of *Puccinia graminis* Pers., the barberry serves as a local source of initial inoculum for stem rust as well as the site of sexual reproduction for the fungus, thus, contributing to the development of new pathogen genotypes capable of attacking grain cultivars bred for rust resistance. In the early decades of the 1900s, stem rust epidemics were common, particularly in the spring wheat-growing region of the U.S (7). When epidemics occurred, yield losses were frequently severe, reaching 50-70% over large areas, while individual fields were often totally destroyed.

Realizing the gravity of the situation in the aftermath of the staggering losses of wheat caused by the stem rust epidemics of 1916, 13 mid western states and the USDA joined in a program three years later to eradicate rust-susceptible, common barberries (3). The major goal of the program was to break the rust life cycle and to prevent local outbreaks of stem rust in the important wheat-growing states. The barberry eradication program continued and grew to 18 states before it was gradually phased out by 1980. Over 500 million barberry bushes were destroyed in the eradication effort and stem rust became a minor problem on wheat and other small grains toward the end of the program (7, 11).

When the USDA withdrew from the cooperative program in 1980, the responsibility for barberry eradication transferred to state regulatory agencies. After 1980, different states furnished monetary support for limited barberry eradication work. In Minnesota, small-scale barberry eradication efforts continued at the state level until 1990 to ensure that properties with active sites were rechecked periodically (Chapter 1). Sites were considered "active" until all barberries were removed and the sites had been periodically rechecked for the absence of bushes over a span of at least 15 years. At the termination of the program in Minnesota, approximately 1,200 active sites remained to be rechecked (Laudon unpublished). If bushes have reemerged on these active sites, they could serve as a source of inoculum for stem rust, provide a means for ***P. graminis*** to reproduce sexually and potentially produce new rust genotypes not found in the asexual rust population (7), and they could act as a seed source for further barberry spread (6).

Barberry bushes may have emerged on active sites in Minnesota after the eradication program ended. Barberry seeds can maintain viability in the soil for at least seven years because of their durability to chemical and physical stresses (Chapter 2). In addition, ***B. vulgaris*** can reproduce asexually by sprouts arising from underground rhizomes. Under ideal conditions these bushes may bear fruit as early as four years after emergence (Chapter 2). Thus, increase and spread of barberry may have occurred in the sites both locally asexually and more widely by seed since 1996 on sites where bushes emerged after the eradication program ended. Therefore, the objectives of this study were to i) conduct a field survey of a sub-sample of the total number of active barberry sites in Minnesota to determine the prevalence of barberry on these sites and to ii) determine the distribution of currently active barberry sites in relation to the major wheat producing areas of Minnesota.

## Materials and Methods

For this survey, sites were chosen from approximately 1200 currently active barberry sites in Minnesota.  Information on these 1200 active sites was obtained from archival data and historical records used during the Barberry Eradication Program, primarily Property Location Forms (L-forms)(Fig 1).  These L-forms documented past eradication activity on individual barberry sites and provided specific information on site location, dates of survey, numbers of bushes found and destroyed and methods of barberry eradication.

After an evaluation of the L-Forms, 72 sites were selected from the 1200 currently active sites in Minnesota.  Criteria for selecting these sites included the high risk of barberry reemergence, coverage of a broad geographical area of the state, and any active sites in areas of major small grains production. These selected sites were distributed in central, northwest, southeast, southwest, south central, east central, and west central districts (Fig. 2). The L-Forms and archival data indicated that historically the southeastern district had the largest populations of barberry and the highest risk for reemergence (Chapter 1), consequently the majority of sites selected for this survey were located in the southeast. The northwest and west central districts are important areas of wheat production (>10,000 ha), therefore all existing active sites in these districts were included.

For this survey, individual sites were located using county, township, section, and property owner/occupant address and name information provided by the L-forms. Current county maps with section number were used to supplement this information.  Township, section, and property owner/occupant address and name information were verified by the current property owner/occupant or nearby property owner.  In a few cases, site information was verified at the county records office.

Detailed hand-drawn maps from the L-forms provided approximate locations of all past survey and eradication activity on an individual site (Figs 1, 3). These maps were used to identify the approximate location(s) of the most recent and all past bushes found and eradicated on each site in this survey. These locations served as the focal points from which each site survey was conducted. Once these approximate locations were ascertained, an immediate site check and random reconnaissance of the area to a 90-meter radius were conducted by two people. Signs of rust (pycnial and/or aecial stages) also were recorded. GPS coordinates were recorded on each site and the locations of any bushes were added to the L-form maps. Surveys were conducted in April and October of 1998, 1999, 2000, 2001 and April 2002. During these times, the bushes are most visible and distinguishable from other bushes and shrubs, because they produce their distinctive small pinnate leaves earlier than surrounding bushes in the spring and hold their leaves well into the fall months, when surrounding bushes have shed their leaves.

**Results**

A total of 662 barberry bushes were found on 32 of the 72 sites surveyed (Table 1, Table 2). All sites where bushes were located were sparsely or densely wooded. Sites with bushes had numbers of bushes ranging from one to 300 (Table 2). One bush was found on each of 15 sites, and on 13 sites, between two and ten bushes were found. One site had 13 bushes and on the remaining three sites more than 100 barberry bushes were found (Table 2).

Barberry bushes were found in five of the seven districts (Table 1). No bushes were found on sites surveyed in the southwest district and the west central district. Of the 662 bushes found, 99% (656) were found in the southeast district (Table 1). Distribution of bushes was not uniform among sites in any district. Within the southeast district, Winona County with 440 and Fillmore County with 184 had the greatest numbers of bushes. In Winona County, 94% of the 440 bushes were distributed between two sites, and 86% of the bushes in Fillmore County were found on a single site. Goodhue and Houston counties each had ten bushes with between one and five bushes per site. Dakota, Mower, Olmstead, and Wabasha counties each had a single site where barberry bushes were found. There were seven bushes on the Wabasha site, four on the Olmstead site, and just one each on sites in Mower and Dakota counties (Table 3). In the central district, two bushes were found on a site in Morrison County and a single bush was found on a site in Todd County. In the northwest district, a single bush was found on one site in Becker County.

The distribution of barberry bushes on active sites in Minnesota was mainly limited to counties with less than 400 ha of wheat planted (Table 3). The greatest numbers of barberry bushes were found in Winona and Fillmore counties with 46 and 92 hectares planted to wheat, respectively. Only three barberry bushes were found on sites in counties with greater than 1,000 ha of wheat planted. A single bush was found on a site in Todd County where 2154 hectares of wheat were planted, a single bush was found on a site in Dakota County where 1030 hectares of wheat were planted and a bush was found on a site in Becker County where 28141 hectares of wheat were planted (Table 3).

## Discussion

The present survey indicates that barberry bushes have reemerged on a number of sites in Minnesota. At the termination of the barberry eradication program, it was suspected that rust-susceptible barberry bushes could reemerge on active sites in the state. The presence of these bushes suggests that they developed from seeds or sprouts since the end of the eradication program. Barberry seeds can remain dormant and viable in the soil for at least seven years and often longer (5, 9, 10). In addition, sprouts from underground rhizomes can enable the barberry to survive independently after the destruction of the parent bush (10). Barberry seeds may also have been deposited on sites by birds, the primary mechanism of seed dispersal. Although not always a food source of choice, when food is scarce, birds of many species are attracted to the bright red berries of *B. vulgaris* (6, 10). Typically the seeds move through the birds' digestive tract and are still viable when expelled. Hence, barberry seeds may be moved several kilometers before being deposited. Some evidence exists to indicate even longer dispersal distances when barberry seeds are consumed by migratory bird species (6).

Most of the sites where bushes have reemerged are in the southeast. There appear to be few sites with bushes in other areas of the state, particularly in the western districts. Aspects of barberry biology and ecology as well as previous eradication efforts probably influenced this distribution of bushes. The first barberry bushes introduced in Minnesota were planted in the southeast where alkaline, sandy loam soils (1) and abundant moisture favor their growth and reproduction over other areas of the state where soils are typically heavier and more acidic (8, 9, 15). In addition, barberry seed germination and seedling survival is favored by shade (2, 4, 5, 16, 17), hence the wooded terrain of southeastern Minnesota provides ideal conditions for barberry growth and development in comparison with the sparsely wooded prairie environment typical of the western districts where seeds and seedlings are exposed to more direct sunlight. Sites containing many barberry bushes, such as the two sites in Goodhue County and the single site in Fillmore County may represent 2$^{nd}$, 3$^{rd}$

and subsequent generations from the original barberry bushes that sprouted on these sites after the termination of the program.

The abundance of barberry bushes in southeastern Minnesota in contrast to the western counties is probably also related to past eradication activities. Historically, locating and removing barberry was much more difficult in the hilly and wooded terrain of the southeast than in the more open, prairie counties in the western districts. Topography in the western districts allowed for more thoroughness in locating and removing bushes, seedlings and sprouts (Chapter 1). Thus, archival data suggests the potential for large numbers of viable seeds and undisclosed sprouting bushes in the southeast at the end of the eradication program.

The distribution of barberry from this survey also suggests that most bushes are not growing in important areas of wheat production in Minnesota. Out of the 72 sites surveyed in the present study, a single bush was found on a site (Becker County) in an area of major wheat production (>10,000 ha). The low occurrence of bushes in these areas is further evidenced by the fact that there have been no significant stem rust epidemics on wheat in the state since the 1960s (11). The lack of epidemics is attributed to the extensive removal of barberry bushes during the eradication program (reduction in the amount of initial inoculum and delay of disease onset) and to the development of stem rust-resistant wheat cultivars by plant breeders (7, 11). For barberry to be a direct problem for grain production, bushes typically need to be in close proximity to wheat fields (<100 m) (12, 13). Barberry must be a short distance from an abundant source of functional telia to become infected with stem rust because short-lived basidiospores do not survive long-distance transport. Also, the wheat field must be nearby for the rusted barberry to initiate infection because although aeciospores are produced in abundance they are forcefully discharged and typically dispersed over a short distance (<100 m)(12, 13, 14).

Although most bushes in the current survey were found growing far from wheat fields, the location of a bush in Becker County could, however, present a potential problem if it were to revive the sexual life cycle of *P. graminis*. The bush in Becker County was found growing at less than 100 m from a wheat field. In addition, evidence suggests that even a single barberry bush can produce aeciospores in large enough numbers to initiate local epidemics which, in turn, can lead directly to the production of urediniospores and regional stem rust epidemics (12, 13). A single barberry bush also has the potential to generate new *P. graminis* genotypes. Sexual recombination on barberry is the major source of new combinations of virulence genes in the pathogen population (12, 13). Removal of *B. vulgaris* during the eradication program disrupted the sexual life cycle of *P. graminis*, limited its genetic diversity, and stabilized the pathogen races. With the reduced genetic diversity of the *P. graminis* population, race-specific resistance became more durable (11). An increase in genetic diversity in the stem rust fungus would make race-specific resistance less durable and would likely lead to breakdown of much of the resistance that has provided protection from stem rust epidemics for the past 40-50 years (7). Thus, with genetic resistance the major source of control against the rust pathogen, even a small number of bushes surviving in areas of major wheat production could result in renewed epidemics of stem rust in Minnesota.

The large numbers of barberry bushes growing outside of important wheat production areas could also impact future stem rust epidemics. These bushes can provide a seed source for the potential long distance dispersal of barberry into areas of major wheat production by migratory bird species known to carry seed. Also, this study has considered the recent distribution of wheat acreage in Minnesota in relation to the prevalence and distribution of barberry.  If for any reason wheat production acreage were to shift into the southeastern district, serious stem rust epidemics might well follow.  Thus, allowing the barberry population to increase in areas either close or far from centers of wheat production could have quite detrimental effects.

## Literature Cited

1. Atwood, H. 1930. Experimental Studies on Common Barberry Seeds and Seedlings, 1926-1930. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

2. Atwood, H. and Stover, W. G. 1936. The Maumee Seed Germination and Seedling Survival Experiments 1930 – 1936. Barberry Eradication Records, University of Minnesota Archives.

3. Campbell, C.L., and Long, D.L. 2001. The campaign to eradicate the common barberry in the United States. In *Stem Rust of Wheat: From Ancient Enemy to Modern Foe,* ed. By P.D. Peterson, 16-51. St. Paul, MN: APS Press.

4. Cotter, R.U., 1942. Ecology of ***Berberis vulgaris***. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

5. Denton, R. R. 1952. Germination and Establishment of the Common Barberry (*Berberis vulgaris* L.). Master of Science Thesis. Iowa State College.

6. Flake, M G. 1945. Birds and Barberry. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

7. Leonard, K. J. 2001. Stem rust – future enemy? In *Stem Rust of Wheat: From Ancient Enemy to Modern Foe*, ed. By P.D. Peterson, 119-146. St. Paul, MN: APS Press.

8. Melander, L.W, and Brueggeman, E. 1935. Report of the progress of the Barberry Eradication Campaign in the State of Minnesota, 1934. Barberry Eradication Records, University of Minnesota Archives.

9. Reddy, W. F. 1924. Experimental Studies with Common Barberry Seed and Seedlings. Michigan Annual Report. Barberry Eradication Records, University of Minnesota Archives.

10. Robbins, W. W. 1921. Notes on Ecology of the Common Barberry and Methods of Eradication. Barberry Eradication Records, University of Minnesota Archives.

11. Roelfs, A. P. 1982. Effects of barberry eradication on stem rust in the United States. *Plant Dis*. 66: 177-181.

12. Roelfs, A.P. 1985. Epidemiology in North America. In *The Cereal Rusts*, ed. By W.R. Bushnell and A.P. Roelfs, vol. 2, 403-434. Orlando, Florida: Academic Press, Inc.

13. Roelfs, A.P. 1985. Wheat and rye stem rust. In *The Cereal Rusts*, ed. By W.R. Bushnell and A.P. Roelfs, vol. 2, 3-37. Orlando, Florida: Academic Press, Inc.

14. Rowell, J.B., to Flaskerd, R., December 2, 1975. Minnesota Department of Agriculture. St. Paul, Minnesota.

15. Shepherd, D. R. 1944. Summary of Ecological, Morphological, and Chemical Eradication Studies of Importance to the Barberry Eradication Project. Unpublished paper. Barberry Eradication Records, University of Minnesota Archives.

16. USDA ARS, Bureau of Entomology and Plant Quarantine. Barberry Eradication Office, Columbus, Ohio. 1931. Unpublished report. Barberry Eradication Records, University of Minnesota Archives.

17. USDA ARS, Forest Service. 1948. *Seed Manual*. Pub. 654: 97-98.

Table 1. Number of counties surveyed, sites visited, numbers of sites with bushes and total numbers of barberry bushes found on selected active sites in Minnesota surveyed between 1998 and 2002

| District | Counties surveyed | Sites visited | Sites with bushes | Total number of bushes |
|---|---|---|---|---|
| Central | 3 | 14 | 2 | 3 |
| East Central | 1 | 1 | 1 | 1 |
| Northwest | 2 | 4 | 1 | 1 |
| South Central | 4 | 9 | 1 | 1 |
| Southeast | 8 | 31 | 27 | 656 |
| Southwest | 2 | 3 | 0 | 0 |
| West Central | 2 | 10 | 0 | 0 |
| Total | 22 | 72 | 32 | 662 |

Table 2. Number of sites and numbers of barberry bushes found on selected active sites in Minnesota surveyed between 1998 and 2002

| | Bushes per site | Number of sites | Total number of bushes |
|---|---|---|---|
| | 0 | 40 | 0 |
| | 1 | 15 | 15 |
| | 2 | 3 | 6 |
| | 3 | 3 | 9 |
| | 4 | 2 | 8 |
| | 5 | 2 | 10 |
| | 7 | 2 | 14 |
| | 8 | 1 | 8 |
| | 13 | 1 | 13 |
| | 120 | 1 | 120 |
| | 159 | 1 | 159 |
| | 300 | 1 | 300 |
| Total | | 72 | 662 |

Table 3. Number of sites and numbers of barberry bushes found on selected active sites in districts and counties in Minnesota surveyed between 1998 and 2002

| District | Counties | Sites with bushes per county | Bushes per site | Wheat production(hectares) |
|---|---|---|---|---|
| Central [a] | Morrison | 1/5 | 2 | 346 |
| | Todd | 1/5 | 1 | 2154 |
| | Wadena | 0/4 | 0 | 286 |
| Northwest | Becker | 1/2 | 1 | 28141 |
| | Polk | 0/2 | 0 | 149886 |
| Southeast | Fillmore | 10/12 | 8,3,1,1,159, 2,2,1,5,1 | 92 |
| | Goodhue | 3/3 | 4,5,1 | 271 |
| | Houston | 6/6 | 1,3,1,1,3,1 | 130 |
| | Mower | 1/1 | 1 | 306 |
| | Olmstead | 1/2 | 4 | 56 |
| | Wabasha | 1/1 | 7 | 235 |
| | Winona | 4/5 | 120,7,13,300 | 46 |
| | Dakota | 1/1 | 1 | 1030 |
| Southwest | Lincoln | 0/1 | 0 | 3165 |
| | Lyon | 0/2 | 0 | 2056 |
| South Central | Nicollet | 1/5 | 1 | 916 |
| | La Sueur | 0/1 | 0 | 937 |
| | Freeborn | 0/1 | 0 | 18 |
| | Brown | 0/2 | 0 | 1029 |

| | | | | |
|---|---|---|---|---|
| East Central | Mille Lacs | 1/1 | 1 | 212 |
| West Central | Ottertail | 0/8 | 0 | 29172 |
| | Yellow Medicine | 0/2 | 0 | 5149 |

[a] Number of sites in each district Central= 14, Northwest = 4, Southeast=31, Southwest=3, South central = 9, East central = 1, West central=10

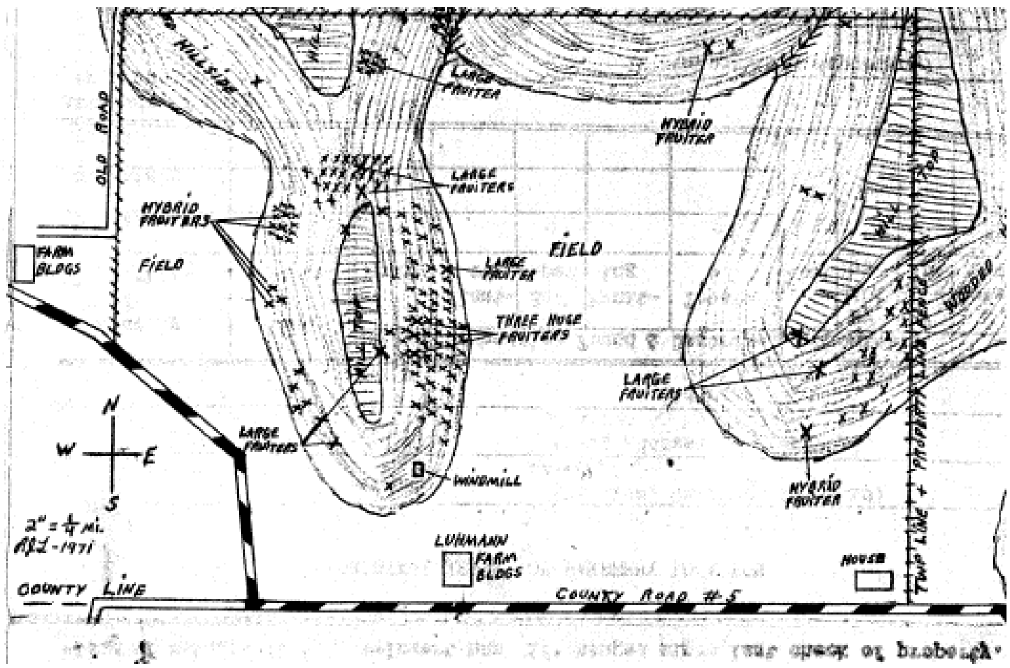



Figure 1. Hand-drawn map of a barberry eradication site in Minnesota.

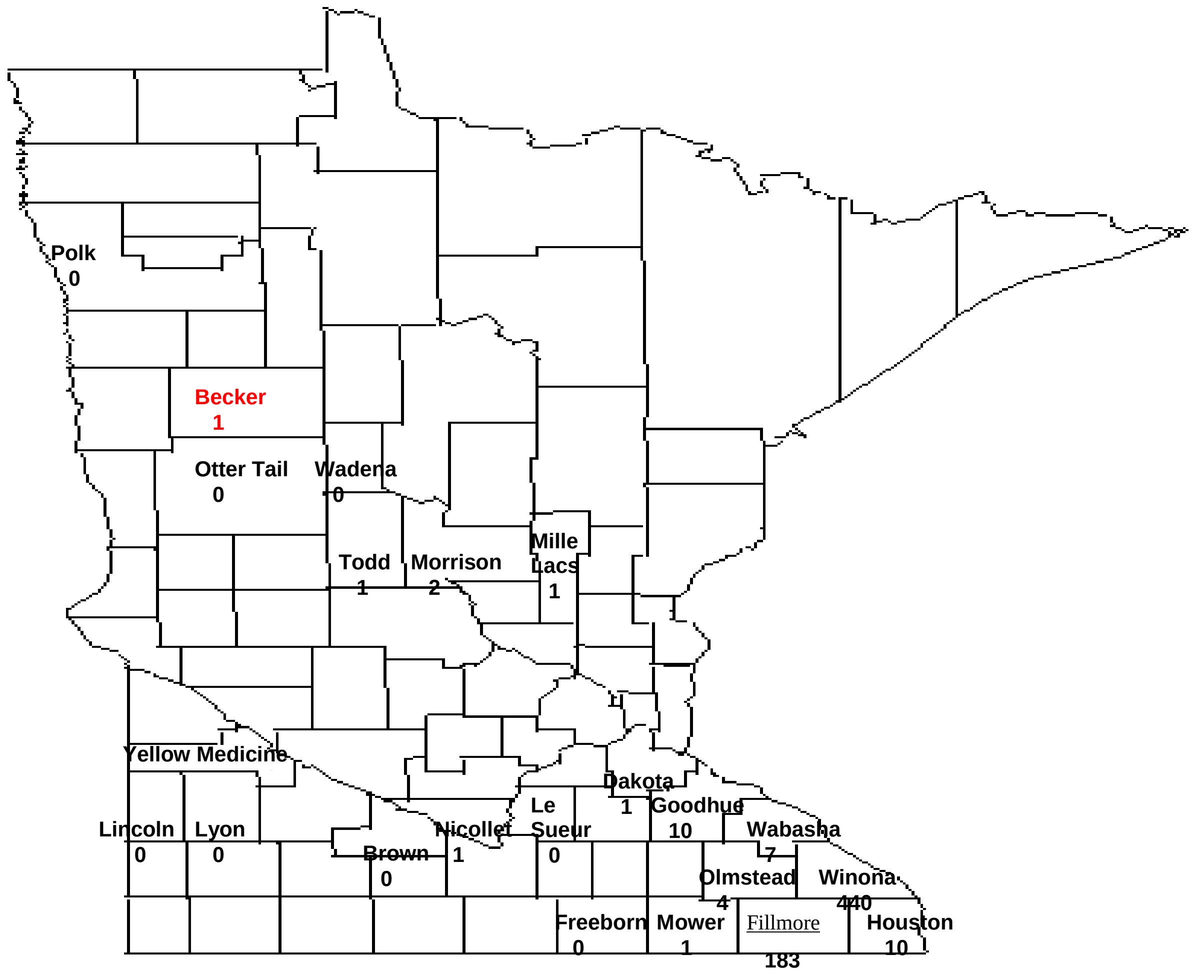
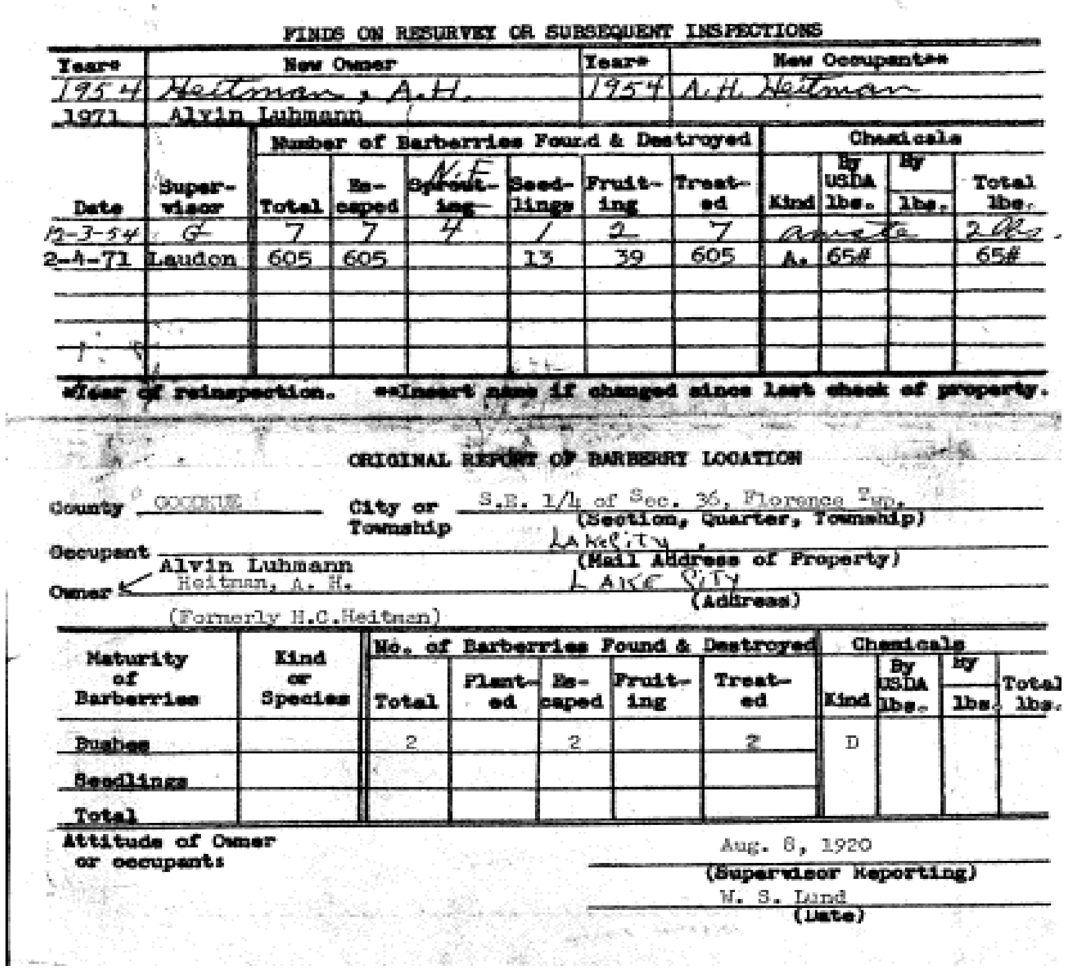



Figure 2. Map of Minnesota, indicating counties surveyed and where barberry bushes were located, 1998-2002



FINDS ON RESURVEY OR SUBSEQUENT INSPECTIONS

| Year* | New Owner | Year* | New Occupant** |
|---|---|---|---|
| 1954 | Heitman, A.H. | 1954 | A.H. Heitman |
| 1971 | Alvin Luhmann | | |

| Date | Supervisor | Number of Barberries Found & Destroyed | | | | | | Chemicals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Escaped | N.E. Sprouting | Seedlings | Fruiting | Treated | Kind | By USDA lbs. | By lbs. | Total lbs. |
| 12-3-54 | G | 7 | 7 | 4 | 1 | 2 | 7 | ammate | | | 2 lbs. |
| 2-4-71 | Laudon | 605 | 605 | | 13 | 39 | 605 | A. | 65# | | 65# |

*Year of reinspection. **Insert name if changed since last check of property.

ORIGINAL REPORT OF BARBERRY LOCATION

County GOODHUE City or Township S.E. 1/4 of Sec. 36, Florence Twp.
(Section, Quarter, Township)

Occupant LAKE CITY
(Mail Address of Property)

Alvin Luhmann

Owner Heitman, A. H. LAKE CITY
(Address)

(Formerly H.C.Heitman)

| Maturity of Barberries | Kind or Species | No. of Barberries Found & Destroyed | | | | | Chemicals | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Planted | Escaped | Fruiting | Treated | Kind | By USDA lbs. | By lbs. | Total lbs. |
| Bushes | | 2 | | 2 | | 2 | D | | | |
| Seedlings | | | | | | | | | | |
| Total | | | | | | | | | | |

Attitude of Owner or occupant:

Aug. 8, 1920
(Supervisor Reporting)

W. S. Lund
(Date)

Figure 3. Locator (L) form used to record data on barberry sites during the barberry eradication campaign

# The Effect of Barberry Eradication on Changes in Populations of *Puccinia graminis* in Minnesota


## Abstract

Aecial isolates of *Puccinia graminis* L. collected from common barberry (*Berberis vulgaris* L.) in Minnesota between 1912 and 2002 were obtained and used to evaluate changes in *forma speciales* over time. Uredinial isolates collected in Minnesota during the same time period were compared to the aecial isolates to evaluate changes in race structure of *P. graminis* f.sp. *tritici* (Pgt). Characteristics of the uredinial and aecial populations were compared and Shannon's diversity index was used to determine differences in the genotypic complexities of the two populations at different times during the 90-year study.

Aecial populations were initially composed of high proportions of Pgt isolates, but these numbers declined in the 1930s, as the proportion of *P. graminis* f. sp. *secalis* (Pgs) isolates increased. Recently, the proportion of Pgt isolates has increased and the proportion of Pgs isolates has decreased. Since 2000, all *P. graminis* isolates collected have been identified as Pgt suggesting possible changes in the pathogen population structure.

Comparisons between the uredinial and aecial populations in each decade of the study indicate that the predominant race in both populations was similar six out of nine decades. However, the genetic diversity of the uredinial population declined sharply over time compared to that of the aecial population, which remained fairly constant throughout the 90-year study.

## Introduction

The relationship between the common barberry (*Berberis vulgaris* Pers.) and the stem rust pathogen, Pu*ccinia graminis* L., is one of the classic host-pathogen interactions in plant pathology. As the alternate host of *P. graminis*, barberry is the key in the sexual stage of the pathogen's life cycle in the northern U.S. Because conditions are typically too cold for *P. graminis* to survive as uredinial infections through the winter, the barberry enables the pathogen to survive locally in the northern states by providing a host for basidiospores produced from overwintering telia (2). In turn, barberry serves as the source of local, initial inoculum through the production of aeciospores in large enough numbers to initiate local epidemics, leading directly to the production of urediniospores and regional stem rust epidemics. Finally, the barberry is the site of sexual reproduction for *P. graminis*. Sexual recombination on barberry is the major source of new combinations of virulence genes in the pathogen population which can result in the development of new pathogen genotypes capable of attacking grain cultivars lacking rust resistance (11).

Eradication of the alternate host has been considered an important step in controlling epidemics of stem rust (11). Between 1918 and 1980, over 500 million barberry bushes were destroyed from major wheat-producing states in the United States during the cooperative federal-state Barberry Eradication Program (11). Eradication of barberry is credited with disrupting the life cycle of *P. graminis*, thus eliminating initial inoculum and reducing early, local epidemics of stem rust (12, 15). A delay in the onset of disease by at least 10 days, a reduction in pathogen genetic variability, and the stabilization of pathogen races is also attributed to the removal of the alternate host (11). Barberry eradication combined with the successful deployment of genetic resistance in wheat cultivars have been credited with reducing stem rust to a minor problem over the last half century.

Federal funding for the Barberry Eradication Program was eliminated by 1980, causing some scientists and field personnel to voice concerns over the possible re-emergence of barberry and its effects on the resurgence of stem rust epidemics (Chapter 1). The potential for barberry to make a comeback in the north central United States could allow the sexual cycle of *P. graminis* to become reestablished (7). Evidence of barberries reemerging has been found in several states, including Minnesota (Chapter 3). Minnesota, a major wheat producing state, was a heavily involved in the barberry eradication program throughout the 20th century.

Studies have been conducted which examine the race diversity in asexual *P. graminis* populations (2, 4, 5, 9, 12) and sexual *P. graminis* populations (4, 12). However, no studies have compared diversity among sexual and asexual populations of *P. graminis* with respect to barberry eradication and the removal of the alternate host for the pathogen. Evaluating changes in population diversity at both a *forma speciales* (f. sp.) level and a race level may help provide insights into the potential role of barberry in future stem rust epidemics if barberry is allowed to spread. Using Minnesota as a case study, the objectives of this study were to document the effect of barberry removal in altering *P. graminis* population structure by i) evaluating data on aecial isolates of *P. graminis* collected from barberry and identifying changes in population structure pre-, during, and post-barberry eradication, and ii) comparing aecial and uredinial populations of *P. graminis* f. sp. *tritici* to determine differences in population complexity and race structure over a 90 year period.

## Materials and Methods

Historical data of aecial collections from barberry made from 1912 to 1998 in Minnesota were located among the records of the Barberry Eradication Program located in the University of Minnesota Archives, and these data were used as a basis for this study. All historical aecial collections were made by personnel of the Cereal Disease Laboratory (CDL) [formerly the Cooperative Rust Laboratory and the Cereal Rust Laboratory (CRL)] and aecial classification of isolates into special forms (forma speciales = f. sp.) and races was also done there. Additional collections of infected barberry leaves were made by the author between 1998 and 2002 and characterized at the CDL using the same methods (16).

Identifications to the f.sp. level had been obtained by collecting isolates and testing their ability to infect different host species including oats, wheat, and rye. Isolates were identified as *P. graminis* f. sp. *avena* (Pga), *P. graminis* f. sp. *tritici* (Pgt), *P. graminis* f. sp. *secalis* (Pgs) or *P. graminis* f. sp. 'unknown' (Pgo). Pgo isolates were those isolates identified as *P. graminis*, which failed to infect any of the test hosts either because the cultures were of f. sp. *agrostidis* or f.sp. *poae* (3), which do not infect cereals or because the aeciospores may have been non-viable (Roelfs, personal communication). These isolates were disregarded from the data analysis. Pgt isolates were further differentiated into races using a set of 12 different wheat species encompassing *Triticum aestivum*, *T. compactum*, *T. durum*, *T. monococcum*, and *T. dicoccum* selected by E.C. Stakman in 1917 (14). This set of lines was later referred to as the 'standard differential varieties' (16). Although other differentials and new race nomenclature were used later in the survey process, care was taken to ensure continuity by establishing connections between 'Stakman' races with the older differential set and the ‘CRL’ races defined with the newer set. For the purpose of this study, all race designations were translated back to the original standard differential designations. In some cases, isolates were identified as Pgt isolates, but their race designation was not defined, i.e. their reaction on the standard differentials was too ambiguous to be conclusive. These isolates were not included in the analysis. Also, some collections identified as Pgt were found to contain more than a single race when single-pustule isolates were made. All such isolates were included in the analysis, which accounts for the numbers of isolates sometimes being larger than the number of collections.

Data on uredinial isolates collected from infected wheat were also obtained from the records of the CDL. Data from 1939 to 1990 have been published annually and data from earlier years were located among USDA files held at the CDL. Data from 1970 to 1973 were unavailable and therefore not included in the analysis. According to procedures outlined in Barberry Eradication records, data on the race structure of the Pgt isolates from wheat were obtained in a similar way to that of the aecial isolates. Infected wheat leaves were collected and urediniospores from rust pustules were used to inoculate a set of standard differentials (5). Races were determined according to the response on the set of standard differentials containing different major genes for resistance to Pgt.

In addition to basic descriptive comparisons of the data from both uredinial and aecial populations, the data were also characterized using the normalized Shannon Index of Diversity (5, 13)

$$H_w = -\Sigma_i \, p_i \, \ln(p_i)/\ln n$$

where $p_i$ = the frequency of the *i*th phenotype and n is the number of different races identified in the sample. This index characterizes populations by using a measure of the number of individuals in a population and the evenness of distribution of individuals throughout a population. Shannon's Index of Diversity has been used frequently in plant pathology to characterize intraspecific diversity in plant pathogens (4, 6). Since the numbers of aecial isolates were much smaller than the numbers of uredinial isolates, aecial isolates were grouped into 20-year intervals and uredinial isolates were grouped into 10-year intervals for the purpose of analysis.

## Results

Historical and recent data on f. sp. of *P. graminis* found in aecial isolates collected in Minnesota are summarized in Table 1. Eight hundred and twenty-six collections were made (not including isolates characterized as Pgo), and identified to the f. sp. level during the 90 years of the survey and 511 (62%) of these isolates were collected during the first three decades of the barberry eradication program (1912-1929). Four hundred and four isolates were collected and identified in the 1930s alone; this period of time coincided with a period of intensive barberry survey and the location of many bushes (Chapter 1). As more barberries were eradicated, the numbers of isolates collected in decades after the 1930s, declined. The numbers of isolates collected from the 1940s until 2002 ranged from 25 in the 1940s to 67 in the 1960s. Seventeen isolates were collected from 2000 to 2002 (Table 1). Although absolute numbers of isolates collected probably depended on the importance of the program and the resources available to collect and identify these isolates, these numbers also relate directly to the declining frequency of epidemics of stem rust from the 1940s onwards (11).

Overall during the 90-year survey, the dominant f. sp. found among aecial isolates was Pgs (Table 1; Fig. 1). Four hundred and thirty-nine isolates (53%) collected were identified as Pgs. The diversity of f. sp. identified at different times during the study varied (Fig. 1). During the initial period of the eradication program (1912-1919), 57% of the isolates collected and classified into f. sp. groups were identified as Pgt (Table 1). There was a change in the population structure in the next decade (1920-1929), when 75% of the isolates collected were identified as Pgs. However, during the 1930s when 404 isolates were collected, 57% if these isolates were identified as Pgt. From the 1940s until the 1980s Pgt isolates composed less than 35% of the total number. This situation changed in the 1990s and from 2000 to 2002. Among the isolated collected during the 1990s, 61% were Pgt and the remaining 39% were identified as Pgs. All isolates collected since 2000 were identified as Pgt.

The race structure of the aecial Pgt isolates fluctuated throughout the course of the survey (Table 2). Race diversity and the predominant races collected also changed over time. Over the 90-year survey, a total of 425 Pgt isolates were classified into 52 different races and the Pgt race found most frequently was race 56, accounting for 19.2% of all races identified. The largest overall number of isolates and the greatest diversity of Pgt races were identified between 1930 and 1939 (Table 2). Out of the 284 isolates collected during the 1930s, 38 different races were identified. However, the most predominant race found among aecial isolates during this decade was race 56, occurring at a frequency of 29.3%.

Based on how frequently any given race occurred, Table 3 shows the most commonly occurring Pgt races found in aecia collected in each decade from 1912 to 2002. In some years a single race occurred frequently, but in other years, two or three races occurred commonly (Table 2; Table 3). Some races appeared consistently during the 10 decades of the survey. Race 11 was the most consistent, appearing in six of the ten decades followed by race 15, which appeared in five of the ten decades. Some races such as race 88 were found only once among the aecial isolates collected and was not observed among isolates collected in subsequent years (Table 2).

Although the overall race structure and diversity of the aecial and uredinial populations varied considerably (Table 3; Table 4), the similarity between the populations is indicated by the dominant Pgt race which was found most frequently in both populations (Table 5). In six of the nine decades in the study, the predominant race was the same in both populations. Importantly, race 15 was consistently the most predominant race found among uredinial isolates collected from wheat since the 1950s. Although race 15 was the predominant aecial race for two decades (1960-1980), the population has since changed, with race 151 being the most predominant race collected among recent collections from infected barberry. In the 1980s three aecial Pgt isolates were found, therefore race 113, although predominant in the aecial population was not found at very high levels.

After 1920, the aecial populations of *P. graminis* f. sp. *trtitici* were considerably more diverse than the uredinial populations as indicated by the Shannon's Diversity Index (Table 6; Figure 2). Overall the uredinial populations showed a rapid decline in diversity between the 1920s and the 1930s (0.5791 down to 0.1880), with much less diversity in the populations from 1930s onwards. The least amount of diversity (0.0845) was found among Pgt isolates collected in the 1980s. Uredinial isolates collected in the 1990s appeared to have increased in diversity from the preceding decade.

These changes in population diversity among the uredinial isolates are in marked contrast with population changes among aecial isolates. At the beginning of the study, diversity index values for aecial populations (0.8756) were similar to index values for uredinial populations (0.9306). The diversity of the aecial populations show a slight decline during the 1920s and 1930s, however, in general, diversity among races in the aecial populations was fairly constant throughout the 90-year period (Figure 2).

**Discussion**

Important changes in the ***P. graminis*** population have occurred over the 90-year period since the initiation of the Barberry Eradication Campaign. Some of these changes may be a direct consequence of the removal of barberry from the proximity of wheat fields and others may relate more to changes in the genetic make up of the wheat host population. Epidemics of stem rust on wheat and yield losses due to stem rust have declined significantly as a result of eliminating vast numbers of barberry bushes and deploying wheat cultivars with genes conferring resistance to the dominant Pgt races (11).

The most obvious changes in aecial populations relate to changes in the predominant *forma speciales* found colonizing barberry. The general picture shows an early abundance of Pgt isolates prior to and immediately following the initiation of the barberry eradication, followed by a decline in Pgt isolates as the numbers of Pgs isolates increase and more recently an increase in the numbers of Pgt isolates. These changes, set against the backdrop of a general decline in numbers of aecial isolates found and characterized, may indicate that without the alternate host and the ability to generate genetic diversity, the Pgt isolates are less fit and therefore less abundant than the Pgs isolates.

The frequency of f. sp. does not correlate well with relative areas of cereal production in the Minnesota during the years of this study (Figure 3). Data indicate that in early decades of the eradication program, the predominant cereal in Minnesota was oats followed by wheat, with much smaller acreages of barley and rye being grown (8,10). Throughout the survey, the total acreage of rye grown was small; hence, the predominance of Pgs isolates seems unusually high. However, the abundance of perennial wild grasses in close proximity to barberry bushes and wheat fields may help explain some of the population changes observed throughout the survey. Quackgrass (*Elytrigia repens =Agropyron repens*) is a very abundant weedy perennial (1) which is susceptible to Pgs (3). Foxtail barley (*Hordeum jubatum*), also an abundant weedy perennial (1), is susceptible to Pgt and Pgs (3). After barberry bushes were eradicated from areas in close proximity to wheat fields, the more remote barberry bushes may have been infected by basidiospores, primarily Pgs, originating from weedy hosts. Hence, this would explain the importance of Pgs in aecial collections from the 1920s to the 1970s. Since the mid 1970s, wheat has been the predominant cereal crop grown in Minnesota with only small acreages of barley, oats and rye. Therefore, the recent increase in Pgt isolates may be related to both the predominance of wheat as the major cereal crop and the re-emergence of barberry bushes in Minnesota (Chapter 3). In addition, all aecial isolates since 1975 have been collected in southeastern and east central districts of Minnesota (Leonard, personal communication) where very little wheat or barley production occurs. Therefore, teliospore inoculum of *P. graminis* from weedy hosts has probably played, and still plays, an important role in determining the predominant rust races present in the pathogen population.

Roelfs (11) suggested that the removal of barberry as an alternate host had a profound effect on the genetic diversity and the stability of pathogenic races collected from wheat. Our data support this hypothesis as this relates to uredinial populations. However, the diversity of the aecial races remained essentially unchanged throughout most of the 20th century. Although more than one million barberry bushes were destroyed during the course of the Barberry Eradication Campaign in Minnesota (Chapter 3), this appears to have had very little effect on the overall diversity of the isolates reproducing and colonizing barberry. Even as the numbers of isolates collected from barberry declined from the 1930s onwards, the diversity of the aecial populations remained consistently greater than that of the uredinial populations. With sexual reproduction occurring on barberry, we would expect the diversity of races among aecial collections to be greater than among uredinial collections and different isolates to predominate in aecial collections than those predominant in uredinial collections. Although we observed a much higher level of diversity among aecial isolates, the predominant race in uredinial and aecial populations was the same in many of the decades studied. One explanation for this could be that many of the aecia could have been produced through selfing. If the virulence loci used to designate the races were homozygous in the predominant races of Pgt occurring in the uredinial population, then selfing would result in progeny identical to the parent for these loci. Even if a few of the loci were heterozygous in the predominant races, a large proportion of the progeny would be identical or very similar to the parent if virulence was recessive and avirulence was dominant. A high degree of selfing would be expected if little genetic diversity occurred in the uredinial population and if the density of germinating teliospores was low. Selection pressure imposed by resistant wheat cultivars could have eliminated many aecial progeny if they lacked virulence necessary to infect the cultivars and lines that were grown in wheat fields and breeders' nurseries. Alternately, a small subpopulation of Pgt with increased fitness on common wild grasses as well as on susceptible wheat and barley cultivars may have developed in Minnesota in recent years. If such a subpopulation predominated on wild grasses around barberry bushes, this could account for the differences between predominant races of Pgt found in aecial compared to uredinial collections in Minnesota since 1980. Development of such a subpopulation could also account for the increased frequency of Pgt among the aecial collections since 1990.

## Literature Cited


1. Anonymous, 1971. *Common weeds of the United States*. Dover Publication, NY

2. Clark, R.V., Seaman, W. L., and Martens, J. W. 1986. *Puccinia graminis* on barberry and oats in eastern Ontario from 1968 to 1983. *Can. J. Plant Pathol*. 8:193-200.

3. Fischer, G. W., and Levine, M. N. 1941. Summary of the recorded data on the reaction of wild and cultivated grasses to stem rust (*Puccinia graminis*), leaf rust (*P. rubigo-vera*), stripe rust (*P. glumarum*), and crown rust (*P. coronata*) in the United States and Canada. *Plant Dis. Reptr*. Suppl. 130. 30 pp.

4. Groth, J. V. and Roelfs, A. P. 1982. Effect of sexual and asexual reproduction on the race abundance in cereal rust fungus populations. *Phytopathology* 72: 1503-1507.

5. Groth, J. V., and Roelfs, A. P. 1987. The concept and measurement of phenotypic diversity in *Puccinia graminis* on wheat. *Phytopathology* 77:1395-1399.

6. Lebeda, A. 1982. Measurement of genetic diversity of virulence in populations of phytopathogenic fungi. *Z. Pflanzenkrankr. Pflanzenschutz* 89: 88-95.

7. Leonard, K. J. 2001. Stem rust – future enemy? In *Stem Rust of Wheat: From Ancient Enemy to Modern Foe*, ed. By P.D. Peterson, 119-146. St. Paul, MN: APS Press.

8. Long, D. L., and Hughes, M. E. 2003. Small grain losses to rust. U.S. Dept. Agric., Agric Res. Serv., Cereal Disease Laboratory on-line publication CDL-EP#007, updated annually.

9. Martens, J.W., Clark, R. V., and Seaman, W. L. 1985. Virulence combinations in sexually and asexually reproducing populations of *Puccinia graminis avenae* in Canada. *Can. J. Plant Pathol*. 7: 127-131.

10. Roelfs, A. P., 1978. *Estimated Losses Caused by Rust in Small Grain Cereals in the United States – 1918-76*. USDA Misc. Publ. 1363. Washington, D.C.: GPO.

11. Roelfs, A. P., 1982. Effects of barberry eradication on stem rust in the United States. *Plant Disease* 72: 177-181.

12. Roelfs, A. P., and Groth, J. V. 1980. A comparison of virulence phenotypes in wheat stem rust populations reproducing sexually and asexually. *Phytopathology* 70:855-862.

13. Sheldon, A. L., 1969. Equitability indices: Dependence on the species count. *Ecology* 50: 466-467.

14. Stakman, E.C. and Levine, M.N. 1922. *The Determination of Biologic Forms of Puccinia graminis on Triticum spp*. Minn. Agric. Exp. Stn. Tech. Bull. 8: 1-10. St. Paul.

15. Stakman, E.C., and Harrar, J.G. 1957. *Principles of Plant Pathology.* Ronald Press Co., New York, NY. 581 pp.

16. Stakman, E. C., Stewart, D. M., and Loegering, W. Q. 1962. *Identification of Physiologic Races of Puccinia graminis var tritici.* USDA-ARS pub. E617. Washington, D.C.: GPO.

Table 1. Number and percentage of isolates of each forma speciales of *Puccinia graminis* identified among aecial collections from barberry in Minnesota, 1912 to 2002.

| | Number of isolates | | | | Percent of total isolates identified | | |
|---|---|---|---|---|---|---|---|
| Dates | Pga[a] | Pgs | Pgt | Total | Pga | Pgs | Pgt |
| 1912-1919 | 1 | 2 | 4 | 7 | 14.3 | 28.6 | 57.1 |
| 1920-1929 | 2 | 79 | 25 | 106 | 1.9 | 74.5 | 23.6 |
| 1931-1940 | 18 | 157 | 229 | 404 | 4.5 | 38.9 | 56.7 |
| 1941-1949 | 1 | 16 | 8 | 25 | 4.0 | 64.0 | 32.0 |
| 1950-1959 | 0 | 37 | 18 | 55 | 0.0 | 67.3 | 32.7 |
| 1960-1969 | 7 | 37 | 23 | 67 | 10.5 | 55.2 | 34.3 |
| 1970-1979 | 1 | 34 | 8 | 43 | 2.3 | 79.1 | 18.6 |
| 1980-1989 | 0 | 63 | 3 | 66 | 0.0 | 95.5 | 4.5 |
| 1990-1999 | 0 | 14 | 22 | 36 | 0.0 | 38.9 | 61.1 |
| 2000-2002 | 0 | 0 | 17 | 17 | 0.0 | 0.0 | 100.0 |
| Total | 30 | 439 | 357 | 826 | | | |

[a] Pga = *Puccinia graminis* f. sp. *avenae*; Pgs = *P. graminis* f. sp *secalis;* Pgt = *P. graminis* f. sp. *tritici.*

Table 2. Percentage of *Puccinia graminis* f. sp. *tritici* races found per decade in aecial isolates collected from barberry, 1912 to 2002.

| | Decades[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Race | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 10 | | | 2 | | | | | | | |
| 11 | 1 | | 29 | 1 | 4 | 3 | 1 | | 6 | 3 |
| 14 | | | 5 | | | | | | | |
| 15 | | | 4 | 3 | 6 | 11 | 5 | | 1 | 2 |
| 16 | | | 2 | | | | | | 2 | 1 |
| 17 | 1 | 1 | 36 | 3 | | 3 | | | | |
| 19 | 1 | | 2 | | | | | | | |
| 21 | | 1 | 14 | | | | | | | |
| 23 | | | 1 | | | | | | | |
| 24 | | | 2 | | | | | | | |
| 28 | | | 1 | | | | | | | |
| 29 | | | | | 1 | 1 | | | | |
| 32 | | 1 | 1 | | | 2 | | | | |
| 33 | | | 1 | | | | | | | |
| 34 | | 1 | 29 | | | | | | | |
| 36 | | 8 | 27 | | | | | | | |
| 38 | | 2 | 19 | 1 | | 1 | | | | |
| 39 | | 1 | 1 | | | | | | | |
| 40 | | | 1 | | | | | | | |
| 44 | | | 3 | | 1 | | | | | |
| 48 | | | | | 1 | 1 | | | | |
| 49 | | 3 | 10 | | | | | | | |
| 56 | | | 68 | 4 | 8 | | | | 1 | 1 |
| 59 | | | 3 | | | | | | | |
| 65 | | | 1 | | | | | | | |
| 68 | | | 2 | | | | | | | |
| 69 | | | 2 | | | | | | | |
| 83 | | | | | | | | | 2 | |
| 87 | | | | | | 1 | | | | |
| 88 | | | 1 | | | | | | | |
| 96 | | | 1 | | | | | | | |
| 97 | | | 1 | | | | | | | |
| 98 | | | | 1 | 1 | | | | | |
| 102 | | | | | | | 1 | | | |
| 104 | | 1 | 1 | | | | | | | |
| 105 | | 1 | | | | | | | | |
| 107 | | | 2 | | | | | | | |
| 109 | | | 1 | | | | | | | |
| 111 | | 1 | | 1 | | | 1 | | | |
| 113 | | | | | 1 | 1 | 2 | 3 | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 116 | | | | | 1 | | | | | |
| 117 | | | 1 | | | | | | | |
| 122 | | 1 | 1 | | | | | | | |
| 125 | | | | 1 | | | | | | |
| 136 | | | 1 | | | | | | | |
| 139 | | | 1 | | 1 | | | | | |
| 140 | | | 1 | | | | | | | |
| 142 | | | | | | 1 | | | | |
| 146 | | | 1 | | | | | | | |
| 147 | | | 5 | | | | | | | |
| 151 | | | | | | 3 | 1 | | 1 | 13 |
| 153 | | | | | | | 1 | | | |
| Isolates | 3 | 22 | 284 | 15 | 25 | 28 | 12 | 3 | 13 | 20 |
| Different Races | 3 | 12 | 38 | 8 | 10 | 11 | 7 | 1 | 6 | 5 |

[a] Decades 1=1912-1919, 2 =1920-1929, 3 =1930-1939, 4 =1940-1949, 5 =1950-1959, 6 =1960-1969, 7 =1970-1979, 8 =1980-1989, 9 =1990-1999, 10 = 2000-2002

Table 3. Most commonly identified *Puccinia graminis* f. sp. *tritici* races from aecia collected from barberry in Minnesota, 1912 to 2002.

| Dates | Races identified | | |
|---|---|---|---|
| 1912-1919 | 19 | 17[a] | 11 |
| 1920-1929 | 36 | 49 | 38 |
| 1931-1940 | 56 | 17 | 11 |
| 1941-1949 | 56 | 17 | 15[b] |
| 1950-1959 | 56 | 11 | 15 |
| 1960-1969 | 15 | 151 | 11 |
| 1970-1979 | 15 | 113 | |
| 1980-1989 | 113 | | |
| 1990-1999 | 11 | 16 | 83 |
| 2000-2002 | 151 | 15 | 11 |

[a] Includes races 17 and 17A

[b] Includes races 15, 15B and 15B-2

No data were available for uredinial isolates 2000-2002.

Table 4. Numbers of isolates of *Puccinia graminis* f. sp. *tritici* races found per decade in uredinial isolates collected in Minnesota, 1912 to 1999.

| | Decades[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Race | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 2 | 6 | 2 | | | | | | |
| 3 | 5 | 8 | | | | | | | |
| 5 | 3 | | | | | | | | |
| 9 | | 7 | | | | | | | |
| 11 | 4 | 28 | 47 | 3 | 31 | 82 | 38 | | 9 |
| 12 | 6 | | | | | | | | |
| 13 | 2 | | | | | | | | |
| 14 | | | 3 | | | | | | |
| 15 | 1 | 2 | 5 | 3 | 475 | 560 | 860 | 574 | 92 |
| 17 | 4 | 29 | 36 | 236 | 15 | 31 | 3 | 7 | |
| 18 | 2 | 18 | | | | | | | |
| 19 | 9 | 19 | 11 | 24 | | | | | |
| 21 | 1 | 39 | 26 | | | | | | |
| 23 | | 8 | 1 | | | 1 | | | |
| 24 | 4 | 6 | | | | | | | |
| 29 | 2 | 10 | | | 12 | 28 | 1 | | |
| 30 | 1 | 16 | | | | | | | |
| 31 | | | | | | | 1 | | |
| 32 | 4 | | | | | 25 | 28 | | |
| 34 | | 2 | 58 | 2 | 6 | | | | |
| 36 | | 50 | 94 | 10 | | | | | |
| 37 | | 4 | | | | | | | |
| 38 | | 18 | 75 | 43 | 1 | 10 | | | |
| 39 | | 1 | | | 1 | | | | |
| 40 | | | | 1 | 1 | | | | |
| 48 | | | | | 3 | 6 | | | |
| 49 | | 36 | 65 | 4 | | | | | |
| 52 | | 1 | 1 | | 1 | | | | |
| 55 | | | | 1 | | | | | |
| 56 | | 1 | 341 | 357 | 149 | 341 | 7 | 3 | |
| 59 | | | 2 | | 1 | 1 | | | |
| 61 | | | 3 | | | | | | |
| 64 | | | 2 | | | | | | |
| 65 | | | 1 | | | | | | |
| 87 | | | | | | 5 | | | |
| 113 | | | | | | 2 | 36 | 4 | 5 |
| 125 | | | 3 | | 1 | | | | |
| 139 | | | 2 | | 1 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 142 | | | | | | | 1 | | |
| 151 | | | | | | 28 | 197 | 43 | 80 |
| 210 | | | | | | | 3 | | |
| 294 | | | | | | | | | 66 |
| Isolates | 50 | 309 | 778 | 684 | 698 | 1120 | 1175 | 631 | 251 |
| Different races | 15 | 21 | 20 | 11 | 14 | 13 | 11 | 5 | 5 |

[a] Decades 1 =1912-1919, 2 =1920-1929, 3 =1930-1939, 4 =1940-1949, 5 =1950-1959, 6 =1960-1969, 7 =1970-1979, 8 =1980-1989, 9 =1990-1999. No data were available for 2000-2002.

Table 5. Most predominant uredinial and aecial races found per decade in isolates of *Puccinia graminis* f. sp. *tritici* collected in Minnesota from 1912 to 2002.

| Dates | Predominant uredinial race | Predominant aecial race |
|---|---|---|
| 1912-1919 | 19 | 19 |
| 1920-1929 | 36 | 36 |
| 1930-1939 | 56 | 56 |
| 1940-1949 | 56 | 56 |
| 1950-1959 | 15[a] | 56 |
| 1960-1969 | 15[a] | 15 |
| 1970-1979 | 15[a] | 15 |
| 1980-1989 | 15[a] | 113 |
| 1990-2002 | 15[a] | 151[b] |

[a] Includes races 15, 15B and 15B-2.
[b] No data were available for uredinial isolates 2000-2002.

Table 6. Shannon's Diversity Index values for aecial and uredinial populations of *Puccinia graminis* f.sp. *tritici* collected each decade in Minnesota from 1912 to 2002.

| Years | Aecial[a] Normalized Shannon's Diversity Index | Uredinial Normalized Shannon's Diversity Index |
|---|---|---|
| 1912-1919 | 0.8756 | 0.9306 |
| 1920-1929 | | 0.5791 |
| 1930-1939 | 0.7196 | 0.1880 |
| 1940-1949 | | 0.2220 |
| 1950-1959 | 0.7575 | 0.2094 |
| 1960-1969 | | 0.3199 |
| 1970-1979 | 0.8403 | 0.1901 |
| 1980-1989 | | 0.0845 |
| 1990-2002 | 0.8338 | 0.2968 |

[a] Diversity Indexes for aecial isolates are reported for 20-year intervals because numbers were too small to calculate indexes for 10-year intervals. Numbers of uredinial isolates were larger and therefore diversity indexes were calculated for 10-year intervals. No data were available for uredinial isolates 2000-2002.

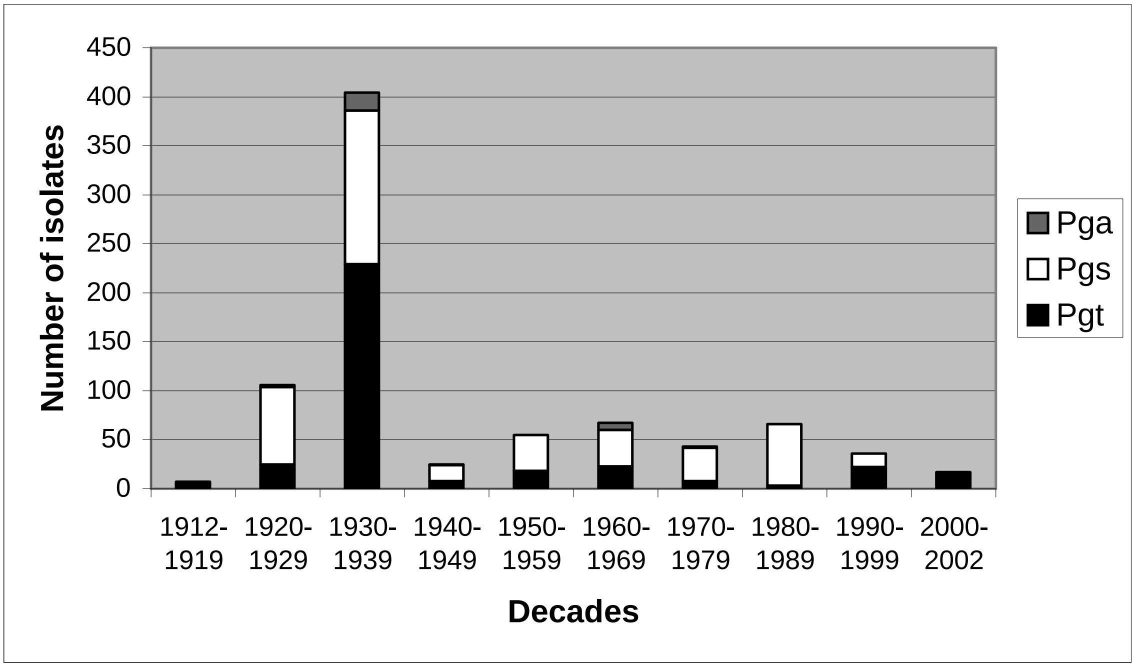



Figure 1 Special forms of *Puccinia graminis* isolates identified from aecia collected from barberry in Minnesota, 1912 to 2002.

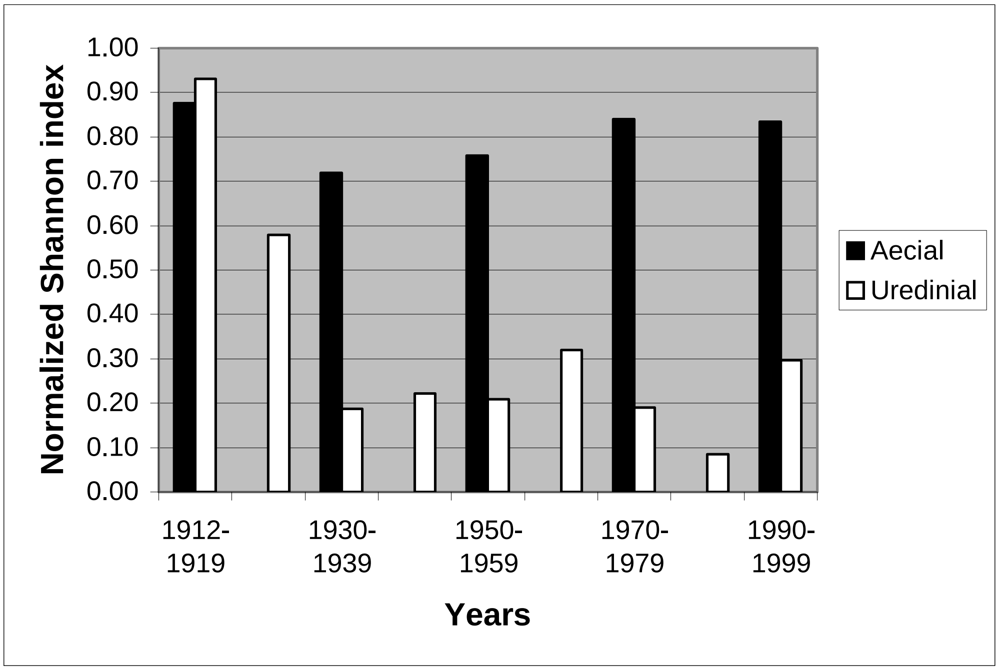



Figure 2 Diversity among aecial and uredinial isolates of *Puccinia graminis* f. sp. *tritici* collected in Minnesota from 1912 to 1999.

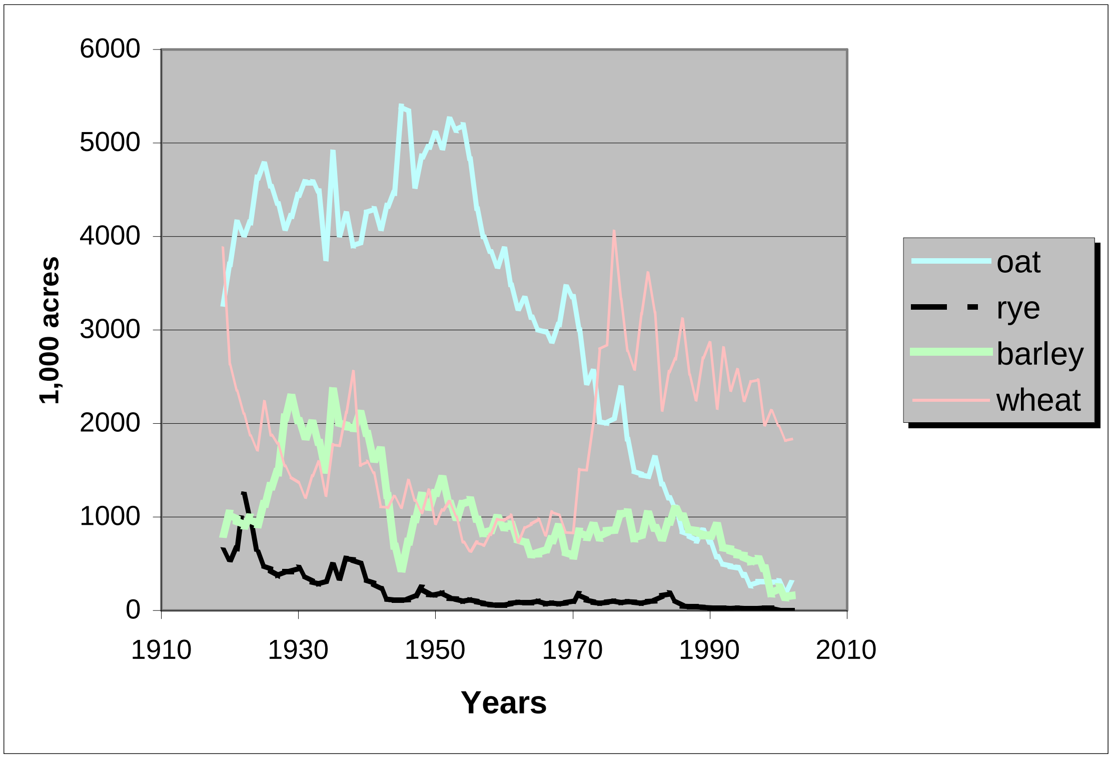



Figure 3 Harvested acreage of cereal crops in Minnesota from 1918 to 2002. Data from 1918 to 1976 from Roelfs (10) and data from 1977 to 2002 from CDL website (8).