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Buprestidae, Cerambycidae, and Scolytidae Associated with Successive Stages of *Agrilus Bilineatus* (Coleoptera: Buprestidae) Infestation of Oaks in Wisconsin

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BUPRESTIDAE, CERAMBYCIDAE, AND SCOLYTIDAE ASSOCIATED WITH SUCCESSIVE STAGES OF *AGRILUS BILINEATUS* (COLEOPTERA: BUPRESTIDAE) INFESTATION OF OAKS IN WISCONSIN[1]

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ABSTRACT

The species of Buprestidae, Cerambycidae, and Scolytidae found in association with *Agrilus bilineatus* (Weber) in declining oaks, *Quercus* spp., in Wisconsin, were *Chrysobothris femorata* (Olivier) and *Dicerca* sp. (Buprestidae); *Amniscus macula* (Say), *Cyrtophorus verrucosus* (Olivier), *Euderces picipes* (Fabricius), *Graphisurus fasciatus* (DeGeer), *Neoclytus acuminatus* (Fabricius), *Sarosesthes fulminans* (Fabricius), and *Xylotrechus colonus* (Fabricius) (Cerambycidae); and *Monarthrum fasciatum* (Say), *Monarthrum mali* (Fitch), *Pseudopityophthorus minutissimus* (Zimmerman), and *Xyloterinus politus* (Say) (Scolytidae). In general, weakened oaks were first attacked by *A. bilineatus*, and at times that same year by *C. femorata*, *G. fasciatus*, and *P. minutissimus*. Infestation by *M. fasciatum*, *M. mali*, and *X. politus* began the season following first attack by *A. bilineatus*. With the exception of *A. bilineatus*, the above mentioned Buprestidae and Cerambycidae appeared to preferentially infest dead wood, often those portions that had died the previous season.

The twolined chestnut borer, *Agrilus bilineatus* (Weber), (Coleoptera: Buprestidae) is a major pest of weakened oaks (*Quercus* spp.) throughout eastern North America. Recent outbreaks (1976–1980) in southern Wisconsin occurred where oaks had been stressed by drought, ice-storm damage, and fall cankerworm, *Alsophila pometaria* (Harris), (Lepidoptera: Geometridae) defoliation. The biology of *A. bilineatus* has recently been studied by Dunbar and Stephens (1975, 1976) in Connecticut; Cote and Allen (1980) in New York and Pennsylvania; and Haack, Benjamin, and Schuh (1981) and Haack and Benjamin (1982) in Wisconsin.

In declining oaks, *A. bilineatus* is normally the first borer to attack (Dunbar and Stephens 1975). Initial attack usually occurs first in the live crown and then proceeds downward along the trunk in succeeding years. Attacked trees usually die during August and September of the second or third year of infestation. Occasionally, tree death occurs in the first year of attack when girdling is complete below the first major branches (Haack and Benjamin 1982).

Once an oak is attacked or killed by *A. bilineatus*, it becomes a suitable host to several other wood borers, inner bark (phloem) borers, bark beetles, and ambrosia beetles in the families Buprestidae, Cerambycidae, and Scolytidae. Study of borer succession is of practical importance when attempting to assess the impact of several insect species on a host. Nevertheless, few such studies have been done. Savely (1939) reported on the succession of animals in oak logs over a four year period in North Carolina, and Cote and Allen (1980)

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listed the associated borers they had reared from *A. bilineatus*-infested oak bolts. We present here observations on the Buprestidae, Cerambycidae, and Scolytidae associated with *A. bilineatus* in oaks in various stages of decline, recorded in Wisconsin in 1979.

MATERIALS AND METHODS

The period of adult emergence was investigated in 1979 by capturing adults in traps (0.4–0.7 m^2) made of nylon mosquito netting stapled at ca. breast height (1.3 m) on 51 oaks (20–70 cm dbh) in four host-condition categories. Trees were assigned to a category based on external symptoms and signs of *A. bilineatus* attack during fall 1978 and spring 1979. Categories were (1) apparently healthy, i.e., having no evidence of 1978 *A. bilineatus* attack; (2) some 1978 crown attack; (3) tree death in 1978; and (4) tree death in 1977. Traps were installed in late May 1979 on 10 white oaks (*Q. alba* L.), 7 black oaks (*Q. velutina* Lam.), 2 red oaks (*Q. rubra* L.), and 1 bur oak (*Q. macrocarpa* Michx.) in an oak woodlot near Madison, Dane County, Wisconsin, and on 10 white oaks, 7 black oaks, 2 red oaks, and 1 bur oak in a natural oak-hickory forest in the Kettle Moraine State Forest, Jefferson County, Wisconsin. Adults were removed and counted twice each week from 20 May through 5 July and then weekly through 14 September. Adults were identified at the University of Wisconsin and at the Insect Identification and Beneficial Introduction Institute, USDA, Beltsville, Maryland.

In an earlier paper (Haack and Benjamin 1982) the within-tree distributions of *A. bilineatus* larvae, larval galleries, and adult exit holes were presented for five host-condition categories of oaks from the Kettle Moraine State Forest site. During that study we also recorded the number and location of all other borers encountered. Briefly, 25 red and black oaks (5/category, 23–46 cm dbh) were sampled in December 1979 after having been assigned to a host-condition category in September 1979, when symptoms of current-year *A. bilineatus* attack were most evident. Categories were (I) apparently healthy, i.e., having no symptoms of 1979 *A. bilineatus* attack; (II) 25–50% crown death in 1979 after one season of attack; (III) tree death in 1979 after one season of attack; (IV) tree death in 1979 after two seasons of attack; and (V) tree death in 1978 after at least two seasons of attack. After felling, bolts 30-cm-long were cut at 2-m intervals from tree base out along one major branch to a final diameter of ca. 5 cm. We recorded the length and diam. (inside the bark) of each bolt. All borers were recovered from the bark, cambial region, and wood by carefully splitting with hammer and chisel; numbers were recorded per square metre of bolt area. The Scolytidae were identified to species. However, the Buprestidae and Cerambycidae (larvae) were only identified to the family and genus level, using the keys of Burke (1917), Craighead (1923), and Peterson (1960); some larvae were reared to adults.

RESULTS AND DISCUSSION

Two species of Buprestidae and seven species of Cerambycidae were collected from the emergence traps. The Buprestidae were *A. bilineatus* and *Chrysobothris femorata* (Olivier). The Cerambycidae were *Amniscus macula* (Say), *Cyrtophorus verrucosus* (Olivier), *Euderces picipes* Fabricius), *Graphisurus fasciatus* (DeGeer), *Neoclytus acuminatus* (Fabricius), *Sarosesthes fulminans* (Fabricius), and *Xylotrechus colonus* (Fabricius). Table 1 presents number collected, collection period, host trees, and host tree condition for each borer species.

Borers were collected only from traps on dead oaks (categories 3 and 4); none were collected from the healthy or crown-attacked oaks. However, later inspection of the crown-attacked oaks revealed *A. bilineatus* exit holes in crown branches and along the upper bole of each, but none along the lower trunks where the traps had been placed. The most commonly collected cerambycid in our study was *G. fasciatus;* it had a similar ranking in the studies of Savely (1939) and Cote and Allen (1980). At times, *A. bilineatus, C. femorata,* and *G. fasciatus* were all found in the same traps suggesting concurrent attack since each is considered to be univoltine (Haack and Benjamin 1982, Chittenden 1905, and Craighead

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Table 1. Adult Buprestidae and Cerambycidae collected from emergence traps at breast height (1.3 m) on *Agrilus bilineatus*-infested oaks in an oak woodlot (Madison, Dane Co., Wisconsin) and in a natural oak-hickory forest (Kettle Moraine State Forest, Jefferson Co., Wisconsin) from 20 May through 14 September 1979.

Species	(n)	Collection Period	Host and Host Condition[a]
BUPRESTIDAE			
Agrilus bilineatus	126	8 June–26 July	*Q. alba* (1), *Q. rubra* (1), *Q. velutina* (1)
Chrysobothris femorata	8	13 June– 4 July	*Q. alba* (2), *Q. rubra* (2), *Q. velutina* (1,2)
CERAMBYCIDAE			
Amniscus macula	2	1 June– 8 June	*Q. velutina* (2)
Cyrtophorus verrucosus	6	8 June– 4 July	*Q. alba* (2), *Q. velutina* (2)
Euderces picipes	3	3 June–11 June	*Q. velutina* (2)
Graphisurus fasciatus	28	8 June–29 June	*Q. alba* (2), *Q. rubra* (2), *Q. velutina* (1,2)
Neoclytus acuminatus	4	17 June–26 June	*Q. rubra* (2), *Q. velutina* (2)
Sarosesthes fulminans	7	20 June– 4 July	*Q. velutina* (2)
Xylotrechus colonus	13	8 June– 4 July	*Q. rubra* (2), *Q. velutina* (2)

[a]Parenthetical numbers represent the host tree condition in 1979 during the period of adult emergence: 1 = oaks dead for ca. 1 year (died fall 1978), 2 = oaks dead for ca. 2 years (died fall 1977).

1923, respectively). On no occasion did we collect *C. femorata* or *G. fasciatus* from category 3 oaks without also collecting *A. bilineatus*, but *A. bilineatus* was at times the only borer recovered from a given trap. Savely (1939) also found the above three borers, as well as *X. colonus*, together in oak logs sampled within a year of felling. Craighead (1923) reported a one-year life cycle for *X. colonus*. However, Gardiner (1960) stated that two years were required for *X. colonus* to complete development in Quebec. A one-year life cycle has also been reported for *N. acuminatus* (Baker 1972), *A. macula* (Craighead 1923), and *C. verrucosus* (Duffy 1953). To our knowledge, voltinism data are not available for *E. picipes* and *S. fulminans*. However, Craighead (1923) and Knull (1946) reported that these two species normally attack dead wood, often the season following tree death. If this was the case in our study, then *E. picipes* and *S. fulminans* would be univoltine in Wisconsin since they emerged from oaks the second summer following tree death.

Although category I oaks had appeared unattacked, two of the five oaks had been attacked by *A. bilineatus* in 1979. Nevertheless, as Haack and Benjamin (1982) reported, all recovered *A. bilineatus* larvae (n = 83) had died as first or second instars. Only one other borer was found, a *Chrysobothris* larva. This larva was found alive in the cambial region of a branch sample (7 cm dia.) where three dead *A. bilineatus* larvae were recovered. Apparently, *A. bilineatus* seldom attacks relatively vigorous oaks, but when it does, larval development is usually not successful. Borers other than *A. bilineatus* seem to attack vigorous oaks even less often; the above *Chrysobothris* larva probably arrived once *A. bilineatus* larvae were already present based on the apparent precedence of the latter's galleries.

Category II oaks had 25–50% crown death after one season of *A. bilineatus* attack. We recovered larvae of *A. bilineatus* and *Chrysobothris*, and pupae and teneral adults of *Pseudopityophthorus minutissimus* (Zimmerman) (Scolytidae); the percentage of samples containing each borer and the host tissues from which they were collected are given in Table II, and their mean densities are presented in Figure 1. Over 90% of the *A. bilineatus* larvae were in pupal cells constructed in outer bark if thick or in sapwood if the bark was thin. However, *A. bilineatus* larvae feed and develop primarily in phloem (inner bark). Two of the

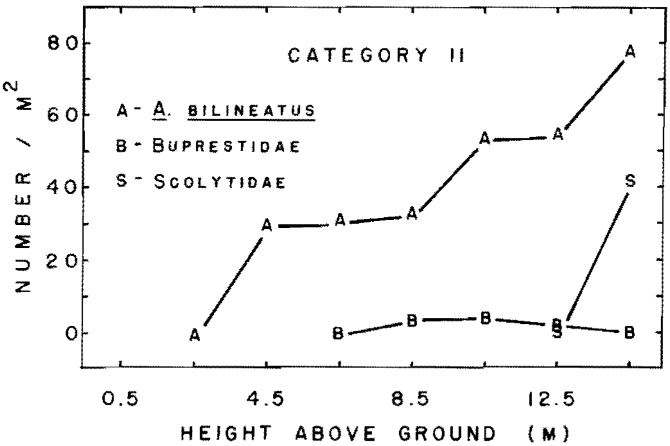

Fig. 1. Mean *Agrilus bilineatus*, Buprestidae (*Chrysobothris*), and Scolytidae (*Pseudopityophthorus*) densities at various heights above ground for five oaks sampled in December 1979 that had 25–50% crown death in September 1979 after one season of *A. bilineatus* attack, Kettle Moraine State Forest, Jefferson Co., Wisconsin.

Chrysobothris larvae were found constructing pupal cells in the sapwood; the others were in the cambial region. *P. minutissimus* was recovered from a single gallery system in a 4-cm-dia. branch sample. Also working in Wisconsin, McMullen et al. (1955) recorded two *P. minutissimus* generations per year with flight periods in May and August, and with last-instar larvae being the overwintering form. In our study, the relatively warm fall temperatures of 1979 may have allowed for more advanced development (pupae and adults) relative to the McMullen et al. (1955) study (larvae). In southern Ohio, *P. minutissimus* successfully overwinters in every stage but the pupal stage (Rexrode 1969). No empty *P. minutissimus* galleries (representing the first generation of 1979) were observed. This is not surprising because this beetle normally infests only dead or dying oaks (Rexrode 1969). Therefore, the category II oaks were probably not suitable for *P. minutissimus* colonization during its May flight period. However, by August, these oaks were suitable for *P. minutissimus*, as a result of the *A. bilineatus* branch-girdling that had taken place that summer.

Category III oaks had died the year of sampling after one season of *A. bilineatus* attack. We recovered larvae of *A. bilineatus*, *Chrysobothris*, and *Graphisurus*, and brood of *P. minutissimus* (Table II, Fig. 2). Larval densities of *A. bilineatus* were highest in the upper clear bole; major branching began between 7 and 9 m in the oaks of this study. Over 90% of the *A. bilineatus* were recovered from pupal cells. We found 24 *Chrysobothris* larvae constructing pupal cells in sapwood and 37 in the cambial region. All *Graphisurus* larvae were collected from the same tree; two of the 17 larvae were constructing pupal cells in the cambial region. We collected last-instar larvae, pupae, and callow adults of *P. minutissimus* from one branch sample (5 cm dia.).

Category IV oaks had died in the year of sampling after two seasons of *A. bilineatus* attack. We collected larvae of *A. bilineatus*, *Chrysobothris*, *Graphisurus*, *Neoclytus*, and *Xylotrechus*, and brood of *P. minutissimus* and the ambrosia beetles (Scolytidae) *Monarthrum fasciatum* (Say), *Monarthrum mali* (Fitch), and *Xyloterinus politus* (Say) (Table II, Fig. 3). Note that the values given for the numbers of ambrosia beetles in Table II represent numbers of active galleries, not numbers of individuals. No living *A. bilineatus* larvae were found above the 6.5-m sampling height where it had attacked the year before; the average lowest extent of *A. bilineatus* exit holes was ca. 7.5 m. Current *A. bilineatus* larval densities

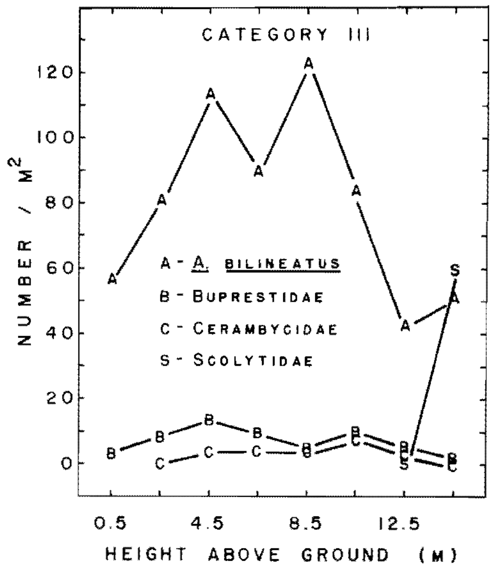

Fig. 2. Mean *Agrilus bilineatus*, Buprestidae (*Chrysobothris*), Cerambycidae (*Graphisurus*), and Scolytidae (*Pseudopityophthorus*) densities at various heights above ground for five oaks sampled in December 1979 that had died in September 1979 after one season of *A. bilineatus* attack, Kettle Moraine State Forest, Jefferson Co., Wisconsin.

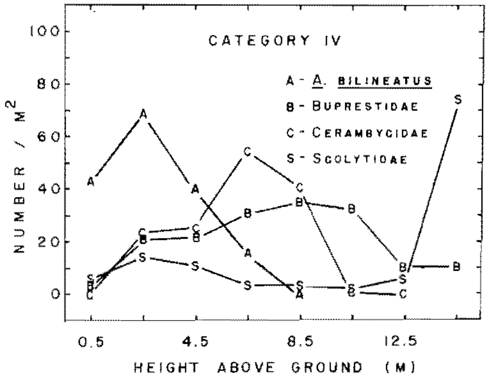

Fig. 3. Mean *Agrilus bilineatus*, Buprestidae (*Chrysobothris*), Cerambycidae (*Graphisurus*, *Neoclytus*, *Xylotrechus*), and Scolytidae (*Monarthrum*, *Pseudopityophthorus*, *Xyloterinus*) densities at various heights above ground for five oaks sampled in December 1979 that had died in September 1979 after two seasons of *A. bilineatus* attack, Kettle Moraine State Forest, Jefferson Co., Wisconsin.

were highest in the 2.5-m samples; lower densities at 4.5 and 6.5 m may be related to the relatively drier condition of the cambial region through either differential larval mortality (if egg density was uniform) or differential oviposition (if parent females oviposited preferentially), or a combination of both. We found 35 *Chrysobothris* larvae constructing pupal cells in sapwood and 112 in the cambial region. *Chrysobothris* densities were highest in the upper trunk of category IV oaks where *A. bilineatus* had attacked the previous year. *Graphisurus* larval densities were highest in the region (6.5 and 8.5 m) that represented the lowest extent of *A. bilineatus* infestation during the previous year. In the cambial region, a few *Graphisurus* larvae but no *Xylotrechus* larvae were preparing pupal cells. *Xylotrechus* and *Neoclytus* larvae were recovered primarily in samples from the zone between previous-year and current-year *A. bilineatus* attack. The active galleries of *M. fasciatum* and *X. politus* contained mostly callow adults and some pupae; *M. mali* galleries had callow adults only. In Indiana, *X. politus* overwinters as adults and is univoltine (MacLean and Giese 1967). In Missouri, *M. fasciatum* overwinters as adults and completes 2–3 generations per year with the initial flight period occurring between late March and mid-May (Roling and Kearby 1974). In Wisconsin, *X. politus* appears to be univoltine with adult emergence occurring mostly from early April to mid-May (J. O. Haanstad, pers. comm.).[5] Flight period data are not available for the *Monarthrum* species in Wisconsin, but they are probably similar to that of *X. politus* because we found galleries of *X. politus* and *Monarthrum* spp. of similar length and having similar life stages in the same oaks sampled in June 1979. Therefore, since the *A. bilineatus* flight period does not occur until early June in Wisconsin (Haack and Benjamin 1982), the lower trunk of these oaks was probably attacked first in 1979 by ambrosia beetles. We also noticed in these category IV oaks that *A. bilineatus* larval mines seldom were found in the stained region of phloem and sapwood surrounding the entrance hole of each ambrosia-beetle gallery, suggesting that the staining (and thus the ambrosia beetles) preceded *A. bilineatus*. The relatively early flight period of the ambrosia beetles may help to explain why none were collected in our adult-emergence study; traps were installed the third week of May which was after their peak flight. The *P. minutissimus* brood (adults and pupae) was recovered from two galleries in the same branch sample (8 cm dia.) that had been infested the previous year by *A. bilineatus*, indicating that this scolytid attacks material both concurrently with and the year following *A. bilineatus* attack.

Category V oaks had died the year prior to sampling after at least two seasons of *A. bilineatus* attack. We found larvae of *Chrysobothris*, *Dicerca* (Buprestidae), *Cyrtophorus*, *Graphisurus*, *Neoclytus*, *Sarosesthes*, and *Xylotrechus*, and brood of *X. politus* (Table 2, Fig. 4). *Chrysobothris* larvae were found only in lower-trunk samples, indicating that they infest material killed the previous year but not material killed two seasons earlier; seven larvae were in sapwood and 17 in the cambial region. However, the *Dicerca* larvae were only found in samples from branches that had died two seasons earlier. Savely (1939) collected *Dicerca* larvae from oak logs sampled ca. two years after felling. The cerambycid larvae were collected primarily from the lower trunk where death had occurred the previous year. Nevertheless, a few *Graphisurus*, *Neoclytus*, and *Xylotrechus* larvae (n = 18) were collected from branches that had died two seasons earlier. It is uncertain if these larvae had developed from eggs laid in 1978 or 1979. However, since (1) most larvae appeared fully grown and were in or constructing pupal cells, (2) cerambycid exit holes were already present in some of these same samples, and (3) the phloem and xylem in these samples appeared very dry relative to the lower-trunk samples, it is probable that these larvae began development in 1978 and thus would have required two years to complete their life cycle. *Sarosesthes* larvae were most common at 2.5 m; this species appeared to prefer the lower trunk of oaks having died the previous season. Active *X. politus* galleries were found mostly in lower trunk samples. Apparently, this scolytid attacks oaks the year after death, but not portions having died two seasons earlier. We found several old galleries of *M. fasciatum*, *M. mali*, and *X. politus* that were active the previous season; old *P. minutissimus* galleries were also present.

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Table 2. Percent of oak samples containing Buprestidae, Cerambycidae, and Scolytidae described by host condition category and height above ground (5 oaks/category; Kettle Moraine State Forest, Jefferson Co., Wisconsin; December 1979).

	Sampling Heights (m)									
Borer	0.5	2.5	4.5	6.5	8.5	10.5	12.5	14.5	(N[a])	Site[b]
Category II Oaks										
A. bilineatus	—	—	80	80	100	100	100	100	(186)	B,C,SW
Chrysobothris	—	—	—	—	60	40	20	—	(6)	C,SW
P. minutissimus	—	—	—	—	—	—	—	20	(8)	C
Category III Oaks										
A. bilineatus	100	100	100	100	100	100	100	100	(638)	B,C,SW
Chrysobothris	60	40	40	20	20	20	60	20	(61)	C,SW
Graphisurus	—	20	20	20	20	20	20	—	(17)	C
P. minutissimus	—	—	—	—	—	—	—	20	(14)	C
Category IV Oaks										
A. bilineatus	100	100	100	60	—	—	—	—	(230)	B,C,SW
Chrysobothris	20	80	80	100	100	80	40	20	(147)	C,SW
Graphisurus	—	60	80	80	60	—	—	—	(137)	C
Neoclytus	—	—	—	60	60	20	—	—	(11)	SW
Xylotrechus	—	—	—	80	80	—	—	—	(14)	C
M. fasciatum	—	20	40	—	—	—	—	—	(3)	SW
M. mali	20	20	—	—	—	—	—	—	(3)	SW
P. minutissimus	—	—	—	—	—	—	—	20	(14)	C
X. politus	60	60	80	60	20	20	—	—	(42)	SW
Category V Oaks										
Chrysobothris	60	80	40	—	—	—	—	—	(24)	C,SW
Dicerca	—	—	—	—	20	20	—	—	(2)	C
Cyrtophorus	—	20	20	20	20	—	—	—	(4)	SW
Graphisurus	100	100	100	100	20	20	—	—	(99)	C
Neoclytus	—	20	60	40	40	40	—	—	(11)	SW
Sarosesthes	60	100	60	20	—	—	—	—	(28)	C,SW
Xylotrechus	80	100	100	60	80	—	—	—	(48)	C
X. politus	80	80	80	20	—	—	—	—	(40)	SW

[a]N = the number of individuals (or gallery systems for the ambrosia beetles: *M. fasciatum*, *M. mali*, *X. politus*) recovered from all samples for the indicated host condition category of oaks.
[b]Site refers to the area(s) in which each borer was recovered: B = outer bark, C = cambial region, SW = sapwood.

SUMMARY

A successional pattern of Buprestidae, Cerambycidae, and Scolytidae can now be approximated for a typical declining oak in Wisconsin. In general, *A. bilineatus* begins the assault by first attacking the branches and upper trunk during the summer of year one. At times, *A. bilineatus* is joined that first summer by small numbers of *Chrysobothris*,

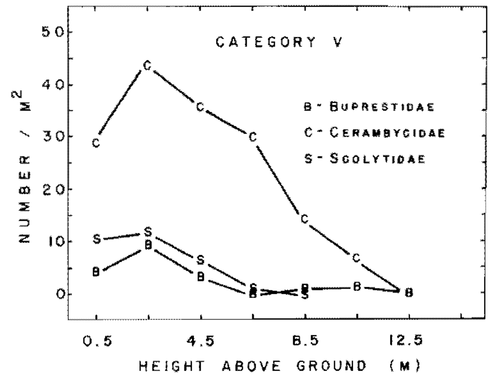

Fig. 4. Mean Buprestidae (*Chrysobothris, Dicerca*), Cerambycidae (*Cyrtophorus, Graphisurus, Neoclytus, Sarosesthes, Xylotrechus*), and Scolytidae (*Xyloterinus*) densities at various heights above ground for five oaks sampled in December 1979 that had died in fall 1978 after at least two seasons of *A. bilineatus* attack, Kettle Moraine State Forest, Jefferson Co., Wisconsin.

Graphisurus, and *P. minutissimus*. During spring of year two, the lower trunk is colonized by ambrosia beetles such as *M. fasciatum, M. mali,* and *X. politus*. In the summer of year two, *A bilineatus* moves its attack to the lower trunk where ambrosia beetles have already begun construction of their galleries. Also at this time, *Chrysobothris* and *Graphisurus* may join *A. bilineatus* in the lower trunk, and also reattack the upper trunk and crown along with *P. minutissimus*. Joining *Chrysobothris* and *Graphisurus* in the upper trunk during the summer of year two are *Neoclytus* and *Xylotrechus*. In spring of year three, *X. politus* continues to colonize the lower trunk which had died in the fall of year two. In the summer of year three, following the exit of *A. bilineatus*, the lower trunk is now infested by *Graphisurus, Neoclytus,* and *Xylotrechus* as well as *Cyrtophorus* and *Sarosesthes*. The upper trunk and major branches which had died two seasons earlier are now suitable for *Dicerca* infestation. In this way the insect fauna in the crown branches, upper trunk, and lower trunk changes from year to year during the decline of an oak tree and also after its death.

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