Bionomics of the pine needle scale (Hemiptera: Diaspididae), an emerging pest in Christmas tree (Pinaceae) plantations in southern Québec, Canada

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Abstract—The pine needle scale, *Chionaspis pinifoliae* (Fitch) (Hemiptera: Diaspididae), has the status of an emerging pest in Christmas tree (Pinaceae) plantations in Québec, Canada. The scale is not known to cause any significant damage yet and is not generally monitored by growers. However, it can be an obstacle for exportation to Christmas tree markets where scale insects are strictly regulated. In this study, we describe its life cycle in Christmas tree plantations in southern Québec. We confirm the presence of both parthenogenetic and sexual forms of the scale on Fraser fir *Abies fraseri* (Pursh) Poiret (Pinaceae) grown as Christmas trees, and of parasitoid and Coccinellidae (Coleoptera) specialists that could contribute to its control.

Résumé—La cochenille des aiguilles du pin *Chionaspis pinifoliae* (Fitch) (Hemiptera : Diaspididae) ne cause présentement pas de dommage significatif aux arbres de Noël (Pinaceae) au Québec, Canada et porte le statut de ravageur émergent. Non dépistée par la majorité des producteurs, elle pose toutefois un problème pour certaines entreprises à l'exportation vers des marchés extérieurs où ce type de ravageur est strictement réglementé. Nos observations récentes ont permis de décrire son cycle vital en plantation d'arbres de Noël au sud du Québec. Nous avons pu confirmer la présence des formes parthénogénétiques et sexuées de la cochenille sur le sapin Fraser *Abies fraseri* (Pursh) Poiret (Pinaceae) cultivé comme arbre de Noël, et de parasitoïdes et Coccinellidae (Coleoptera) qui pourraient favoriser son contrôle.

The pine needle scale, *Chionaspis pinifoliae* (Fitch) (Hemiptera: Diaspididae), is a native insect species of North America commonly reported as a pest on several ornamental conifer species, some of which are cultivated as Christmas trees (Pinaceae) (Tooker and Hanks 2000; Fondren and McCullough 2005; Miller and Davidson 2005). Identification of the pine needle scale is complex, mostly due to its close proximity with another species of the same genus, *Chionaspis heterophyllae* Cooley (Hemiptera: Diaspididae). Both species often share the same hosts and overlap in geographical distribution (Philpott *et al.* 2009). Several cryptic species may exist within these two morphologically recognised species, thus complicating proper identification (Gwiazdowski *et al.* 2011; Vea *et al.* 2012).

The life cycle of the pine needle scale is geographically variable. In Canada, it is believed to be univoltine, whereas in the United States of America, a second generation has been observed (Cumming 1953; Stimmann 1969; Nielsen and Johnson 1973). Both sexual and parthenogenetic forms of the scale have been documented (Brown 1959, 1965; Stimmann 1969; Luck and Dahlsten 1974).

Among its known natural enemies are several specialist micro-Coccinellidae (Coleoptera: Coccinellidae: Sticholotidinae: Microweisini) (Luck and Dahlsten 1974; Cooper and Cranshaw 1999). A complex of relatively specialised Hymenoptera parasitoids, most of which belong to the Chalcidoidea, is also associated with the pine needle scale (Luck and Dahlsten 1974;

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Burden and Hart 1993; Cooper and Cranshaw 1999; Gwiazdowski and Normark 2014).

The scale was reported by Martel and Sharma (1968) to develop on indigenous red pine trees *Pinus resinosa* Aiton (Pinaceae) in Québec, but mentions on balsam fir, *Abies balsamea* (Linnaeus) Miller (Pinaceae), and Fraser fir, *Abies fraseri* (Pursh) Poiret (Pinaceae), grown as Christmas trees are relatively recent. Although *C. pinifoliae* is not known to cause any significant damage, it can be an obstacle for exportation to certain Christmas tree markets where scale insects are strictly regulated. Thus, the objective of this study was to acquire new knowledge about this emerging pest in Christmas tree plantations of Québec. This involved properly identifying *C. pinifoliae*, studying its phenology by regular monitoring throughout the summer, and searching for potential natural enemies. Based on the current sporadic reports of scale insects in Christmas trees in Québec, we hypothesised that *C. pinifoliae* infestations in Christmas tree plantation landscapes could originate from tree nurseries rather than from wild conifers.

Sampling was conducted from May to October 2014 in a commercial Fraser fir plantation located in Saint-Évariste-de-Forsyth, Québec, Canada (45.950°N, 70.923°W). An experimental plot of 20 rows of 60 fir trees free of insecticide treatment was established, where systematic screening of trees for presence of scale insects was carried out. Each week, 10 infested shoots were randomly collected from different trees within the plot and examined in the laboratory. Each scale was identified according to development stage and dissected to determine the presence of parasitism or signs of predation. Any indigenous conifers species located on the borders of the plantation were similarly screened for the presence of scales. Prior to retaining our experimental site, sampling was performed in 10 Christmas tree plantations and their surroundings, located within a 50 km radius in the Estrie region. For each site, 50 trees were randomly screened in a plot of 15 rows of 45 trees. Scales were found in only two of those sites: Saint-Évariste-de-Forsyth and Weedon (see below).

Scale identification was based on morphological characteristics according to Vea *et al.* (2012). Validation was performed by experts from the Canadian National Collection of Insects, Arachnids, and Nematodes, Agriculture and Agri-Food Canada (Ottawa, Ontario, Canada) for both the scales and natural enemies and voucher specimens were deposited in this institution. Molecular typing was also carried out when possible, using the 28S rDNA gene (see Morse and Normark (2006) and Gwiazdowski *et al.* (2011) for methods), as a reliable alternative to the cytochrome oxidase 1 mitochondrial gene in scale insects (Campbell *et al.* 2014).

Identification based on morphological characteristics confirmed that the scale specimens collected on all cultivated and indigenous conifer hosts were indeed the pine needle scale *C. pinifoliae.* This diagnosis was confirmed by molecular typing (GenBank accession number MH032862), showing up to 99% similarity with available *C. pinifoliae* sequences (Gwiazdowski *et al.* 2011).

Pine needle scales were observed on about 21% of Fraser firs in the plantation ($n = 996$) and also regularly on naturally growing balsam fir; white spruce, *Picea glauca* (Moench) Voss (Pinaceae); and black spruce, *Picea mariana* (Miller) Britton (Pinaceae) surrounding the plantation, but not on eastern white-cedar, *Thuja occidentalis* Linnaeus (Cupressaceae). Pine trees were absent in the study site, but they are known as hosts of the scale in Québec (Martel and Sharma 1968).

The life cycle observed at Saint-Évariste-de-Forsyth in 2014 on cultivated Fraser fir was that of a single-generation parthenogenetic form (Fig. 1). The hatching of overwintering eggs (Fig. 2A) occurred around mid-June, after which the mobile larvae stage 1 or crawlers (Fig. 2B) settled on fir

Fig. 1. Phenology of pine needle scale *Chionaspis pinifoliae*, as observed on Fraser fir, at Saint-Évariste-de-Forsyth, Québec, Canada, in 2014. L1, larval stage 1; L2, larval stage 2.

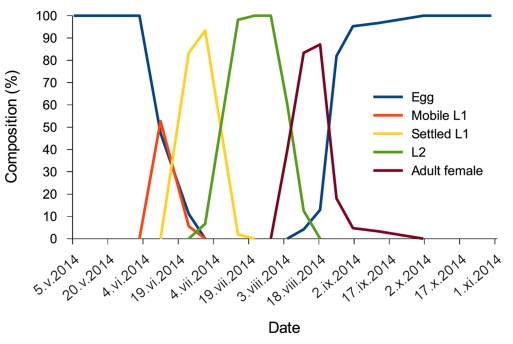


Fig. 2. Development stages of pine needle scale *Chionaspis pinifoliae*. **A**, Eggs; **B**, mobile larval stage 1; **C**, settled larval stage 1; **D**, larval stage 2; **E**, adult female; **F**, adult male (sexual form only).

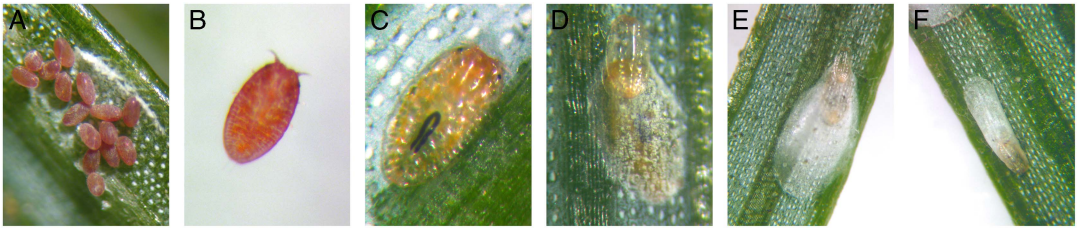
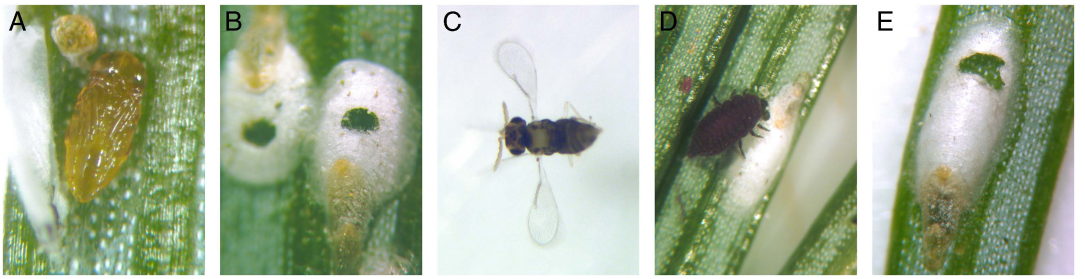


Fig. 3. Natural enemies of pine needle scale *Chionaspis pinifoliae*. **A**, *Encarsia* pupa; **B**, emergence holes of a parasitoid wasp; **C**, *Encarsia* wasp; **D**, micro-coccinellid larva; **E**, predation traces caused by a micro-coccinellid.



needles (Fig. 2C). The transition to the larvae stage 2 (Fig. 2D) began in early July. At the beginning of August, the first female adults appeared (Fig. 2E). Oogenesis, followed by egg laying, began in mid-August and continued until late September, with an average of 27 eggs per female (SE $\pm$ 0.69; $n = 237$) on Fraser fir. A sexual form of *C. pinifoliae* with males (Fig. 2F; GenBank accession number MH032863) with a comparable phenology with that of the parthenogenetic form (Cumming 1953) was observed at Weedon but not at the Saint-Évariste-de-Forsyth site, confirming the occurrence of both reproductive forms in Québec. In Weedon, scales were observed on Fraser fir and on wild conifers surrounding the plantation, but very low occurrence (only a few trees were infested) did not allow for the implementation of a similar sampling setup as in our main site.

Dispersion of mobile larval stage 1 was apparently limited to adjacent needles and shoots, with nymphs of the new generation sometimes developing directly below scales of adults of the previous generation (8.62% of cases; $n = 2632$), thus creating stacks of up to three scales. Observed mortality of immature stages was very high, with an overall estimate of 62.21% of settled immatures dying before reaching the adult stage (settled larval stage 1 and larval stage 2; $n = 3075$).

A parasitoid belonging to the genus *Encarsia* Förster (Hymenoptera: Aphelinidae) (most likely *Encarsia bella* (Gahan); GenBank accession number MH032865) was observed at low incidence, with 4.16% of adult scales ($n = 2859$) being parasitised (Fig. 3A–C). *Encarsia bella* has been reported several times on *C. pinifoliae* (see Cooper and Cranshaw 1999) and its close relative *C. heterophyllae* (Fondren and McCullough 2005). Predation by micro-coccinellids was observed on 1.12% of adult scales ($n = 2859$) (Fig. 3D–E). Larvae were sometimes present among samples, though no adults were observed for species identification. Molecular typing of immature larvae allowed us to identify them to the tribe Microweiseini (GenBank accession number

MH032864). Martel and Sharma (1970) reported the presence of *Coccidophilus marginata* (LeConte) (previously *Microweisea marginata*) as a predator of *C. pinifoliae* in Québec.

The presence of well-established specialist natural enemies of *C. pinifoliae* in Christmas tree plantations does not support the hypothesis of sporadic and recent introductions from local nurseries when a plantation is first established. Previous reports of *C. pinifoliae* associated with multiple natural enemies in a nearby locality (Sherbrooke) (Martel and Sharma 1968, 1970, 1975) also indicate that it has long been established in southern Québec on pine and possibly other conifer trees. Its presence on several wild conifers in landscapes surrounding Christmas tree growing areas could explain its sporadic presence on Christmas trees, since passive wind dispersal of the mobile larval stage 1 at distances of up to 3 km has been reported (Brown 1958). Phoretic dispersal of the crawlers by other insects is also possible (Magsig-Castillo *et al*. 2010). Increased reports in Christmas tree plantations of southern Québec probably result from improved monitoring techniques for this pest, but genetic susceptibility of fir trees (species and varieties) or local adaptation of the scale could also play a role in its spreading (Nielsen and Johnson 1973; Eliason and McCullough 1997; Glynn and Herms 2004). It should also be noted that our findings are limited in spatial scale and time, and could differ from other sites in Québec, especially for natural enemies.

Specialist natural enemies such as parasitoids and predators could theoretically help control the pine needle scale in Christmas tree plantations. However, based on our study and in accordance with previous works (Cumming 1953; Nielsen and Johnson 1973; Martel and Sharma 1968, 1975), they apparently inflict only a tiny fraction of the high mortality observed for immature stages. Other biotic or abiotic factors, such as water availability (Eliason and McCullough 1997), could play a role in pre-adult scale mortality. Moreover, in the case of parasitoids, control potential could be limited due to the low dispersal rate of Aphelinidae wasps, as opposed to Coccinellidae predators (Tooker and Hanks 2000). A strategy to increase natural enemy abundance and impact requires modifying current farming practices, including weed control, to promote the establishment of native plants as additional food sources and shelters (Tooker and Hanks 2000).

The phenology of *C. pinifoliae* on pine trees, as described 50 years ago in Québec (Martel and Sharma 1968), is similar to the one observed here on Christmas trees. Hatching of overwintering eggs in late spring and egg laying by new adult females in late summer are consistent with relatively high heat requirements for this species, as we reported in a parallel study (Doherty *et al*. 2018). High heat requirements to complete adult development limit the possibility of a second generation in southern Québec latitudes in the near future, in the context of climate change. Further work is, however, needed to address *C. pinifoliae* natural enemies and how their conservation could benefit Christmas tree growers in their efforts to control this pest while limiting the use of chemical insecticides.

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