Radial Growth Rate and Susceptibility of *Picea rubens* Sarg. to *Tetropium fuscum* (Fabr.)

K. O'Leary[1], *J.E. Hurley*[2], *W. Mackay*[2] *and J. Sweeney*[2,3]

[1]Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, NB, Canada
[2]Natural Resources Canada, Canadian Forest Service-Atlantic Forestry Centre, PO Box 4000, Fredericton, NB, Canada, E3B 5P7
[3]Presenter

Abstract

The brown spruce longhorn beetle, *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae) recently became established in Halifax, Nova Scotia, Canada, where it is infesting and killing apparently healthy red spruce, *Picea rubens* Sarg. In its native range, *T. fuscum* is a secondary pest of Norway spruce, *Picea abies* L., breeding in recently felled trees or trees weakened by root rots, lightning or other factors. To test the relationship between tree vigor and susceptibility to infestation by *T. fuscum,* we felled 18 pairs of infested and uninfested red spruce in the winter of 2001 in Point Pleasant Park, Halifax, and measured radial growth rates as a correlate of vigor. Mean 5-year radial increment peaked in 1956-1960 and declined steadily thereafter for all red spruce. However, radial growth was significantly lower in attacked trees than in unattacked trees in seven of nine 5-year periods between 1956 and 2000. Our data indicate that red spruce with reduced growth rates and low vigor were more susceptible to infestation by *T. fuscum* than faster growing, more vigorous trees.

In March of 2000, it was determined that the brown spruce longhorn beetle, *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae), had established in Point Pleasant Park, Halifax, Nova Scotia (Smith and Hurley 2000), and was infesting and killing apparently healthy red spruce, *Picea rubens* Sarg. The park is 75 ha in size, most of which is forested, with red spruce being the most common conifer species. The year of introduction is unknown, but recent examination of *Tetropium* specimens from the Nova Scotia Museum of Natural History revealed that 17 specimens of *T. fuscum* (misidentified as the native *T. cinnamopterum* Kirby) had been collected in a naturalist's bark beetle survey of Point Pleasant Park in 1990. Route of entry is uncertain but *T. fuscum* adults likely emerged from softwood packing material from shipping containers in the Halifax port facility located directly adjacent to Point Pleasant Park. *Tetropium fuscum* has been found in solid wood packing material at the ports of Montreal and Vancouver (Smith and Humble 2000, Humble and Allen 2001) and it is possible that the Halifax population is the result of more than one introduction. The chronology of the beetle's discovery in Halifax is described in Sweeney et al. (2001) and at the following website: http://www.atl.cfs.nrcan.gc.ca/BSLB/chronology-e.htm#july1998. A large scale survey and eradication program began in 2000 under the lead of the Canadian Food Inspection Agency.

Tetropium fuscum is native to coniferous forests in northern and central Europe, and western Siberia. Its main host is Norway spruce, *Picea abies* (L.) Karst., but it has also been found on *P. sitchensis* (Bong.) (Francke-Grosman 1954) Carr., *P. pungens* Engelm. (Juutinen 1953), *Pinus sylvestris* L. (Reineck 1919),–*Abies alba* L. and *Larix* spp. (Schaufuss 1916). In Halifax, *T. fuscum* is infesting red spruce, white spruce (*P. glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), and Norway spruce. Larvae feed in the phloem and cambium, producing an extensive network of irregular galleries that eventually girdle the stem. It is univoltine, overwintering as a larva in most of its range, but may require 2 years to complete its life cycle in cooler climates or when the nutritional quality of the host is poor (Schimitschek 1929). Trees are often reinfested annually until desiccation and death (Juutinen 1955).

Tree Health and Susceptibility to *T. fuscum* Infestation

In its native range, the brown spruce longhorn beetle, *T. fuscum* is a secondary pest, breeding in recently felled trees or live trees weakened or stressed by biotic or abiotic factors such as root rots (Juutinen 1955) or lightning (Kula and Z´becki 1997). In Halifax, however, investigations in 1999 and 2000 in Point Pleasant Park found little evidence for a direct association between root disease and *T. fuscum* attack. Although both *Armillaria ostoyae* (Romagnesi) Herink and *Inonotus tomentosus* (Fr.:Fr.) S. Teng. were present at many scattered locations in the park, examination of the stumps of *T. fuscum*-attacked and non-attacked trees for wood stain and decay at ground line did not reveal any consistent pattern (G. Warren and Ken Harrison, pers. comm.). However, it is possible that the many root disease centers within the park created a reservoir of stressed, susceptible hosts that allowed the *T. fuscum* population to build to levels at which both stressed and non-stressed hosts became infested (Gary Warren, pers. comm.). A wood stain fungus, *Ophiostoma tetropii* Mathiesen, has been found associated with *T. fuscum* infestation in Halifax (Jacobs et al. 2003); it appears to be only weakly pathogenic but its biology is poorly known and currently under investigation (Doug Strongman and Ken Harrison, pers. comm.).

Juutinen (1955)[1] rated the health or "desiccation" status of 39 Norway spruce trees recently infested with *T. fuscum* in northern Finland as follows:

Health rating	Description	Distribution of *T. fuscum*-attacked trees (%)
I	Completely healthy trees.	0
II	Onset of desiccation. Desiccation factors are sparse and do not appreciably affect the condition of the tree as a whole. Crown completely without discoloration and the tree— except for possible traces of activity by woodpeckers and slight resin flow— by and large resembles a healthy tree externally.	4.1
III	Desiccation further advanced. Desiccation factors are more prominent, but are not yet able to cause desiccation of the tree. Symptoms of desiccation are already discernible externally, the crown is thinned and already partly dried up.	74.3
IV	Desiccation factors already present to such an extent that rapid desiccation of the tree appears certain. Crown only partly green.	21.6
V	Desiccation just completed. Crown completely dry, but still some fresh parts here and there in the bark.	0
VI	Completely withered trees. Crown and bark dried up throughout.	0

Juutinen (1955) found that most *T. fuscum*-infested Norway spruce had "thinned…and partly dried up" crowns (category III); only 4% of infested trees appeared green and healthy (II) with "slight resin flow." It is worth noting that Juutinen considered most of these trees (in categories II and III) as sub-lethally weakened, i.e., "not yet able to cause desiccation of the tree," prior to *T. fuscum* infestation.

[1]English translation available from NRCAN-CFS, Atlantic Forestry Centre

Table 1.—Crown condition and infestation by *Tetropium fuscum* of red spruce, *Picea rubens* in Point Pleasant Park, Halifax, NS, 3 May 2000 (Hurley and MacKay 2000)

Crown class	Crown description	No. red spruce (% of total)	No. with *T. fuscum* signs (% within class)
1	no defoliation	4 (3.5)	1 (25.0)
2	< 25% defol. current foliage only	0 (0)	0 (0)
3	< 25% defol. all foliage	73 (63.5)	35 (47.9)
4	25-50% defoliation	5 (4.3)	4 (80.0)
5	51-75% defoliation	4 (3.5)	0 (0)
6	76-90% defoliation	0 (0)	0 (0)
7	> 90% defoliation	0 (0)	0 (0)
8	recent dead	0 (0)	0 (0)
9	old dead	29 (25.2)	24 (82.7)

He states: "Especially after outbreaks of caterpillars, the spruce longhorn beetles attacked trees which could have undoubtedly recovered and they therefore caused considerable economic damage." (Juutinen 1955). So even in its native range, it appears that *T. fuscum* does not infest only dying trees but also attacks trees undergoing temporary periods of stress or low vigor. Once infested by *T. fuscum,* however, eventual girdling of the stem increases the tree's susceptibility to other pests, and results in death within 1 to 5 years of infestation (Juutinen 1955).

In contrast, the majority of *T. fuscum*-infested red spruce in Halifax appear green and healthy with copious resin flow down the stem. Hurley and MacKay (2000) assessed the crown condition and the presence or absence of signs of *T. fuscum* infestation on 115 red spruce (selected by prism point samples) in Point Pleasant Park on 3 May 2000. Crown condition was visually rated using standardized Canadian Forest Service forest health survey methods (D'Eon et al. 1994) on a scale from 1 to 9, where 1 = no defoliation and 9 = dead for more than a year. Most of the trees surveyed were classified as either green and healthy (67%) or dead for more than a year (25%). Less than 10% of live trees exhibited more than 25% defoliation (Table 1). Signs of *T. fuscum* infestation, i.e., resin flow on the stem and exit holes, were present on almost 50% of the trees with healthy crowns (classes 1–3) and on more than 80% of dead trees. It is difficult to directly compare the two methods of tree health classification, but we suggest that most of the infested trees in our park survey would correspond to Juutinen's health rating of II, i.e., "Crown completely without discoloration … By and large resembles a healthy tree externally." For whatever reason, red spruce infested by *T. fuscum* in Halifax appeared healthier than *T. fuscum*-infested Norway spruce in Finland.

A green and full crown is not always indicative of tree health or vigor, e.g., completely girdled trees may remain green for several months until the roots begin to weaken and die due to lack of photosynthates. Radial growth rate is related to vigor in red spruce; average 10-year radial increments of 2.3 and 0.75 cm are rated as superior and inferior vigor, respectively (Blum 1990). To investigate the relationship between tree vigor and susceptibility to infestation by *T. fuscum,* we compared the radial growth rates of infested and uninfested red spruce in Point Pleasant Park, NS. If *T. fuscum* was infesting red spruce regardless of health status or vigor, then the radial growth rate preceding infestation should be similar in infested and uninfested trees.

Methods

Twenty pairs of spruce trees were selected and tagged in Point Pleasant Park, Halifax, NS, in the fall of 2000. Each pair consisted of a tree with external signs of *T. fuscum* infestation, e.g., resinosis and exit holes, and a tree without such signs, hereafter referred to as attacked and unattacked, respectively.

Within pairs, trees were selected to have the same (± 2 cm) diameter at breast height (dbh) and were growing within 1–15 m of each other. For each tree, the crown condition and canopy position were rated and the north-facing side of the bole was marked. Trees were felled in January 2001 and length of live crown, total height, and live crown ratio were measured. After felling, we learned that one tree in each of two pairs was white spruce instead of red spruce. Therefore, only 18 pairs of red spruce were included in this analysis. A line was marked along the north (or nearest to it) face of the length of the bole and 4–5 cm thick disks were sampled from the center of every 4th discernible internode, and every 0.5 m thereafter. Wood disks were stored at -10ºC until radial increments were measured.

Two measures of radial increment (on both radii along the north–south line marked on the bole) were recorded for each year of growth per disk using a stereomicroscope and a Holman Digi-mic (Holman Electronic Controls Ltd., Fredericton, NB). Ring widths were subsequently checked and re-measured using a high resolution scanner and the "WinDENDRO ™ 2001a" software package (Regent Instruments Inc., www.regentinstruments.com), which also allowed us to save an electronic image of each tree disk. Although increments were measured along the north–south radii, the entire disk surface was examined under the stereomicroscope to check for discontinuous or incomplete rings. Rings that discontinued along a north or south radius were given an radial increment of zero.

For the purpose of this analysis, we assumed there were no completely missing rings and dated the rings using the outermost ring (assumed as year 2000) as a reference. However, missing rings are not uncommon, especially near the base of older, slow-growing trees (Glock 1937). If some of the trees did have missing rings, then the actual year of growth will have been assigned incorrectly, and we will have overestimated some of the 5-year periodic increments for those trees. For example, what we estimated as a 5-year increment may really have represented 6 or 7 years of growth. However, the possibility of missing rings does not seriously affect the main (null) hypothesis tested in this paper, i.e., that attacked and unattacked trees have similar growth rates or vigor. If attacked and unattacked trees are of similar age and vigor, then the probability of having missing rings will be the same. If attacked trees are truly older and less vigorous than unattacked trees, the probability of missing rings (and of overestimating growth and underestimating age) is greater in the attacked trees, resulting in a more conservative test of the our null hypothesis. We plan to use cross-referencing to accurately date rings and conduct a complete stem analysis of these trees in a subsequent paper.

To check the accuracy of our designation of attacked and unattacked trees, we collected one or two 35-cm bolts from each of 11 attacked trees and seven unattacked trees. Bolts were stored at -10ºC and subsequently incubated at 21°C in a containment facility and the emergence of adult *T. fuscum* recorded daily.

In the present analysis, we calculated the mean radial increment per 5-year period, e.g., 1996-2000, from the breast height disk of each tree. Live crown ratio, age (estimated from the bottom-most disk), crown condition, dbh, and height, were compared between attacked and unattacked trees, using paired t-tests. Periodic radial increment (PRI) for each of 19 5-year periods, from 2000 back to 1906, were compared between attacked and unattacked trees using ANOVA, with tree-pair locations as blocks. Residuals were checked for normality using the Shapiro-Wilk test (Zar 1984, SAS 1999-2001). The periodic annual increment of red spruce normally peaks at about age 45 (Meyer 1929). To account for a negative correlation between tree age and radial growth rate, we included age as a covariate and compared the PRI of attacked and unattacked trees for each 5-year period between 1960 and 2000, when most trees were more than 45 years old.

Results and Discussion

Adult *T. fuscum* emerged from bolts from seven of 11 attacked trees; bolts from the four attacked trees that did not produce adult *T. fuscum* had been stored at -10°C for more than 6 months and it is possible that prolonged exposure to cold caused some mortality. No *T. fuscum* emerged from the bolts sampled from the seven unattacked trees. Because *T. fuscum* may reinfest the same host tree year after year, it is possible that some of the attacked trees had been infested before 1999. However, as trees

Table 2.—Mean (± S.E.) size, age, and crown condition of 18 pair of red spruce trees in Point Pleasant Park, Halifax, NS, with signs of *Tetropium fuscum* infestation (attacked) and without such signs (unattacked)

Variable	Attacked		Unattacked		*P* value (paired t-test)
dbh (cm)	27.5	(1.4)	27.3	(1.4)	0.49
height (m)	17.8	(0.5)	17.2	(0.6)	0.31
age (at breast height)	88.2	(4.3)	79.1	(6.3)	0.06
live crown ratio	0.48	(0.03)	0.51	(0.03)	0.59
crown class[1]	3.8	(0.4)	2.9	(0.1)	0.04

[1]crown class assigned using the system described in Table 1.

usually die within 1 to 5 years after first becoming infested (Juutinen 1955), it is unlikely any of the sample trees were infested before 1996.

By design, trees within pairs did not differ in dbh, but attacked trees were on average 9 years older, and had slightly worse crown condition than unattacked trees (Table 2). The overall mean 10-year radial increment at breast height for the period from 1960-2000 was 1.5 cm, which for red spruce corresponds to a vigor class between acceptable (1.2 cm) and good (1.65 cm) (Blum 1990). The mean age at peak PRI did not differ between attacked (43 years) and unattacked trees (40 years) and was similar to that reported for second-growth red spruce (Meyer 1929). Mean PRI peaked in 1956-1960 and declined steadily afterwards for both attacked and unattacked red spruce (Fig. 1). A similar decline in growth rate was observed for red spruce across the Adirondack and northern Appalachian Mountains (Johnson and Siccama 1983; Hornbeck and Smith 1985). Cook and Zedacker (1992) concluded that neither stand dynamics nor climate change, alone or in combination, could be accepted as the cause of the regional decline in red spruce. Johnson et al. (1992) suggest that air pollution has played a significant role in the decline of red spruce in eastern North America, by increasing the sensitivity to winter injury, aluminum mobilization and cation loss. The soil in Point Pleasant Park is a podzol derived from Precambrian slate with pH ranging from 3.5 to 3.9 (Jotcham et al 1991), which is lower than optimal for red spruce (4.0–5.5, Blum 1990). Whatever the mechanism(s) may be, a regional decline in red spruce growth rate and vigor increases the probability of infestation by *T. fuscum* and other species known to exploit weakened or stressed hosts.

Mean PRI was significantly lower in attacked trees than in unattacked trees in seven of nine 5-year periods between 1956 and 2000 (Fig. 1a). This trend persisted when tree age was held constant using covariance analysis, except that differences were significant in only four of eight 5-year periods (Fig. 1b). The mean 5-year PRIs of unattacked trees ranged from 0.6 to 1.07 cm in the last 40 years, which corresponds to good (0.82 cm) or acceptable (0.58 cm) vigor classes for second-growth red spruce (Blum 1990). In contrast, the 5-year PRIs of attacked trees fell below those associated with acceptable vigor for the period of 1991–1995, and below those associated with inferior vigor (0.38 cm) from 1996–2000 (Fig. 1). Thus it appears that *T. fuscum* infestation occurred in red spruce that, on average, were of inferior vigor.

Reasons for the difference in growth rates between attacked and unattacked trees are unknown. Differences due to site, e.g., soil, exposure, etc., were minimized by the close proximity and size of trees within pairs. Feeding damage by *T. fuscum* likely accounts for some of the difference from 1996–2000, but infestation before 1996 is unlikely. Trees attacked by *T. fuscum* sometime within the last 1–5 years, were on average 9 years older and had been growing more slowly than unattacked trees for the last four decades. Age accounted for some but not all of the difference in growth rates. Other factors possibly responsible for differences in growth rate are genotype and root disease at a stage where infection was not discernible on cut stumps.

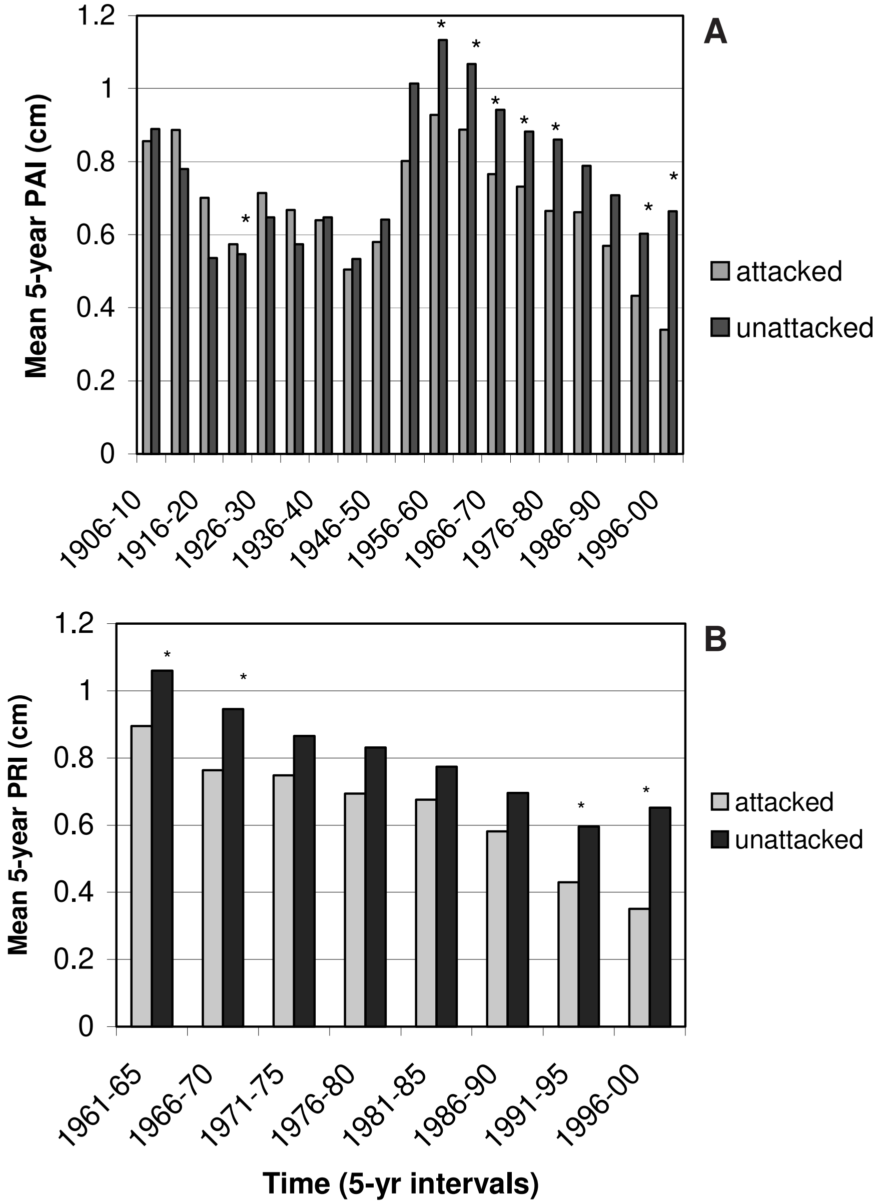

Figure 1.—Mean periodic radial increment per 5-year period (PAI) at breast height of 18 pair of red spruce, *Picea rubens* Sarg., growing in Point Pleasant Park, Halifax, NS, that either had signs of attack by *Tetropium fuscum* in 2000, or did not. A. Raw means for 19 intervals between 1906 and 2000. B. Least square means from covariance analysis where tree age was held constant. Asterisks denote significant differences in PAI between attacked and unattacked trees (ANOVA and COANOVA, P=0.05).

In conclusion, our data indicate that red spruce with reduced growth rates and low vigor were more susceptible to infestation by *T. fuscum* than faster growing, more vigorous trees. However, our data do not suggest these trees were weakened to the point that death was imminent before attack by *T. fuscum.* Red spruce is a long-lived, shade-tolerant species that can survive more than 100 years of suppressed growth and still respond to release (Blum 1990). Indeed, the PRI of unattacked trees increased slightly in the period from 1996–2000, possibly in response to openings in the canopy due to *T. fuscum*-related tree mortality (O'Leary 2002). *Tetropium fuscum* remains a threat to red spruce and other *Picea* spp. in North America, because it can infest and kill trees that may be undergoing periods of stress and suppressed growth due to drought, defoliator outbreaks, or a complex of factors.

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