The fate of an intentional introduction of *Formica lugubris* to North America from Europe

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Abstract

Red wood ants (*Formica s.str.*) are not prevalent in the forests of North America, but commonly occur in conifer and mixed conifer forests in northern Europe and Asia. In 1971, a European red wood ant species, *Formica lugubris*, was intentionally established in a 35-year-old predominantly mixed conifer plantation approximately 30 km north of QC, Canada. The purpose of its introduction was to evaluate the potential of this species as a biological control agent against conifer-defoliating Lepidoptera species. This red wood ant introduction was monitored periodically for about 5 years after establishment, but its long-term fate has not been reported. We visited this field site in 2005 and found that this species was well established, and we could locate some of the nests that resulted from the original release. We mapped and measured over 100 nests around the site of original release, which ranged from 5 cm in height to over 1 m. We estimated the population of introduced ants to have grown to over 8 million in the last 34 years. Significant clustering of nests suggests that these nests may be one supercolony. *F. lugubris* has become a dominant understory arthropod in this mixed forest, and is likely to have ecological impacts, including effects at the community and ecosystem level.

Introduction

Red wood ants, *Formica s.str.*, are common components of conifer and mixed conifer forests in Northern Europe and Asia. They construct large aboveground organic nests and are valued as predators of pestiferous insects (Hölldobler and Wilson 1990). In North America, species of red wood ants are placed in the *Formica rufa* group. The occurrence of red wood ants in forested ecosystems of North America seems less frequent than in Northern Europe and Asia, although some notable reports of their occurrence do exist such as that of a supercolony of *F. obscuripes* in a Douglas-fir and grand fir forest in Oregon (McIver et al. 1997). The reported distribution of red wood ant species in North America is often disjunct, suggesting that they are poorly described (Hedlund 2002; Jurgensen et al. 2005).

Some ant species, including some red wood ant species, have been shown to prey on forest defoliators, such as the spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae) in North America (Youngs and Campbell 1984 and references therein). However, it is not clear why red wood ants do not dominate North American forest communities as Eurasian species do in Europe and Asia. The paucity of red wood ants in North America may be explained by several factors, including environmental conditions, disturbances through human activity,

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fire and large predators as well as competition for resources (Jurgensen et al. 2005).

Over the past 40 years, a number of attempts have been made to introduce red wood ants as generalist predators to reduce the negative impacts of defoliating forest insects. This includes the movement of native North American species as well as species from Europe (e.g. Morris 1963; Bradley 1972; Finnegan 1977). Determining the long-term fate of these introductions is an important first step in evaluating how they influence ecosystem function, and how they interact with other native organisms.

In the 1970s, *F. lugubris* was selected for introduction from Italy into QC, Canada, based on its aggressiveness, the similarity of climate in its native range and that at the release site, and its ability to establish on a wide range of forest sites (Finnegan 1975). While it is unlikely that the transcontinental movement of a generalist predator into forest ecosystems would meet with approval today, the justification in the 1970s was summarized by Finnegan (1975): ''Owing to the absence in Canada of suitable, aggressive, predacious species of red wood ants (Finnegan 1971, 1974), and the conviction that an efficient, facultative predator of this type would be beneficial to the forest ecosystem, it was decided to introduce *F. lugubris* from northern Italy to eastern Canada.''

Formica lugubris was introduced from northern Italy into a 35-year-old plantation of *Pinus resinosa*, *P. strobus*, *Picea glauca, Abies balsamea* and *Betula papyrifera* in eastern Canada in 1971. By the end of 1972, the ants had formed five large (60–80+ cm tall) nests, which increased in size during the 1973 growing season (Finnegan 1975). Evaluations of predation by these ants were performed in 1976 using information collected from the three largest nests (McNeil et al. 1978). The fate of these nests since that time has been unclear, although reports indicate that they persisted into the mid-1980s (Jurgensen et al. 2005). The work reported here involved revisiting the release site at Valcartier, QC, Canada, and evaluating the status of this exotic ant species introduction into North America. Our specific objectives were to: (a) determine whether these ant colonies had survived, (b) if so, what was the ant population at this site in terms of nests and of individuals, (c) compare the density of nests at this site with other reports of nest density for this species in Europe, and (d) to determine whether the distribution of nests was random or clustered in order to gain insight into whether the nests were part of a supercolony.

Methods

Nests were located throughout a forested area of approximately 3.8 ha near Valcartier. Coordinates for each nest were recorded on a GPS unit, and the height and radius of each nest was measured in four cardinal directions to calculate mean height (to allow for slope) and mean radius. In the case of small nests where the nest peak was located over the centre of an oval when viewed from above, and the nest was located on flat ground, we measured the minimum and maximum radii of the nest. Nests were listed as either active or abandoned, and other characteristics, including the presence of old labels or tags, were recorded. Some nests had previously been protected using wood and chicken wire or hardware cloth and wood. Based on the condition and the presence of chicken wire and wood associated with nests that were established in the 1970s, we assumed that these nests had persisted since that time. The condition of the hardware cloth enclosures suggested that they were more recent, and likely date back to the mid-1980s.

Analyses

We calculated the nest volumes using the formula for a conical structure, and produced a size distribution of the nests by defining groups of nests using Jenks' method for optimal data classification (Jenks 1977) in ArcMap. Because only height information was available for the original nests, we calculated the mean ratio of radius to height for the nests that exist today, and used this to estimate nest volumes for nests during the years following the introduction.

In order to determine whether the nests were clustered or randomly distributed, we calculated a Z-score in ArcMap that tested the significance of a nearest neighbour index. This index was based on the average distance from each nest to its nearest neighbouring nest, and was expressed as the ratio of the observed distance divided by the expected distance. The expected distance is the average distance between neighbours in a hypothetical random distribution.

Results

After 34 years, the introduction of *F. lugubris* at Valcartier has resulted in the production of a total of 114 nests, of which 21 were considered abandoned. The range of heights of active nests was 2–105 cm (Mean = 64.6 cm, SE = 7.2 cm) and the range of the

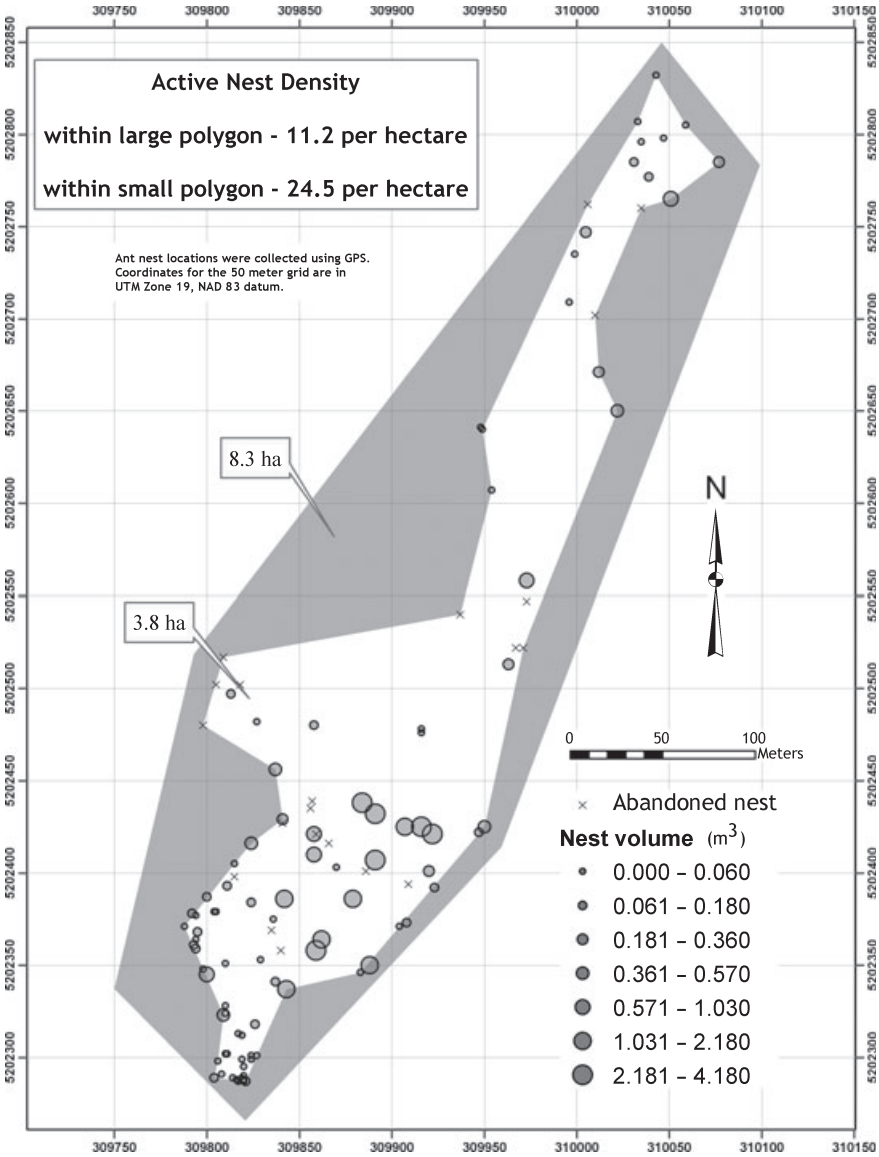

Fig. 1 Distribution of *Formica lugubris* nests at Valcartier, QC, Canada, in 2005 by volume class. Maximum nest density is based on the forested area in blue. Locally (such as in the southern portion of the stand) nest density is higher. The stand is bordered by roads in the eastern edge and by roads and open areas on the western side.

maximum radius was 5–192 cm (Mean = 33.7 cm, SE = 5.3 cm). The largest nest had a volume of 4.18 m^3. Mean nest volume was 0.404 m^3 (SE = 0.09 m^3).

All nests that were mapped were on the edge or in the 3.8-ha forested area, and the average nest density was 24.5 nests/ha (fig. 1). In cluster analysis, the clustering of nests was significant ($Z = -20.23$, $P < 0.01$). Other nests were observed at the base of open-grown *Larix* spp., and these were not included in cluster analysis as the open-grown distribution of trees would have influenced the spacing of the nests.

The size distribution of nests was dominated by small nests, although a number of larger nests were present (fig. 2). Fifty-seven percent of nests were less than 0.1 m^3 (maximum height = 45 cm) while 14.0% of nests were over 1 m^3 (maximum height = 1.05 m). Relationships between nest height and nest diameter were positive and significant ($r = 0.876$, 91 d.f., $P < 0.001$).

A number of large nests at the Valcartier site have persisted since the 1970s, as witnessed by the presence of broken enclosures associated with the nest. These were erected in the 1970s to protect the nests

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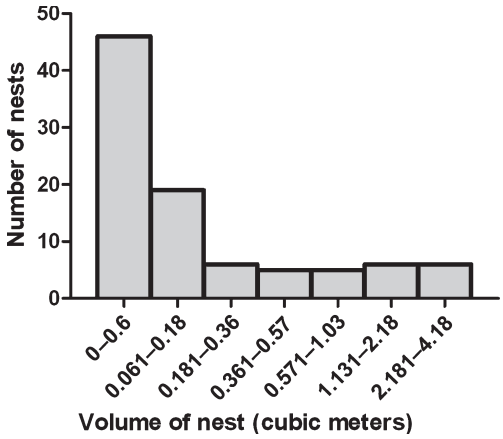

Fig. 2 Size distribution of nests of *Formica lugubris* at Valcartier, QC, Canada. Groups of nests were defined using Jenks' method for optimal data classification in ArcMap.

from avian predators. A total of nine nests had evidence of having been protected in the 1970s, and of these two were abandoned. The volume of the surviving nests ranged from 0.79–4.18 m^3. The remains of one of these nests was evident during our survey along with a large wooden viewing platform was constructed in the 1970s to allow visitors to the site to observe some of the nests. Of the 17 nests with evidence of having been protected in the 1980s, five had been abandoned. The surviving nests ranged in size from 0.13–3.26 m^3.

Finnegan (1975) estimated that ~3 million ants were established at Valcartier by the end of the 1973 growing season, which were contained in five nests, two of which were over 125 cm tall. The initial release was estimated to be up to 1.3 million ants (excluding the queens). While the sizes of other three nests were not reported, they were likely to be close to 100 cm tall, because they were 60–80 cm tall in 1972 and had reportedly increased height by 1973. Using our data relating nest height to diameter, we estimated the volume of the nests in 1973. On average, the nests we surveyed had radii 2.13 times their height (95% confidence interval = 0.22 m). For a nest that was 1.25 m tall, we estimated its radius to be 2.66 m (95% confidence interval = 0.27 m), and for a nest that was 1 m tall, we estimated its radius to be 2.13 m (95% confidence interval = 0.22 m). This equates to estimated nest volumes for 1.25-m-tall nests of 4.35 m^3 (95% confidence interval = 0.44 m^3) and for 1-m-tall nests of 2.23 m^3 (95% confidence interval = 0.23 m^3). Hence, we estimated the nest volume in 1973 to be approximately 15.4 m^3. This equates to approximately 195,000 ants per cubic metre of nest. Our estimated total nest volume for current nests was 41.6 m^3, and this equates to a population of over 8.1 million ants. While these calculations make many assumptions, including ant density being consistent in different size nests, it does provide an indication that along with the nearly 20-fold increase in the number of individual nests, there has been an increase in the total population of ants at this site.

Discussion

The number of nests of *F. lugubris* and the number of individual ants have clearly increased at Valcartier over the past 34 years. The persistence of smaller nests that had been protected with hardware cloth indicates that even smaller nests can persist for many years and do not necessarily attain the size of the larger nests. We do not know how many larger nests may have completely overgrown hardware cloth protection and therefore were not recorded as having persisted since the 1980s. Unprotected nests are of unknown age, and Breen (1979) suggested that some smaller nests may only exist for a single season of activity. In his study, 87% of nests persisted for 3 years. This is certainly possible for the smaller nests at Valcartier.

The nest densities of *F. lugubris* at the Valcartier site were higher than those reported for the same species from Ireland and England. In the mixed conifer plantations in Ireland, Breen (1979) reported a maximum density of 2.2 nests/ha. In the mixed conifer plantations in North Yorkshire, England, Sudd et al. (1977) found a mean density of 1.61 nests/ha and a maximum in a forest compartment of 5.6 nests/ha. For these nests, the maximum height was 60 cm and the maximum diameter was 110 cm. At Valcartier the nest density was 24.5 nests/ha, which was above the upper 95% confidence limit of 3.89 nests/ha calculated from the nest densities of occupied areas in the North Yorkshire study. Maximum nest height (1.05 m) and diameter (3.9 m) were higher at Valcartier than that reported in North Yorkshire.

The ant nests in the study of *F. lugubris* in Ireland were not significantly clustered and, therefore, were considered to be monocalic with individual colonies residing in single nests (Breen 1979). Our cluster analysis of data from the Valcartier site suggests that the nests were polycalic with the colony residing in many nests. During data collection, it was noted that nests were interconnected by trails of ants, providing support to the hypothesis that these nests are

polycalic. If nests were part of a supercolony, the chance of this ant species to spread to other areas may be reduced. Further work is needed to determine whether the range of this insect has expanded much beyond the original release site that we visited.

The limits to the range expansion of *F. lugubris* are unclear, and need to be more fully evaluated. It is not known to what extent it has already spread beyond the site we surveyed. As a dominant component of the forest ecosystem at Valcartier, further study of this introduction is needed to provide insight into how an introduced insect such as this can change a forest ecosystem.

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