Risk Analysis and Guidelines for Harvest Activities in Wisconsin Oak Timberlands to Minimize Oak Wilt Threat

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Abstract

Oaks (*Quercus* spp.) are an important species group in the forests of Wisconsin. The State's timberland typed as oak-hickory forest was estimated at 2.9 million acres in 1996. Growing stock volume for red oak was estimated at 2.4 billion cubic feet, whereas select white oak volume was estimated to be 927 million cubic feet. Oak wilt, the oak disease of greatest concern in Wisconsin, is widespread in the lower two-thirds of the State. Harvest activities in oak stands may result in introduction of the disease agent, *Ceratocystis fagacearum* (Bretz), into the stand or promote intensification of the disease within the stands or both. A risk-rating system based on scientific- and experience-based knowledge was used to develop a statewide system for oak wilt risk analysis. Guidelines for timber harvest activities in oak stands were then developed based on results of the risk analysis. The analysis and recommendations have been published (http://www.dnr.wi.gov/forestry/fh/oakWilt/guidelines.asp [Date accessed: July 8, 2010]) in three different formats. The formats include a pdf version of decision-trees with accompanying tables, a simple spreadsheet application allowing the user to obtain specific guidelines based on his/her response to five questions about the stand and timing under consideration, and an interactive online format derived from the spreadsheet version. The query page of the interactive formats is linked to a concealed table containing the risk analysis and recommendation matrix. The tool provides consistent, statewide guidelines for harvest activities that will, when applied, minimize spread and reduce the biological and economic impacts of oak wilt to Wisconsin's oak timberlands. The rule-based, expert-driven system approach used to develop these guidelines could be used to assess risk and develop large-scale management guidelines for other established forest pathogens.

Keywords: *Ceratocystis fagacearum*, oak wilt, *Quercus* spp., risk analysis, timber harvest guidelines.

Introduction

Oak Forests of Wisconsin

Oaks (*Quercus* spp.) are a dominant component of the extensive oak-hickory forests of the Central U.S.A. (Leopold and others 1998). In Wisconsin, timberland typed as oak-hickory forest was estimated at 2.9 million acres in 1996 (Schmidt 1997). Growing stock volume for red oak (section Lobatae) was estimated at 2.4 billion cubic feet, whereas white oak (section Quercus) volume was estimated to be 927 million cubic feet (Schmidt 1997).

Oak Wilt – Primary Disease of Concern

Oak wilt, the oak disease of greatest concern in Wisconsin, occurs in 51 of the State's 70 counties (http://www.na.fs.fed.us/fhp/ow/maps/ow_dist_fs.shtm [Date accessed: July 8, 2010]). Thousands of oaks in woodland and urban settings succumb to the disease every year. The causal fungus, *Ceratocystis fagacearum* (Bretz), is spread from diseased to healthy oaks belowground through functional root grafts or aboveground by insect vectors (Tainter and Baker 1996). Species of the sap beetle family (Coleoptera: Nitidulidae) are considered the primary vectors in Wisconsin. New disease centers are established when *C. fagacearum*-contaminated beetles visit fresh xylem-penetrating wounds (e.g., axe blazes, logging wounds, branch-pruning wounds) on healthy oaks and successfully inoculate them with propagules of the fungus (Gibbs et al. 1980, Juzwik and others 2004). Stump surfaces created by tree felling and wounds to branches, stems, and roots by heavy equipment or adjacent falling trees are avenues for infection during timber stand improvement or harvesting activities. In a timber sale unit near Waube Lake, Wisconsin, many new infection centers occurred over a large area following a May 2001 timber harvest (M. Mielke 2006. Plant pathologist, Northeastern Area State and Private Forestry, USDA Forest Service).

Felling of diseased oaks adjacent to healthy oaks can lead to intensification of the disease within stands if root connections exist. Slow movement of the pathogen through grafted roots of healthy trees felled within 50 feet of a diseased tree explained the sporadic appearance of oak wilt in subsequent years at the edge of clear-felled areas (Yount 1955).

Need for Statewide Guidelines

The Wisconsin Department of Natural Resources (DNR) identified the need to develop consistent, statewide guidelines for timing harvest activities in oak timberland in order to minimize potential for oak wilt introduction or spread or both in existing and future stands where oak regeneration is the management objective. A committee of government, industrial, and consulting foresters was formed to develop such guidelines. Both scientific and experience-based knowledge of the oak wilt host – pathogen system were the basis of the guidelines. The approach used to (1) analyze the risk and the potential for introduction and spread of oak wilt in stands targeted for harvest, and (2) develop guidelines for timing harvest are described in this paper.

Approach

Risk Assessment

Risk refers to the chance of injury or loss defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value (North American Forest Commission 2004). Our risk analysis includes (1) the assessment of risk posed by the oak wilt pathogen to oak timberland scheduled for harvest and regeneration to oak, and (2) recommendations for minimizing frequency of pathogen introduction to and spread within such stands. A rule-based, expert-driven model, such as that used for pest risk assessment in the Exotic Forest Pests (ExFor) system (North American Forest Commission 2004), was adapted for this analysis. This approach falls under the umbrella term of multicriteria decision analysis, which seeks to take multiple criteria into account when groups explore decisions that matter, e.g., natural resource management decisions (Mendoza and Martin 2006). Two criteria were evaluated within the risk assessment process.

Criterion 1: Risk of *Ceratocystis fagacearum* introduction to the stand [between-stand spread] or for initiation of new centers within the stand [within-stand spread] by insect vectors—
Statements were developed for this criterion that considered two factors: (1) time of year during which harvest activities would occur (resulting in fresh wounds suitable for infection), and (2) proximity of existing oak wilt centers in other locations to the stand in which harvest activities would occur. A risk rating, ranging from very low to very high, was then assigned to each of the possible combinations of time and proximity. The risk values were determined through a group consensus process after review of pertinent scientific literature and of each individual's experience working with the disease.

Criterion 2: Risk of *C. fagacearum* belowground spread within an oak stand following pathogen establishment—
Statements for this criterion included three factors (i.e., stand conditions): (1) density of oaks, (2) general topographic relief, and (3) general soil type in the stand to be harvested. Each of these factors is known, either through scientific studies or experiential knowledge or both, to influence the frequency and the distance over which intraspecific root grafting occurs. Two or more levels were selected for each factor. Basal area (square feet per acre) levels for describing red oak species composition and density were less than 15, between 15 and 35, and greater than 35. The general levels for topographic relief were (a) flat to rolling terrain, and (b) steep hills with deep valleys terrain. Soil type was divided into light textured (sandy, loamy sand, and sandy loam) and heavier textured (all other types depicted in classic soil texture triangle). A risk rating, ranging from very low to very high was then assigned to each of all possible combinations of statements by factor. The risk values were determined by a group consensus process.

Overall risk: combined risk rating for the two criteria—
The ratings for each criterion were then used to generate the overall risk of oak wilt's threat to the stand of interest following a timber harvesting event. The overall rating, ranging from very low to very high, was assigned to each stand scenario based on the combination of introduction and

Table 1—Combined risk ratings for Criterion 1 factors - proximity of oak wilt centers to stand under consideration and proposed timing of harvest activities

Proximity of oak wilt centers to stand of interest			
Within county?[b]	**Within stand?**	**Proposed timing of harvest activities**	**Risk rating[a]**
No	No	Spring to early summer	M
No	No	Summer to early fall	L
No	No	Mid-fall through winter	VL
Yes	No	Spring to early summer	VH
Yes	No	Summer to early fall	M
Yes	No	Mid-fall through winter	VL
Yes	Yes	Spring to early summer	AP
Yes	Yes	Summer to early fall	AP
Yes	Yes	Mid-fall through winter	AP

[a] Explanation of ratings: VH (very high), M (moderate), L (low), VL (very low), AP (oak wilt already present in the stand).
[b] Includes stands occurring in oak-wilt-free counties, but within 6 miles of oak-wilt-affected counties.

root graft spread factors. As before, the risk values were determined through a group consensus process.

Timber Harvesting Guidelines

Timber harvest guidelines for minimizing the initiation of new infection centers and subsequent tree loss from spread within stands were developed based on results of the risk assessment. The risk rating for each stand condition scenario was considered and harvest recommendations determined through a group consensus process.

Display of Risk Analysis Results and Guidelines

Three methods were used to display results of the risk analysis. For the first method, graphical decision-trees were constructed, and associated tables were developed for harvest guidelines for three proximity levels (i.e., no oak wilt in county, oak wilt in county but not in stand, and oak wilt in the stand [not shown]). This output was used in the development of the electronic displays. Initially, the risk analysis and associated harvest guidelines were combined in a simple electronic spreadsheet. The spreadsheet features a front query page that allows the user to obtain risk ratings and recommendations for specific stand scenarios. The query page is linked to a concealed table containing the risk analysis and recommendation matrix. Later, an interactive, Web version of the spreadsheet product was developed for online use.

Results

Risk Analysis Results with Scientific Knowledge Basis

The combined risk ratings for Criterion 1 ("Criterion 1: Risk of *Ceratocystis fagacearum* Introduction to the Stand [Between-Stand Spread] or for Initiation of New Centers within the Stand [Within-Stand Spread] by Insect Vectors") are shown in Table 1. The risk of overland pathogen transmission by sap beetles was considered to increase as proximity to an existing oak wilt center decreased. The existing centers would be the source from which inoculum-laden beetles would originate, assuming oak wilt mats were formed on recently wilted red oaks in that originating center. Menges and Loucks (1984) and Shelstad and others (1991) found higher efficiencies of vector spread over short distances (e.g., ≤ 300 m); longer distance spread occurs very infrequently and on a random basis. Although the number of new centers occurring at greater distances is small, over time they can have a significant influence on distribution of oak wilt within the total forest area (Shelstad and others 1991). Timber harvest activities would result in wounding of residual oaks in shelter wood cut situations or create stump surfaces of removed healthy oaks or both. Such xylem-exposing cuts are attractive to dispersing sap beetles. The risk of pathogen transmission to such wounds by certain sap beetle species is high during the spring months, low from

Table 2—Combined risk ratings for Criterion 2 factors – density of oaks, topographic relief, and general soil type

Density of oaks[a] (ft^2/acre)	Topographic relief	Soil category[b] (texture)	Risk rating[c]
< 15	Flat – rolling	Light	L
15 – 35	Flat – rolling	Light	H
> 35	Flat – rolling	Light	VH
< 15	Flat – rolling	Heavy	L
15 – 35	Flat – rolling	Heavy	M
> 35	Flat – rolling	Heavy	H
< 15	Hills & valleys	Light	L
15 – 35	Hills & valleys	Light	H
> 35	Hills & valleys	Light	H
< 15	Hills & valleys	Heavy	VL
15 – 35	Hills & valleys	Heavy	M
> 35	Hills & valleys	Heavy	M

[a] Density of oaks measured as basal area.
[b] Light texture includes sandy, loamy sand, sandy loam, sandy clay loam, and loam; Heavy texture includes sandy clay, clay, clay loam, silt, silt loam, silty clay loam, and clay loam. Based on classic soil texture triangle.
[c] Explanation of ratings: VH (very high), H (high), M (moderate), L (low), and VL (very low).

Table 3—Stand condition scenarios for which overall risk ratings were high (H) to very high (VH), where oak wilt is not yet present in the stand of interest but occurs elsewhere in the same county or in a second county that is less than 6 miles from the first

Timing for harvest	Oak density[a] (ft^2/acre)	Topographic relief	Soil category[b] (texture)	Overall risk rating
Spring to early summer	>35	Flat - rolling	Light	VH
Spring to early summer	> 35	Hills & valleys	Light	H
Spring to early summer	> 35	Flat - rolling	Heavy	H
Spring to early summer	> 35	Hills & valleys	Heavy	H
Spring to early summer	15 – 35	Flat - rolling	Light	H
Spring to early summer	15 – 35	Hills & valleys	Light	H
Spring to early summer	15 – 35	Flat - rolling	Heavy	H
Spring to early summer	15 – 35	Hills & valleys	Heavy	H

[a] Density of oaks measured as basal area.
[b] Light texture includes sandy, loamy sand, sandy loam, sandy clay loam and loam; heavy texture includes sandy clay, clay, clay loam, silt, silt loam, silty clay loam, and clay loam. Based on classic soil texture triangle.

midsummer to early fall, and none during the late fall and winter (Ambourn and others 2005, French and Juzwik 1999, Juzwik and others 2006).

The combined risk ratings for Criterion 2 ("Criterion 2: Risk of *C. fagacearum* Belowground Spread within an Oak Stand Following Pathogen Establishment") are shown in Table 2. Frequencies of root graft spread increase with increasingly lighter textured soils, e.g., from silt loam to sands (Menges 1978). Furthermore, frequency of root graft transmission is highest for stands with > 60 percent red oak density (Menges and Loucks 1984). Lastly, oak wilt is very common in areas of low topographic relief in portions of Iowa, Michigan, Minnesota, and Wisconsin (e.g., Albers 2001, Menges and Loucks 1984). In areas with obvious

Table 4—Summary of management guidelines for timing of timber harvest activities based on oak wilt risk analysis results

Stand proximity to oak wilt centers	Guidelines by timing of timber harvest activities		
	Spring – early summer	**Summer – early fall**	**Fall – winter**
Not in county or within 6 miles of county with oak wilt and not in stand	No restrictions April 1 - July 15 (south)[a] and April 15 - July 15 (north). (12)[b]	No restrictions July 16 - September 30. (12)	No restrictions October 1 - March 31 (south) and April 14 (north). (12)
In county or within 6 miles of a county with oak wilt, but not in stand	May cut between April 1 - July 15 (south) and April 15 - July 15 (north) IF new stumps are treated. (4) Do not harvest or conduct activities that may wound oaks April 1 - July 15 (south) and April 15 - July 15 (north). (8)	No restrictions July 16 - September 30. (12) 15	No restrictions October 1 - March 31 (south) and April 14 (north). (12)
In county & in stand	First consider owner interest in oak wilt control; otherwise, no restrictions April 1 - July 15 (south) and April 15 - July 15 (north) if new stumps are treated. (4) First consider owner interest in oak wilt control; otherwise, do not harvest or conduct activities that may wound oaks April 1 - July 15 (south) and April 15 - July 15 (north). (8)	First consider owner interest in oak wilt control; otherwise, no restrictions July 16 - September 30. (12)	First consider owner interest in oak wilt control; otherwise, no restrictions October 1 - March 31 (south) and April 14 (north). (12)

[a] South denotes stands located south of the tension zone in Wisconsin; north denotes stands located north of the tension zone. Wisconsin's tension zone is a border between northern and southern floristic provinces (Curtis 1959). Data on average monthly temperatures and flight of oak wilt insect vectors support use of different risk dates for these portions of the State.
[b] Twelve scenarios are possible for each timing-proximity combination. Number of scenarios to which the particular guideline applies is stated in parentheses.

topographic relief, oak wilt is most common on upper slopes and ridge tops (Anderson and Anderson 1963, Bowen and Merrill 1982, Cones and True 1967).

Each of the 108 stand condition scenarios described by combinations of the five factors was assessed for overall risk of oak wilt occurrence based on the individual criterion ratings. Overall risk ratings were high to very high for eight stand-condition scenarios where oak wilt was not known to be present in the stand (Table 3). Overall risk rating of very low, however, was often determined by a late fall–winter timing for the harvest.

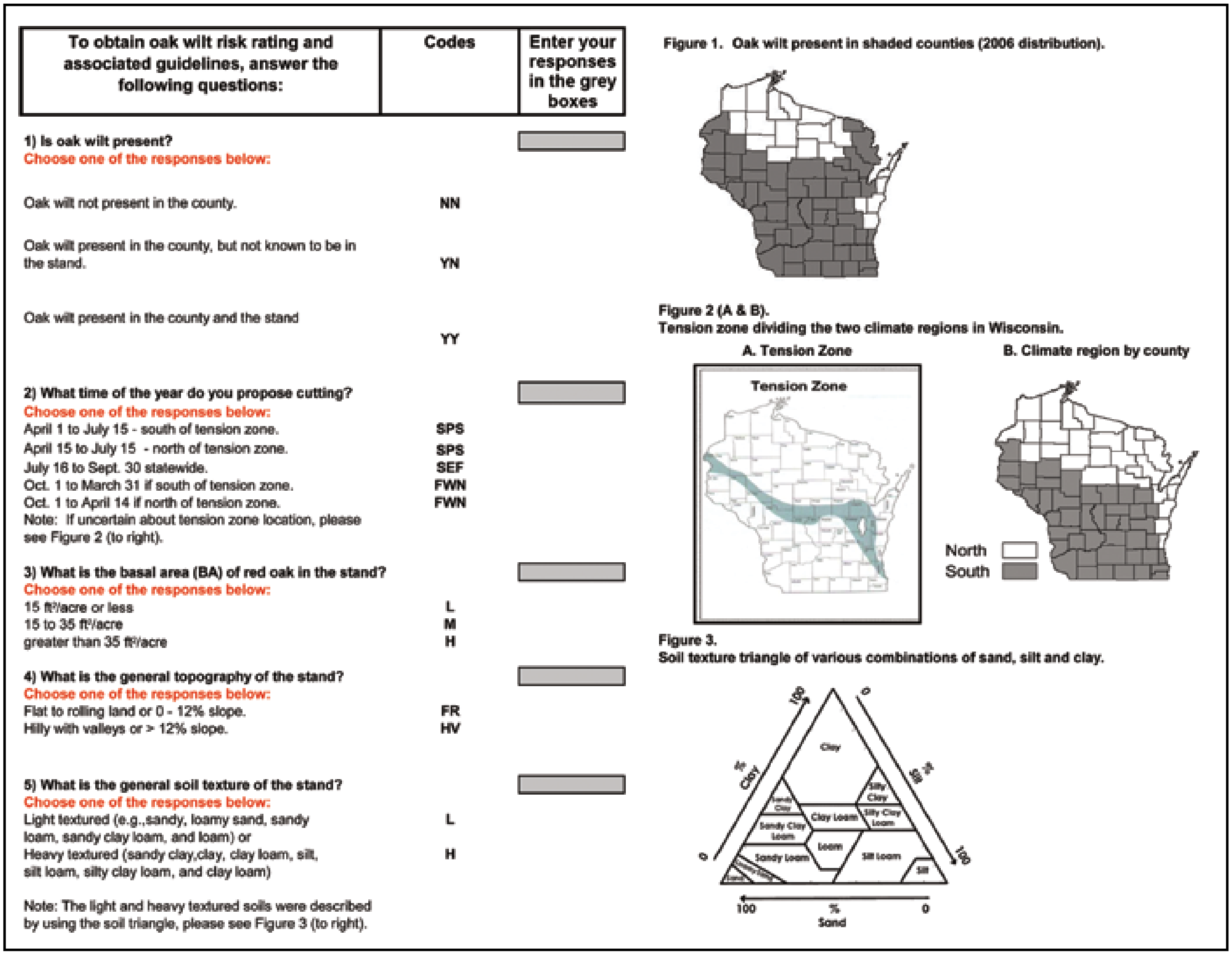

Figure 1—Query section of user page of spreadsheet application for oak wilt risk rating and associated management guidelines. Shaded boxes are where user enters information.

Timber Harvest Guidelines

Preventive measures developed for minimizing initiation of new oak wilt infection centers and the potential for future tree losses owing to oak wilt in regenerated stands were described in three brief statements: (1) Do not harvest or conduct activities that may wound oaks, (2) Harvesting may be conducted if stumps are treated, and (3) No restrictions. The first two measures largely apply to stand harvest activities being considered for spring and early summer. A summary of the stand/harvesting scenarios associated with each of the preventive recommendations when categorized by timing and proximity factors is presented in Table 4. For timber stands where oak wilt centers already exist and harvest of and regeneration to oak are planned, the guidelines include some further considerations. Specifically, foresters are advised to first consider the landowner's tolerance for future tree losses to oak wilt in the regenerated stands. Disease control actions, such as stump extraction or soil trenching, could be valuable for greatly reducing the carryover of oak wilt into the future stand.

Risk Analysis and Guidelines Tool Formats

Three different formats of the risk analysis results and the harvest guidelines were developed for end users. A hard-copy, decision-tree format (filename: oakwiltguide031507.

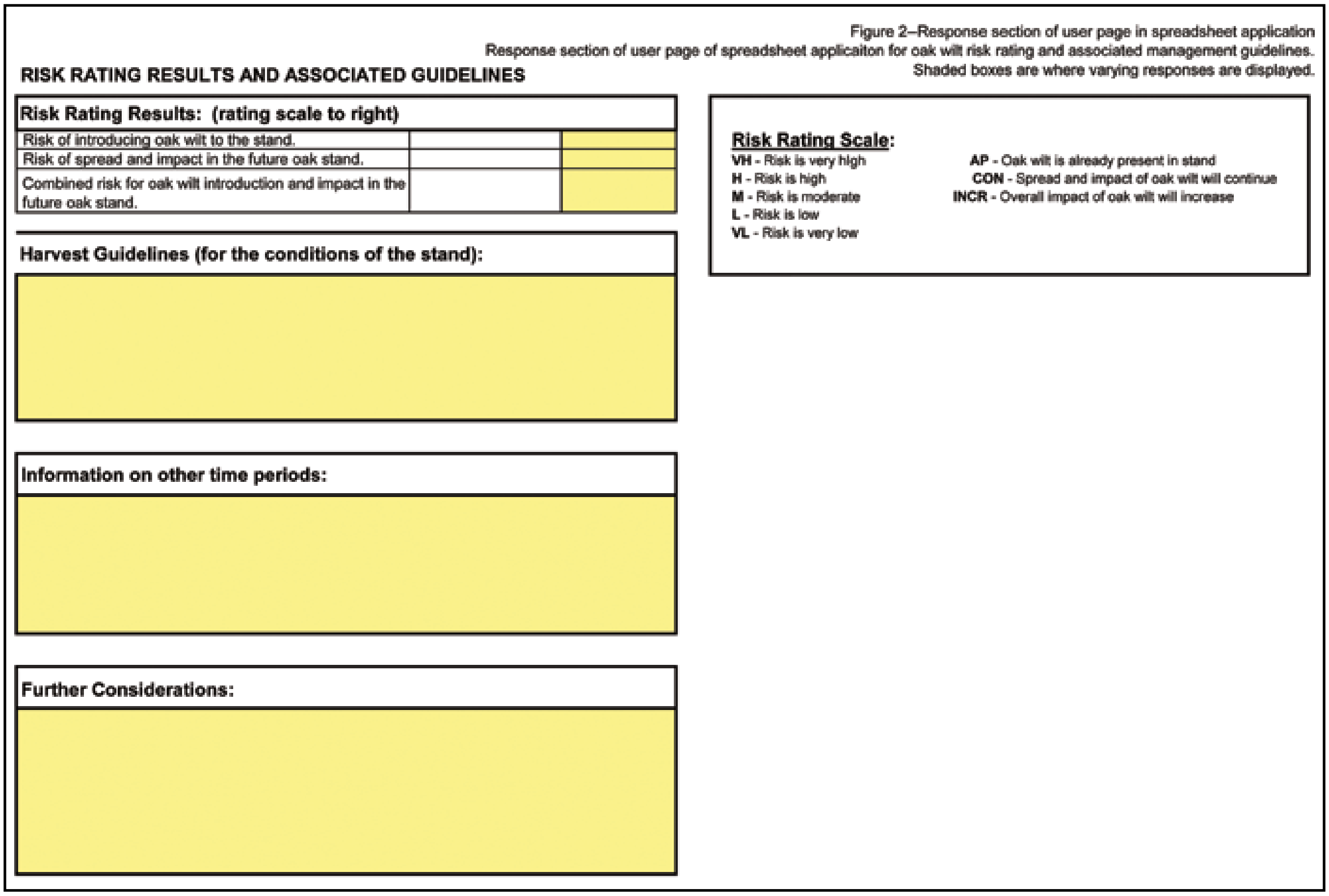
Figure 2–Response section of user page in spreadsheet application
Response section of user page of spreadsheet applicaiton for oak wilt risk rating and associated management guidelines.
Shaded boxes are where varying responses are displayed.

RISK RATING RESULTS AND ASSOCIATED GUIDELINES

Risk Rating Results: (rating scale to right)		
Risk of introducing oak wilt to the stand.		
Risk of spread and impact in the future oak stand.		
Combined risk for oak wilt introduction and impact in the future oak stand.		

Risk Rating Scale:
VH - Risk is very high
H - Risk is high
M - Risk is moderate
L - Risk is low
VL - Risk is very low
AP - Oak wilt is already present in stand
CON - Spread and impact of oak wilt will continue
INCR - Overall impact of oak wilt will increase

Harvest Guidelines (for the conditions of the stand):

Information on other time periods:

Further Considerations:

Figure 2—Response section of user page of spreadsheet application for oak wilt risk rating and associated management guidelines. Shaded boxes are where varying responses are displayed.

pdf) with accompanying tables is available from the Wisconsin DNR Web site (http://dnr.wi.gov/forestry/fh/oakWilt/guidelines.asp). The electronic spreadsheet version of the results (filename: oakwiltguide031507.xls) is also available from the same site. The interactive, online format was adapted from the spreadsheet version. The front user page of the spreadsheet-based tool (Figure 1) and of the online tool requires the user to input conditions of the stand being considered for harvest. The questions asked of the user include (1) Is oak wilt present? (2) What time of the year do you propose cutting? (3) What is the basal area of red oak in the stand? (4) What is the general topography of the stand? and (5) What is the general soil texture of the stand? The user selects a response from the multiple-choice answers offered for each question. The spreadsheet application then selects and displays the appropriate ratings and recommendations for the conditions described by the user (Figure 2), as does the online version.

Discussion

The rule-based, expert-driven model used in an exotic pest risk analysis context (North American Forestry Commission 2004) was adapted for use in assessing risk of oak wilt introduction to and potential for subsequent spread within oak timberland based on spatial, temporal, and site factors. Such a system may be useful for analyzing spread and impact risks in the management of other significant forest diseases. The Wisconsin DNR plans to use the same approach to analyze risk and develop guidelines for reducing spread of *Heterobasidion annosum* in pine forests of the State. The model was also considered for use in modifying existing guidelines for managing oak wilt in urban and periurban forests of Wisconsin. Existing guidelines were, however, considered sufficiently robust and did not warrant such an effort.

The success of our approach relied on a collaborative planning and decisionmaking environment. The participatory method sought and obtained the involvement of multiple experts, stakeholders, and end users. The committee responsible for developing the criteria, conducting the risk analysis, formulating guidelines appropriate to risk ratings, and reviewing the prerelease product met for 4 hours on each of 4 days. Solicitation of stakeholder and user response and suggestions to the proposed system occurred over a 7-month time period through presentations and subsequent comment sessions held at numerous meetings, e.g., the Wisconsin Chapter of the Society of American Foresters' annual meeting and the Wisconsin Woodland Owners' Association annual meeting.

Several research questions were raised during the exercise of developing criteria, conducting the risk analyses, and developing guidelines appropriate for the assigned risks. The need for observed frequency or estimated probability for successful overland transmission of the oak wilt fungus between mid-July and early October is being addressed in a 3-year study initiated in summer 2006. Questions were also raised about the ultimate quantitative impact of oak wilt introduced during shelter wood preparatory cuts or clearcutting on future oak stocking in stands regenerated on dry and dry-mesic sites. On the basis of results of a West Virginia study (Tyron and others 1983), we hypothesize that the impact would be low in areas where regeneration is mostly of seedling origin. However, where coppice or stump-sprout regeneration predominates, the ultimate impact of oak wilt on stand stocking would likely be higher. A long-term study is needed to address these questions. New knowledge or previously overlooked scientific knowledge pertinent to our risk assessment system will be considered in future revisions of the product.

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