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Transportation of phytopathogenic fungi by the bark beetle *Ips sexdentatus* Boerner and associated mites

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Abstract

The bark beetle *Ips sexdentatus* carries several types of conidiospores and ascopores in the pronotal punctures located around the setae on the sides of the pronotum. For swarming beetles, some of the spores seem to be germinating.

Nine species of mites were phoretic on swarming *Ips sexdentatus* in France. Hypophoretic on these mites were 16 morphologically distinct types of fungal ascopores and conidia, but lesser kinds of spore types were seen on the beetles. Although the spores seemed to stick anywhere on the mites, masses of spores were concentrated in punctures on the sides of the beetle pronota. Ascospores of *Ophiostoma brunneo-ciliatum* were the most common ascospores both on the mites and the beetle, but ascospores of the potentially pathogenic *O. minus* were present on five mite species.

1 Introduction

In Europe, bark beetles are the most important pests of Scots pine (*Pinus sylvestris* L.) and the damages caused by these insects have increased for the past several years in France. In many scolytids, some associated fungi are necessary for larval survival, others may be pathogenic to the tree and/or the beetles. Transmission of phytopathogenic fungi is often a prerequisite for the successful establishment of beetle populations in the host trees (Berryman 1972; Raffa and Berryman 1983; Christiansen and Horntvedt 1983). This note is a contribution to a study dealing with the relationships between bark beetles, Scots pine and associated fungi (Lieutier et al. 1988). It concerns the transportation of spores by *I. sexdentatus.*

Many xylophagous insects carry fungi. However, their methods of transportation, as well as the level of intimacy between these two types of organisms varies considerably. Some associations are truly symbiotic (Buchner 1953; Francke-Grossman 1963a, 1976; Graham 1967; Whitney 1982). The ways by which fungi are carried by bark and ambrosia beetles are relatively well known. In the closest associations, special organs called mycangia contain the spores. A detailed classification of these structures can be found in Francke-Grossman (1963b). These storage zones are supplied with one or more secretory cells whose secretions may promote the preservation and propagation of the spores (Happ et al. 1971; Schneider and Rudinsky 1969).

The roles of the bark beetles associated fungi are diversified. Some of them are saprophytic in the wet wood, others decompose cellulose and pectins (Buchner 1930), while still others are fed on by mycetophagous or xylomycetophagous bark beetle larvae (Hartig 1872; Doane and Gilliland 1929; Mathiesen-Käärik 1953; Wood 1982; Whitney 1982). Some of these fungi can be pathogenic to the trees and are inoculated by bark beetles or their associated mites, more or less accidentally (Reid et al. 1967; Berryman 1972; Barras and Perry 1971, 1972; Safranyik et al. 1975; Wood 1982; Bridges and Moser 1983; Christiansen and Horntvedt 1983).

2 Materials and methods

In 1986, 51 male and female adult beetles were examined during two stages of their life-cycle, the end of overwintering and swarming. Overwintering beetles were collected from attacked trees in the forest of Orléans (France). For the swarming beetles, attacked logs were cut in the forest before swarming, stored in the lab at 20–25 °C, and the insects caught while flying as they emerged from the logs. All these beetles were examined with a scanning electron microscope (STEREOSCAN 100 of Cambridge EIL with a resolution capacity of 70 Å) after being stained with a silver-ethyl glycol ring, dehydrated under vaccuum and coated with platinum. The observations were made either on the whole beetles or on pieces of their cuticle after dissection.

Ninety-four swarming *I. sexdentatus* were captured and immediately preserved in 70 % ethyl alcohol for examination for phoretic mites. Mites were cleared in lactophenol, mounted on slides in Berlese's Media, identified, and then carefully examined for spores of fungi.

3 Results

3.1 Observations with insects

The beetles were very clean, with little or no frass on most of the exposed parts of the body (vertex, mandibles, legs, pronotum, dorsal part of the elytra). No differences between males and females were noticed. The elytral declivity was often littered with wood fragments and frass. Masses of spores of various shape were regularly seen on overwintering beetles in the pronotal punctures located around the setae on the sides of the pronotum (fig. 1 and 2). Most of them were conidiospores, but it was possible, in addition, to notice rectangular ascospores, about 4 to 5 μm long, slightly depressed in their center and

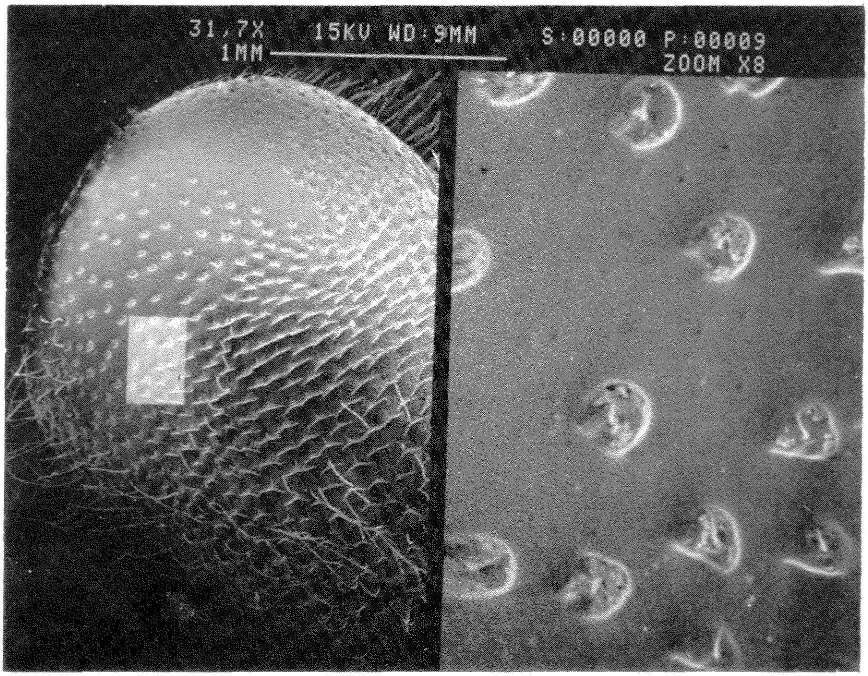


Fig. 1. Ips sexdentatus. Left: lateral view of the pronotum with punctures containing spores located around the setae (× 32); *right*: magnification of the same zone (× 254)

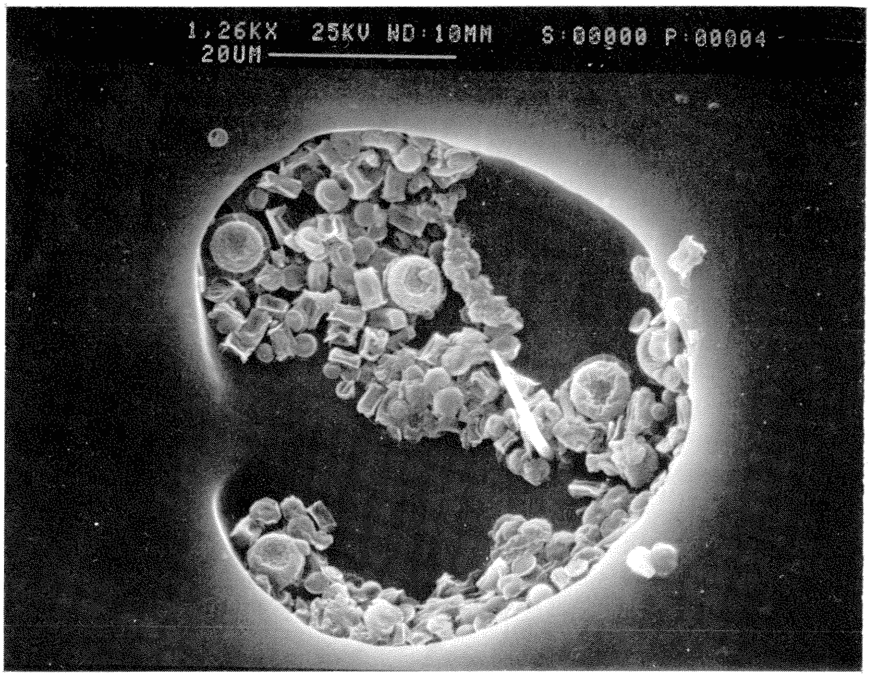


Fig. 2. Pronotal punctures with six apparently different types of spores (× 1260)

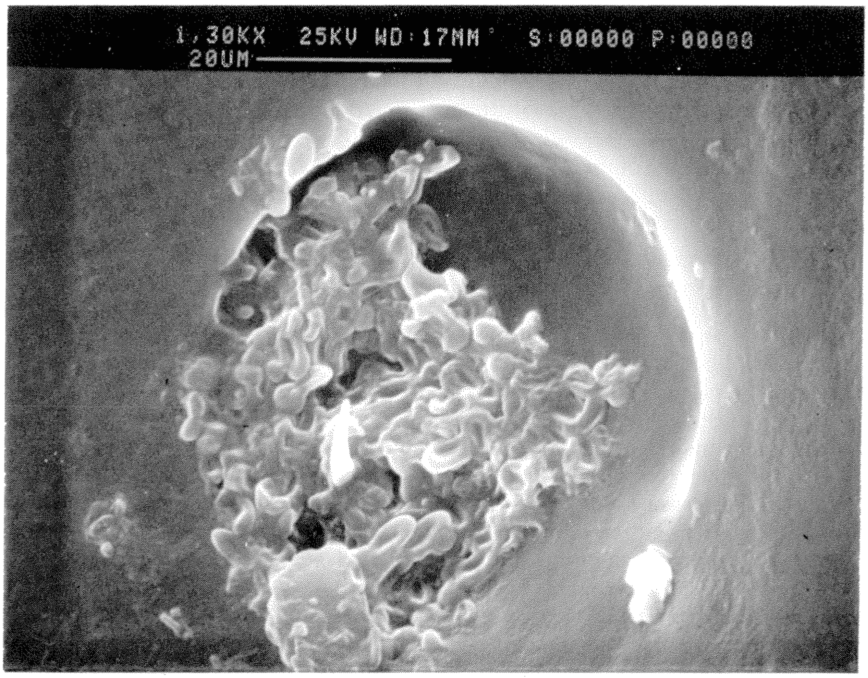


Fig. 3. Spores germinating in a elytral puncture of a swarming *Ips sexdentatus* (× 1300)

ornamented with small expansions at the angles, these ascospores seemed characteristic of the ascospores of *Ophiostoma* (section 2) *ips* (UPADHYAY 1981). The top of the pronotum was always absolutely clean. Other groups of spores, sometimes mixed with frass, were infrequent in the rounded hollows of the strial punctures on the elytra and its declivity. Occasionally, spores could be noticed at various locations on the body, such as under the abdominal sternites or in the punctures of the external side of the mandibles. These occasional locations changed from beetle to beetle. After dissection, no special zone of anchorage could be seen internally, or on those external body parts unable to be observed from outside the beetle.

For swarming beetles these observations sometimes showed that some of the spores located in the above mentioned sites seemed to be germinating (fig. 3).

3.2 Phoretic mites

A total of ten of the 94 beetles were examined for phoretic mites. All ten possessed mites, with an average number of 7.7 and extremes of 3 and 14. This is a conservative estimate, since many mites fell off the beetles after they were placed in alcohol.

Five mite species were found on the 10 beetles with total numbers as follows. *Histiostoma ovalis* (33), *Trichouropoda polytrichasimilis* (24), *Uroobovella ipidis* (11), *Iponemus gaebleri* (5), and *Dendrolaelaps quadrisetus* (4). A survey of another 10 beetles shows where these mites were attached as they rode the beetles (table 1).

The alcohol sediments revealed 9 species of mites, including the five species mentioned above (table 2). The four additional species were as follows with the total number recovered in parentheses. *Vulgarogamasus* n. sp. (10), *Calvolia* sp. (3), *Proctolaelaps fiseri* (3), and *Lasioseius penicilliger* (1). Since the latter were taken from the total population of 94 beetles, it follows that they were much less common than the five species attached to the 10 beetles.

U. ipidis, I. gaebleri, D. quadrisetus, Vulgarogamasus n. sp., and *P. fiseri* were also documented by MOSER and BOGENSCHÜTZ (1984) as associates of the spruce bark beetle *Ips typographus*. *H. ovalis, T. polytrichasimilis* and *L. penicilliger* are known from other bark beetles, but the *Calvolia* sp. (probably a new species) apparently is known only from *Ips sexdentatus*.

The biologies of most of the above mites are unknown, except for *D. quadrisetus,* which feeds on nematodes, and *I. gaebleri,* which parasitizes the eggs of *Ips* spp. (GAEBLER 1947).

3.3 Hyperphoretic fungi on mites

Of the 135 mites found on the beetles and vial sediments, 134 were scanned for fungal spores (table 2). Ascospores were seen on eight of the nine species of mites, and all nine species carried conidia; bodies of all except eight of the 134 mite specimens had spores. Those ascospores (figs. 4–11) and conidia (fig. 8, 12–16) that could be typed are listed in table 2; these include unidentifiable conidia [MSC (fig. 16)]. The spores seemed to stick anywhere on the mite bodies, with no special housing structures (sporothecae) evident. In table 2 the numbers of spores carried by the mites may be conservative because it is possible that large numbers of spores were washed off in the alcohol used for storing the bark beetle specimens or in processing the mites for mounting on slides.

The second most common mite species, *Trichouropoda polytrichasimilis,* carried all of the ascospore and conidial types, but two other common species, *Histiostoma ovalis* and *Uroobovella ipidis* carried all but one rare ascospore type. Although *H. ovalis* is smaller than the other two common mite species, this species may have had access to unusually large numbers of spores because mites of the genus *Histiostoma* tend to live in "soupy" environments where numbers of spores may be greater. Even the tiny scolytid egg parasite,

Table 1. **Attachment sites by phoretic mites on *Ips sexdentatus***

Mite species	Under elytron	On elytron	Elytral declivity	Abdomen ventral	Thorax dorsal	Thorax ventral	Coxa	Leg	Head	Unknown	Total
Histiostoma ovalis	2	1	3	1	0	14	5	0	7	14	47
Trichouropoda polytrichasimilis	0	0	32	0	0	10	9	0	0	1	53
Iponemus gaebleri	0	0	3	0	0	1	0	0	1	0	5
Uroobovella ipidis	0	1	1	0	1	9	5	2	1	0	20
Dendrolaelaps quadrisetus	5	0	0	0	0	0	0	0	0	0	5

Table 2. **Mite species examined and estimates of ascospore numbers**

		Ascospore types												Conidia types						
		ACAR	SH	LH	PIC		MIN		B/B		MUS		LHU	FUS	LEP	CHAL	CLAD	YST	MSC	SPO 1/
	N	L	L	L	L	H	L	H	L	H	L	H	L	P	P	P	P	P	P	P 2/
		Number of mite individuals with ascospore type												Number of mite individuals with conidia types						
MITE SPECIES																				
Histiostoma ovalis	43	.	6	6	4	.	1	.	25	1	4	.	1	2	7	3	9	7	32	1
Trichouropoda polytrichasimilis	29	.	2	2	5	.	3	1	12	.	1	.	1	10	17	2	10	12	25	1
Iponemus gaebleri	15	.	.	1	.	.	1	.	3	.	.	.	.	1	6	1	.	1	11	.
Uroobovella ipidis	21	2	2	2	4	1	2	1	10	1	1	.	1	3	6	1	4	6	18	1
Dendrolaelaps quadrisetus	9	.	3	1	.	.	.	.	3	.	.	1	.	1	4	.	3	4	6	.
Vulgarogamasus n. sp.	10	.	.	4	.	.	.	.	8	.	2	.	1	7	6	3	5	6	7	.
Lasioseius penicilliger	1	.	2	.	.	.	.	.	.	.	.	.	.	1	1	.	1	1	1	.
Calvolia sp.	3	.	1	.	1	.	.	.	3	.	1	.	.	.	.	.	.	.	1	.
Proctolaelaps fiseri	3	.	1	2	.	.	.	.	3	.	.	.	.	.	.	.	.	.	2	. .
All	134	2	15	18	14	1	7	2	67	2	9	1	4	25	47	10	32	37	103	3

1/ Abbreviations for spore types are explained in figure captions.
2/ L = less than 30 spores/mite individual. Example: Two individuals of *Uroobovella ipidis* had less than 30 spores each on the bodies of the mites. H = More than 30 spores/mite individual. P indicates that spores were present on mite individuals regardless of the number of spores.

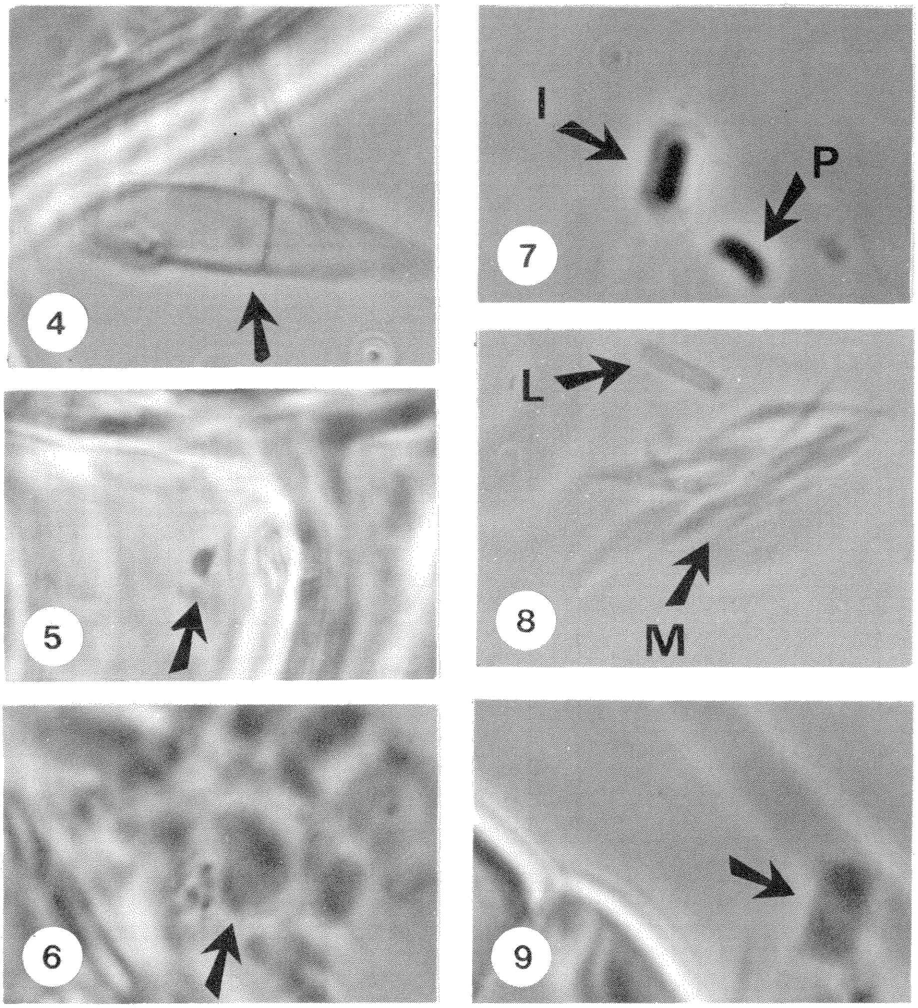


Fig. 4. A spindle-shaped, two celled spore of *Pyxidiophora* (as *Acariniola subbasilipunctata*) (ACAR of table 2) attached by a darkened holdfast appears to be detached from the rest of the body, but it is not. Spore measures 28 × 5 microns (slide = 34,470). This and all mites in the following figures were phoretic *Ips sexdentatus* reared and collected in May 1986 by F. LIEUTIER from bolts of *Pinus sylvestris* from the Forest of Orléans, France. – *Fig. 5.* A small, hat-shaped ascospore (arrow) of a yeast (probably *Hansenula* or *Pichia* (SH of table 2) hypophoretic on *Trichouropoda polytrichasimilis* female (× 2500). Spore measures 2.5 × 2 microns (slide # 34,422). – *Fig. 6.* A group of large, hat-shaped ascospores (arrow) of *Ophiostoma* section *Ceratocystis* (LH of table 2) hypophoretic on *Histiostoma ovalis* deutonymph (× 2500). Spore measures 5 × 3 microns (slide # 34,461). – *Fig. 7.* Orange-section shaped ascospore of *Ophiostoma picea* (P) (PIC of table 2) (spore measures 3.0 × 1.5 microns), and *O. bicolor* (I) (B/B of table 2) (Spore measures 5.6 × 4.0 microns). Hypophoretic on *Trichouropoda polytrichasimilis* female (× 2500) (slide # 34,471). – *Fig. 8.* A group of spindle-shaped ascospores (M) of *Ceratocystiopsis minuta* (MIN of table 2) (Spore measures 13 × 1 microns), and a single, rod-shaped *Leptographium/graphium* conidia (L) (LEP of table 2) (spore measures 5 × 1 microns). Hypophoretic on *Iponemum gaebleri* female (× 2500) (slide # 31,943). – *Fig. 9.* A rectangular-shaped ascospore (arrow) of *Ophiostoma brunneo-ciliatum* (B/B of table 2) hypophoretic on *Histiostoma ovalis* deutonymph (× 2500). Spore measures 5 × 2.5 microns (slide # 34,419)

Iponemus gaebleri, carried moderate numbers of spores. Numbers of spores on individual mites varied from a single spore to hundreds, but most ascospores, at least, were present on mites in numbers of less than 30 (table 2). Numbers of conidia tended to be higher, and for this reason we only recorded them as "present (= P)", when seen.

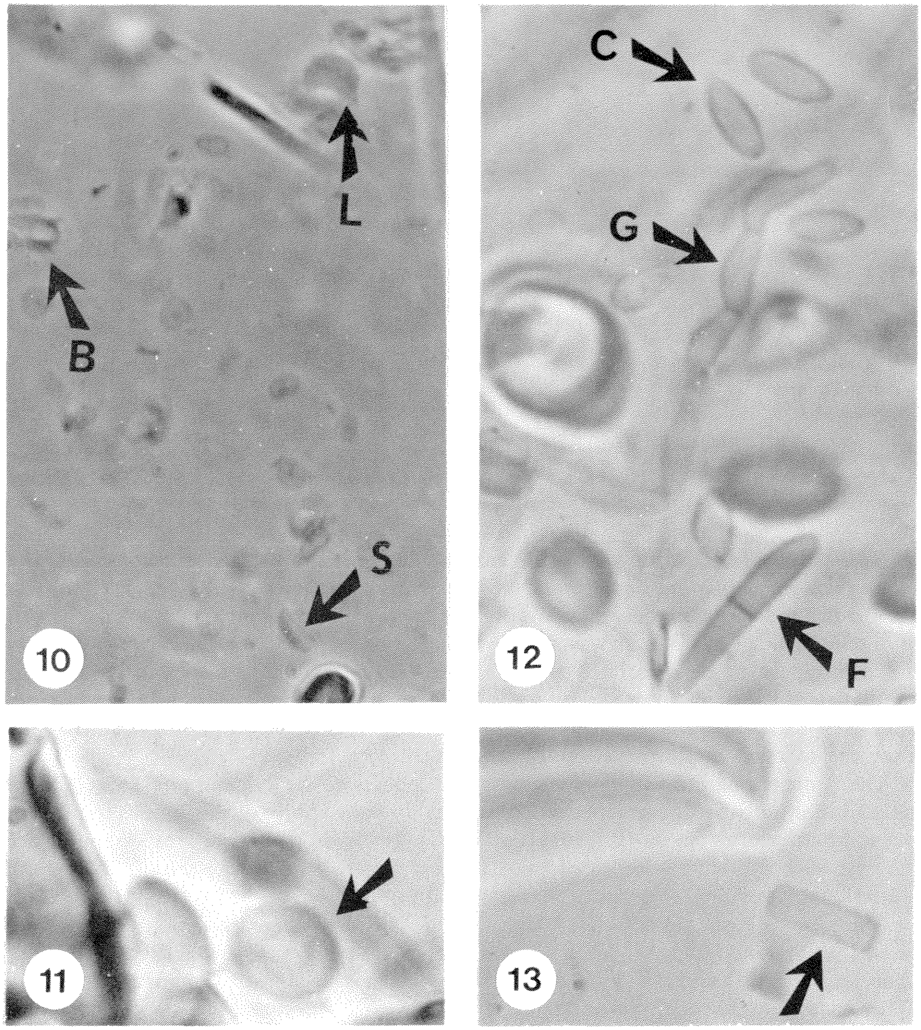
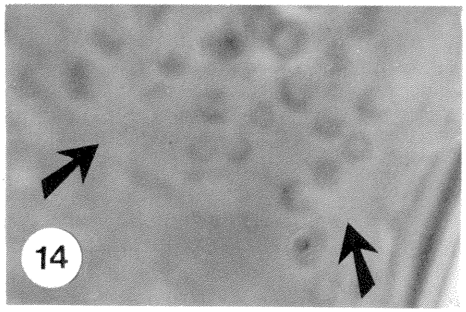
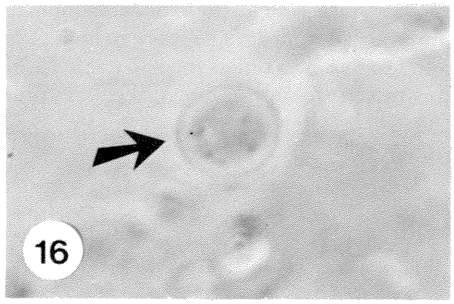


Fig. 10. Ascospores of *Ophiostoma brunneo-ciliatum* (B) (B/B of table 2) (spore measures 5 × 3 microns), *O. europhioides* Solheim (L) (LH of table 2) (spore measures 7 × 4 microns), and *Ophiostoma minus* (S) (MUS of table 2) (spore measures 5 × 1 microns) hypophoretic on *Dendrolaelaps quadrisetus* deutonymph (× 2500) (slide # 34,515). – *Fig. 11.* A large, hat-shaped undetermined species of *Ophiostoma* (Section *Ceratocystis* [arrow] (LHU of table 2) hypophoretic on *Histiostoma ovalis* deutonymph (× 2500). Spore measures 7 × 5 microns (slide # 34,441). – *Fig. 12.* Conidia of *Fusarium* sp. (F) (FUS of table 2) (spore measures 12 × 2 microns and *Cladosporium* sp. (C) (G – germinating) (CLAD of table 2) (spore measures 6 × 2.2 microns) hypophoretic on *Lasioseius penicilliger* female (× 2500) (slide # 34,516). – *Fig. 13.* Conidium of *Chalara* sp. (arrow) (CHAL of table 2) hypophoretic on *Vulgarogamasus* n. sp. deutonymph (× 2500). Specimen measures 7 × 2 microns (slide # 34,502)





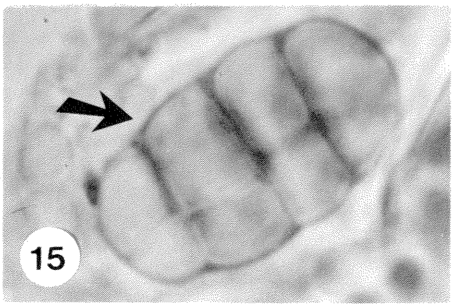


Fig. 14. Spores of an unidentified species of yeast (arrow) (YST of table 2) hypophoretic on *Dendrolaelaps quadrisetus* female (× 2500). Specimen measures 2 × 2 microns (slide # 34,489)
Fig. 15. Conidium of *Altenaria* sp. (arrow) (one of a number of species of miscellaneous conidia – MSC of table 2) hypophoretic on *Trichouropoda polytrichasimilis* (× 2500). Specimen measures 20 × 12 microns (slide # 34,439). – *Fig. 16.* Chlamydospores of *Sporothrix* sp. (arrows) (SPO of table 2) hypophoretic on *Uroobovella ipidis* deutonymph (× 2500). Specimen measures 6 × 6 microns (slide # 34,483)

All ascospores except the yeast were either *Ophiostoma* or closely related genera. The rectangular-shaped *Ophiostoma brunneo-ciliatum* (figs. 9, 10)/*O. bicolor* (fig. 7) (B/B) was the most abundant in numbers of ascospores, and was seen on the most mite species as well as mite individuals; *O. bicolor* was seen less often. In related studies, *O. brunneo-ciliatum* did not appear to be associated with *Ips typographus,* whereas *O. bicolor* was most common (Moser et al., in press; Solheim 1986). Five other species of ascospores listed in table 2 [ACAR (fig. 4), SH (fig. 5), LH (figs. 6, 10), PIC (fig. 7), and MIN (fig. 8)] may share the subcortical habitats of both bark beetles.

The presence of limited numbers of what appears to be *Ophiostoma minus* [MUS fig. 10)] is of potential concern because of the highly toxic nature of this fungus to pines in the southern United States (Bridges and Moser 1986). In this latter area its abundance may be related to the presence of two "carrier" mites, *Tarsonemus ips* and *T. krantzi* (Moser 1985), neither of which were found in this study.

The genus *Pyxidiophora* [ACAR (fig. 4)] and its related genera form one of the most fascinating and least understood of all the fungi (Blackwell et al. 1986). These two-celled spores adhere to the mites with a darkened holdfast specialized for phoretic dispersal. Whereas large numbers of this or related species have been found on other mites associated with bark beetles, only one and two spores respectively were seen on the mites in this study.

The small-hat yeasts [SH (fig. 5)] seem to be ubiquitous associates of mites associated with bark beetles, a number being found with spruce attacked by *Ips typographus* (Leufven and Nehls 1986). They listed *Hansenula* and *Pichia* as common genera. Spores were found on most mite species.

Sporothrix spp. [SPO (fig. 16)] and *Leptographium/Graphium* spp. [LEP (fig. 8)] are the conidial stages of one or more species of *Ophiostoma/Ceratocystiopsis* spp. Hence, these conidia may be the same species of one or more of the ascospores discussed in figures 4–11. On the other hand, *Chalara* spp. [CHAL (fig. 14)] is the conidial stage only of the genus *Ceratocystis,* ascospores of which we could not identify in this study.

4 Discussion

Our microscopical observations are consistent with those of MATTHIESEN (1950), RENNERFELD (1950), MATTHIESEN-KÄÄRIK (1953) and LIEUTIER et al. (1988), about isolations on malt agar medium. Nevertheless, some species such as *Ceratocystiopsis* sp. were observed on the bodies of mites but had not been noticed in the malt agar cultures. Otherwise, only one species of *Ophiostoma* was found on the beetle itself whereas at least 12 were observed on the acari. Possibly some hidden sites of transport have not been found on the beetle body, but it is also possible that the phoretic acari play an important role in the transportation of the fungi, as BRIDGES and MOSER (1983) have suggested.

In the european fauna, individuals of *Ips sexdentatus* do not seem to utilize specialized parts of their body (mycangia) for transportation. They rely either on thoracic cuticular depressions to carry spores of their associated fungi, phoretic mites, or perhaps associated insects. Another example of this phenomenon is *Scolytus ventralis* which carries fungal spores in cup-shaped pits covering the top and portions of the side of the head (LIVINSGTON and BERRYMAN 1972). Mites are associated with several other european bark beetles such as *Ips curvidens* and *Dendroctonus micans,* (WOODRING and MOSER 1970), *Ips typographus*, (MOSER and BOGENSCHÜTZ 1984), *Tomicus piniperda* and *T. minor, Pityogenes, chalcographus, Hylurgus ligniperda* etc... (COOREMAN 1963; KIELCZEWSKI and al. 1983...) or with american bark beetles such as *Scolytus unispinosus*, (CROSS and MOSER 1971), *D. frontalis*, (BRIDGES and MOSER 1983), A detailed study of these relationships has been presented by MOSER and ROTON (1971).

Nevertheless, these mainly phoretic relationships do not always imply a direct or indirect role in the transportation of pathogenic fungi by the mites. Two species of the Acarii *Tarsonemus* linked with *D. frontalis* can carry, for example, ascospores of *Ophiostoma minus* (BRIDGES and MOSER 1983, 1986; MOSER and BRIDGES 1986). Six species of *Ophiostoma* associated with european bark beetles may be at least transmitted by tarsonemid mites (FRANCKE-GROSSMAN 1966; KIELZCZEWSKI et al. 1983). In many other cases however, the role of mites in the transportation is unknown. Very often, the major impact of many mites may be predation of larvae or adults of bark beetles (RUST 1933; HETRICK 1940; MOSER and ROTON 1971, 1975) or more likely, symbiotic (WILSON 1980). A detailed study of the respective roles of the 3 components of this complex association beetle-acarii-fungi must be analyzed in each case.

Résumé

Mode de transport de champignons phytopathogènes associés au Scolyte Ips sexdentatus Boerner et à ses acariens phorétiques

Le Scolyte *Ips sexdentatus* peut le plus souvent transporter divers types de conidiospores et d'ascospores dans les dépressions cuticulaires entourant les soies des faces latérales du pronotum. Chez plusieurs esaimants, certaines spores étaient en phase de germination.

9 espèces d'Acariens phorétiques ont été localisées sur des *I. sexdentatus* essaimants. Seize types d'ascospores et de conidies morphologiquement différentes leur sont associées. Bien que ces spores semblent pouvoir se coller n'importe où sur l'Acarien, les masses principales sont localisées dans les dépressions cuticulaires latérales du pronotum. Les ascospores d'*Ophiostoma brunneo-ciliatum* paraissent les plus fréquentes tant sur le Scolyte que sur les Acariens et celles des champignons potentiellement pathogènes *Ophiostoma minus* sont fixées sur 5 espèces d'Acariens.

Le Scolyte *Ips sexdentatus* peut le plus souvent transporter divers types de conidiospores et d'ascopores dans les dépressions entourant les voies des faces latérales du pronotum.

Zusammenfassung

Zur Übertragung phytopathogener Pilze durch den Borkenkäfer Ips sexdentatus Boerner und durch assoziierte Milben

Ips sexdentatus trägt mehrere Konidio- und Ascosporen verschiedener Pilze in der Punktierung des Pronotums, die an der seitlichen Pronotumbeborstung lokalisiert ist. Bei schwärmenden Käfern scheinen einige Sporen auszukeimen.

Auf schwärmenden *I. sexdentatus* konnten in Frankreich 9 phoretische Milbenarten festgestellt werden. Auf diesen Milben konnten die Asco- und Konidiosporen von 16 morphologisch verschiedenen, hyperphoretischen Pilzen festgestellt werden; auf den Käfern selbst wurden jedoch weniger Sporen gefunden. Obwohl die Sporen offensichtlich überall auf den Milben vorhanden sind, waren bei den Käfern größere Sporenmengen in der Punktierung des seitlichen Pronotums vorhanden. Die Ascosporen von *Ophiostoma brunneo-ciliatum* waren die häufigsten Ascosporen, sowohl bei den Käfern als auch bei den Milben. Dagegen konnten die Ascosporen des potentiell pathogenen Pilzes O. *minus* an 5 Milbenarten festgestellt werden.

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