The Douglas-fir Beetle in Minnesota: Locating an Indigenous Exotic in Northern Forests

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ABSTRACT. Forest insects that are not native to a region can pose serious ecological threats to forest communities and serious economic threats to the forest products industry. The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, and the eastern larch beetle, *Dendroctonus simplex* LeConte, are believed to have evolved from a common ancestor, whose populations likely became geographically isolated during the Wisconsin period of glaciation. Both of these bark beetles are capable of killing living host trees via mass attack. The Douglas-fir beetle was recently detected in north-central Minnesota and concerns have been raised about the possibility of it becoming established in tree species native to Minnesota. We used two species of trap logs (Douglas-fir and tamarack) in combination with two pheromone baits: 1) frontalin (~9mg/day), seudenol, and ethanol and 2) frontalin (~3 mg/day), methylcyclohexenol, and ethanol, to attempt to determine whether there is a breeding population of the Douglas-fir beetle in Minnesota. In Minnesota, the eastern larch beetle successfully colonized cut logs of Douglas-fir, but we did not capture the Douglas-fir beetle. In a complimentary study in Montana, we found that the Douglas-fir beetle produced eggs in cut logs of tamarack when the logs were placed in an area infested by the Douglas-fir beetle.

KEYWORDS. Douglas-fir beetle, eastern larch beetle, forest entomology, forest health, invasive species, Minnesota, Montana, silviculture, tamarack

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INTRODUCTION

Forest insects that are not native to a region can pose serious ecological threats to forest communities and serious economic threats to the forest products industry. In May 2001, the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, was collected in Lindgren funnel traps baited with pheromones targeting the eastern larch beetle, *Dendroctonus simplex* LeConte, as part of a research project in north-central Minnesota (Dodds et al. 2004). The source of this indigenous exotic was determined to be a wood processing facility west of Grand Rapids, Minnesota.

The Douglas-fir beetle (DFB) is a bark beetle found throughout western North America wherever its primary host, Douglas-fir, *Pseudotsuga menziesii* (Mirb.) (Franco), grows. DFB can successfully colonize dead, but not living western larch, *Larix occidentalis* Nutt., and brood production in western larch equals that of its primary host. DFB has also been reported to attack felled western hemlock, *Tsuga heterophylla* (Raf.) Sarg., western redcedar, *Thuja plicata* Donn, and Brewer spruce, *Picea breweriana* S. Wats. (Furniss 1976). Of all these hosts, only Douglas-fir is attacked successfully when alive. A laboratory study demonstrated that DFB is capable of colonizing and reproducing in dead tamarack, *Larix laricina* (Du Roi) K. Koch (Furniss 1976). There is, however, no overlap in the range of Douglas-fir and tamarack (Figure 1). Consequently, DFB does not encounter tamarack in its natural range.

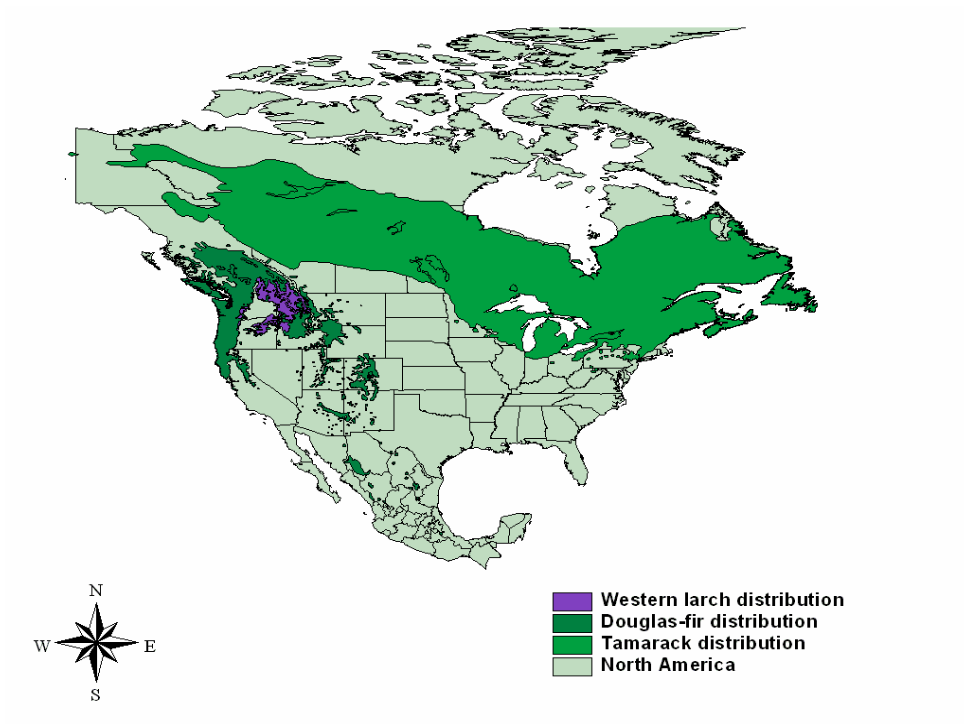

Figure 1. Geographic distribution of host tree species for the Douglas-fir beetle and eastern larch beetle.

The eastern larch beetle (ELB) is a bark beetle found throughout the natural range of tamarack, which is its primary host (Seybold et al., 2002). Until recently, ELB was not considered to be a serious pest as it was observed only attacking weakened or severely damaged eastern larch. ELB has also been reported to infest red spruce in Maine (Baker 1972), black spruce in Minnesota (Seybold and Albers, unpublished), and in a laboratory study has successfully colonized and reproduced in dead Douglas-fir (Furniss 1976). There is no overlap in the range of Douglas-fir and tamarack and ELB does not encounter Douglas-fir within its natural range (Figure 1).

The two bark beetles have similar morphology and are believed to have evolved from a common ancestor when populations became geographically isolated during the Wisconsin period of glaciation (Wood 1963). A controlled experiment was conducted to test the ability of the DFB and ELB to hybridize and successfully complete their respective life cycles in cut logs of their own and the reciprocal hosts (Furniss 1976). Results suggested that DFB was a minimal risk to tamarack should it be introduced to the east and that ELB was a minimal risk to Douglas-fir should it be introduced to the west.

The purpose of this study was to determine if ELB would successfully colonize Douglas-fir and if DFB would successfully colonize tamarack in field settings. We defined successful colonization to be brood production followed by emergence of new adults. Since pheromones were used to attract ELB and DFB to the general vicinity of the test logs, a secondary objective was to test the efficacy of two pheromone blends for their ability to attract ELB and DFB.

METHODS AND MATERIALS

Study sites

Four sites were selected to sample for DFB and ELB within 8.5 miles of Grand Rapids, Minnesota, USA (Table 1). Sites were chosen based on either their proximity to the probable DFB introduction site or areas where adults had been captured in pheromone-baited traps in previous years. A single site (N45 54.881 W113 49.506) was chosen in the Bitteroot National Forest in western Montana (Table 2). This site was located within a current (2005) infestation of DFB.

Table 1. Location of study sites in Minnesota.

Field Site	Installation Number	Latitude & Longitude	Elevation
Arbo	9	N47 20.951 W93 34.367	1347 ft
	10	N47 21.060 W93 34.384	1349 ft
	11	N47 21.173 W93 34.387	1350 ft
	12	N47 21.195 W93 34.240	1350 ft
	13	N47 21.236 W93 34.093	1356 ft
	14	N47 21.127 W93 34.084	1354 ft
	15	N47 21.086 W93 34.228	1347 ft
	16	N47 21.018 W93 34.003	1342 ft
	17	N47 20.991 W93 34.157	1341 ft
NCROC	S 3	N47 14.883 W93 29.804	1440 ft
	S 4	N47 14.894 W93 29.959	1302 ft
	S 5	N47 14.901 W93 30.124	1309 ft
	S 6	N47 14.994 W93 29.984	1295 ft
	S 7	N47 15.020 W93 30.138	1301 ft
	S 8	N47 15.122 W93 29.948	1424 ft
	S 9	N47 15.140 W93 30.100	1423 ft
	S 1	N47 14.991 W93 29.795	1068 ft
	S 2	N47 15.106 W93 29.804	1429 ft
Sugar Lake	B1	N47 12.341 W93 39.893	1365 ft
	B2	N47 12.333 W93 40.054	1359 ft
	B3	N47 12.328 W93 40.210	1345 ft
	B4	N47 12.233 W93 40.012	1368 ft
	B5	N47 12.238 W93 39.856	1332 ft
	B6	N47 12.236 W93 40.160	1357 ft
	B7	N47 12.141 W93 39.780	1353 ft
	B8	N47 12.134 W93 39.936	1364 ft
	B9	N47 12.122 W93 40.097	1357 ft
Larex	L 1	N47 15.969 W93 39.016	1375 ft
	L 2	N47 16.037 W93 38.939	1328 ft
	L 3	N47 16.061 W93 38.824	1316 ft
	L 4	N47 15.997 W93 38.758	1309 ft
	L 5	N47 16.016 W93 38.644	1296 ft
	L 6	N47 15.968 W93 38.873	1306 ft
	L 7	N47 15.886 W93 38.863	1291 ft
	L 8	N47 15.868 W93 38.579	1297 ft
	L 9	N47 15.860 W93 38.714	1296 ft

Table 2. Location of field sites in Montana.

Installation Number	Latitude & Longitude	Elevation
1	N45 54.881 W113 49.506	5817 ft
2	N45 54.844 W113 49.502	5801 ft
3	N45 54.850 W113 49.541	5821 ft
4	N45 54.813 W113 49.527	5836 ft
5	N45 54.776 W113 49.485	5817 ft
6	N45 54.750 W113 49.474	5729 ft
7	N45 54.740 W113 49.508	5746 ft
8	N45 54.738 W113 49.564	5763 ft
9	N45 54.711 W113 49.537	5749 ft
10	N45 54.692 W113 49.520	5759 ft
11	N45 54.689 W113 49.498	5748 ft
12	N45 54.671 W113 49.486	5738 ft
13	N45 54.660 W113 49.461	5776 ft
14	N45 54.642 W113 49.436	5763 ft
15	N45 54.585 W113 49.443	5804 ft
16	N45 54.564 W113 49.469	5826 ft
17	N45 54.544 W113 49.505	5823 ft
18	N45 54.517 W113 49.493	5800 ft
19	N45 54.455 W113 49.430	5782 ft
20	N45 54.407 W113 49.419	5792 ft

Experimental design

Minnesota installations

At each of four sites in Minnesota, nine pairs of 1 m Douglas-fir and tamarack logs were placed in a systematic grid pattern, with at least 150 m between pairs (Table 1). Each site represented a 400 x 400 m block that consisted of three parallel 400 m transects with sampling points at the beginning (0 m), middle (200 m), and end (400 m) of the transect. Douglas-fir and tamarack logs were placed 2 m apart in a horizontal position and fixed in place with wooden stakes and nylon wire ties. DFB pheromone attractants were tied to a wooden stake located equidistant between each log in the pair. Two pheromone combinations were used: 1) racemic frontalin (~8 mg/day), racemic seudenol (3 mg/day), and ethanol (Ross & Daterman 1995), and 2) racemic frontalin (~3 mg/day), methylcyclohexenol (1.5 mg/day) and ethanol (20-40 mg/day) (Phero-Tech, Inc., Delta, B.C.). Baits were placed in the field on 30 April and 1 May, 2004. Logs were on the field sites from 29 April, 2004 through 22 June, 2004. Douglas-fir logs were obtained from Shell Canyon, ~30 mi. east of Greybull, Bighorn National Forest, Big Horn Co., Wyoming and harvested in early-April 2004. Tamarack logs were obtained from the University of Minnesota Experimental Forest in Grand Rapids and harvested on 28 April, 2004

Montana installations

At one site in Montana, twenty pairs of 1 m Douglas-fir and tamarack logs were placed along an access road in an area that was heavily infested with DFB. Each log pair was 50 m apart. Habitat type was *Pseudotusga menziesii/Linneae borealis* (Pfister et al. 1977). Site indices and yields in this habitat type are considered moderate to high (Pfister et al. 1977). This design differs from the Minnesota installation because in Minnesota we allocated the treatments more widely across the landscape because we were attempting to detect individual DFB from low density populations. DFB was ubiquitous in the Montana site.

The Douglas-fir logs in Montana were cut from live trees on 7 April, 2005 from state forest lands adjacent to the Bitterroot National Forest (45^o 53.269 N, 113^0 54.602 W). The tamarack logs were cut from live trees in Warba, Minnesota (47^o 5.339 N, 93^o 18.494 W) during the last two weeks of March 2005 and stored frozen outdoors. The 1 m logs of each species were placed and baited identically as they were in Minnesota. Logs and baits were placed in the field on 8 April, 2005 and collected on 15 June, 2005.

Data collection and analyses

<u>Minnesota installations</u>

After removal from the field, logs were brought back to Grand Rapids where each log was cut in half. One half of each log was randomly chosen for destructive sampling. All bark was carefully removed from each log and the number of attacks, adult galleries, and successful colonizations were counted for each log. The other half of the log was placed in a sealed screen bag that served as a rearing chamber and stored over the winter. Emerged insects were collected and counted in mid-June 2005.

Separate analyses of variance (ANOVA) of the form:

Y = site + species + bait + site*species + site*bait + species*bait + site*species*bait + Є, **(1)**

where,

Y = number of attacks, adult galleries, successful bouts of colonization, or number of insects reared,

site = location (Arbo, NCROC, Sugar Lake, Larex)

species = Douglas-fir or tamarack,

bait = R (Ross & Daterman 1995) or P (Phero-Tech, Inc., Delta, B.C.),

*** designates interaction terms**, and

Є = error NID ~ $(0,\sigma^2)$,

were used to test the hypothesis of equal number of attacks, adult galleries, successful bouts of colonization (as determined by the presence of larval mines), and number of insects reared between species, baits, among sites, log species, baits, and all possible combinations of interactions between the independent variables.

Montana installations
After removal from the field, logs were brought back to the Bitterroot National Forest Sula Ranger District Headquarters for destructive sampling and rearing. One-half of each log (top or bottom) was randomly selected based on a coin toss for destructive sampling. The other half of the log was placed in a sealed screen bag that served as a rearing chamber and stored over the winter at the USDA Forest Service Laboratory in Davis, California.

The lateral surface area of each half was calculated based on the assumption of a conic section shape using the formula:

$$\textbf{Surface area} = \pi \bullet (\textbf{top radius} + \textbf{bottom radius}) \bullet \textbf{section length} \qquad \textbf{(2)}$$

Visual inspection of the logs indicated that DFB had colonized the Douglas-fir at a higher rate than tamarack. Because of this a slightly different sampling protocol was used for each tree species. A sub-sample of each Douglas-fir log was taken, whereas the entire tamarack bolt was sampled as described below.

Douglas-fir
Because of the extremely high colonization density of the Douglas-fir logs, the logs were sub-sampled for assessment of colonization and brood densities. Three locations were randomly selected on each half-meter log section and a 36 cm^2 section of outer and inner bark was carefully removed down to the xylem surface. The sample was gently removed and all adult beetles and egg galleries were tallied. Additional bark was removed to trace and measure the entire length (in cm) of each egg gallery. The total number of eggs in each gallery were counted. For each one-half meter bolt, colonization density (entrance holes cm^{-2}), gallery density (number of galleries cm^{-2}), and egg density per gallery (eggs cm) were calculated.

Tamarack
Because of the relatively lower colonization density of the tamarack logs, the half-meter logs were sampled entirely for colonization and brood densities. All bark was carefully removed from each log and all DFB adults, galleries, and eggs were counted or measured. For each one-half meter log, beetle density (beetles cm^{-2}), gallery density (no. galleries cm^{-2}), and egg density per gallery (eggs cm) were calculated. For each one-half meter bolt, colonization density (entrance holes cm^{-2}), gallery density (number of galleries cm^{-2}), and egg density per gallery (eggs cm) were calculated.

Separate ANOVAs of the form:

$$\mathbf{Y = species + bait + species*bait + \epsilon,} \qquad \textbf{(3)}$$

where,
Y = number of attacks, adult galleries, successful colonizations, or number of insects reared,
species = Douglas-fir or tamarack,
bait = R (Ross & Daterman 1995) or P (Phero-Tech, Inc., Delta, B.C.),
species*bait = the interaction between species and bait, and

ϵ = error NID ~ $(0,\sigma^2)$,

were used to test the hypothesis of equal number of beetle density (beetles cm^{-2}), gallery density (no. galleries cm^{-2}), and egg density per gallery (eggs cm) among log species and bait.

RESULTS

Minnesota installations

We did not detect the presence of DFB in Minnesota. No significant interactions were detected among any of the independent variables used in ANOVAs (eq. 1). Therefore, interaction terms were omitted from the results presented (Table 3). Results were not affected by location. The number of attacks, galleries, success of attack as determined by the presence of egg galleries, and the number of reared insects were all affected by the host log species (Tables 3 and 4). Pheromone bait combination did not affect the number of insects reared but did affect the number of attacks, galleries, and the number of successful attacks as determined by the presence of larval mines (Tables 3 and 4). In general, the Phero-Tech bait performed better than the Ross & Daterman (1995) bait in attracting the ELB (Table 4).

Table 3. *P*-values for ANOVAs testing the effects of installation location, host species, and pheromone bait on the number of reared eastern larch beetle, and the number of detected attacks, galleries and successful attacks as determined by the presence of larval mines for the eastern larch beetle on the Minnesota sites.

Effect	Reared insects	Attacks	Galleries	Success of attack
Location	0.054	0.373	0.154	0.688
Species	0.001	0.001	0.001	0.001
Bait	0.140	0.011	0.002	0.013

Table 4. Mean (standard errors in parentheses) values of reared eastern larch beetle, and number of detected attacks, galleries, and successful attacks as determined by egg galleries for the eastern larch beetle by host log species and pheromone bait (R = Ross & Daterman (1995) bait and PT = Phero-Tech bait) combination in Minnesota.

	Douglas-fir logs		Tamarack logs	
Measured attribute	R (n = 17)	PT (n = 19)	R (n = 17)	PT (n = 19)
Reared ELB	6.5 (3.61)	14.1 (4.20)	105.1 (25.57)	192.2 (50.28)
Attacks	0.4 (0.30)	1.3 (0.58)	1.8 (0.673)	4.3 (0.83)
Galleries	4.0 (1.92)	9.2 (4.00)	19.9 (4.38)	32.6 (3.53)
Success of attack	1.1 (0.67)	2.4 (1.01)	5.4 (1.97)	11.6 (1.58)

Montana installations

Significant interactions between the host log species and the pheromone bait combination were detected for the number of reproducing adults, gallery density (cm^{-2}), and egg density (cm^{-2}) in all ANOVAs (eq. 2) (Table 5). Thus, we are unable to comment further on main effects of host log species and pheromone bait. Further experimentation is necessary to explore the relationship between these two factors. In general, the Phero-Tech bait performed better than the Ross & Daterman (1995) bait in attracting the DFB to trap logs (Table 6).

Table 5. *P*-values for ANOVAs testing the effects of host species, pheromone bait and the interaction of host species and pheromone bait on the number of reproducing adult Douglas-fir beetles, gallery density, and egg density for the Douglas-fir beetle on Montana study sites.

Effect	Adult insects	Gallery density	Egg density
Species	0.001	0.001	0.001
Bait	0.001	0.001	0.064
Species*bait interaction	0.001	0.001	0.021

Table 6. Mean (standard errors in parentheses) values of adult Douglas-fir beetle, gallery density, and egg density for the Douglas-fir beetle by host log species and pheromone bait (R = Ross & Daterman (1995) bait and PT = Phero-Tech bait) combination in Montana.

	Douglas-fir logs		Tamarack logs	
Measured attribute	R (n = 10)	PT (n = 10)	R (n = 10)	PT (n = 10)
	------------------------ Density per cm^2 ----------------------------			
Adult insects	0.011 (0.007)	0.064 (0.009)	0	0.002 (0.001)
Gallery density	0.009 (0.005)	0.062 (0.006)	0	0.001 (0.0001)
Egg density	0.335 (0.190)	1.262 (0.248)	0.058 (0.058)	3.604 (1.034)

DISCUSSION

DFB has had a documented presence in Minnesota since May 2001 and was likely introduced multiple times after the importation of western larch began in 1996 (Dodds et al. 2004). Since that time, there have been concerns about the presence of a breeding population of DFB in Minnesota. While we did not detect the presence of the DFB in our baited log study in Minnesota, our negative results should be carefully interpreted. The known source of the DFB is one small wood yard. This, coupled with a high population of ELB during our study may have impacted our results. In other words, there may be too few DFB in north-central Minnesota relative to the number of our installations for detection and the ELB may have colonized the test logs at high densities precluding potential colonization by DFB.

The Montana portion of our study indicated that the DFB is capable of successfully colonizing tamarack. But, given a preference between Douglas-fir and tamarack, DFB appears to prefer Douglas-fir (Table 6). The thin bark of tamarack relative to Douglas-fir may prevent extensive colonization of tamarack by the DFB (Furniss 1976).

ACKNOWLEDGEMENTS

Funding was provided by the USDA Forest Service, Forest Health Protection, Northeastern Area Office, the USDA Forest Service Pacific Southwest Research Station, and the Department of Forest Resources, University of Minnesota. We thank Kurt Allen (USDA Forest Service, Forest Health Protection, Region 2, Rapid City Service Center), Brad Jones (Itasca County Land Department), Scott Pitak (Pitak Logging), Kurt Gelderman (Montana Department of Natural Resources & Conservation), Ken Gibson (USDA Forest Service, Forest Health Protection, Region 1, Missoula), Sheryl Meekin (USDA Forest Service, Bitteroot National Forest, Sula Ranger District), and Allison Hanson (University of California – Riverside) for logistical support and field assistance.

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