J. Appl. Ent. 123, 529–534 (1999)

ISSN 0931-2048

Integrated pest management of *Ips pini* (Col., Scolytidae) populations in south-eastern Montana

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Abstract: Second growth ponderosa pine forests of the Northern Cheyenne Reservation of south-eastern Montana sustained a chronic *Ips pini* outbreak between 1978 and 1994. Studies determined the emergence and seasonal flight patterns of the scolytids with regards to temporal and spatial distribution of host material as well as population changes during the year. These changes related to the dry-down rate of host material (thinning and logging slash) and the availability of slash; an index of population change (IPC) was developed to estimate seasonal changes in the *Ips* population from spring to autumn. Principal management components of an integrated pest management system included (1) an emphasis on creating thinning and logging slash between August and December, a time that provides quickly degrading host material for the overwintering *Ips* population while not providing suitable host material for the subsequent spring flight; (2) restrictions on winter logging as slash produced during this period provided suitable hosts for the first spring flights of *I. pini*; and (3) restrictions on the use of trap logs or pheromones to lower *Ips* populations as these materials provide kairomones for the predators (*Enoclerus lecontei*, *Enoclerus spegeus* and *Temnochila chlorodia*) that partition their *I. pini* host across the spring, summer and autumn.

1 Introduction

Pine engraver beetles, *Ips pini* (Say) are nonaggressive bark beetles since they normally reproduce in logging slash, wind-thrown trees, broken limbs and severely stressed trees. When populations increase due to an abundance of host material, *I. pini* frequently invade trees. After droughts, when the hosts become stressed, large populations of these beetles even kill groups of trees (Sartwell et al., 1971; Livingston, 1979).

Forest management policies on lands of the Northern Cheyenne Reservation of south-eastern Montana favoured outbreaks of *I. pini* in 80 to 90-year-old ponderosa pine forests, *Pinus ponderosa* (Dougl. ex Laws) var. *scopulorum*, during 1978–94. Outbreak conditions were maintained because continual thinning and logging operations provided successive sources of host material for these scolytids. Drought conditions, during about 1984–94, further aggravated the intensity of the outbreak. During these years, trees were under water stress and many stands became susceptible to bark beetle attack. For these reasons, there was a constant *Ips*-caused tree mortality of 5 to 8% across Northern Cheyenne lands throughout this period.

During the time of this outbreak, attempts were made to control it by minimizing slash production during the spring dispersal flights of the beetles; treating slash during high risk months by lopping and scattering; bulldozer tractor trampling of the material; burning when appropriate and so forth. Forest managers began to implement a trap tree/pheromone programme. Despite these efforts, tree mortality continued. This lack of success was due to a need for basic data on timing of scolytid flights and the persistent availability of host material in time and space. Accordingly the general objective of our 1992–94 study was to understand the life history and host selection behaviour of *I. pini* and determine how to use this information in the development of an integrated pest management (IPM) programme aimed at reducing losses in the Northern Cheyenne forests. Specific objectives were as follows: (1) to monitor seasonal flight patterns with regards to temporal and spatial distribution of host material; (2) to determine the flight patterns of the scolytid's main predators; and (3) to determine relationships between population changes and host quality during the year.

2 Materials and methods

2.1 Emergence and flight patterns

During the summers of 1992 and 1993, emergence patterns associated with *I. pini* flights were documented through the use of emergence cages containing freshly infested bolts of ponderosa pine. Cages were checked daily and the numbers of newly emergent beetles recorded. Seasonal flight was monitored by the establishment of 10 funnel traps (Lindgren, 1983) baited with the synthetic pheromone, ipsdienol (Raffa, 1991). Beginning on 1 April, 19 traps were placed at the border or within freshly logged areas. Traps were monitored three times a week, and all scolytids and associates counted.

Seasonal bark beetle flight patterns were correlated with hourly or daily temperature and relative humidity measurements. These measurements were obtained from two automated weather recording stations located within the forests.

2.2 Population changes and host quality

The population levels of *I. pini* generated by pieces of logging slash was estimated by developing an index of population

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change (IPC). The IPC analysis predicted whether the scolytid population would increase, decrease or stay the same from one generation to the next.

IPC analyses were done as follows: population levels in infested slash were approximated by the establishment of 0.008 ha (1/50th acre) plots within a 1.01 ha (2.5 acre) sampling unit. These units were located in logging sites that were harvested at different times of the year. The sampling was carried out in the following manner: (1) within each 0.008 ha plot, each piece of slash greater than 7.6 cm (3.0 in.) at its large end, was sampled; (2) a 929 cm^2 (1 ft^2) section of bark was removed from about 20% of the sampled pieces; (3) the numbers of nuptial chambers, egg galleries, larval starts and insects present were recorded and; (4) an estimate of phloem moisture was made by subjective estimations of relative dryness and colour of the phloem as well as by quantitative methods. In the latter case, a Shigometer® (Osmose, Inc., Buffalo, NY, USA) was used to determine the rate of moisture loss from the sapwood of logging slash during a 16 week period starting in June. This instrument determines resistance to an electrical current applied between two probes inserted into the sapwood; as the wood desiccates, resistance increases and is displayed on the instrument in ohms.

In practice, the Shigometer® was used in conjunction with IPC analysis of slash material. Resistance measurements of logging slash for different lengths of dry-down time were recorded. The time at which *I. pini* no longer attacked the slash was also recorded; presumably when attacks ceased, the phloem was no longer suitable as brood material. With this information the IPC was calculated in the following manner:

1. (Pieces infested slash/1.01 ha) × (average attacks/piece) = the initial attacking population/1.01 ha.
2. (Initial attacking pop./1.01 ha) × (average brood/attack) × survival constant = the new brood density/1.01 ha.
3. (New brood density/2 per 1.01 ha)/(the initial attacking population per 1.01 ha) = IPC; see Appendix I for more details about the IPC.

3 Results

3.1 Emergence and flight patterns

Emergence of *I. pini* began in early April and continued throughout the month with a peak on the 21st. The largest emergence was in mid-June with continuing emergence throughout the summer and early autumn (fig. 1).

In 1992 the first flights of the overwintering population began during early April when ambient temperatures were above 15.5°C and peaked on 27 April as temperatures reached 25°C. There were two additional flight periods, the first overlapped the overwintered-adult flight and continued through June, whereas the last flight peaked in early July and continued through August (fig. 2). In subsequent years *I. pini* flights also responded to ambient temperatures; in 1993 and 1994, however, a late spring delayed the first flights until the first week of May and the last flights terminated in early September.

3.2 Predator relationships

The flight patterns of the scolytid's three principle coleopteran predators [*Enoclerus lecontei* (Wolcott)], *Enoclerus sphegeus* (F.), and *Temnochila chlorodia* (Mannerheim)] overlapped. However, *E. lecontei* had its major flight from mid-April to mid-May, whereas the densest *E. sphegeus* flights occurred between mid-May and the end of June. The trogositid, *T. chlorodia*, flew from late May until August with its densest flights during late July and August, a time of minimal *I. pini* flight (fig. 3).

3.3 Population changes

Having IPC values ranging from 3.5 to 2.8, logging slash produced in winter, had the greatest potential of increasing *I. pini* populations. The potential to generate progeny decreased in slash produced from April to June: the IPC of 1.0 in June meant broods produced in this slash would sustain the same populational level (fig. 4).

3.4 Host quality

Field studies beginning in June, demonstrated that the phloem of slash was too dry for *I. pini* colonization after 8 weeks of desiccation. This relationship is seen in fig. 5, as scolytids ceased attacks when sapwood resistance (a surrogate to phloem moisture) reached 90 ohms. This information was used in tracing the dry-down rate of slash.

4 Discussion

Ips pini flights were closely correlated with ambient temperature regimes. As temperatures rose above 15.5°C the first flights of the overwintering population began in April, a condition similar to other scolytid species (Wood and Stark, 1964; Seybert and Gara, 1970; Billings and Gara, 1975; Bakke et al., 1977; Ohmart and Voight, 1982; Struble and Hall, 1995). The delayed spring flights of the pine engraver beetle during 1993–94 would have the following consequences: (1) as pine engraver beetles depend on scattered and degrading habitats (Hard, 1985; Fox et al., 1990), a postponed dispersal would lower the chances of locating and colonizing high quality hosts; and (2) delayed spring flights would prolong brood development during the summer and late emerging adults (e.g. during September) would face inclement weather before locating overwintering sites.

In low bark beetle populations there is an asynchrony between peaks in daily emergence and dispersal flights. This relationship holds, because host material is scarce and scattered and, accordingly, periods between adult emergence, dispersal and ultimately host finding are protracted. Host finding is particularly critical. It is a moment and a point in space when pheromones are produced and beetles within range of the cues concentrate towards the semiochemicals; it is a time when dispersal ends. Conversely, when *Ips* populations reach epidemic levels, there is an increased tendency for synchrony between emergence, dispersal and concentration on host material. With synchrony of host selection activities, scolytids find suitable/susceptible host material shortly after emerging from their previous hosts because semiochemical cues are invariably present (Gara and Vité, 1962). In 1992 the first flights in spring were coincident with pine engraver catches as were the peak flights during late April and May. These relationships

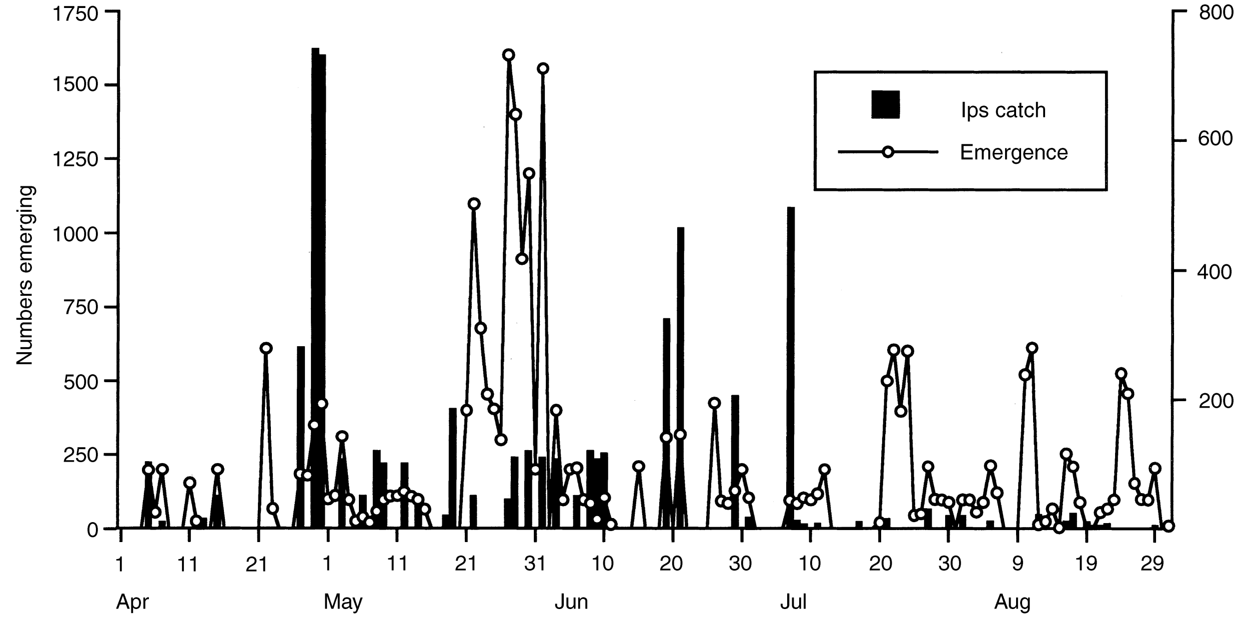

Fig. 1. *The 1992 daily emergence pattern of* Ips pini *as related to seasonal flight patterns*

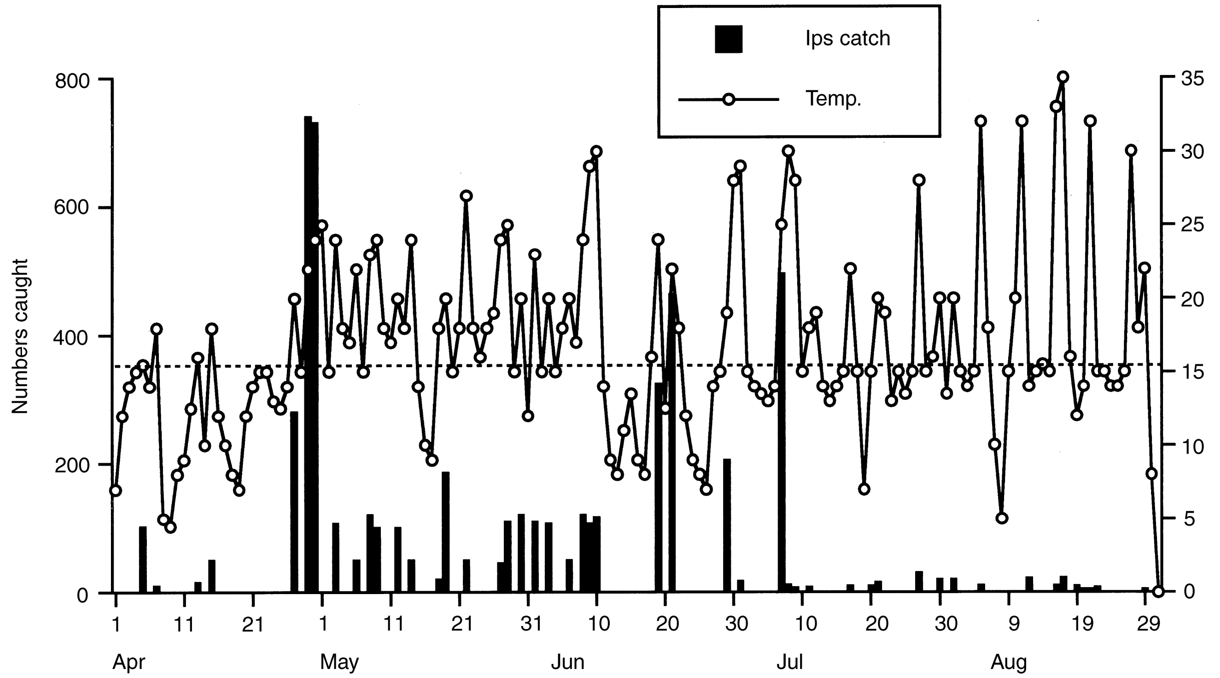

Fig. 2. *The 1992 seasonal flight pattern of* Ips pini *as they responded to funnel traps baited with ipsdienol and as related to mean daily temperature*

indicated that *I. pini* population levels were high and, in part, accounted for subsequent timber loss on the Northern Cheyenne Reservation.

Although density-independent mortality factors are important in regulating scolytid populations, natural enemies play key roles in regulating low populations (WOOD, 1972; STEPHEN et al., 1993). This co-evolutionary connection is noted as both *E. lecontei* and *E. sphegeus* as well as *T. chlorodia* respond to scolytid pheromones, a response to kairomones (RAFFA and KLEPZIG, 1989; HERMS et al., 1991; RAFFA, 1991). In the ponderosa pine forests of north-eastern Montana, these three predators effectively partitioned the resource as *E. lecontei* flies in spring, *E. sphegeus* is active mid-season and *T. chlorodia* predation serves to reduce scolytid populations as they seek overwintering sites (see fig. 3). There were three *I. pini* flight periods during the year (fig. 6). Supplies of fresh logging slash and thinning residues were fundamental in providing food for pine engraver beetles emerging from their overwintering sites. As seen in fig. 4, the IPC for broods reared from slash produced between December and March had IPC

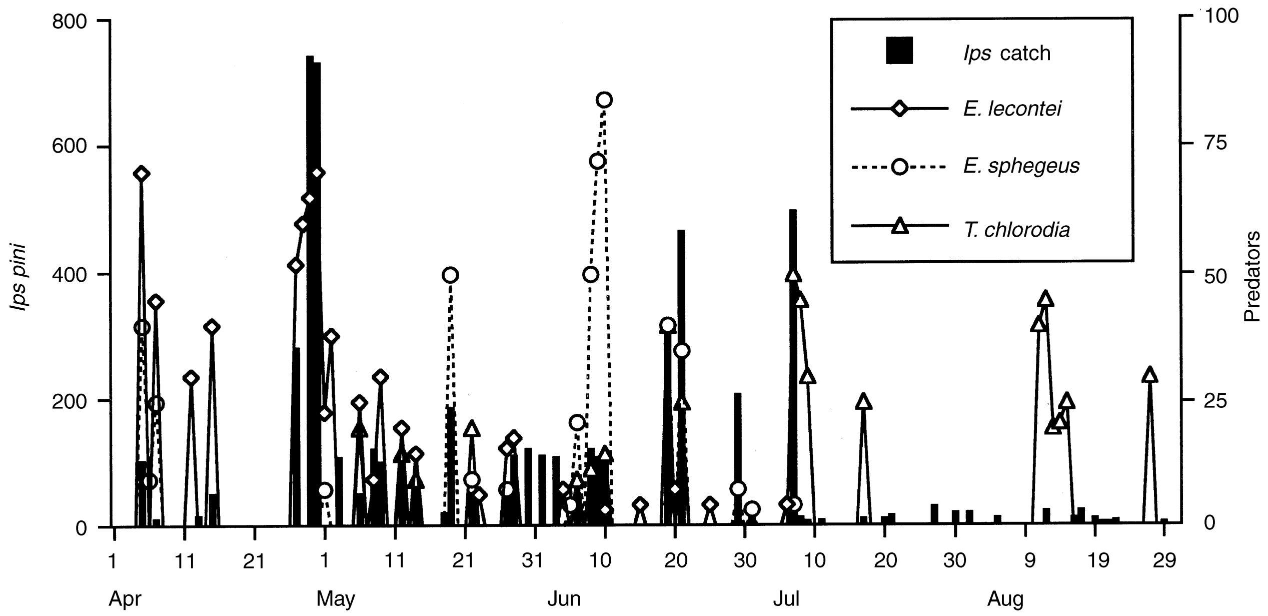

Fig. 3. The 1992 flight patterns of the predators Enoclerus lecontei, Enoclerus sphegeus *and* Temnochila chlorodia *as related to the* Ips pini *seasonal flight*

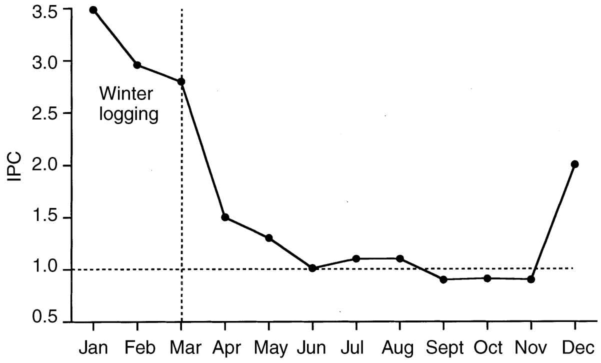

Fig. 4. Relationship between time of logging slash production during 1992 and subsequent development of Ips pini *broods. Brood production is expressed as an Index of Population Change (IPC)*

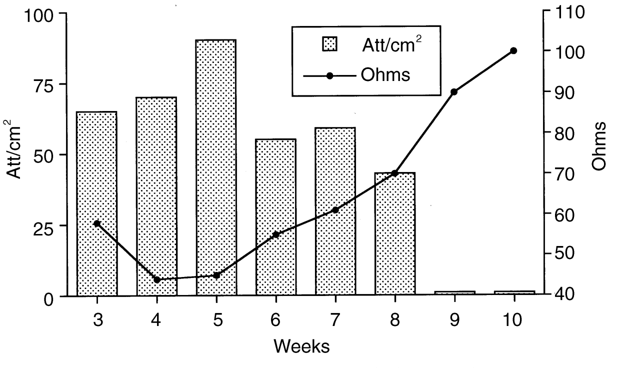

Fig. 5. Relationship between Ips pini *attacks on logging slash and sapwood moisture content as determined in ohms with a Shigometer®. The sapwood moisture served as a surrogate for phloem dry down rate*

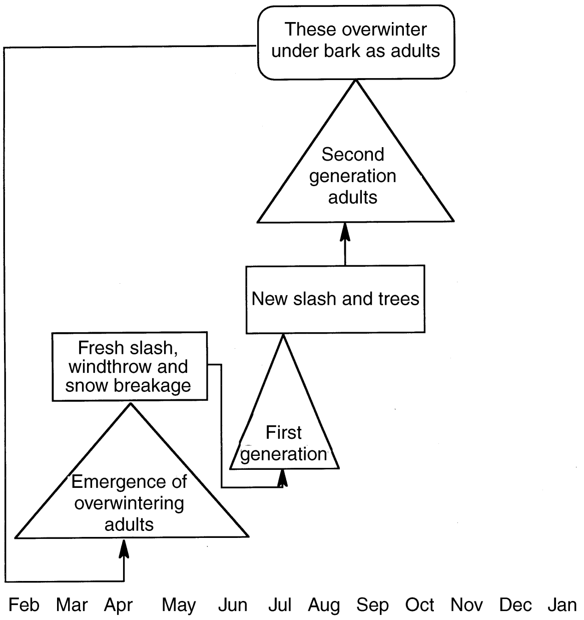

Fig. 6. Ips pini *activity patterns and type of host material attacked during 1992 and 1993 within forests of the Northern Cheyenne Reservation – near Lame Deer, Montana (modified from Livingston, 1979)*

values of 2.0, 3.5, 3.0 and 2.8, respectively. This means that slash produced in winter did not dry out and remained succulent and nutritious until the overwintering *I. pini* generation utilized this material in spring. On the other hand, slash created in October had about 3 months to dry out before it was frozen, so that by the time the spring scolytid flights occurred, the slash was too dry for development of *Ips* broods.

With this information, an effective IPM programme to lower the general equilibrium of *I. pini* populations, would include the following guidelines:

1. The safest time to create slash and log decks is between late August and December. This activity creates overwintering sites for pine engraver populations but does not provide suitable host material for the following spring. Slash created during this period will dry rapidly and brood success will be minimal (see figs 4 and 5).

2. Fresh pine slash has to be minimized during January to May. In this manner, the overwintering broods would not have fresh host material to absorb their population in spring. The same results would occur if slash produced in winter were piled and burned before the spring dispersal flights. Managing slash production in late autumn and winter is the most important management component of the IPM scheme.

3. Until further study, use of trap logs and pheromones to trap out *I. pini* is not recommended since three predator species have partitioned the three flight periods of *I. pini*. Preliminary studies show that, together with the drying of scolytid host material, the predators effectively regulate low-level *Ips* populations.

Acknowledgements

Study supported by the U. S. Department of the Interior, Bureau of Indian Affairs, Billings, Montana Area Office and the Northern Cheyenne Forestry Division.

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Appendix

Computation of the index of population change

1. Harvesting units are classified with regards to age of the slash material inside the unit. Sample areas are established within each harvesting unit and are designated to be 1.01 ha (2.5 acres) – the spatial base of the *I. pini* population analysis. Sets of 12–13 circular plots each 1/50 acre (0.00809 ha) in area are established during the season in selected harvesting units.

2. Each set therefore represents β0.101 ha (0.25 acres) or β10% of 1.01 ha (2.5 acres).

3. Each 1/50 acre (0.008089 ha) sample is done as follows:
   (a) a circle of 5.15 m radius is established;
   (b) the length and mid-point diameter of each piece of slash within the plot is measured;
   (c) A 1 ft^2 (929.03 cm^2) of bark is removed from about 20% of the slash pieces and the following information is recorded:
   The number of nuptial chambers (i.e. representative of the initial attack density of the sample);
   The number of completed egg galleries;
   The number of eggs or larval mines and;
   The number of pupae, callow adults and adults.

4. The difference between larval starts and number of pupae, callow adults and adults is considered to represent an integrative brood survival constant: in this case a k of 0.113.

Calculation of IPC

1. (Pieces of infested slash/12.5 plots) = (Infested slash/ha);

2. (Pieces of infested slash/ha) × (10) = (Infested slash/1.01 ha)
3. (Pieces of infested slash/1.01 ha) × (Average attack/piece) = (Initial attacking population/1.01 ha)
Note: Average attack/piece = (Average number nuptial chambers/929.03 cm^2) × ($2\pi \times r \times l$)
4. (Initial attacking population/1.01 ha) × (Larval starts/attack) × k = New generation density
5. New generation density/2 = New attacking population
Note: only males attack the new host, i.e. the nuptial chamber count
6. New attacking population/Initial attacking population = Index of population change