MANAGING AN OAK DECLINE CRISIS IN OAKVILLE, ONTARIO: LESSONS LEARNED

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Abstract.—The town of Oakville, Ontario, is located along the north shore of Lake Ontario between Toronto and Hamilton. In the fall of 2002, significant oak (*Quercus* spp.) mortality was observed at Oakville's Iroquois Shoreline Woods Park, an environmentally significant forest remnant noted for its oak-dominated forests. Investigations suggested that oak decline was responsible for the widespread mortality and that other nearby forest lands were also affected. Oak decline is a disease complex brought on by multiple stresses (e.g., drought, defoliation, high stocking, tree senescence) and secondary pests such as *Armillaria* root rot (*Armillaria gallica*) and twolined chestnut borer (TLCB), *Agrilus bilineatus*. We present a case study that describes the steps that were taken to assess the situation, communicate issues to the public, resolve critical problems (e.g., salvage and hazard reduction), employ trap-tree strategies for TLCB, and develop silvicultural and restoration strategies that include aspects of oak management, regeneration, and prescribed fire. From a municipal forestry perspective, the most important aspects that led to a successful program were accessibility to experts with practical experience and development of effective communication strategies. This is a good case study for municipal foresters who must deal with catastrophic tree mortality in their woodlands similar to that caused by emerald ash borer (*Agrilus planipennis*).

INTRODUCTION

The town of Oakville is located on the northwestern corner of Lake Ontario about 12 miles west of Toronto (Fig. 1). Historically, Oakville has been a leader in managing its trees and urban forests and incorporating forests into the urban environment. In the fall of 2002, John McNeil, town forester and coauthor, became aware of significant oak (*Quercus* spp.) mortality at one of Oakville's high-profile natural parks, Iroquois Shoreline Woods (ISW), noted for its oak-dominated forests (Hanna 1984). After several weeks of assessments and consultations, it was apparent that most of the oaks throughout the park were affected. The park was determined to be unsafe for recreational use and was closed to the public in December 2002. This case study describes the response to this urban forest crisis and has provided some lessons learned that can be helpful to other urban forest managers.

Area municipal and provincial specialists identified the twolined chestnut borer (TLCB), *Agrilus bilineatus*, and *Armillaria* root rot as the causal agents of the oak mortality. Coauthor Peter Williams, a consulting forester and forest biologist with forest health management experience, was retained by Oakville to complete the diagnostic and assessment process, develop a plan for the removal and salvage of hazardous trees, and develop a restoration and management strategy for ISW.

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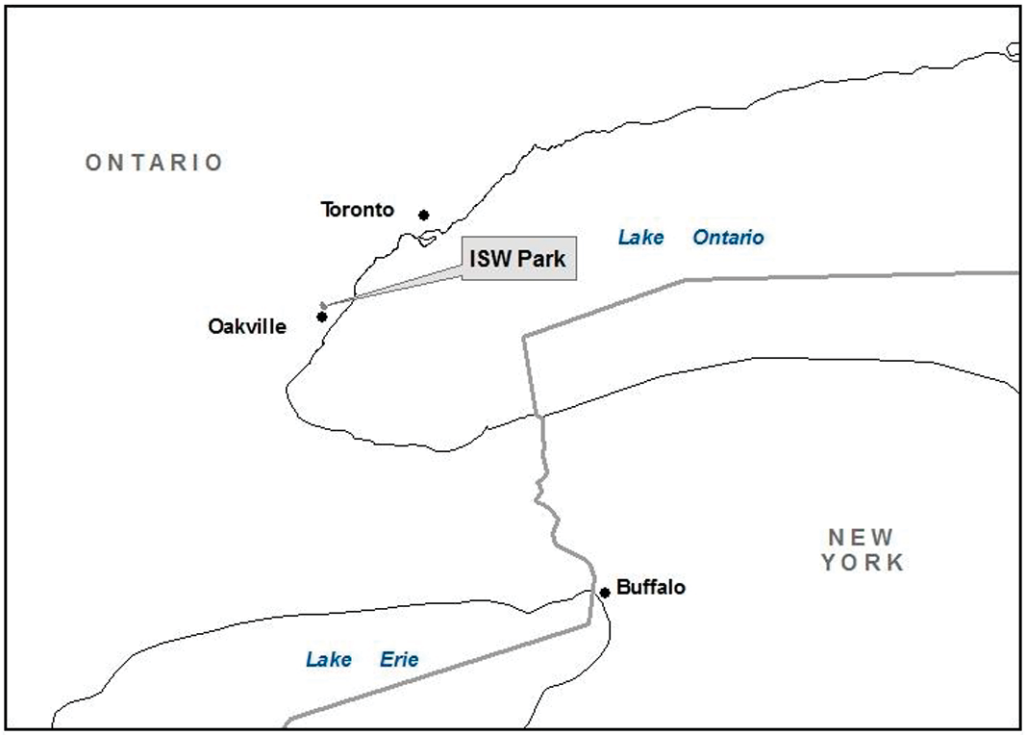

Figure 1.—Location of Oakville, Ontario and Iroquois Shoreline Woods Park.

Williams suggested that ISW forests were exhibiting extreme dieback symptoms that were similar to problems observed on oaks in other area woodlands and previously discussed at oak and mixed hardwood workshops in the United States. Forest managers in southern Ontario primarily use uneven-aged management in the tolerant hardwood forests that are abundant in the region and do not have much experience with even-aged management of oak-dominated forests like those at ISW. Therefore, consultation with U.S. Forest Service researchers experienced with oak ecology and its associated pest complex was recommended. Coauthor Kurt Gottschalk described the dieback as catastrophic oak decline, a stress-related disease complex where over 50 percent of the forest stand is affected. It was later determined that oak comprised about 88 percent of the forest, and approximately 90 percent of the oaks were dead or dying. The need for immediate action required that many steps had to be developed, integrated, and implemented nearly simultaneously in just a few months. These included:

1) Diagnosis of the oak health problem and causal agents and status assessment.
2) Development and implementation of communication strategies.
3) Development and implementation of mitigation strategies.
4) Compilation of lessons learned.

DIAGNOSIS AND ASSESSMENT PROCESS

Concepts of Oak Decline

Oak decline is a complex malady brought on by stress factors followed by successful attack by opportunistic (secondary) pests (Houston 1981; Wargo 1977, 1981; Wargo and Haack 1991). It is a progressive disease where trees can decline in health for several years before dying (Houston 1981,

Mannion 1991). Using the decline disease spiral model of Mannion (1991), predisposing factors, inciting factors, and contributing factors represent oak decline events. Common predisposing factors include soil and stand factors, genetics, tree or stand age, and pollution. Common inciting factors include defoliating insects, diseases, frost, drought, and mechanical damage. Common contributing factors include opportunistic insects and diseases. Once a tree is weakened by predisposing and inciting factors, it becomes more susceptible to a variety of insects and pathogens that normally do not affect healthy trees (Mattson and Haack 1987).

Drought and defoliation are the most common stressors that trigger oak decline episodes around the world (Gottschalk and Wargo 1997, Gottschalk et al. 2010). Another important predisposing factor in oak decline is physiological maturity. The cohort senescence theory of decline (Mueller-Dombois 1986) suggests that as trees age and become physiologically mature, their vigor can decline sufficiently to make the entire cohort present in a stand or geographic area susceptible to secondary pests. In southern Ontario, the oak decline episode covered a broad area, and landscape-level defoliation by gypsy moth (*Lymantria dispar*) and successive years of drought were likely inciting factors in this decline episode. High stand density, a cohort of overmature trees, and soil conditions were predisposing factors, and *Armillaria, Hypoxylon* canker, and TLCB were contributing factors to the observed decline.

Background on the twolined chestnut borer

The twolined chestnut borer is a member of the beetle family Buprestidae, which includes primarily species that feed and develop in the inner bark (phloem) and wood (xylem) of their host plants. The TLCB is native to eastern North America, occurring from the Canadian Maritime Provinces of Canada, west to the Rocky Mountains, and south to Florida and Texas (Haack and Acciavatti 1992). The principal hosts of the TLCB are chestnut (*Castanea* spp.) and oak. The TLCB is a secondary pest, commonly attacking trees stressed by drought and defoliation (Dunbar and Stephens 1975; Muzika et al. 2000; Wargo 1977, 1996; Wargo and Haack 1991). The TLCB preferentially attack trees with low root starch levels (Dunn et al. 1987, Haack and Benjamin 1982), a trait common in stressed trees.

Gallery construction by TLCB larvae girdles the tree's conducting tissues, which can result in crown dieback and eventual tree death. In heavily infested portions of the tree, crown foliage will prematurely wilt and turn brown in late summer. Dieback from the crown downward usually occurs over multiple years. As dieback progresses, it is common for epicormic branches to develop along the living portions of the trunk. The TLCB tends to infest stressed trees and little can be done once a tree is infested, especially in forest situations. Therefore, management programs usually focus on prevention by promoting tree and stand vigor by thinning overstocked and overmature stands, reducing defoliation, and avoiding damage to residual trees. In urban areas, managers and landowners can consider mulching, watering, soil aeration, and fertilization programs. Once infestation occurs, local TLCB populations can be reduced through a combination of pesticide applications, use of girdled oaks as trap trees, and early removal and prompt processing of infested trees. Girdled oaks serve as trap trees because TLCB adults are highly attracted to oaks girdled in spring and early summer and will readily lay eggs on such trees (Cote and Allen 1980; Dunn et al. 1986, 1987; Haack and Benjamin 1982).

Background on *Armillaria* Root Rot

Armillaria is the most common root-rotting fungus in the eastern hardwood forest with *Armillaria gallica* being the dominant species in oak-hickory stands (Blodgett and Worrall 1992, Wargo 1993, Worrall 1994). The fungus produces brown to black rhizomorphs (shoestrings) that grow along the surfaces of living or dead roots, outward into soil, and between the bark and wood of roots and trunks of recently-dead trees. Oaks with high starch levels in their roots produce defensive chemicals that prevent invasion by *Armillaria*. However, when oak trees are defoliated the starch is mobilized to sugars, and these chemical changes in the stressed root system predispose the tree to successful *Armillaria* invasion (Wargo 1972, 1984, 1996; Wargo and Haack 1991). *Armillaria* fungi can grow in the cambial region and girdle roots, but usually advances more quickly towards the root tip than the trunk. Given that *Armillaria* species are ubiquitous, there are no real treatments for the disease. However, maintaining tree health can make trees more resistant to infection. Trees infected by Armillaria are often subsequently attacked by TLCB (Dunbar and Stephens 1975, Sinclair et al. 1987, Wargo 1977).

Iroquois Shoreline Woods Park

Iroquois Shoreline Woods Park is located on the upper section of the glacial Lake Iroquois shoreline in Halton County. The site is at the edge of the till plain that had been eroded by the waves of glacial Lake Iroquois and contains relatively-heavy, clay loam till soil (Gillespie et al. 1971). Site index at ISW is 75 ft. at 50 years, or site class 3+ for red oak, which is average site quality for the area (Taylor and Jones 1986). However, site conditions vary depending on the landscape position, with the best site conditions found in the drainages, lower slope positions, and parts of the lower lakebed. The higher level areas had the poorest site conditions due to shallower clayey soils and imperfect to poor drainage, with a tendency to be inundated or saturated in the spring and droughty in the summer.

The local area was settled by Europeans around 1800, and by 1850 it was mostly cleared for agriculture. A large forested area was likely clearcut around 1900 and used for grazing. The ISW is a 70 acre remnant of this larger woodland which contains 55 acres dominated by forest species and 15 acres dominated by hawthorn (*Crataegus* spp.) (Fig. 2). The canopy trees were between 80 and 100 years old. The stand was dominated by red and white oaks with sugar and red maple (*Acer saccharum* and *A. rubrum*), bitternut and shagbark hickory (*Carya cordiformes* and *C. ovata*), beech

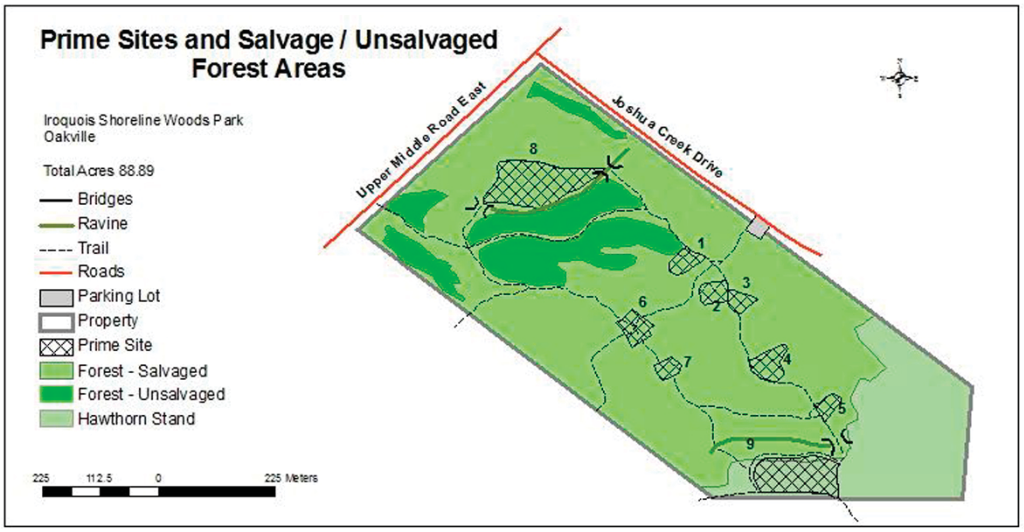

Figure 2 —Map showing the salvaged and unsalvaged forest areas and the prime site locations (numbers 1-9) for oak regeneration within Iroquois Shoreline Woods Park.

(*Fagus grandifolia*), and eastern hophornbeam (*Ostrya virginiana*) making up much of the understory (Perkins 1986). Estimates suggested that the overstory and understory of ISW consisted of 88 percent red oak and 12 percent white oak. The southern part of the property was still undergoing succession from a hawthorn-old field ecosystem to forest in 2003.

The ISW property is bordered by residential subdivisions to the west and north while the south and east are bordered by vacant and commercial land and a major four lane highway. ISW is owned by the Province of Ontario and leased to Oakville until 2033 for use for recreation and conservation purposes. The property includes a trail system used by local residents and the public in general, many of whom frequently express their concerns and interests in the property. A management plan including a description of the history and forests of the property and management objectives and methods was developed for ISW in 1986 (Perkins 1986), but management objectives were never fully implemented.

Oak Decline at ISW

The oak-dominated forest (red, white, and bur oak [*Q. macrocarpa*]) became established under challenging site conditions, and since 1950 there has been no significant forest management activity. As the stand aged, many areas became overstocked and stagnated. Basal area averaged between 135 and 148 ft^2/ac, and oak heights ranged between 65 and 75 ft. Because of the high basal area and age, many oaks had small crowns. Examination of the growth rings on cut trees and stumps confirmed that in general, the trees were growing slowly and were of low vigor.

From 1995 to 1999, the area experienced below average precipitation during four of the five growing seasons. The drought conditions likely exacerbated other unfavourable site conditions (clayey soils and high stand density). Gypsy moth entered Ontario in the mid-1980s and first impacted this area around 1987. Since then, there have been several defoliations from insects, including oak leaf shredder (*Croesia semipurpurana*) in the 1980s and fall cankerworm (*Alsophila pometaria*) in the early 2000s. In 2000, a hard late frost was followed by severe gypsy moth defoliation, resulting in two defoliations in the same growing season.

Inciting factors in this decline episode at the Iroquois Shoreline Woods Park included defoliation by gypsy moth (*Lymantria dispar*), late frost, and successive years of drought. High stand density (overstocked stand), a cohort of overmature low-vigor oak trees, and soil conditions (clayey sites) were predisposing factors. *Armillaria, Hypoxylon* canker, and TLCB were contributing factors to the observed decline. *Armillaria* was associated with many of the dead and dying oaks at ISW as was *Hypoxylon* canker to a lesser extent. TLCB also became an aggressive pest once the problem became epidemic, making it difficult to tell which agent actually killed the most oaks. By January 2003, approximately 96 percent of the oak trees in the understory and 90 percent of the oak trees in the overstory were dead or dying.

COMMUNICATIONS STRATEGY

The use of large-scale forest operations were necessary to respond to the oak decline crisis in the ISW. Due to the importance of ISW as a local park and natural area and because of its location in an urban setting, an effective communications program was necessary to the success of this operation. The important interest groups included municipal administration, municipal council, the general public, and public interest groups. Because oak decline was a poorly-understood disease complex in southern Ontario, the regional forestry and urban forestry communities were important clients as well.

Municipal Staff and Council

The closure of ISW Park for safety reasons in December 2002 placed pressure on the town administration and the town council to rectify the situation quickly. As the nature and scale of the remedies became clear, it was apparent that significant time and resources would be needed and that the required remedial work would be unusual for an urban situation. A report (McNeil 2002, personal communication) was presented to the town council that explained the situation and recommended the closure of the park and a public communications program. The recommendation was approved, and work commenced on developing remedial plans. A silvicultural and regeneration plan for ISW was prepared (Williams 2003, personal communication) that included procedures for removal of hazard trees, harvest and salvage in the majority of the property, and forest restoration plans. Activities and plans were vetted and communicated through the town administration and town council with resounding approval.

Public

The public was advised of the situation and plans through news releases and the local media. However, because of the complexity of the oak decline scenario and the large scale of the problem and planned work, a more direct and personal approach was also used. Two on-site field tours were planned for the public, and written notifications were hand-delivered to residents near ISW describing the situation and inviting those with concerns to contact staff or attend the field tours. Residents were also invited to join a local group, "Friends of ISW", to help with forest restoration efforts such as tree planting.

Public Field Tours

Two public field tours took place in February 2003, just prior to the start of tree removal operations. Because participants would likely represent a range of backgrounds and levels of understanding in forest health and resources, experienced professionals presented basic-level information but were also able to respond to higher-level concerns expressed by some participants.

Five stations (Table 1) were staffed with professional leaders and experienced assistants and were conveniently located in the forest where examples could be demonstrated. The leaders presented the primary information for the station, led discussions, and answered questions. The assistants helped with discussion and questions as appropriate, but also engaged agenda-driven individuals in attendance by drawing them off to the side where they could discuss their concerns individually. Several assistants moved between stations and helped keep the groups synchronized for rotation to the next station.

Table 1.—Topics and staff for the five stations of the public tours

Topic	Staff
Introduction and background	Oakville staff professional forester
Oak decline, *Armillaria* and salvage operations	Professional forester-ecologist
Oak decline and twolined chestnut borer	Forest biologist
Invasive exotic plants and their control	Forest technician
Hazard trees and safety concerns	Arborist and forest technician

The use of highly-qualified station leaders with experience in all aspects of forest ecology and forest health was important so they could answer questions participants had about the project. Providing clear and correct answers to potential questions (e.g., bird habitat) prevented individuals from undermining the credibility of the planning and threatening the project. As expected, a wide variety of citizens including lay persons, council members, and experienced naturalists and ecologists participated. With minor exceptions, the participants accepted that ISW was being managed for forest health rather than income and were comfortable with the knowledge and planning that had gone into the project.

Volunteer Programs and Other Communications

After the park was reopened in August 2003 and restoration efforts were started, programs were implemented to allow volunteers to contribute to tree planting programs and to learn about ISW and other urban forest issues. Volunteer tree planters included members of several interested groups (e.g., Friends of ISW, Oakville Green, and the Oakville Horticultural Society), families and individuals, and school groups.

A prominent and accessible location in ISW was used as the site for events such as Arbor Day celebrations that featured awards by the Mayor's office and announcements such as Oakville's designation as Canada's Forest Capital in 2007, certification as responsibly managed through the Forest Stewardship Council (FSC) Smartwood program, and funding from Green Streets Canada. Events often included presentations by staff or consultants on ISW or other forest health topics, reenactments by First Nations groups, horse logging, and tree-planting events with school groups.

Summary

The pubic communication efforts successfully demonstrated Oakville's interest and support of urban forestry and a commitment to manage its forests for the community. In addition, they provided Oakville with greater credibility in managing forest health crises and contributed to ongoing support and acceptance of forest health management programs, such as aerial spraying for gypsy moth control and emerald ash borer management programs. Similarly, the communication efforts have also resulted in a certain level of expectation by the community that Oakville will be proactive in managing the health of its urban forests.

Professional Education

Consultation with experts in the United States proved critical in elucidating the oak decline scenario and putting together remedial plans. In March 2003, Oakville invited Kurt Gottschalk of the U.S. Forest Service to visit the area, assess the situation, and make management recommendations. Representatives from provincial and local organizations attended the session to become more familiar with oak decline issues. As a result of this visit, Oakville sponsored a workshop to bring together forest health specialists with professional foresters and urban forest managers to develop a better local understanding of oak forest health and decline issues.

Workshop

A workshop entitled "Managing for Oak Decline: A Workshop for Managers of Oak Forests" was held 8-9 July 2003 and sponsored by Oakville with numerous cosponsors. Staff from the U.S. Forest

Service, Williams & Associates, the town of Oakville, Ontario Ministry of Natural Resources, and Conservation Halton developed the workshop and made presentations. The workshop was well received and helped to fill a significant knowledge gap in the region regarding its important oak resources. The success of the workshop was due to the cooperation among local municipalities and agencies to address critical forest management needs that were not being addressed by provincial or federal agencies in Canada. This informal network worked together in subsequent efforts to coordinate gypsy moth and emerald ash borer management programs in southwestern Ontario.

Field Tours

ISW has been used as a stop for a number of forestry professional and educational groups since 2003. In all cases, Oakville has provided experienced personnel to guide the tour and to provide background and advice. These tours have included groups from Canadian Institute of Forestry, the Ontario Professional Foresters Association, and University of Toronto (Urban Forestry Program).

MITIGATION STRATEGIES

Addressing the oak decline crisis in ISW required the development and implementation of mitigation strategies that included silvicultural prescriptions for salvage and regeneration, invasive plant management, and implementation and monitoring.

Silvicultural and Salvage Prescriptions

Silvicultural Strategy

A four-class rating system (Gottschalk and MacFarlane 1993) (Table 2) was used in concert with tree form, crown class, public safety concerns, TLCB signs and symptoms, and TLCB population reduction strategies to guide tree removals. Hazardous trees within one tree length of developed trails and all oaks in condition classes 3 and 4 within 30 ft. of developed trails, parking areas, and property lines, were marked for removal. Trees located 30 to 70 ft from trails, parking areas, or property lines were retained if they posed little potential hazard. These choices were reviewed by forestry technicians, foresters, and certified arborists several times during the process.

Away from the trails, sound dead trees ≥ 6 inches diameter at breast height (d.b.h.) were marked for salvage harvest (Gottschalk 1993). Dead trees with significant wildlife habitat characteristics (e.g., nesting or feeding cavities, or significant decay) that did not threaten trail safety were retained. All Class 3 and Class 2 trees that were heavily infested with TLCB were marked for removal to salvage their value, encourage stump sprouting, and reduce TLCB population by removing them from the area (Gottschalk 1993, Haack and Benjamin 1980). Oaks often regenerate from stump sprouts, but the tree must be alive at the time of cutting to sprout. Oaks with significant decline seldom recover

Table 2.—Oak health and decline rating system used (Gottschalk and MacFarlane 1993)

Class	Class name	Dead branches	Epicormic sprouting	Foliage		
				Density	Size	Color
1	Good	<25%	Little/None	Healthy	Normal	Normal
2	Fair	25 to 49%	Some evident	Subnormal	Smaller	Subnormal
3	Poor	>50%	Heavy	Subnormal	Smaller	Chlorotic
4	Dead	100%	n/a	n/a	n/a	n/a

but may sprout from their live stumps. In the interest of maintaining oak in ISW, it was deemed better to cut declining trees to encourage stump sprouting than to let them die completely.

Wildlife Habitat Considerations

ISW is an important stopover for migrating birds in the spring and fall because it is the largest forest patch on the north shore of Lake Ontario between Toronto and Hamilton. Wildlife habitat was an important consideration throughout the planning process. Trees with significant wildlife value (i.e., snags, trees with cavities used for nesting, feeding, or dens, and trees with stick nests used by raptors) were identified and retained if they did not threaten trails. Areas adjacent to these trees were disturbed as little as possible. Tree removal work took place during February and early March during frozen conditions to minimize disturbance to forest soils and associated plant and animal communities, and to reduce the potential impacts on nesting and migratory birds.

Harvest and Salvage Implementation

Salvage harvest operations began in February 2003 and were completed by the end of March 2003. Two cut and skid crews worked full time and harvested approximately 4,000 trees and 250,000 board feet of sawtimber (net scale). A large volume of firewood was also salvaged. About 80 percent of the work was completed with relatively little site disturbance and no damage to the developed trail network. The remaining unharvested area was not salvaged and left to develop naturally except for the removal of hazard trees in the proximity of public use trails. Despite the industrial scale of the harvest in a major urban park surrounded by residential areas and busy roads, there were few public inquiries and many of these regarded firewood availability. The apparent broad public acceptance to this level of activity was attributed to the vigorous communications and frank explanations of the oak decline situation.

Because some hazard trees still remained along the trails, a horse logger was retained to remove these trees so the park could be reopened. These trees were cut and skidded to a landing and sold. Arborists removed dead and hanging branches from the remaining trees near the trails. Damage to the trail from hazard-tree removal was repaired and the park was reopened for public use in June 2003. During 2004 and 2005, new hazard trees and declining oaks were removed as part of the hazard management program or the trap-tree project described below.

TLCB Assessment and Control

Surviving oaks were assessed for general health and evidence of TLCB infestation in June 2003. To reduce the TLCB population, 45 deteriorating Class-2 oaks were girdled at approximately 18 inches above ground to encourage egg-laying by TLCB as part of a trap-tree program as described in Haack and Benjamin (1982). Trap trees would be cut and removed from the site prior to TLCB emergence. In early 2004, additional infested and trap trees were removed from the ISW by skidding with horses to minimize impacts to the forest floor.

Concurrent with trap-tree identification in 2003, non-oaks that were competing with the surviving oaks were also marked for removal to increase the vigor of the surviving oaks (Gottschalk 1993). More vigorous trees are better able to withstand attack by TLCB and *Armillaria*, or are less attractive to these pests (Gottschalk 1993, Haack and Acciavatti 1992, Wargo 1996). Additional declining oaks and hazard trees were identified in August 2004 and removed during the 2004-2005 winter using a tractor and skidding winch.

Oak Regeneration Strategies

Oakville made a commitment to maintain an oak component at ISW, so efforts to maintain the health of surviving oaks in the forest and fostering the development of oak regeneration throughout ISW became a high priority. Two other strategies that were used included enhancing the oak component where appropriate stand conditions existed and using a group selection strategy to develop oak regeneration (Brose et al. 2008). The latter two were implemented using a prime site approach where regeneration efforts were concentrated.

Release of Existing Oak

Surviving oaks were located and released from competition to improve their vigor. Trees competing with surviving oaks were marked for removal so that the residual oaks were free from competition on at least two sides. All trees were felled concurrently with removal of the trap trees during the winter of 2003-2004 and salvaged where operationally convenient. The improved vigor and increased light to the oak crowns should foster production of acorns for development of oak regeneration.

In the hawthorn (*Crataegus*) and buckthorn (*Rhamnus*) dominated compartment at the south end of ISW, some oak and white pine (*Pinus strobus*) seedlings and saplings had colonized and grown above the hawthorn canopy, mostly along the established forest edge. Non-oaks that were competing with these trees were marked and felled. This process was repeated every few years as competing trees encroached on the oaks.

Prime Site Strategy

Because the high financial cost and limited societal acceptance of oak regeneration efforts throughout the whole park was a concern, direct oak regeneration efforts were focused on nine prime sites as indicated in Figure 2. Regenerating oaks in an established forest is often challenging, and this approach allowed the concentration of management activities in a smaller total area, in an effort to improve success, while allowing the remaining forest to develop with minimal human disturbance.

Eight prime sites were established in 2003 and a ninth was added in 2006. Seven sites were located in forest areas where there were few remaining canopy trees, representing a group selection strategy (#1-7 in Fig. 2). These sites ranged in size from 0.2 to 0.5 acres and had nearly all of the slash and any remaining trees and shrubs cut and chipped. The chips were blown into piles and some used to mulch planted seedlings. One of the original sites was in a hawthorn and buckthorn stand (#9 in Fig. 2). As plans were being made for buckthorn control, this site represented a natural succession strategy with elements of a shelterwood.

Once the cutting and chipping was completed, prime sites were planted with red oak seedlings and some white oak, bur oak, white pine, and eastern hemlock (*Tsuga canadensis*) seedlings starting in April 2004. The prime site in the hawthorn/buckthorn area was planted after the buckthorn was treated chemically. Most seedlings were planted by contractors, with some areas reserved for planting by volunteer groups. A high rabbit population in the southern end of the park resulted in up to 100 percent seedling mortality in some areas. Tree wraps were used to protect seedlings and the bases of larger trees after 2004. Tall potted red oak (5 ft.) stock was planted in a number of the prime sites. Oak developed well in some sites but did poorly in others. Oak survival in the prime sites and in the general forest was monitored in permanent sampling plots (Table 3).

Table 3.—Natural and planted oak populations in permanent sampling plots (PSP) in 2003 and 2009 in prime sites and other areas

			2003		2009	
Vegetation	PSPs	Condition	Natural	Planted	Natural	Planted
Forest	9	prime sites	33	944	22	778
Forest	8	salvaged	25	50	25	0
Forest	6	unsalvaged	33	0	33	0
Hawthorn	3		0	267	0	0
Hawthorn	2	prime sites	300	50	300	400

Shelterwood Treatment

The prime site added in 2006 (#8 in Fig. 2) was in an area that was appropriate for a classic shelterwood strategy. Before the decline episode, this site had a very high stand density with approximately 80 percent oak. All of the oak died from decline, but the plot still had a residual canopy of 50 percent to 80 percent canopy closure of residual upper and mid-canopy sugar maple and a dense understory of elderberry (*Sambucus* spp.) that had become established as the oak declined. The site was added to the 2006 prescribed burn plan so that fire could be used as a site preparation treatment to control the elderberry.

Local acorns were collected and planted on site. Additional acorns were planted in greenhouses and nurseries for future planting stock. The direct-seeded acorns did not develop, and the area was planted to seedlings in 2006 after the prescribed burn. The site was planted by volunteers and contractors on several occasions using bareroot tall stock or potted seedlings.

The elderberry and much of the woody debris left from the salvaged oaks were treated with a prescribed burn in 2006, and the site was planted to red oak that spring. Subsequent weak oak-seedling growth was attributed to excess shading from the residual canopy, and a release cut was made in 2008 by removing the mid-canopy maples and utilizing the wood for firewood. The release cut left 40 to 50 percent canopy cover. The site was planted in 2008 with red oak seedlings grown from the 2005 acorn crop.

The oaks planted on this site are growing better than in other parts of the park, likely a result of good site conditions, less browsing from rabbits, and less competition. Although monitoring data has not been analyzed, there is significantly less competition from herbaceous plants and shrubs. A planned 2012 prescribed burn should help reduce the weedy perennial competition and foster oak development.

Prescribed Burning

Prescribed burning is an important tool in oak silviculture for site preparation and competition control. Oak seedlings are adapted to aggressively sprout after low-level fires that kill competing woody and herbaceous vegetation (Brose et al. 2008). It was anticipated that competition would be a problem and that prescribed burning would be an effective control method. A prescribed burn plan (Bruin 2004) and communications plan were prepared for 2004 and scheduled for some of the prime sites in late April 2004.

The 2004 burn was successful, and most competing woody vegetation was killed or damaged by the fire. Despite raking around seedlings to remove fuels, the fire scorched the needles and killed most of the white pine seedlings. Because the soil drainage is impeded at ISW by the clayey soils, wet patches resulted in variable burn coverage on some sites. Visual observations showed that the fire was very effective in reducing first-year buckthorn seedlings that had become established in the hawthorn and buckthorn stand following herbicide treatment in 2003. Garlic mustard (*Alliaria petiolata*) seedlings were also reduced significantly in this area, perhaps because the first year seedlings were susceptible to fire and the tight clay soils. The clayey soil may have kept most of the seed above the mineral soil, and with the leaf litter being the only significant organic layer, much of the seed may have been consumed or killed by the fire.

Prescribed burns have been used four times since 2004 at ISW and a fifth burn is planned for 2012. The burns have been successful in limiting the establishment of woody perennials, fostering oak regeneration, and keeping oak management in the public view. However, patchy wet site conditions that limit fire effectiveness, herbivory by rabbits and considerable amounts of perennial herbaceous competition have caused variable results. The apparently lower rabbit population and partial shade and reduced weed competition seem to be linked to the good results noted in the traditional shelterwood situation.

Monitoring

Permanent sampling plots (PSPs) were installed to monitor forest health conditions at ISW. Overall, 27 PSPs each 0.025-ac in size were installed at ISW. At least one plot was placed in each prime site, and the remaining PSPs were located in representative forest conditions throughout ISW, including the area not salvaged. Data has not been analyzed completely, but preliminary analysis of PSP data showed some reduction in buckthorn seedlings and honeysuckle (*Lonicera*) plants after burning in the hawthorn and buckthorn stand (Table 4). Other preliminary results (Table 3) indicated that between 2003 and 2009 there was no new natural oak regeneration at ISW, and no planted oak seedlings survived outside of the prime sites (Table 3). Planted seedlings did become established in the prime sites following years of planting, prescribed burning, and replanting.

Invasive Plant Management

Populations of common buckthorn (*Rhamnus cathartica*) and garlic mustard were well-established in parts of the hawthorn stand and other forest areas. Glossy buckthorn (*Frangula alnus*) and honeysuckle were scattered throughout the forest in lower numbers. Coltsfoot (*Tussilago farfara*) was present in 2002 or was introduced by horses during salvage operations. It was anticipated that the demise of the oak canopy would provide ideal opportunities for invasive exotic plants to expand their populations. Control programs were developed to limit or reduce the populations of these plants.

Table 4.—Percent ground cover of buckthorn and honeysuckle in burned and unburned permanent sampling plots in 2004 and after prescribed burn in the hawthorn stand in 2005

	Burned plots (3)		Unburned plots (2)	
	2004	2005	2004	2005
	%	%	%	%
Buckthorn	53	44	50	57
Honeysuckle	2	0	4	13

In 2002, the canopy and understory in the hawthorn stand was dominated by buckthorn, and the forest understory in many areas of ISW was infested with common buckthorn. The increasing dominance of buckthorn was causing the decline in the hawthorn stand and interfering with natural succession. All buckthorn over 0.5 inches d.b.h. were treated with a basal bark application of 25 percent tryclopyr in oil, successfully killing most of the buckthorn throughout the park. However, surviving and missed stems required treatment in subsequent years. Continued treatment of smaller stems as they grow will be needed to keep buckthorn populations suppressed.

Garlic mustard heavily infested parts of the forest and the hawthorn stand, and lighter infestations radiated out from the population centers. Site-specific attempts to control garlic mustard have been somewhat effective in limiting infestation growth but were generally not persistent enough to provide effective long-term control. Broadcast spraying of dense patches of garlic mustard with glyphosate and hand-pulling by volunteers and staff was conducted sporadically in prime sites and along infestation fringes to stabilize garlic mustard populations. Prescribed burning dramatically reduced garlic mustard. Efforts to control coltsfoot by spraying in the fall with glyphosate have been successful in limiting its population but insufficient in reducing or eradicating it. Honeysuckle has been treated sporadically along with buckthorn, limiting its population growth.

LESSONS LEARNED

Managing the oak decline crisis in Oakville, Ontario has resulted in six lessons learned that can be shared with other urban forest managers:

1) Reach out to a variety of knowledgeable experts quickly when faced with unfamiliar challenges. Networks of professionals who can help should be fostered through professional groups and by attending technical workshops and conferences. This is critical in an institutional environment of reduced agency budgets and shifting extension and support priorities.
2) Networking with many jurisdictions at different levels helps with problem solving and can help develop programs that may seem beyond the capability of a local or municipal group. In this case, the local network established with area municipalities regarding oak decline facilitated the development of multi-jurisdictional control programs for gypsy moth and communications on strategies to deal with emerald ash borer.
3) It is critical to implement timely, effective, technically-accurate and sensitive communications to interested parties, including staff and administration, politicians, and interest groups. This can lead to general public and institutional support for potentially controversial management activities. The communications efforts for this project helped build municipal and public interest in forest health and acceptance and support of later projects including gypsy moth control programs.
4) Salvage and hazard tree removal activities can be implemented in urban forest situations by a combination of proper management planning and communication of the goals and treatment objectives to interested parties.
5) Prescribed burning has helped reduce the level of woody and perennial competition. The shelterwood approach has also helped to reduce competition, but an appropriate canopy closure must be maintained to both reduce competition and maintain oak vigor.

6) Oak is being successfully established on intensively-managed prime sites, but only with persistent efforts. Although oaks that survived the oak decline episode have revived, partially due to some release treatments, there has been negligible development of natural or planted oak in other parts of the park.

The overall lesson learned is that important natural areas need to be managed to maintain the health of the forest and significant or keystone species. Where significant areas or associations like the oak forest at ISW are successional in nature, a hands-off approach will eventually result in the demise of those associations. Proactively monitoring forest health, maintaining knowledge about the forests and potential health problems, and taking action to keep forests and trees healthy are important. The alternative can be very expensive and unrewarding.

LITERATURE CITED

Blodgett, J.T.; Worrall, J.J. 1992. **Site relationships of Armillaria species in New York.** Plant Disease. 76: 170-174.

Brose, P.H.; Gottschalk, K.W.; Horsley, S.B.; Knopp, P.D.; Kochenderfer, J.N.; McGuinness, B.J.; Miller, G.R.; Ristau, T.E.; Stoleson, S.H.; Stout, S.L. 2008. **Prescribing regeneration treatments for mixed-oak forests in the mid-Atlantic region.** Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p.

Bruin, F. 2004. **Operational prescribed burn plan for Iroquois Shoreline Woods Park.** 29 p. Unpublished report. On file with: Lands & Forests Consulting, Ontario, Canada.

Cote, W.A., III; Allen, D.C. 1980. **Biology of twolined chestnut borer, *Agrilus bilineatus*, in Pennsylvania and New York.** Annals of the Entomological Society of America. 73: 409-413.

Dunbar, D.M.; Stephens, G.R. 1975. **Association of twolined chestnut borer and shoestring fungus with mortality of defoliated oak in Connecticut.** Forest Science. 21: 169-174.

Dunn, J.P.; Kimmerer, T.W.; Nordin, G.L. 1986. **The role of host tree condition in attack of white oaks by the twolined chestnut borer, *Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae).** Oecologia. 70: 596-600.

Dunn, J.P.; Kimmerer, T.W.; Potter, D.A. 1987. **Winter starch reserves of white oak as a predictor of attack by the twolined chestnut borer, *Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae).** Oecologia. 74: 352-355.

Gillespie J.E; Wicklund, R.E.; Miller M.H. 1971. **The soils of Halton county.** Report No. 43 of the Ontario Soil Survey. Ottawa, Ontario: Research Branch, Canadian Department of Agriculture; Toronto, Ontario: Ontario Agricultural College. 79 p.

Gottschalk, K.W. 1993. **Silvicultural guidelines for forest stands threatened by the gypsy moth.** Gen. Tech. Rep. NE-171. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 49 p.

Gottschalk, K.W.; Long, R.P.; Wargo, P.M. 2010. **Oak (*Quercus*) decline around the world: a review.** In: Parrotta, J.A.; Carr, M.A., eds. Forests for the future: sustaining society and the environment; XXIII IUFRO World Congress; 23-28 August 2010; Seoul, Republic of Korea. The International Forestry Review 12(5): 373.

Gottschalk, K.W.; MacFarlane, W.R. 1993. **Photographic guide to crown condition of oaks: use for gypsy moth silvicultural treatments.** Gen. Tech. Rep. NE-168. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Gottschalk, K.W.; Wargo, P.M. 1997. **Oak decline around the world.** In: Proceedings, U.S. Department of Agriculture interagency gypsy moth research forum 1996. 1996 January 16-19; Annapolis, MD. Gen. Tech. Rep. NE-230. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 3-13.

Haack, R.A.; Acciavatti, R.E. 1992. **Twolined chestnut borer.** Forest Insect and Disease Leaflet 168. U.S. Department of Agriculture, Forest Service.

Haack, R.A.; Benjamin, D.M. 1980. **Influence of time of summer felling of infested oak trees on larval development and adult emergence of the twolined chestnut borer, *Agrilus bilineatus*.** University of Wisconsin Forest Research Notes 236. Madison, WI: University of Wisconsin, Department of Forestry. 4 p.

Haack, R.A.; Benjamin, D.M. 1982. **The biology and ecology of the twolined chestnut borer, *Agrilus bilineatus* (Coleoptera: Buprestidae), on oaks, *Quercus* spp., in Wisconsin.** The Canadian Entomologist. 114: 385-396.

Hanna, R. 1984. **Life science areas of natural and scientific interest in site district 7-4: a review and assessment of significant natural areas in site district 7-4.** SR OFER 8404. Ontario, Canada: Ontario Ministry of Natural Resources, Parks and Recreational Areas Section: 69 p. + folded map.

Houston, D.R. 1981. **Stress triggered tree diseases: the diebacks and declines.** NE-INF-41-81. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Manion, P.D. 1991. **Tree disease concepts.** Englewood Cliffs, NJ: Prentice Hall.

Mattson, W.J.; Haack, R.A. 1987. **The role of drought in outbreaks of plant-eating insects.** BioScience. 37: 110-118.

Mueller-Dombois, D. 1986. **Perspectives for an etiology of stand-level dieback.** Annual Review of Ecology and Systematics. 17: 221-243.

Muzika, R.M.; Liebhold, A.M.; Twery, M.J. 2000. **Dynamics of twolined chestnut borer *Agrilus bilineatus* as influenced by defoliation and selection thinning.** Agricultural and Forest Entomology. 2: 283-289.

Perkins, R.G. 1986. **Management plan for Iroquois Shoreline Woods.** Unpublished report. 25 p. On file with: Department of Parks & Open Spaces, P.O. Box 310, Oakville, Ontario L6J 5A6.

Sinclair, W.A.; Lyon, H.H.; Johnson, W.T. 1987. **Diseases of trees and shrubs.** Ithaca, NY: Cornell University Press. 575 p.

Taylor, E.P.; Jones, K.T. 1986. **Soil interpretation and training for forestry 1981-1985 in central and southwestern regions.** Guelph, Ontario: University of Guelph, Ontario Institute of Pedology. 66 p.

Wargo, P.M. 1972. **Defoliation induced chemical changes in sugar maple roots stimulate growth of *Armillaria mellea*.** Phytopathology. 62: 1278 1283.

Wargo, P.M. 1977. ***Armillaria mellea* and *Agrilus bilineatus* and mortality of defoliated oak trees.** Forest Science. 23: 485-492.

Wargo, P.M. 1981. **Defoliation and secondary action organism attack: with emphasis on *Armillaria mellea*.** Journal of Arboriculture. 7(3): 64 69.

Wargo, P.M. 1984. **How stress predisposes trees to an attack by *Armillaria mellea*: a hypothesis.** In: Kile, G.A., ed. Proceedings, 6th International Conference on root and butt rots of forest trees; IUFRO Working Party 52.06.01; 25-31 August 1983; Melbourne, Australia. International Union of Forestry Research Organizations: 115-121.

Wargo, P.M. 1993. **Ecology of *Armillaria gallica* in mixed oak forests.** In: 6th International congress of plant pathology; 1993 July 28-August 6; Montreal, Canada. 124 p.

Wargo, P.M. 1996. **Consequences of environmental stress on oak: predisposition to pathogens.** Annals of Forest Science. 53: 359-368.

Wargo, P.M.; Haack, R.A. 1991. **Understanding the physiology of dieback and decline diseases and its management implications for oak.** In: The oak resource in the upper Midwest: implications for management, proceedings; 1991 June 3-6; Winona, MN. NR-BU-5663-S. St. Paul, MN: University of Minnesota, Extension Service: 147-158.

Worrall, J.J. 1994. **Population structure of *Armillaria* species in several forest types.** Mycologia. 86(3): 401-407.