NOTE

Diurnal Flight Pattern of *Dendroctonus brevicomis* LeConte (Coleoptera: Scolytidae) in Northern California[1]

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Bark beetles are commonly recognized as the most important mortality agent in North American forests (Furniss and Carolin 1977, U.S. Dept. of Agric. For. Serv. Misc. Publ. 1339). The western pine beetle, *Dendroctonus brevicomis* LeConte, is a major cause of ponderosa pine, *Pinus ponderosa* Dougl. ex Laws, mortality in western North America, particularly in California. The beetle aggressively attacks apparently healthy trees of all ages and size classes. Severe droughts are often accompanied by increased amounts of *D. brevicomis*-caused tree mortality.

Dendroctonus brevicomis produces two aggregation pheromone components, (+)-*exo*-brevicomin and (−)-frontalin. *exo*-Brevicomin is produced and released by females and induces an aggregation response from both sexes (Wood et al. 1976, Science 192: 896-898; Browne et al. 1979, J. Chem. Ecol. 5: 397-414). Males release frontalin in relatively small quantities (Browne et al. 1979). Myrcene, a host monoterpene of *P. ponderosa,* enhances the response of both sexes (Bedard et al. 1969, Science 164: 1284-1285).

Aggregation pheromones have been synthesized for several bark beetle species (Skillen et al. 1997, U.S. Dept. of Agric. For. Serv. FHTET-96-15). Their availability has led to advances in bark beetle management through the forecasting of infestation trends (Billings 1988, *In* T. L. Payne and H. Saarenmaa, [eds.], Integrated Control of Scolytid Bark Beetles, Virginia Polytechnic Institute and State University, Blacksburg, VA), development of containment methods (Borden et al. 1983, Can. J. For. Res. 13: 325-333), stand protection and spot suppression (Shea et al. 1992, Can. J. For. Res. 22: 436-441; Ross and Daterman 1994, Can. J. For. Res. 24: 2184-2190; Clarke et al. 1999, South. J. Appl. For. 97: 26-31), and mass trapping efforts (Shea and Neustein 1995, U. S. Dept. of Agric. For. Serv. Gen. Tech. Rep. INT-GTR-318).

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Pheromones also are used to assess presence of an insect and to describe the spatial and temporal distributions or flight activity patterns (Peck et al. 1997, Pan-Pacific Entomol. 73: 204-212; Martikainen 2000, J. Appl. Ent. 124: 57-62). The objective of this experiment was to describe the diurnal flight pattern of *D. brevicomis* in northern California by using synthetic aggregation pheromones to capture flying adults.

This study was conducted on the Shasta-Trinity National Forest, Siskiyou Co., CA, in June 1998 (McCloud Flats, 41°19.99′ N, 121°59.87′ W, elevation 1219 m). Forest composition, in order of decreasing abundance, was comprised of *P. ponderosa, Abies concolor* (Gond. and Glend.) Hildebr., *Libocedrus decurrens* Torr., *Pseudotsuga menziesii* (Mirb.) Franco, *P. lambertiana* Dougl., and miscellaneous other species. Ten 16-unit Lindgren® multiple-funnel traps (Lindgren 1983, Can. Entomol. 115: 299-302) were baited with frontalin [racemic], *exo*-brevicomin [racemic], and myrcene and were hung on 3-m metal poles with collection cups 5 to 8 cm from the ground. Traps were spaced 320 m apart and deployed along an existing road within an area that contained significant *D. brevicomis* infestations and associated tree mortality. Trapping was initiated at 0700 daily (PDT), and collections were made hourly from 0800 to 2200 on seven consecutive days from 23 June through 29 June 1998. In general, peak seasonal flight activity occurs between mid-June and mid-July in California (Fettig et al., unpubl. data) and Oregon (Peck et al. 1997, Pan-Pacific Entomol. 73: 204-212). Temperature, relative humidity and wind speed were recorded continuously at 2 m in height from the ground surface. Specimens were tallied and identified using available keys (Wood 1982, Great Basin. Nat. Mem. No. 6) and reference collections. Voucher specimens have been deposited in the USDA Forest Service Bark Beetle and Common Associates Collection housed in Placerville, CA.

A test of normality showed that the data deviated significantly from a normal distribution. The data were normalized by square root transformation and subjected to a one-way analysis of variance using $\alpha = 0.05$ (Sigma Stat Version 2.0, Jandel Scientific, San Rafael, CA; Sokal and Rohlf 1995, Biometry, 3rd edition). Tukey's honestly significant difference procedure (Tukey's HSD) was used for separation of treatments means. The relationship between hourly trap catch and temperature, humidity, and wind speed was analyzed using Pearson's correlation coefficient (r) with square root transformed trap catch data and arcsine square root (angular) transformed relative humidity data.

A total of 8,999 *D. brevicomis* was captured in multiple-funnel traps over the 7-d period. Hour of day significantly affected trap catch ($F = 33.7$; df = 14, 936; $P < 0.001$) (Table 1). Average temperature, humidity, and wind speed are reported for each hour (Table 1). There was no significant difference in trap catch among 0800, 0900, 1000, 2100, and 2200 (Table 1). Little or no flight occurred during this portion of the day. *Dendroctonus brevicomis* was not captured prior to 0800 and after 2100, which agrees with an early report that suggests *D. brevicomis* does not fly at night (Fig. 1, Table 1) (Miller and Keen 1960, U. S. Dept. of Agric. For. Serv. Misc. Public. 800). Sunrise and sunset times for 25 June 1998 were 537 and 2046, respectively (PDT, McCloud, CA; U. S. Naval Observatory, Washington, DC). In general, there were two peaks in diurnal flight occurring between 1000 and 1300 (35.7% of total trap catch), and between 1700 and 2000 (58.9% of total trap catch) (Fig. 1). On an hourly basis, peak flight occurred from 1800 to 1900 (20.5% of total trap catch). Trap catch during this period of time was significantly greater than at any other (Table 1).

There were highly significant correlations between mean hourly trap catch and

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Table 1. Mean (± SEM) of adult western pine beetle, *Dendroctonus brevicomis* LeConte, caught per hour in multiple-funnel traps baited with frontalin, *exo*-brevicomin, and myrcene, Shasta-Trinity National Forest, CA, 23-29 June 1998

Hour	Trap catch*	Average temperature (°C)	Average relative humidity (%)	Average wind speed (ms^{-1})
800	0.0 ± 0.0 a	9.2	85.8	0.631
900	0.1 ± 0.1 a	12.9	72.7	0.637
1000	4.4 ± 0.9 ab	15.9	58.8	0.789
1100	15.9 ± 3.0 cd	17.6	52.1	0.807
1200	16.3 ± 3.1 cd	18.9	49.8	1.028
1300	9.3 ± 1.9 bc	21.1	46.5	1.224
1400	7.6 ± 1.5 bc	22.5	42.6	1.057
1500	7.9 ± 1.5 bc	21.4	42.5	1.268
1600	5.6 ± 0.9 b	20.6	43.7	1.076
1700	10.4 ± 1.9 c	19.2	45.9	1.213
1800	14.9 ± 1.7 cd	19.4	50.2	0.869
1900	36.9 ± 4.2 e	19.4	52.9	0.767
2000	19.2 ± 2.7 d	18.1	59.9	0.647
2100	0.4 ± 0.1 a	16.2	71.1	0.519
2200	0.0 ± 0.0 a	14.0	75.5	0.858

* Means followed by the same letter are not significantly different ($P > 0.05$ all cases; Tukey's HSD).

temperature ($r = 0.672$, $P = 0.006$, n = 15), and humidity ($r = -0.731$, $P = 0.002$, n = 15), but not wind speed ($r = 0.289$, $P = 0.30$, n = 15). As expected, temperature and humidity were strongly negatively correlated ($r = -0.956$, $P < 0.0001$, n = 15). Visual observations suggested that flight was suppressed during hours that were overcast or partly cloudy, which differs from that reported for the southern pine beetle, *D. frontalis* Zimmerman (Vite et al. 1964, Contrib. Boyce Thompson Inst. 22: 461-470). On warm, sunny days heat is absorbed by the air surrounding the upper canopy, creating highly unstable conditions within and above the canopy itself (Fares et al. 1980, J. Theor. Biol. 84: 335-359). At the same time, inversions occur in the stem zone that are characterized as quite stable. These conditions, which together create a chamber of stable air, are thought to enhance pheromone communication and, presumably trap catches in this study, during late afternoon (Fares et al. 1980, J. Theor. Biol. 84: 335-359; Schmitz et al. 1989, Can. J. For. Res. 19: 566-574; Shea et al. 1992, Can. J. For. Res. 22: 436-411).

During 1991-1993, we conducted a similar study to describe the seasonal flight periodicity of the four major pine infesting bark beetles along a latitudinal gradient of

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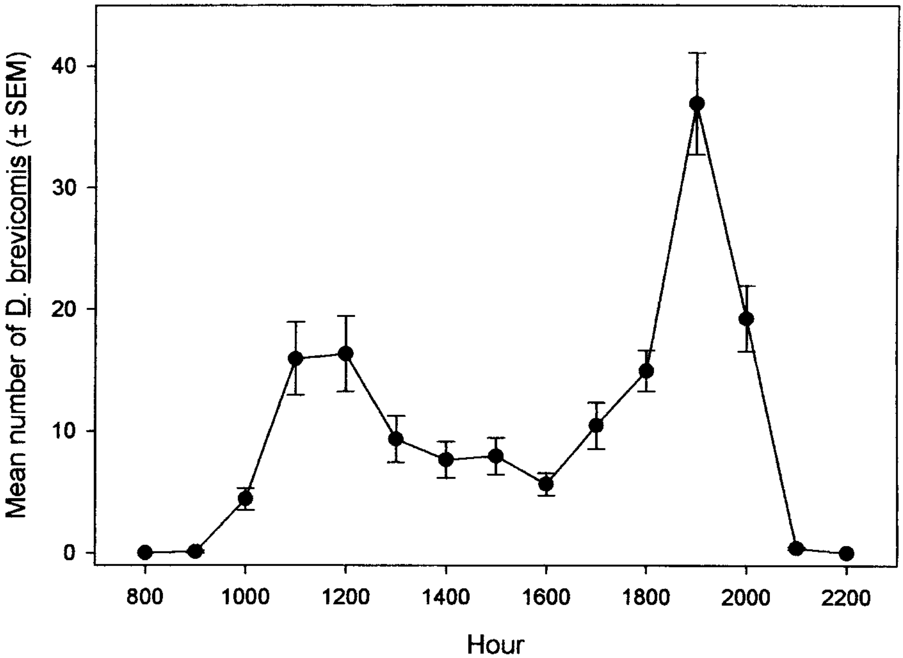

Fig. 1. The diurnal flight pattern of adult *D. brevicomis* at Shasta-Trinity National Forest, CA, 23-30 June 1998.

725 km within the Sierra Nevada and Cascade Mountains, CA (Fettig et al., unpubl. data). *Dendroctonus brevicomis* peak activity occurred between mid-June and mid-July at all locations, however, the beetle was active continually from May through October. Few other apparent trends in flight periodicity were observed. In 1991, trapping was conducted continuously throughout the year at a single location, and during a 2-wk period of warm temperatures in February (i.e., temps >15.5°C for 4 h/d) a small amount of flight was detected. Peck et al. (1997) described the seasonal flight trends of several bark and ambrosia beetles in Oregon and reported that although most species showed a single peak in activity, *D. brevicomis* was collected in relatively large numbers throughout the year. They also reported that peak activity occurred in June. Our current results are based on analysis of diurnal flight patterns during a single week in late June when *D. brevicomis* exhibits its major seasonal flight. The patterns described here may be limited to late June and the relatively small geographic area in which the study was conducted. However, based on our experience with *D. brevicomis* seasonal flight patterns, we believe the results are more widely applicable.

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