Seasonal occurrence and spatial distribution of resinosis, a symptom of *Sirex noctilio* (Hymenoptera: Siricidae) injury, on boles of *Pinus sylvestris* (Pinaceae)

Kathleen Ryan,[1] Peter de Groot,[✠] Sandy M. Smith, Jean J. Turgeon

Abstract—An established population of the exotic woodwasp *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) was first detected in North America in 2004. In order to develop survey guidelines for the detection of this major pest of *Pinus* Linnaeus species in the Southern Hemisphere, we examined 231 *Pinus sylvestris* biweekly to establish the timing and spatial distribution of resinosis symptoms of attack, and the timing of subsequent tree mortality. Fresh resin appeared between mid-July and late August, and on 70% of infested trees was observed on the mid bole. The occurrence of tree death varied between sites, from 2 weeks after the first detection of resinosis in one site to several months in seven other sites. Findings from our study provide key information to improve detection of *S. noctilio* and predict its impact on forest stands in its new range in northeastern North America.

Résumé—On a observé pour la première fois en 2004 une population bien établie du sirex exotique *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) en Amérique du Nord. Afin de rédiger des notes d'orientation pour la détection de cet important ravageur des espèces de *Pinus* Linnaeus dans l'Hémisphère austral, nous avons examiné à toutes les deux semaines 231 *P. sylvestris* afin d'établir le calendrier et la répartition spatiale des symptômes de résinose lors de l'attaque et le moment de la mortalité subséquente des arbres. De la résine fraîche apparaît entre la mi-juillet et la fin d'août et se retrouve, chez 70% des arbres infestés, à la mi-hauteur du tronc. Le moment de la mort des arbres varie d'un site à l'autre, de deux semaines après la première détection de résinose dans un site à plusieurs mois dans sept autres sites. Les résultats de notre étude fournissent des informations essentielles pour améliorer la détection de *S. noctilio* et pour prédire son impact sur les peuplements forestiers dans sa nouvelle aire de répartition dans le nord-est de l'Amérique du Nord.

Sirex noctilio Fabricius (Hymenoptera: Siricidae) is an introduced woodwasp recently detected in *Pinus* Linnaeus (Pinaceae) trees in eastern North America (Hoebeke *et al*. 2005; de Groot *et al*. 2006). Its presence in North America is of great concern because, unlike our native species of woodwasps, it attacks and kills living pines, albeit more typically those that are already physiologically stressed (Neumann and Minko 1981; Dodds *et al*. 2010). Another reason for this concern is that *S. noctilio* has caused considerable economic impact in countries of the Southern Hemisphere, where it has been accidentally introduced on exotic pines (Bedding and Iede 2005).

Ground surveys are an effective method for detecting trees infested by *S. noctilio* in the early stages of establishment (Haugen *et al*. 1990). In the Southern Hemisphere, visible symptoms include resinosis, the tree's defensive response to the wasp's oviposition activity, and needle chlorosis and/or wilting; signs include round exit holes 3–7 mm in diameter (Rawlings 1948;

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K. Ryan,[1] S.M. Smith, Faculty of Forestry, University of Toronto, 33 Wilcocks Street, Toronto, Ontario, M5S 3B3 Canada
P. de Groot,[✠] J.J. Turgeon, Natural Resources Canada – Canadian Forest Service, Great Lakes Forestry Centre, 1219 Queen Street East Sault Ste Marie, Ontario, P6A 2E5 Canada

[1]Corresponding author (e-mail: kathleen.ryan@utoronto.ca).
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[✠]Deceased.

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Neumann *et al*. 1987; Haugen *et al*. 1990). Resinosis is an accepted symptom of woodwasp oviposition activity (Ryan 2011), and *S. noctilio* is believed to be the only woodwasp capable of producing this symptom because native woodwasps colonise dead trees that are not capable of producing this defensive response (Dodds *et al*. 2010). Knowledge of the location and timing of the appearance of resinosis on the tree stem would greatly enhance the effectiveness of detection using ground surveys. Female *S. noctilio* generally emerge between early July and mid-September in eastern Canada (Ryan *et al*. 2012a). This period of emergence is established from felled trees held in rearing containers, and therefore does not necessarily reflect when symptoms of *S. noctilio* appear on *Pinus* boles. To locate infested trees in the 1st year of *S. noctilio* attack, it would be useful to determine whether ground surveys should focus on living *Pinus* trees or include recently dead ones as well. After *S. noctilio* attack, the timing of tree mortality in the Southern Hemisphere is variable, ranging from 2 weeks to 8 months (Madden 1988); the timing of tree mortality after *S. noctilio* attack is unknown in North America.

The goals of our study were to identify spatial and temporal distribution of resin symptoms of attack to optimise sampling, specifically: (i) to study the seasonal incidence of fresh resinosis to optimise the timing of ground surveys by determining when the greatest proportion of fresh symptoms appeared; (ii) to identify the region of the bole where fresh resin symptoms were found; and (iii) to establish the relationship between the occurrence of resinosis on a tree and the timing of tree mortality to determine whether newly dead trees could represent current-year *S. noctilio* attack. Our study focused on *Pinus sylvestris* Linnaeus because it is the most commonly attacked and killed *Pinus* species in the wasp's current range in North America (see Dodds *et al*. 2010).

Eight sites were selected in southwestern and central Ontario, Canada according to the following criteria: pure *P. sylvestris* overstorey composition; closed canopy (as evidenced by the presence of overlapping crowns within the main canopy); presence of *S. noctilio* adults in attractant-baited traps; presence of trees with weathered resinosis from the previous year (2006); and relatively unobstructed sightlines, necessary for examination of the bole from the ground with binoculars or spotting scope. Site characteristics (basal density, mean tree height, mean diameter at breast height (dbh), and stand mortality) were measured using methods described in Ryan (2011) and are summarised in Table 1. We established a transect (10 m × 100 m) in each of the eight sites, and within each transect we identified trees favourable to *S. noctilio*. A tree was considered favourable when it was suppressed or intermediate in dominance, had a deteriorating crown (⩽25% of expected foliage) or had stem injury (Dodds *et al*. 2010). A total of 231 trees considered favourable to attack by *S. noctilio* were labelled serially.

The bole of each labelled tree was inspected at 2-week intervals during a time period that corresponded approximately to the expected flight period of *S. noctilio* females (Ryan *et al*. 2012a), to determine whether resin beads were present. Each inspection consisted of scanning the entire stem of each tree in three overlapping, vertically oriented swaths from three equally spaced points around the tree using either binoculars or a spotting scope mounted on a tripod, depending on tree height and the vantage point available for the scan. Each stem was visually partitioned along its length into three equal sections (upper, middle, and lower bole), and for each section, the presence or absence of fresh resinosis was recorded for each one-third section of the bole. The initial scanning inspection took place the 1st week of July 2007. At that time, we also determined whether resin beads from the previous year (yellowed or with a weathered, irregular surface) were present anywhere on the bole. On each biweekly inspection, tree foliage was also examined for evidence of colour changes or wilting, and those with no remaining green foliage were deemed dead. Biweekly inspections ended in mid-September. The final assessment of 2007 was performed between mid-September and late October 2007 after the hardwood trees and shrubs had dropped their leaves. This was done to ensure that all resin symptoms had been recorded because, despite our best efforts to select sites with good visibility of the bole, the Cavan and Bolton sites had understorey shrubs that could have limited detection of the symptoms. In late April and

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Table 1. Location and attributes of eight *Pinus sylvestris* stands southern Ontario, Canada.

Stand location	Latitude (N) Longitude (W)	Stand origin	Mean age (years)	Basal area (m^2/ha) Mean (SE)	dbh (cm) Mean (SE)	Height (m) Mean (SE)	Initial stand mortality – all causes (%)	Number of trees monitored biweekly for resinosis	Number of (%) monitored trees with fresh *Sirex noctilio* resinosis in 2007
Sauble Beach	44°39′13.64″ 81°15′22.11″	Planted	57	15.0 (7.5)	18.9 (0.8)	14.0 (0.6)	50	27	10 (37)
Elmwood	44°14′13.27″ 80°58′7.024″	Planted	38	20.8 (5.4)	18.4 (0.5)	13.1 (0.4)	34	15	15 (100)
Orangeville	43°54′45.47″ 80°4′29.15″	Planted	21	13.6 (2.7)	13.4 (0.5)	7.6 (0.2)	24	33	23 (70)
Tottenham	44°0′19.86″ 9°50′42.48″	Natural	20	14.4 (0.9)	11.5 (0.8)	8.6 (0.4)	30	37	31 (84)
Bolton	ca. 43°52′55.35″ 79°42′0.90″	Planted	34	29.2 (6.7)	24.0 (0.6)	17.7 (0.4)	35	34	23 (68)
Cavan	44°11′8.56″ 78°31′45.07″	Planted	42	32.7 (4.1)	16.3 (0.7)	13.6 (0.5)	24	22	16 (73)
Sandbanks Provincial Park A	ca. 43°54′18.68″ 77°16′14.08″	Planted	52	10.0 (1.8)	10.3 (0.7)	6.7 (0.3)	24	26	24 (92)
Sandbanks Provincial Park B	43°54′13.70″ 77°16′6.63″	Planted	59	36.0 (2.5)	15.0 (0.8)	10.0 (0.4)	62	37	32 (86)

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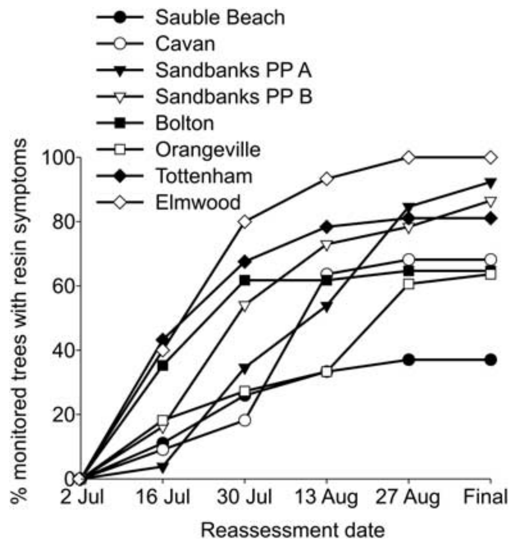
early May 2008, all 231 trees were re-examined and those with no remaining green foliage were deemed dead. Trees that had died and had evidence of *S. noctilio*-induced resin symptoms, we assumed to have been killed by *S. noctilio* unless there was evidence of another cause of death.

Of the 231 *S. noctilio*-favourable trees followed biweekly, 75% (174) showed new symptoms of *S. noctilio* oviposition activity in 2007 (Table 1). Eighty-eight of the total 231 trees monitored (38%), and 65 of the 174 (37%) trees with fresh *S. noctilio* symptoms from 2007, also had evidence of *S. noctilio* resin symptoms from preceding years. Whether our finding that 74% (65 of 88) of the trees having old *S. noctilio* symptoms had new symptoms in 2007 was indicative of residual physiological stress to the tree from that previous *S. noctilio* activity (Madden 1971; Madden 1977), or simply that the tree was declining for other reasons, and therefore becoming more favourable to the wasp, is unknown.

Fresh resinosis began to appear in mid-July, and the number of trees detected with resinosis increased until late August (Fig. 1). In Elmwood, Orangeville and Bolton, there was an early accumulation of trees with resinosis and by the end of July ⩾80% of the trees with resinosis had already been detected. In all sites but Sandbanks Provincial Park A & B and Tottenham, there were few new trees with resinosis detected after mid-August. The three sites that continued to have new trees with fresh symptoms after mid-August had many declining trees and a high proportion with resinosis, and therefore they may have had higher wasp populations (Table 1). The temporal appearance of resinosis in 2007 was consistent with the temporal emergence pattern of *S. noctilio* females observed from logs collected in southern Ontario and held in rearing containers that same year; >65% of females had emerged from these logs by late July and nearly 85% by mid-August (Ryan *et al*. 2012a).

Resinosis was found throughout the bole on 33 of the 174 (19%) trees with fresh resinosis in 2007, and 56 (32%) trees had fresh symptoms in two of the three sections (18 [10%] lower and middle, 33 [19%] middle and upper, 5 [3%] lower and upper sections). The remaining trees had symptoms in only one section: 13 (7%) in the lower one-third only, 41 (24%) in the middle only and 31 (18%) in the upper third only.

Fig. 1. Cumulative proportion of monitored *Pinus sylvestris* boles with resinosis between July and September 2007 in each of eight stands located in southern Ontario, Canada.



The observed distribution of resinosis along the bole is consistent with the distribution of *S. noctilio* individuals emerging from each section of the bole (Ryan *et al*. 2012b), and with the distribution of symptoms reported by Haugen and Hoebeke (2005).

Of the 174 trees with evidence of *S. noctilio* injury in 2007, 31 (18%) of them from five sites subsequently died over the following 10 months (Fig. 2). At all sites except Sandbanks Provincial Park B, tree mortality was low and mostly occurred during the winter following attack (Fig. 2). In Sandbanks Provincial Park B, tree mortality was highest and became apparent within 2 weeks of initial detection of resinosis: most trees in this site died within 6 weeks of the detection of resinosis (Fig. 2). This site was a densely stocked stand of older trees (Table 1) planted on sandy substrate with evidence of a variety of insect pests and pathogens, including exit holes consistent with Siricidae. Thus, trees in this site were subject to a number of predisposing factors and *S. noctilio* attack may have merely been the final factor contributing to tree mortality. This range in the timing of mortality is similar to that described in Australia by Madden (1988), who also attributes this variability to the

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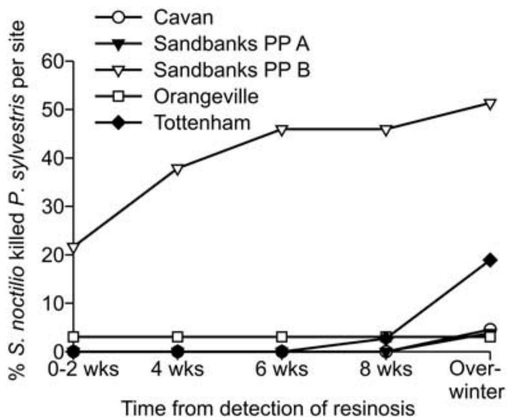
Fig. 2. Cumulative proportion of monitored *Pinus sylvestris* that were classified as *Sirex noctilio* killed in 2007 as a function of the number of weeks after the first detection of resinosis in each of five sites located in southern Ontario, Canada.



effect of location and site characteristics on tree resistance. These findings demonstrate that newly dead as well as live *P. sylvestris* should be examined for recent resinosis when surveying for current-year *S. noctilio* in stressed sites.

The foliage of trees that died turned red; however, we never observed needle wilting on any *P. sylvestris* during our observation period. This is in contrast to observations from other regions where the woodwasp has been introduced (Neumann *et al*. 1987) and from initial reports that wilting could be expected as a symptom of *S. noctilio* damage in North America (Haugen and Hoebeke 2005). Whether needle wilting is a symptom of *S. noctilio* attack on other species of pines remains to be established.

Our findings will improve detection of *S. noctilio*-infested trees in northeastern North America as well as other regions.

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