MITES ASSOCIATED WITH FOREST INSECTS

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Reply to Roger Sandquist's DG memo of Dec 8, requesting the expansion of the narrative report for the key environmental factors and partial correlations, the key ecological functions, special habitats, and management scenarios. Figures 1 and 2 and other selected sections from the draft of Narrativ.CRB forwarded to Sandquist Nov 21 is included in this draft of Narativ2; other sections of the original Narrativ.CRB are incorporated in the comment sections of CRBFORMS 1-7.

The food chain relationships may be complex as illustrated by Kinn (1971) for the bark beetle, ***Ips paraconfusus*** (Fig. 1). This emphasizes that one cannot just discuss the mites without also taking into consideration the host insect, fungi, and nematodes. They all interact and depend on one another in the galleries; this is best illustrated by the keystone species, ***Tarsonemus*** n. sp. and its mutualism with the bark beetle mycangial fungus.

Fig. 1. Food chain relationships among some of the mites species, fungi, and nematodes found in the galleries of *Ips paraconfusus*. Broken lines indicated possible food relationships. (After Kinn, 1971).

The association/predation index devised by Wilson (1980) is a useful tool for predicting the impact of mites on their phoretic hosts. Figure 2 (after Stephen et al.) shows that the closer the phoretic relationship between a mite and bark beetle (as measured by the index of association), the less threat that mite may be to the beetle. Thus, mite species with a low index of association may possess high probabilities for predation, whereas mites with a high index may tend to be benign. Although Wilson's concept appears to apply to the southern pine beetle, the model needs to be tested on the mites associated with the various bark beetles in the CRB. A similar model should also be constructed for mites associated with the foliage-feeding insects to see if the mites phoretic on these insects substantially harm them.

Fig. 2. Relationship between the relative closeness of association of mites and *Dendroctonus frontalis* and the observed degree of predation of those mites on *D. frontalis*. (J. C. Moser data, adapted from Wilson, 1980.)

Because of their phoretic habits, we tend to think that subcortical mites are host specific. In reality, most mites in the food web (Fig. 1) are probably more habitat- than beetle specific. Again, this depends on the mite. For instance, *Iponemus* parasitoids of bark beetle eggs are certainly beetle specific, whereas certain predators such *as Proctolaelaps* ***hystricoides*** tend to be more habitat specific because they are associated ***with*** many species of *Dendroctonus, Ips,* and ***Orthotomicus*** (Lindquist 1969b). At the extreme range of habitat preference is ***Histioguster arborsignis*** which not only is ubiquitous in subcortical spaces of both angiosperms and conifers, but can also colonize fungal fruiting bodies growing on wood. This mite's phoretic associations are also broad, with the common factor among hosts being an attraction to or development in wood (OConnor 1990).

Lindquist (1969b) notes that "the introduction and manipulation of new or exotic natural enemies appear to have little potential against scolytids. This is because nearly all of our major scolytid pests are native species, well adapted, and with a complex of many biotic associates." However, Miller et al. (1987) points out that biological control has never been seriously attempted in the United States and should be reconsidered in light of Pimentel's theory of "new associations" (Pimentel 1963). Miller et al. (1987) hypothesize that because the two extraregional and exotic predators ***Thanasimus undulatus*** and *Rhizophagus grandus* ***are*** attracted to pheromones of certain North American bark beetles, that the potential for biological control may be high.

CRBFORM 1 - Keystone species, ***Tarsonemus endophloeus.***

Key Environmental Correlates:

1. Availability of the insect disperser (phoront). Partial correlation: 0.4

Mites associated with bark beetles occupy temporary habitats and must disperse as soon as the living conditions within the gallery begin to deteriorate. Since mites do not have wings, they must rely on organisms that do, such as the bark beetles, and/or their insect associates, or' in very rare instances, birds. In the case of ***T.*** n. sp., this mite is programmed to ride only the western pine beetle (WPB), and only the female mite is capable of phoresy. The mite females crawl to the surface of the bark and wait for the WPB to emerge. When they do, the ***T.*** n. sp. crawl under the elytra and remain there until the new gallery is constructed. Hence., it is crucial that the bark beetle phoront (=phoretic host) be available for the mite to be able to disperse to new habitat.

2. Availability of subcortical fungal food sources. Partial correlation: 0.4

The female ***T.*** sp. carry ascospores of both bluestain (probably ***Ophiostoma nigrocarpum)*** and the mycangial fungus, *Ceratocystiopsis ranaculosus* in a special pouch called the sporotheca. *T.* n. sp. has never been observed in beetle galleries, but a closely related species associated with the southern pine beetle, ***T. krantzi,*** has colonies composed of eggs, larvae, "pupae", and adults, which occur directly on the fungal mats of bluestain, on which the larvae and adults of the mite presumably feed. The mites have not been observed with the mycangial fungus, but the mite may feed on this fungus also since its ascospores are carried in the mite sporotheca. Hence, the mite assures its own food supply by carrying the ascospores of its own food source. It is not known if the mite has other food sources, but Bridges and Moser (1968) speculate that 0. ***minus*** bluestain is the primary food source because the mite was absent in bluestain-free trees infested by the bark beetle. Hence, survival of ***T.*** sp. is dependent on the availability of the subcortical food source.

3. Availability of space under bark beetle elytra. Partial correlation: 0.1

It is not known if the mites compete for the subelytral space available to the mite for phoresy, but this is a possibility. A number of species of mites as well as nematodes occupy this phoretic niche, and some of the mites may be quite large. It is possible, then, that small mites such ***as Tarsonemus*** could be crowded out from the subelytral space, with the result that the "weaker" mite could not be transported to its new destination.

4. Temperature of galleries for mite survival and development. Partial correlation: 0.1

The mite and bark beetle presumably coevolved and with the result that their life histories, including emergence times, are probably synchronized. But if development times of mite and phoront host are not synchronized, then the degree days needed for mite development could be crucial regarding the time needed for development so that the mite could emerge in time to hop on the beetle for dispersal. We also need to know what minimum and maximum temperatures are lethal for survival of the various mite stages in relation to those lethal for the beetle.

Key Ecological Functions:

1. Transports ascospores of mycangial fungus to gallery.

This is necessary not only for nutrition of the beetle brood, but perhaps for the feeding of the mite brood (see 2 above).

2. Transports ascospores of bluestain fungus to tree.

Hobson et al. (1994) presents forceful arguments to show that general occlusion of the xylem, as occurs during mass attack by ***D. brevicomis,*** is not associated with the penetration of the sapwood by hyphae of bluestain fungi. If this is so, then what benefit is this fungus to the beetle? One possible reason is that the mite ***Tursonemus*** n. sp. is dependent on this bluestain as a food source (see 2 above), and in turn the beetle is dependent on the mite to transport its nutritional fungus.

3. Mycangial and bluestain fungal spores within mite sporotheca may be protected from exposure to oleoresins exuding from beetle-induced wounds in the tree.

Unless the spores on the bodies of the incoming beetles and mites are protected, they will probably be washed off by the tree oleoresins. The beetle mycangia and the mite sporotheca protects selected spores to circumvent this washing process.

4. Ascospores transported by ***Tursonemus*** n. sp. may be responsible for establishing sexual compatible colonies of the mycangial fungus in beetle galleries either by themselves or in combination with the beetle mycangial fungus.

Ceratocystiopsis ***ranaculosus*** inhabits the mycangium of ***Dendroctonus brevicomis as*** conidia in a budding yeast-like form. Ascospores are not known to occur in mycangia of bark beetles, and the means of ascospore dispersal has not been previously reported. It is postulated that ascospores transported by the phoretic mite, *Tarsonemus* n. sp., may be responsible for establishing sexually compatible colonies of the fungus in beetle galleries either by themselves or in combination with the mycangial fungus type.

Special Habitats:

There are no special habitats in need of protection for this species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years: Mid-term: 50 years: Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs:

Key research needs to expand the knowledge of the beetle-mite-fungus relationship are A) to determine the abundance of the mite in bluestain-free areas of WPB attack; B) to determine the proportion of phoretic female mites that actually carry ascospores of the mycangial and/or bluestain fungi. Preliminary unpublished studies ***with Tursonemus krantzi*** associated with the southern pine beetle indicate that the percentage of mites actually carrying the spores of the mycangial fungus may be as low as two percent. C) To determine what and how many spores are "washed off" the mite and/or beetle from the time that it leaves the inner bark until after it penetrates the bark of the target tree. D) Mating studies to determine if the ascospores can establish sexual compatible colonies of the mycangial fungus by themselves, or if a combination of the spores from both the mite and the beetle are needed. E) Studies to determine if the name ***Tarsonemus endophloeus*** is a single species or species complex. I suspect that it is the latter because it is recorded from other bark beetles which are not associated with this mycangial fungus. F) In what stage(s) does the mite overwinter? What are the minimum and maximum lethal temperatures for the mite?

CRBFORM2 - Subcortical Mycetophagous Mites.

Key Environmental Correlates:

1. Availability of phoretic disperser (phoront). Partial correlation: 0.1

Mites don't have wings so they must rely on organisms that fly (usually subcortical insects) to be able to disperse. Some mycetophagous mites, such ***as Tursonemus*** n. sp., rely on a single phoront species whereas others of this mite group utilize a large number of insect phoronts. In general those having single phoronts also occupy a single habitat, whereas those riding more than one phoront may occupy many habitats.

2. Availability of subcortical fungal food source or non-fungal alternate food source. Partial correlation: 0.8.

Mites such ***as Tursonemus*** n. sp. rely on specific food sources such as the mycangial fungus and/or bluestain. When these sources become scarce, populations of the mite may also crash (Bridges and Moser 1986). Other mites such ***as Histiogaster arborsignis*** feed on many other foods besides fungi, and populations of these mites may remain more stable in the event that one of its trophic sources becomes scarce.

3. Temperature of galleries for mite survival and growth. Partial correlation: 0.1.

The bark beetle and its associated mites presumably coevolved and with the result that their life histories are probably synchronized. However, this is not known for sure. But if development times are not synchronized, then the degree days for mite development could be crucial so that the mites could develop in time to hop on the beetle for dispersal. We also need to know what minimum and maximum temperatures are lethal for survival of the various mite stages in relation to those lethal for the beetle.

Key Ecological Functions

1. Ascospores transported by certain species may be responsible for establishing sexual compatible colonies of the mycangial fungus.

   Cerutocystiopsis ranaculosus inhabits the mycangium of ***Dendroctonus brevicomis as*** conidia in a budding yeast-like form. Ascospores are not known to occur in mycangia of bark beetles, and the means of ascospore dispersal has not been previously reported. It is postulated that ascospores transported by the phoretic mite, ***Tarsonemus*** n. sp., may be responsible for establishing sexually compatible colonies of the fungus in beetle galleries either by themselves or in combination with the mycangial fungus type.

2. The mite exploits and requires fungi directly as food (mycetobionts).

   Mycetobionts are mites which require fungus for food. In addition to the filter-feeding histiostomatid mites (see functional group. #3), only one subcortical mycetobiont ***(Tczrsonemus* n.** sp.) had been encountered in this study. This mite feeds on bluestain and/or mycaugial fungi. Other mites will also undoubtedly demonstrate true mycophagy with a better understanding of the WPB subcortical ecosystem. Prime mycetobiont candidates for this ecosystem may be species of ***Siteroptes*** such as S. *fusari* and S. ***trichoderma*** described by Smiley and Moser (1976), ***Tarsonemus ips*** (Moser et al., 1995), and ***Schwiebia*** spp. (Oconnor, 1984) ***(e.g. S. pseudotsugae*** { Woodring 1966b}).

3. The mite utilizes fungi in ways other than a direct food source (mycetophiles).

   Mycetophiles are represented by a number of species in this study including ***Histiogaster arborsignis, Trichouropoda australis***, and perhaps *Calvolia furnissi* (Woodring 1966a). The former two mites, at least, readily consume fungi, in addition to other items such as beetle brood and nematodes.

4. Some of ***these*** mites (e. ***g. Histiogaster arborsignis)*** may prey on brood of bark beetles and that of other arthropods (Moser 1975).

   Some of the fungi-feeding mites (see figures 1 and 2) are also important predators of the brood of bark beetles and perhaps other subcortical insects, mites and nematodes.

5. At least one subcortical fungus, the *Thaxteriola* anamorph of ***Pyxidiophoru,*** is specialized for dispersal by mites carried on pine bark beetles (Blackwell et al. 1986).

   Thaxteriola is a highly unusual fungus in that it is specialized for dispersal by mites carried on pine bark beetles. Other fungi dispersed by arthropods in this symbiotic assemblage rely primarily on arthropod specializations. This discovery was reported in the journal SCIENCE.

6. Most species of subcortical fungal ascospores stick anywhere on the mites, with no special spore-carrying structures (sporothecae) evident. Most mites transport one or more species of ascospores, sometimes in large numbers (Moser et al. 1989).

   In one study (Moser et al. 1989), ten morphologically distinct types of ascospores were recognized from the bodies of 17 species of mites associated with adults of ***Ips typographus*** collected from pheromone traps in Sweden. The ascospores seemed to stick anywhere on the mites, with no special spore-carrying structures (sporothecae) evident. Most of the 739 mite individuals in this study transported one or more species of ascospore, sometimes in large numbers. A similar situation has been observed with the mites associated with the southern pine beetle (Moser, unpublished). It is expected that the situation will be the same for the mites associated with WPB.

Special Habitats:

There are no special habitats in need of protection for these species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of *Pinus ponderosa*. Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs:

Key research needs to expand the knowledge of the beetle-mite-fungus relationships are A) How habitat specific is each mite or insect phoront? Some mites may occupy habitats other than subcortical, such as bracket fungi which may be sources of adventitious fungi. B) What fungi are preferred by each mite species? Various species of subcortical fungi may be dispersed by different mites because the various mite species may have selective trophic preferences for the various fungi. C) What fungi are toxic to each of the mite species? Okabe (1994) reports that shiitake mushroom mycelia kill eggs of *Histiogaster* n. sp. Are there similar toxic mechanisms operating in the subcortical environment? D) What fungi are preferred by both the mite and insect phoront? Is the mycangial fungus preferred by both WPB and *Tarsonemus* n. sp.? Are there any other examples of this kind of possible mutualism? E) Detailed investigations of the host-fungal pathogen interactions are needed to clarify the role(s) of these fungi and/or their metabolites in tree mortality (Stephen et al. 1993). Hobson et al. 1994 presents data showing that *Ophiostoma nigrocarpum* does not contribute to the mortality of the tree. But does the mycangial fungus kill the tree?

CRBFORM3. Subcortical mite filter feeders.

Key Environmental Correlates:

1. Substrate must be wet and support water films in which the mite(s) feed (Oconnor 1984). Partial correlate: 0.8.

Dry substrates where the tree quickly dries out may be lethal or result in low populations of this mite.

2. Phoretic latitude of mite (how many phoronts does the mite ride). Partial correlate: 0.1.
The number of phoronts may be important to the dispersal of this mite. The subcortical space may become wet only after the scolytid has left the tree, meaning that the mite may have to rely on the insect associates to give it a ride. At least one histiostomatid, ***H. media,*** is restricted to turpentine beetle habitats, and another, ***Bonomia certa*** is apparently restricted to the Douglas fir beetle on Douglas fir.

3. Temperature of galleries for mite survival and growth. Partial correlate: 0.1.
The bark beetle and its associated mites presumably coevolved and with the result that their life histories are probably synchronized. However, this is not known for sure. But if development times are not synchronized, then the degree days for mite development could be crucial so that the mites could develop in time to hop on the beetle for dispersal. The minimum and maximum temperatures lethal to the survival of the various mite stages in relation to those lethal for the beetle can also affect beetle/mite survival in the galleries.

Key Ecological Functions:

1. Presence of filter-feeding mites in damp galleries may control potentially inimical midroorganisms (Oconnor 1982).
It is possible that certain bacteria and/or fungi are toxic to the bark beetle and this mite may have coevolved as a defense against them.

2. Can histiostomatid mites disperse microorganisms?
Histiostomatid mites may serve to disperse propagules of their fungal associates, as they have a particularly sticky cuticle to which debris, including fungal spores, adhere; but long distance dispersal of such spores is unlikely because the dispersing histiostomatid deutonymphs lack the sticky cuticle (Oconnor 1984). Perhaps the "slicky" surface of the phoretic deutonymph is a mechanism to restrict the types of spores to the spores advantageous to the survival of the mite and/or bark beetle.

3. This functional group does not feed on bark beetles (Moser 1975a; Wilson 1980).
The mouthparts of this group of mites is such that it is incapable of predation on anything except microorganisms. The result of this is that it is incapable of bark beetle predation unlike its related genus ***Histioguster.***

Special Habitats:

There are no special habitats in need of protection for these species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs:

1. Only a few bark beetles and other forest insects have been examined for these histiostomatid mites with the result that a number of new species may have yet to be discovered.

2. We need to determine on which microorganisms and other foods these mites feed, and which foods may be toxic to the mites. Okabe (1994) demonstrates that certain mushroom fungi are toxic to ***Histiogaster sp. and which fungi that this and other mites prefer.***

3. Many histiostomatid mites are close associates of subcortical beetles and are often host-specific (Woodring and Moser 1970; Oconnor 1982). These narrow phoretic latitude mites need to be investigated further to determine if they convey selective advantages to their specific hosts that the broad phoretic latitude mites do not (or vice-versa).

CRBFORM4. Mite parasitoids and predators of forest insect eggs.

Key Environmental Correlates:

1. Availability of suitable bark beetle phoront. Partial correlate: 0.1.

Mites don't have wings so they must rely on organisms that fly (usually subcortical insects) to be able to disperse. Some mycetophagous mites, such ***as Iponemus confusus***, rely on a single phoront species whereas others of this mite group utilize a large number of insect phoronts. In general those having a single phoront are egg parasitoids of a single host, whereas those riding more than one phoront may feed on the egg(s) of a number of bark beetle species.

2. Availability of subcortical bark beetle egg(s). Partial correlate: 0.7.

The egg predators and parasitoids must locate the bark beetle eggs which may be difficult to find in the galleries. Along the gallery, the eggs are laid in egg niches which are usually covered with a frass "plug" that the mite must remove or break into. In addition, the mite may have to bore through the frass deposited in galleries of some bark beetles such ***as Dendroctonus*** spp. The galleries of other genera such as ***Ips*** remain clear.

3. Presence of specialized ***Pyemotes*** female morph for phoresy (phoretomorph). Partial correlate: 0.1.

Many members of the family Pyemotidae and certain other related genera have distinct female morphs specialized for phoresy (Moser and Cross 1975). Other morphs are specialized for reproduction but are incapable of riding the beetles. The phoretomorphs apparently appear as a response to dispersal. If for some reason this morph would not appear when the beetles are ready to fly, then the mite could not disperse to a new temporary habitat.

4. Temperatures required for transport of mites on flying phoronts to new habitats. Partial correlate: 0.1.

Bark beetles and other phoronts vary widely in their ability to fly in extremes of hot and cold (Moser and Thompson 1986). One would think, for instance, that the southern pine beetle (which inhabits warm climates) would be limited in its ability to fly in cold weather. However, the observed minimum of 6.7°C is the lowest ever recorded for any scolytid. This behavior is apparently allows this scolytid to fly during the southern winters and attack trees in this season, and ability which the more northern scolytids do not have. The ability to fly in cold weather also allows the mite to disperse at cooler temperatures.

Key Ecological Functions

1. Mite is mortality factor of bark beetle (Moser 1975a; Lindquist and Bedard 1961)

Mortalities attributed to egg-feeding mites vary from 90 percent (Gabler 1947) to less than one percent (Balazy and Kielczewski 1965.) Better life tables are needed to better understand these dynamics

2. Mite is biological indicator of prospects for. increase or decline of host populations (Lindquist 1970).

Although there are no studies to support a mite biological indicator hypothesis, there is evidence from predators such as clerids that an increase in the number of predators is related to population increases of the host and vice versa (Reeve and Turchin 1993).

Special Habitats:

There are no special habitats in need of protection for these species.

Management Scenarios Affect Abundance. Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs:

1. The searching capacity of these natural enemies.

The effectiveness of a natural enemy depends greatly on its ability to located its host. If, for instance, the parasitoid is able to navigate through frass tightly packed in a gallery, then its searching capacity may be greatly increased.

2. Power of increase relative to the prey.

The more progeny the mite can produce, the more effective the parasitoid may be.

3. Life cycle synchrony with prey species.

Those parasitoids whose life cycles are synchronized with the host tend to be more effective natural enemies.

4. Regional variability of natural enemy populations.
Regional conditions such as temperature and humidity may favor some species of natural enemies over others.

5. Are Balaustium deutonymphs and adults predatory on the eggs of the western spruce budworm?
Although Welboum reports ***Balaustium*** deutonymphs and adults in the forests of North California, there have yet to be reports of this mite feeding on the eggs of SBW.

CRBFORM5. Mite parasitoids and predators of forest insect larvae an pupae.

Key Environmental Correlates
1. Mite species is habitat vs host specific (Lindquist 1970; Walters and Campbell 1955). Pa&al correlate: 0.4.
Some mite species such ***as Dendrolaelaps quadrisetus, Histioguster arborsignis, Proctolaelaps fiseri*** and ***Vulgarogamasus lyriformis*** are found in a large number of habitats (such as bracket fungi). These mite species also tend to ride a large number of insect host species.

2. Number of host larvae and pupae required for mite development Partial correlate: 0.3.
The predators and parasitoids must locate the bark beetle brood which may be difficult to find. ***The galleries*** of some bark beetles such ***as Dendroctonus*** spp. may be plugged with frass which the mite may have to bore through. The galleries of other genera such as ***Ips*** remain clear.

3. Temperature of galleries for mite survival and growth. Partial correlate: 0.3.
The bark beetle and its associated mites presumably coevolved and with the result that their life histories are probably synchronized. However, this is not known for sure. But if development times are not synchronized, then the degree days for mite development could be crucial so that the mites could develop in time to hop on the beetle for dispersal. The minimum and maximum temperatures lethal to the survival of the various mite stages in relation to those lethal for the beetle can also affect beetle/mite survival in the subcortical environment.

Key Ecological Functions:
1. ***Histiogaster arborsignis, Vulgarogamasus lyriformis,*** and ***Proctolaelaps fiseri*** **may** qualify as biological control agents for bark beetle brood (Moser 1975a).
Of 5 1 species of mites found with brood of the southern pine beetle and tested in the laboratory, the above 3 species were judged primary candidates for use as natural control agents in reducing field infestations.

2. Mite is biological indicator of prospects for increase or decline of host populations (Lindquist 1970). Although there are no studies to support a mite biological indicator hypothesis, there is evidence from predators such as clerids that an increase in the number of predators is related to population increases of the host and vice versa (Reeve and Turchin 1993).

Special Habitats:

There are no special habitats in need of protection for these species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs;

1. The searching capacity of these natural enemies.

The effectiveness of a natural enemy depends greatly on its ability to located its host. If, for instance, the parasitoid is able to navigate through frass tightly packed in a gallery, then its searching capacity may be greatly increased.

2. Power of increase relative to the prey.,

The more progeny the mite can produce, the more effective the parasitoid may be.

3. Life cycle synchrony with prey species.

Those parasitoids whose life cycles are synchronized with the host tend to be more effective natural enemies.

4. Regional variability of natural enemy populations.

Regional conditions such as temperature and humidity may favor some species of natural enemies over others.

CRBFORM6. Larval parasitengona mites parasitic on forest insect adults.

Key Environmental Correlates:

1. Ability of the mite to contact the host. Partial correlate: 0.2.

The parasitic larvae of the mites get from tree to tree by riding the adult moths and beetles. However, the deutonymph and adult mites produced by the engorged larvae that drop off the hosts may have to drop to the ground because they are predacious and may require another host. How, then do the new larvae get back up the trees so that they can contact new adult hosts? Once the mite larvae are in the vicinity of the hosts, how do they contact them? Is the stimulus odor, touch, or visual?

2. Ability of mite to select suitable attachment site on host (Houseweart et al. 1980). Partial correlate: 0.1.

Both the erythraeid parasitic on the SBW moths and the trombidid larvae from bark beetles seem to have random sites of attachment on their adult hosts. Thus the "fleshy" sites may provide better access to the insect blood than the harder "chitinous" sites.

3. Greater percentage of late-flying moths are infested than those of early-flying moths (Houseweart et al. 1980). Partial correlate: 0.1.

The reason for this increased percentage on the late-flying moths is not fully understood.

4. Synchronization of parasite with life cycle of moth. Partial correlate: 0.6

The better the parasite is synchronized with the host, the more efficient it will be in locating the host. Perhaps this is the reason that the late-flying SBW moths have an increase percentage of the parasitic mites.

Key Ecological Functions:

1. Parasite may kill host (Welbourn 1983).

Erythraeids usually do not kill the host whereas trombidiids usually are lethal. This means that the trombidiids are the most efficient biological control agents.

2. Parasite may affect fecundity of host (Houseweart et al. 1980).

Although erythraeids may not kill the host, they may reduce its future fecundity. Studies are needed to quantify this.

3. Parasite may affect flight behavior of the host (Houseweart et al. 1980).

Since trombidiids are supposedly more "lethal" than erythraeids, the former probably cause more flight reduction. But the nonlethal erythraeids still may affect flight reduction by reducing the amount of nutrients available to the host.

Special Habitats:

There are no special habitats in need of protection for these species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Key Research Needs;

THE key unknown is whether or not this group of parasites is present in the Columbia River Basin Assessment Area. I can find no concrete evidence (i.e. specimens or records) of these parasitic larval mites on western forest insects. But there is substantial evidence from the Eastern U. S. that this or a similar species will turn up once that workers become aware of them, and a search for these mites is initiated.

The following quoted from Welboum 1983 summarizes the known information about this mite from its only known location in Maine. "Houseweart et al. (1980) reported that 28 percent of nearly 2,300 male spruce budworm moths, *Choristoneura fumiferana* (Clemens), collected in pheromone traps over a 3-day period, were parasitized by larvae of ***Leptus treati***."

Other key unknowns are:
1. Determination of the species of each parasite.
2. The effects on the flight behavior of the host.
3. The effects on the fecundity of the host adult.
4. Do these parasites also affect eggs, larvae, and pupae of the insects?
5. What are the regulatory effects of the mite?
6. Does the mite kill the host (i.e. is it a parasite or parasitoid)?
7. What is the life cycle of the mite?
8. Is the life cycle of the mite synchronized with that of the host?
9. Does the mite parasite have alternate hosts?
10. What does the deutonymph and adult of the mite prey on?
11. Does the deutonymph and adult of the mite prey on the eggs of this host?

CRBFORM7. Nematophagous mites of subcortical bark and sawyer beetles.

Key Environmental Correlates:
1. Specialized mite developmental stages feed on nematodes. Partial correlate: 0.1

   Only ***the*** larval stages of some mites such ***as Vulgarogamasus Zyriformis*** attack subcortical nematodes whereas the deutonymphs and adults of other mites such as ***Dendrolaelaps quadrisetus feed on nematodes. Presumably those mites whose postlarval stages do the feeding would make the more effective biological control agents.***

2. Mite species preference for nematodes. Partial correlate: 0.6

   Some mites such ***as Cercoleipus coelonotus and*** Dendrolaelaps neodisetus prefer nematodes over other prey. On the other hand, other mites such ***as Dendrolaelaps quadrisetus*** prefer the brood of bark beetles to that of nematodes.

3. Preferred phoront of mite species. Partial correlate: 0.3

A number of nematophagous mites are recorded for the CRB assessment area on multiple host types. Examples of these ***are Cercoleipus coelonotus, Dendrolaelaps quadrisetus, Trichouropoda australis, T. lamellosa, and Vulgarogamasus lyriformis.*** Andre (1980) points out that a high phoretic preference of a mite for a particular phoront **may** not mean that it preys on that host. ***An*** example of this is ***Cercoleipus coelonotus*** which rides ***Ips paraconfusus*** and ***Ips montanus;*** this mite prefers nematodes (Kinn 1971), but ***also*** preys on ***eggs*** and larvae of ***Dendrolaelaps quadrisetus,*** which prefers eggs and larvae of its scolytid phoront, ***Ips paraconfusus*** (Kinn 1967, 1971). ***Trichouropodu lamellosa*** which is phoretic on cerambycid beetles fed on the pinewood nematode (Kinn 1987).

Nematodes are also phoretic with the mites on flying bark beetles and cerambycids. In Japan, deutonymphs of at least one phoretic mite, ***Dendrolaelaps unispinatus*** has been recorded to feed on the pinewood nematode phoretic on cerambycids (Enda and Tamura 1977; Tamura and Enda 1980). This behavior should be watched for in the U.S. where the pinewood nematode is native.

<u>Key Ecological Functions</u>:

1. Deutonymphs of ***Trichouropoda lamellosa*** placed in isolation cells were observed to feed on the pinewood nematode (Kinn 1987).

So far as known, the mite ***T. lamellosa*** only rides cerambycid beetles. Kinn (1987) has shown in the laboratory, at least, that this mite also feeds on the economically important pinewood nematode. Further studies need to be done to see if the mite feeds on any other organisms.

2. Dendrolaelaps neodisetus can be reared on nematodes of several species (Kinn 1983b)

The ***mite D. neodisetus*** which commonly rides many species of bark beetles including WPB and SPB **seems** to specialize on nematodes.

3. Mite **may** be beneficial to beetle development.

Certain nematophagous mites (e.g. ***Dendrolaelaps neodisetus)*** associated with bark beetles may be beneficial to beetle development, and the association mutualistic, because the mite preys on nematodes which are bark. beetle endoparasites (e.g. the nematode ***Contortylenchus brevicomi).*** This same type of relationship is likely to exist between ***Cercoleipus coelonotus*** and other nematophagous acarines associated with bark beetles (Kinn 1983b).

4. Many nematophagous mites attack and kill other mites (Kinn 1983b).

The eggs and larvae of ***Dendrolaelaps quadrisetus*** are preyed upon by ***Cercoleipus coelonotus; Histiogaster arborsignis*** is fed ***on*** by ***Mexecheles, Proctolaelaps dendroctoni,*** and ***Hypoaspsis; Macrocheles boudreauxi feeds on digamasellids;*** and ***Eugamasus lyriformis*** nymphs and adults eat digamasellids, cheyletids, and uropodid mites.

Special Habitats

There are no special habitats in need of protection for these species.

Management Scenarios Affecting the Distribution, Abundance, and Ecological Functions of the Mite Over Time (Short term: 10-15 years; Mid-term: 50 years; Long term: 100 years):

Management scenarios over time depend on the health and management of ***Pinus ponderosa.*** Forestry practices such as fire, basal area, and environmental insults greatly affect the health of the'tree and determine if it will live just a few years or to an age of 100 or more. When the health of the tree declines, it is subject to attack by a variety of bark beetles and diseases including WPB.

Kev Research Needs:

1. Which species of nematophagous mites are symbiotic with bark beetles and enhance brood production?

2. Which mites are general nematode feeders and which are specific to certain nematode species?

LITCITE.CRB Draft 5
1994: 10/19, 11/2, 4, 9, 10, 11, 18, 21; 12/10; 1995: 1/23

EASTSIDE EM STRATEGY PROJECT
COLUMBIA RIVER BASIN
INVERTEBRATE ASSESSMENT TEAM
MITES ASSOCIATED WITH FOREST INSECTS

John C. Moser

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APPENDICES

AND

BIOGRAPHICAL DATA

MOSER\CRBFORM1

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION Page 1 of

Date: 10\25\94; revised 11/21;1995: January 20, 25,
Panelist Name: John C. Moser
Species or Species Group: ***Tarsonemus endophloeus*** group

Geographic Area and/or Habitat Type: The distribution of T. endophloeus in the CRB is at least the same as that of its phoretic host (=phoront) the western pine beetle (Wood 1982) (See attached map overlay). CT 25; SS 5,6,7; OSC 2,3,4,5.
Lindquist (1969) also ***lists Scolytus unispinosus, Ips emarginatus,*** and ***Dendroctonus ponderosae as*** phoronts. However, in light of the new information below concerning this mite, it remains to be seen if the mites phoretic on the latter scolytids will turn out to be sibling species.

Representative Species: ***Tarsonemus*** n. sp. near ***endophloeus.*** Note: in the text, this species is referred to as ***Tarsonemus*** n. sp.

Key Environmental Correlates

1. Availability of the insect disperser (phoront), ***Dendroctonus brevicomis.***	
Categorical X	**Continuous**
Suitable Categories: ***Dendroctonus brevicomis*** (Moser et al. 1995)	Unit of Measure: Minimum: Maximum:
Applies seasonally? Yes **Which seasons?** Growing season **Theme name: Disturbance - insect pests** **Attribute: Agent:** ***Dendroctonus brevicomis***	

2. Availability of subcortical fungal food sources.'	
Categorical X	**Continuous**
Suitable Categories: ***Ophiostoma nigrocarpum*** and/or ***Ceratocystiopsis ranaculosus*** Moser et al. (1995); Harrington (1993 a,b); Harrington and Zambino (1990).	Unit of Measure: Minimum: Maximum:
Applies seasonally? Yes **Which seasons?** growing **Theme name: ?** **Attribute: ?**	

Key Environmental Correlates

3. Availability of space under bark beetle elytra	
Categorical X	**Continuous**
Suitable Categories: Subelytral spaces cannot be occupied by other species of mites.	Unit of Measure:
	Minimum: Maximum:
Applies seasonally? No **Which seasons? Growing** **Theme name: ?** **Attribute: ?**	

4. Temperature of galleries for mite survival and development (Moser and Thompson 1986).	
Categorical	**Continuous X**
Suitable Categories:	Unit of Measure: Centigrade.
	Minimum: Unknown Maximum: Unknown.
Applies seasonally? Yes **Which seasons?** Growing **Theme name: Climate** **Attribute:** Daily minimum and Maximum temperatures; Degree days.	

Key Ecological Functions

1. Transports ascospores of mycangial fungus, ***Ceratocystiopsis ranaculosus*** to the tree and gallery (Moser et al. (1995).

2. Transports ascospores of bluestain fungus, ***Ophiostoma nigrocarpum*** to tree (Moser 1985).

3. Mycangial and bluestain fungal spores within mite sporotheca may be protected from exposure to oleoresins exuding from beetle-induced wounds in the tree (Moser et al 1995).

4. Ascospores transported by ***Tarsonemus*** n. sp. may be responsible for establishing sexual compatible colonies of the mycangial fungus in beetle galleries either by themselves or in combination with the beetle mvcaneial fungus (Moser et al. 1995).

Key Assumptions

The ascospores of the mycangial fungus of ***Dendroctonus brevicomis are*** transported by *Tarsonemus* n. sp. in a manner very similar or identical to that described by Moser et ***al.*** (1995) for *Dendroctonus frontalis* by ***Tarsonemus krantzi.***

Key Unknowns and Monitoring or Research Needs

1. Are there epidemic populations of ***Dendroctonus brevicomis*** where few of the beetles carry bluestain fungus such as documented for that of *Dendroctonus frontalis* (Bridges and Moser 1986).

2. What percent of ***Tarsonemus*** n. sp. females ***carry*** ascospores of C. ***ranaculosus?***

3. Mycangial and bluestain fungal spores within mite sporotheca may be protected from exposure to oleoresins exuding from beetle-induced wounds in the tree (Moser et al. 1995).

4. Ascospores transported by ***Tarsonemus*** n. sp. may be responsible for establishing sexual compatible colonies of the mycangial fungus in beetle galleries either by themselves or in combination with the mycangial fungus type (Moser et al. 1995).

5. Is ***Tarsonemus endophloeus*** a species complex?

Dispersal

Dispersal mode: Phoresy

Requirements for dispersal:
Brood or parent adults of ***Dendroctonus brevicomis*** emerging at the bark surface encounter the mites which then crawl under the beetle elytra (Roton 1978).

Degree of Confidence in Knowledge of Species

High____

Med.____

Low X___

Comments

[speculate that the association of this mite in galleries of the WPB must be close to 100%; that is, a rating of 10. However, this is not to say that every WPB flying adult carries the mite, which I suspect could have an association rating of less than 1.

This mite is selected as a keystone species because it appears to perform a pivotal role central to the existence of all of the biota associated with the western pine beetle (WPB) and the pines that WPB attacks, mostly ***Pinus ponderosa.*** It is also a bioindicator of the ecosystem health, because the WPB has probably killed more merchantable timber than any other organism in historic time (Wood 1982).

Like many wood-boring insects, larvae of the WPB depend on a symbiotic nutritive fungus, which the female beetle carries in a special pouch called a mycangia. The fungus inhabits the mycangium as conidia in a budding yeast-like form. The fungus is inoculated ahead of the growing larvae and alters the wood so that the larvae can digest it. Until recently this fungus was reputed to be the common bluestain fungus, ***Ophiostoma nigrocarpum*** (=***Ceratocystis nigrocarpum),*** but mating studies by Harrington (1993a) have shown that the **mycangial** fungus is actually ***Ceratocystis ranaculosus. 0. nigrocarpum*** is still present in the galleries, but it is not the mycangial fungus.

Ascospores are not known to occur in mycangia of bark beetles, and the means of ascospore dispersal has only recently been reported for this heterothallic fungus (Moser et al. 1995). They showed that ascospores of the fungus are transported in special sacs called sporothecae on the bodies of ***Tarsonemus*** n. sp. These mites are phoretic (i.e. ride) on flying adults of the western pine beetle. Ascospores transported by phoretic mites may be responsible for establishing sexually compatible colonies of the fungus in beetle galleries either by themselves or in combination with the mycangial fungus type. Thus there is a three-way association among the mite, ***T.*** n. sp., the WPB, and the fungus, ***C. ranaculosus. The*** beetle carries both the mites bearing ascospores, and the yeast-like conidiospores in its mycangium. The fungus is food for the mites and the beetle larvae, and may aid beetle development by contributing to the death of the tree. The mite assures transmission of the fungal ascospores. Hence, it is postulated that without this phoretic mite the western pine beetle may not be able to survive, and for this reason I regard this mite as a keystone species.

The distribution of ***T.*** n. sp. in the CRB is at least the same as that of its phoretic host (=phoront) the western pine beetle (Wood 1982). Lindquist (1969b) also lists ***Scolytus unispinosus, Ips emarginatus,*** and ***Dendroctonus ponderosae*** as phoronts, and these hosts may extend the geographic distribution of this mite. However, in light of the above new information concerning this mite, it is possible that the mites phoretic on the latter scolytids may turn out to be sibling species. Hence the present concept of ***Tarsonemus endophloeus*** may really be that of a species complex, and if this is so the real distribution of this keystone species would be limited to that of the WPB.

MOSER\CRBFORM2

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION Page 1 of

Date: 1994: 10/26, 11/2,

Panelist Name: John C. Moser

Species or Species Group:
Subcortical mycetophagous mites

Geographic Area and/or Habitat Type:
Range throughout forested area of interior Columbia River Basin assessment area on multiple host types. SS 5,6,7; *OSC* 2,3,4,5.

Representative Species:
Tarsonemus n. sp., ***Histiogaster arborsignis, Calvolia furnissi, Schwiebea spp., Trichouropoda australis.***

Key Environmental Correlates

1. Availability of phoretic insect disperser (phoront) (Oconnor 1984).

Categorical X

Continuous

Suitable Categories:
1. Mite has a single phoront and occupies a single habitat; ***e.g. Tarsonemus*** n. sp. (Moser et al. 1995).

2. Mite has many phoronts and occupies many habitats (habitat specific); ***e.g. Histiogaster arborsignis*** (Oconnor 1990, 1991).

Unit of Measure:

Minimum:

Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: Disturbance: insect pest
Attribute: Agent: Bark beetles and/or insect associates on conifers and broad-leafed trees (Moser and Roton 1971; Moser, unpublished)

Key Environmental Correlates

2. Availability of subcortical fungal food source or non-fungal alternate food source.

Categorical X

Continuous

Suitable Categbries:

1. Specific feeder ***(e. g. Tarsonemus*** n. sp. (Moser et al., 1995)
2. General feeder ***(e. g. Histiogaster arborsignis) (Oconnor** 1990, 1991).*

Unit of Measure:

Minimum:

Maximum:

Applies seasonally? Yes

Which seasons? Growing season

Theme name: ?

Attribute: ?

3. Temperature of galleries for mite survival and growth (Moser and Thompson 1986).

Categorical

Continuous X

Suitable Categories:

Unit of Measure: Centigrade degrees

Minimum: Unknown

Maximum: Unknown

Applies seasonally? Yes No

Which seasons? Growing Season

Theme name: Climate

Attribute: Daily minimum and maximum temperatures; degree days.

Key Ecological Functions

1. Ascospores transported by certain species may be responsible for establishing sexual compatible colonies of the mycangial fungus (Moser et al., 1995).

2. The mite exploits and requires fungi directly as food (mycetobionts) (Oconnor 1984).

3. The mite utilizes fungi in ways other than a direct food source (OConnor 1984).

4. Some of these mites ***(e. g. Histiogaster arborsignis)*** may prey on brood of bark beetles and that of other arthropods (Moser 1975).

5. At least one subcortical fungus, the *Thaxteriola* anamorph of ***Pyxidiophora,*** is specialized for dispersal by mites carried on pine bark beetles (Blackwell et al. 1986).

6. Most species of subcortical fungal ascospores stick anywhere on the mites, with no special spore-carrying structures (sporothecae) evident. Most mites transport one or more species of ascospores, sometimes in large numbers (Moser et al. 1989).

Key Assumptions

The majority of the species of this functional group involve mites which inhabit fungal substrates either as fungivorous mycetobionts (require the fungus for food) or as mycetophiles (use fungi in ways other than as a direct food source), and which use insects as phoronts to disperse them among preferred habitats (OConnor 1984).

Key Unknowns and Monitoring or Research Needs

1. How habitat specific is the mite or insect phoront?

2. What fungi are preferred by each mite species?

3. What fungi are toxic to each of the mite species?

4. What fungi are preferred by both the mite and insect phoront?

5. Detailed investigations of the host-fungal pathogen interactions are needed to clarify the role(s) of these fungi and/or their metabolites in tree mortality (Stephen et al. 1993).

Dispersal

Dispersal mode: Phoresy

Requirements for dispersal:

1. Presence of the phoront and proper phoretic stage of the mite.

2. Both mites and potential phoronts must possess compatible morphological modifications (e. g. mite caudoventral attachment organ; claws; stalk secreted by perianal glands) to allow phoretic attachment.

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X____

Comments

This group contains a large number of mite species, which OConnor (1984) divides into three ecological categories. Mycetobionts, which require the fungus for food; mycetophiles, which utilize fungi in ways other than as a direct food source; and mycetozenes, which occur in fungi only accidentally.

In addition to the filter-feeding histiostomatid mites (see functional group #3), only one subcortical mycetobiont ***(Tarsonemus*** n. sp.) has so far been encountered in this study. Other mites will also undoubtedly demonstrate true mycophagy with a better understanding of the WPB subcortical ecosystem. Prime mycetobiont candidates for this ecosystem may be species of ***Siteroptes*** such ***as S. fusari*** and ***S. trichoderma*** described by Smiley and Moser (1976), ***Tarsonemus ips*** (Moser et ***al.,*** 1995), and ***Schwiebia*** spp. (OConnor, 1984) (e.g. ***S. pseudotsugae*** {Woodring 1966b}). Mycetophiles are represented by a number of species in this study including ***Histiogaster arborsignis, Trichouropoda australis,*** and perhaps *Calvolia furnissi* (Woodring 1966a). The former two mites, at least, readily consume fungi, in addition to other items such as beetle brood and nematodes. Mycetozenes include all of the rest of the mites in the galleries such ***as Pyemotes giganticus,*** which is strictly predatory on bark beetle eggs.

Although a few mycetobionts may carry specific fungal ascospores, hyperphoretic inside a special morphological, spore-carrying structure called a sporotheca, both ascospores and conidia of most other fungi are dispersed not only by the bark beetles and their insect associates, but by mycetophile and mycetoxenes mites phoretic on bark beetles. Moser et al. (1989) showed that these spores seem to stick anywhere on the mites, with no special spore-carrying structures evident. Mites have been demonstrated to carry as many as six species of fungi, including some that are highly pathogenic to conifers such as ***Ophiostomapolonicum.***

MOSER\CRBFORM3

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION Page 1 of

Date: October 26, 1994 **Panelist Name:** John C. Moser

Species or Species Group: Subcortical mite filter feeders

Geographic Area and/or Habitat Type:
Range throughout forested area of interior CRB assessment area on multiple host types. SS 5,6,7. **OSC** 2,3,4,5.

Representative Species: (All are histiostomatid mites)
Histiostoma varia, H. media, Bonomia certa

Key Environmental Correlates

1. Substrate must be wet and support water films m-which the mite(s) feed (OConnor 1984).

Categorical X **Continuous**

Suitable Categories:
Bark beetle galleries

Unit of Measure:

Minimum:
Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

2. Phoretic latitude of mite (will the'mite ride only one phoront species or a number of them?)

Categorical X **Continuous**

Suitable Categories:
1. Narrow phoretic latitude (e.g. ***Histiostoma media*** will ride only "turpentine beetles".) Woodring and Moser 1970; Moser, unpublished.
2. Wide phoretic latitude (e.g. ***Histiostoma varia*** carried by large number of bark beetle species as well as by large numbers of associated'insects). Woodring and Moser 1970; OConnor 1991.

Unit of Measure:
Minimum:
Maximum:

Applies seasonally? Yes
Which seasons? Growing Season
Theme name: Disturbance - Insect pests
Attribute: Agent - Bark beetles and/or insect associates on conifers and broad-leafed trees (Moser and Roton 197 1; Moser, unpublished).

Key Environmental Correlates

3. Temperature of galleries for mite survival and growth (Moser and Thompson 1986).

Categorical **Continuous X**

Suitable Categories:

Unit of Measure: C°

Minimum: Unknown
Maximum: Unknown

Applies seasonally? Yes X No
Which seasons? Growing season
Theme name: Climate
Attribute: Daily minimum and maximum temperatures; degree days.

Key Ecological Functions

1. Presence of filter-feeding mites in damp galleries may control potentially inimical microorganisms (OConnor 1982).

2. Histiostomatid mites may serve to disperse propagules of their fungal associates, as they have a particularly sticky cuticle to which debris, including fungal spores, adhere, but long distance dispersal of such spores is unlikely because the dispersing histiostomatid deutonymphs lack the sticky cuticle (OConnor 1984).

3. This functional group does not feed on bark beetles (Moser 1975a; Wilson 1980).

Key Assumptions

Gnathosoma [the mouth] is modified for filter feeding (Hughes and Jackson 1958). This allows mites to exploit habitats containing microorganism-rich water films in which to feed (OConnor 1982.

Mite sex determination is haplodiploid (Heinemann and Hughes 1969). This enables these mites to very quickly colonize new habitats, in that a single female deutonymph can found a colony (OConnor 1982).

Key Unknowns and Monitoring or Research Needs

1. Only a few bark beetles and other forest insects have been examined for these histiostomatid mites and many new species have yet to be discovered.

2. We need to determine on which microorganisms and other foods these mites feed, and which foods may be toxic to the mites.

3. Many histiostomatid mites are close associates of subcortical beetles and are often host-specific (Woodring and Moser 1970; OConnor 1982). These narrow phoretic latitude mites need to be investigated further to determine if they convey selective advantages to their specific hosts that the broad phoretic latitude mites do not (or vice-versa).

Dispersal

Dispersal mode:

Phoresy

Requirements for dispersal:

1. Presence of the phoront and proper phoretic stage of the mite.

2. Both mites and phoronts must possess compatible morphological modifications (e.g. corporal suckers) to allow phoretic behavior (OConnor 1984).

Degree of Confidence in Knowledge of Species

High_____

Med_____

Low X_____

Comments

The mites involved in this group all belong to one mite family (the Histiostomatidae); they all appear to be true mycetobionts, feeding on bacteria and yeasts when the subcortical substrate is wet and support water films. The presence of these filter-feeding mites in damp galleries may control potentially inimical microorganisms (OConnor 1982). These mites may also serve to disperse propagules of their fungal associates within galleries as they have a particularly sticky cuticle to which debris, including fungal spores, adheres. Long-distance dispersal of such spores in this fashion is unlikely, however, as the dispersing (=phoretic) histiostomatid deutonymphs lack this sticky cuticle (OConnor 1984). The mite sex determination of histiostomatids is haplodiploid (Heinemann and Hughes 1969). This enables these mites to very quickly colonize new habitats, in that a single female deutonymph can found a colony (OConnor 1982).

Representative species in the CRB assessment area include ***Histiostoma varia, H. media,*** and ***Bonomia certa.*** Whereas ***H. varia*** has a wide phoretic latitude, appearing to ride any bark beetle and/or beetle associate, the phoretic latitude of the latter two mites seems to be more restricted In the ***CRB, H. media*** rides only the red turpentine beetle; ***Dendroctonus valens.*** But this mite's tree habitat is much broader since ***D. valens*** attacks many species of pine, spruce, larch, and fir (Wood 1982). ***B. certa*** has only been collected with ***Dendroctonus pseudotsugae*** on Douglas fir.

MOSER\CRBFORM4

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION Page 1 of

Date: October 27, 1994 **Panelist Name:** John C. Moser

Species or Species Group: Mite parasitoids and predators of forest insect eggs.

Geographic Area and/or Habitat Type:
Range throughout forested area of interior CRB assessment area on multiple tree and insect hosts. SS 5,6,7; OSC 2,3,4,5.

Representative Species:
Pyemotes giganticus, Iponemus confusus, Paracarophaenax sp., Dendrolaelaps quadrisetus, Balaustium.

Key Environmental Correlates

1. Availability of suitable bark beetle phoront.

Categorical X **Continuous**

Suitable Categories: Unit of Measure:

1. Wide phoretic latitude (mite rides large number of insects [= phoronts]) ***(e.g. Pyemotes giganticus).***

2. Narrow phoretic latitude (mite rides single or few insects ***(e.g. Iponemus confusus)*** (Lindquist 1964).

Minimum:

Maximum:

Applies seasonally? Yes
Which seasons? Growing season.
I'heme name: Disturbance: insect pest
Attribute: Agent - Bark beetle and/or insect associates on conifers and broad-leafed trees (Moser and Roton 1971; Moser, unpublished.

Key Environmental Correlates

2. Availability of subcortical bark beetle egg(s).

Categorical

Continuous X

Suitable Categories:

Unit of Measure: Number of barkbeetle eggs required for mite brood development.

Minimum: One egg (e.g. *Iponemus*)(Lindquist 1969a).

Maximum: >One egg (e.g. ***Dendrolaelaps)*** (Kinn 1967).

Applies seasonally? Yes

Which seasons? Growing season

Theme name: ?

Attribute: ?

3. Presence of specialized ***Pyemotes*** female morph for phoresy (phoretomorph).

Categorical X

Continuous

Suitable Categories:

1. Phoretomorph female (Moser and Cross 1975)
2. Normal female (Smiley and Moser 1984)
3. Heteromorphic (giant) female (Smiley and Moser 1984).

Unit of Measure:

Minimum:

Maximum:

Applies seasonally? Yes

Which seasons? Growing season

Theme name: ?

Attribute: ?

1. Temperatures required for transport of mites on flying phoronts to new habitats (Moser and Thompson 1986).

Categorical

Continuous X

Suitable Categories:

Unit of Measure: C°

Minimum: Depends on species of phoront

Maximum: Depends on species of phoront

Applies seasonally? Yes **No**

Which seasons? Growing season

Theme name: Climate

Attribute: Daily minimum and maximum temperatures; degree days.

Key Ecological Functions

1. Mite is mortality factor of bark beetle (Moser 1975a; Lindquist and Bedard 1961)

2. Mite is biological indicator of prospects for increase or decline of host population (Lindquist 1970, 1983).

Key Assumptions

1. Parasitoid mite feeding stage is female only (Moser 1975a).

2. Predator mite feeding stage can be any stage past the egg (Moser 1975a).

3. Biological control involving the introduction and manipulation of new or exotic natural enemies appear to have little potential against scolytids. This is because scolytids are native species, well adapted, and with a complex of biotic associates (Lindquist 1969b).

4. The "new association" concept may have potential for the biological control of bark beetles (Miller et al. 1987: Moser and Branham 1988).

Key Unknowns and Monitoring or Research Needs (Lindquist 1983)

1. The searching capacity of these natural enemies.

2. Power of increase relative to prey.

3. Life cycle synchrony with prey species.

4. Regional variability of natural enemy populations.

5. Are Balaustium deutonymphs and adults predatory on the eggs of the western spruce budworm? (Welbourn 1983).

Dispersal

Dispersal mode: Phoresy

Requirements for dispersal:

1. Presence of the proper phoront and phoretic stage of the mite.

2. Both mite and potential phoront must possess compatible morphological modifications (e.g. mite specialized claws) to allow phoretic attachment.

Degree of Confidence in Knowledge of Species

High____

Med____

Low__X_

Comments

Of the above representative species:
Egg predator ***is Dendrolaelaps quadrisetus*** and possibly ***Balaustium.***

Egg parasitoids: ***Pyemotes giganticus, Iponemus confusus, Acarophaenax sp.***

A large number of subcortical mite parasitoids specialize on the eggs of bark beetles. Examples of these include ***the*** entire genus ***Iponemus*** containing at least 18 species and subspecies (Lindquist 1969a), and several other egg specialists such ***as Pyemotes giganticus*** and ***Paracarophaenax*** sp. Egg predators of bark beetles are not so specialized in their habits. They include *Dendrolaelaps* ***quadrisetus*** (Kinn 1967) and perhaps other predatory mites that normally feed on other items such as insect larvae, nematodes, and even fungi.

Balaustium deutonymphs and adults prey on the eggs, at least, of certain insects infesting the foliage of trees. Welboum and Jennings (1991) report that ***"Balaustium*** spp. have been collected from Douglas-fir forests in Montana (Fellin 1968) and from lodgepole pine in California (Struble 1972). A species of ***Balaustium*** was found to be predacious on eggs of the spruce budworm (Jennings and Crawford 1985). Bennett (1952) and Neilson (1963) also reported a "red mite" (probably ***Balaustium)*** found during spruce budworm egg sampling in New Brunswick. In North America there are only two, previously named species of ***Balaustium: B. dowelli*** from Arkansas and ***B. putmani*** from Canada and North Carolina." Gerson and Smiley (1990) report that ***Balaustium putmani*** feeds on many arthropods and their eggs, including moths, scales, and spider mites. All motile stages (larvae, deutonymphs, and adults) were predatory.

CRBFORM5

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION Page 1 of

Date: October 28, 1994 **Panelist Name:** John C. Moser

Species or Species Group: Mite parasitoids and predators of forest insect larvae and pupae.

Geographic Area and/or Habitat Type: Range throughout forested area of interior CRB assessment area on multiple host types. SS 5,6,7; OSC 2,3,4,5.

Representative Species: ***Pyemotes scolyti, P. barbara, Dendrolaelaps quadrisetus, Histiogaster arborsignis,*** *Proctolaelaps fiseri,* ***Vulgarogamasus lyriformis.***

Key Environmental Correlates

1. This mite is habitat vs insect host specific (Lindquist 1970; Walters and Campbell 1955).

Categorical X | **Continuous**

Suitable Categories:
Mite is found in a large number of habitats and rides many insect hosts ***(e.g. Dendrolaelaps quadrisetus, Histiogaster arborsignis, Proctolaelaps*** *fiseri,* ***and*** *Vulgarogamasus lyriformis*) (Kinn 1967; OConnor 1990, 1991; Moser and Roton 1971).
Mite is found in single or few habitats and ride only a single or few insect hosts ***(e.g. Pyemotes scolyti*** rides ***Scolytus spp.; Pyemotes barbara*** probably rides only ***Barbara*** *colfaxiana*) Moser and Roton 1972; Moser et al. 1987)

Unit of Measure:

Minimum:

Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: Disturbance - Insect pest
Attribute: Agent - Bark beetles and/or insect associates on conifers and broadleafed trees (Moser and Roton 1971; Moser, unpublished).

Kev Environmental Correlates

2. Number of host larvae and pupae required for mite development.

Categorical | **Continuous X**

Suitable Categories:

Unit of Measure: Number consumed
Minimum: one
Maximum: unknown

Applies seasonally? Yes
Which seasons? Crowing season
Theme name: ?
Attribute: ?

3. Temperature of galleries for mite survival and growth (Rudinsky 1962; Rudinsky and Vite 1956).

Categorical | **Continuous X**

Suitable Categories:

Unit of Measure: C°
Minimum: 10
Maximum: 34

Applies seasonally? Yes
Which seasons? Growing season
Theme name: Climate
Attribute: Daily minimum and maximum temperatures; degree days.

Key Ecological Functions

1. *Histiogaster arborsignis, Vulgarogamasus* *lyriformis,* ***and*** *Proctolaelaps fiseri* may qualify as biological control agents for bark beetle brood (Moser 1975a).

2. Mite is biological indicator of prospects for increase or decline of host populations (Lindquist 1970).

Key Assumptions

Lindquist 1970

1. Most predacious species ***(Proctolaelaps, Dendrolaelaps,*** at least) are not very host specific within the Scolytidae but tend to be habitat specific.

2. Bark beetles usually do not serve as hosts to both egg and larval parasitic mites, even though one group (e.g. ***Ips)*** having an egg parasitoid may be exposed through coexistence to the larval parasitoids of another group ***(e.g. Dendroctonus).***

3. The frequent coexistence in bark beetle galleries of two or three species of mites of the same family and often of ***the same*** genus ***(e.g. Proctolaelaps,*** *Dendrolaelaps*)

Key Unknowns and Monitoring or Research Needs

Lindquist 1983:
1. Searching capacity
2. Power of increase relative to prey
3. Life cycle synchrony with prey species
4. Regional variability of mite populations

Dispersal

Dispersal mode: Phoresy

Requirements for dispersal: Presence of phoront and phoretic stage of mite. Both mite and potential phoronts must possess compatible morphological modifications (e.g. enlarged leg 1 claws of mite; caudogenital attachment of mite; phoront setae) to allow phoretic behavior.

Degree of Confidence in Knowledge of Species

High____

Med____

Low_X_

Comments

Unlike the nematode parasites, there are no mite parasites of bark beetle larvae and pupae in the CRB assessment area. But like the insects, there are parasitoids and predators. The parasitoids are limited to two species of the genus ***Pyemotes.*** One species, ***P. scolyti,*** attacks the brood of the bark beetle genus *Scolytus*, which include a number of bark beetle species in the CRB assessment area including ***S. rugulosus*,** which attacks ***Prunus*** and *Pyrus* fruit ***trees, S. piceae*** (spruce), ***S. Zaricis*** (larch), ***S. tsugae*** (hemlock), S. ***ventralis*** (Douglas-fir), and ***S. multistriatus*** (elm) (Moser and Roton 1972).

The parasitoid ***Pyemotes barbara*** has been recorded to attack and kill pupae of the Douglas-fir cone moth in the field (Moser et al. 1987). In the laboratory, however, the mite also killed pupae of ***Dendroctonus ponderosae*** and larvae of the saltmarsh caterpillar, ***Estigmene** acrea*, showing that this mite may prey on a variety of insects. But whether or not it does depends on its method of dispersal. If, like S. ***scolyti,*** it rides only a restricted number of hosts (phoronts), then its prey species will be restricted; but ***if, like S. tritici,*** it is not phoretic, then it may attack almost any animal, including humans (Moser 1975b).

Although the number of CRB parasitoids attacking forest insects is so far restricted to the above two species of ***Pyemotes,*** several other species have been recorded from pine bark beetles and needle-sheath midges in other parts of the U. S (Cross et al. 1981). As more information on the biodiversity of mites associated with CRB forest insects accumulates, then the number of known parasitoids should increase.

Most will probably be new species.

The mite predators have been discussed in detail by Kinn (1983a,b), Lindquist (1969b), and Moser (1975a). Three representative species ***are Dendrolaelaps quadrisetus, Histiogaster arborsignis,*** and ***Proctolaelaps fiseri***. Although all attack scolytid brood, only ***D. quadrisetus*** feeds primarily on scolytids; ***H. arborsignis*** prefers fungi, and ***P. fiseri*** prefers nematodes.

MOSER\CRBFORM6

Date: October 28, 1994 **Panelist Name:** John C. Moser

Species or Species Group: Larval parasitengona mites parasitic on forest insect adults.

Geographic Area and/or Habitat Type: Range throughout forested area of interior CRB assessment area. SS 5,6,7; *OSC* 2,3,4,5. See also key unknowns.

Representative Species: ***Leptus treati, Neotrombidium*** spp. (Kinn 1987; Moser 1979)

Key Environmental Correlates

1. Ability of the mite to contact the host

Categorical X **Continuous**

Suitable Categories: Unit of Measure:

1. Ability of mite to reach suitable height in tree to contact the host.
2. Mite uses odor to locate host.
3. Mite uses touch to locate host.

Minimum:

Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

2. Ability of mite to select suitable attachment site on host (Houseweart et al. 1980).

Categorical X **Continuous**

Suitable Categories: Unit of Measure:

1. Head
2. Thorax
3. Abdomen

Minimum:

Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

Key Environmental Correlates

3. Greater percentage of late-flying moths are infested than those of early-flying moths (Houseweart et al. 1980).

Categorical X

Suitable Categories:
Percent infestation of early-flying moths
Percent infestation of late-flying moths

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

Continuous

Unit of Measure:

Minimum:

Maximum:

4. Synchronization of parasite with life cycle of moth.

Categorical X

Suitable Categories:
Egg-laying period of moth (Loughton et al. 1963).
Other periods of egg laying.

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

Continuous

Unit of Measure:

Minimum:
Maximum:

Key Ecological Functions

1. Parasite may kill host (Welbourn 1983).

2. Parasite may affect fecundity of host (Houseweart et al. 1980).

3. Parasite may affect flight behavior of the host (Houseweart et al. 1980).

Key Assumptions

Key Unknowns and Monitoring or Research Needs

THE key unknown is whether or not this group of parasites is present in the Columbia River Basin Assessment Area. I can find no concrete evidence (i.e. specimens or records) of these parasitic larval mites on western forest insects. But there is substantial evidence from the Eastern U. S. that this or a similar species will turn up once that workers become aware of them, and a search for these mites is initiated.

The following quoted from Welboum 1983 summarizes the known information about this mite from its only known location in Maine. "Houseweart et al. (1980) reported that 28 percent of nearly 2,300 male spruce budworm moths, *Choristoneura fumiferana* (Clemens), collected in pheromone traps over a 3-day period, were parasitized by larvae of ***Leptus*** *treati*."

Other key unknowns are:

1. Determination of the species of each parasite.
2. The effects on the flight behavior of the host.
3. The effects on the fecundity of the host adult.
4. Do these parasites also affect eggs, larvae, and pupae of the insects?
5. What are the regulatory effects of the mite?
6. Does the mite kill the host (i.e. is it a parasite or parasitoid)?
7. What is the life cycle of the mite?
8. Is the life cycle of the mite synchronized with that of the host?
9. Does the mite parasite have alternate hosts?
10. What does the deutonymph and adult of the mite prey on?
11. Does the deutonymph and adult of the mite prey on the eggs of **this** host?

Dispersal

Dispersal mode: Larval phoresy (Welboum, personal communication) using the definition of Houck and OConnor, 1991.

Requirements for dispersal:

1. Presence of host (=phoront) and the larval stage of the mite.
2. If the mite is specific, then the proper species of host and/or stage of the host must be present.

Degree of Confidence in Knowledge of Species

High____

Med____

L o w - x ,

Comments

The terrestrial Parasitengona in the super-families Trombidoidea and Erythraeoidea contain a number of genera and species that as chigger-like larvae parasitize forest insects, especially those feeding on the foliage of trees.

Although there is substantial evidence from other areas of the U. S. that this group of mites attack spruce budworm and gypsy moth in the Eastern U. S. (Welboum 1983), there is little evidence from the literature that these mites occur with forest insects in the CRB. However, Welboum (personal communication) states that he has collected many trombidiids and erythraeids (including the important genus ***Leptus)*** in pitfall traps and by beating the foliage of trees in the forests of Nevada and Northern California. From this it is apparent that these parasitic mites are present in the CRB and will turn up once that workers learn to recognize the characteristic mite larvae, which are usually bright red in color. Some examples of larval parasitengona that should be searched for include the following.

Trombidiid larvae may attach to and parasitize scolytids in rare instances. Moser and Vercammen-Grandjean (1979) recorded two species of Trombidiidae, ***Diathrombium diaphane*** and ***Megophthrombium gracile*** attached to southern pine beetle (SPB) adults collected in water-filled pheromone traps. The larvae seemed to attach to ***any*** body part of these scolytids. Curiously, ***Megophthrombium*** may not be the normal host for SPB since the other two described species in this genus parasitize mosquitoes (Welboum 1983). The trap in which they were caught was adjacent to a water-filled ditch, and the larvae apparently climbed the pole and entered this nearby trap; they then attached to the beetles trapped inside.

Borland (1956) reports larvae of another trombidiid, ***Neotrombidium tricuspidium,*** parasitic on adults of cerarnbycids. Kinn (1987) noted that of five cerambycids reared from field-collected bolts of pine, it parasitized all but ***Neacanthosinus obsoletus.***

Welboum and Jennings (1991) and Houseweart et al. (1980) record that larvae of ***Leptus treati*** parasitized as many as 28% of spruce budworm male moths collected in pheromone traps in Maine. They concluded that parasitism by ***Leptus*** may indirectly affect budworm egg production by reducing fecundity. Other species of ***Leptus*** parasitize large numbers of other forest insects including bark beetles (Moser 1979).

MOSER\CRBFORM7

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: October 3 1, 1997 **Panelist** Name: John C. Moser

Species or Species Group:
Nematophagous mites of subcortical bark and sawyer beetles.

Geographic Area and/or Habitat Type:
Range throughout forested area of Columbia River Basin assessment area on multiple host types.
SS 5,6,7; ***OSC*** 2,3,4,5

Representative Species:
Cercoleipus coelonotus, Dendrolaelaps quadrisetus, Trichouropoda australis, T. lamellosa, Vulgarogamasus lyriformis.

Key Environmental Correlates

1. Specialized mite development stages feed on nematodes.

Categorical X **Continuous**

Suitable Categories:
Larvae only (e.g. *Vulgarogamasus lyriformis)* (Kinn 1983b).
Deutonymph and adult (e.g. ***Dendrolaelaps quadrisetus)*** (Kinn 1967).

Unit of Measure:
Minimum:
Maximum:

Applies seasonally? Yes
Which seasons? Growing season
Theme name: ?
Attribute: ?

2. Mite species preference for nematodes.

Categorical X **Continuous**

Suitable Categories:
1. Mite prefers nematodes over other prey (e.g. ***Cercoleipus coelonotus,*** Kinn 1971; ***Dendrolaelaps neodisetus,*** Kinn 1984).
2. Mite prefers bark-beetle prey over nematodes (e.g. ***Dendrolaelaps quadrisetus,*** Kinn 1967).

Unit of Measure:
Minimum:
Maximum:

Applies seasonally? Yes
Which seasons? Growing Season
Theme name: ?
Attribute: ?

Key Environmental Correlates

3. Preferred phoront of mite species.

Categorical X | **Continuous**

Suitable Categories: Kinn and Linit 1989

1. Cerambycids - E.g. ***Trichouropoda lamellosa.***
2. Scolytids - E.g. ***Vulgarogamasus lyriformis, Cercoleipus coelonotus***
3. Both - E.g. ***Histiogaster arborsignis***

Unit of Measure:

.

Minimum:

Maximum:

Applies seasonally? Yes

Which seasons? Crowing Season

Theme name: Disturbance - insect pest

Attribute: Agent - Bark beetles of and/or insect associates of conifer and broad-leafed trees (Moser and Roton 1971; Moser, unpublished).

Key Ecological Functions

1. Deutonymphs of ***Trichouropoda lamellosa*** placed in isolation cells were observed to feed on the pinewood nematode (Kinn 1987).

2. Dendrolaelaps neodisetus can be reared on nematodes of several species (Kinn 1983b)

3. Certain nematophagous mites ***(e.g. Dendrolaelaps neodisetus)*** associated with bark beetles may be beneficial to beetle development, and the association mutualistic, because the mite preys on nematodes which are bark beetle endoparasites (e.g. the nematode ***Contortylenchus brevicomi).*** This same type of relationship is likely to exist between ***Cercoleipus coelonotus*** and other nematophagous acarines associated with bark beetles (Kinn 1983b).

4. Many nematophagous mites attack and kill other mites (Kinn 1983b).

Key Assumptions

1. The behavior of the Columbia River Basin mite populations of ***Dendrolaelaps neodisetus, Trichouropoda australis, T. lamellosa, and Vulgarogamasus lyriformis*** are the same as those populations associated with the southern pine bark beetles in Louisiana.

2. A complex food chain exists as described by Kinn 197 1 (see narrative fig.l.)

Kev Unknowns and Monitoring or Research Needs

1. Which species of nematophagous mites are symbiotic with bark beetles and enhance brood production?

2. Which mites are general nematode feeders and which are specific to certain nematode species?

Dispersal

Dispersal mode: Phoresy

Requirements for dispersal:

1. Presence of proper phoront and phoretic stage of mite.
2. Both mites and potential phoronts must possess compatible morphological modifications to allow phoretic behavior (e.g. mite caudoventral attachment organ) (OConnor 1984; Houck and OConnor 1991.)
3. Environmental cues that signal habitat degradation is a potential trigger [for hypopal or phoretic stage] (Houck and OConnor 1991.)

Degree of Confidence in Knowledge of Species

High____

Med____

Low _X_

Comments

The food chain relationships may be complex (see fig. 1 in Narrative).

A number of nematophagous mites are recorded for the CRB assessment area on multiple host types. Examples of these are ***Cercoleipus*** coelonotus, ***Dendrolaelaps quadrisetus, Trichouropoda australis, T. lamellosa,*** **and** ***Vulgarogamasus lyriformis***. Andre (1980) points out that a high phoretic preference of a mite for a particular phoront may not mean that it preys on that host. An example of this is ***Cercoleipus coelonotus*** which rides ***Ips paraconfusus*** and ***Ips montanus;*** this mite prefers nematodes (Kinn 197 1), but ***also*** preys on ***eggs*** and larvae of ***Dendrolaelaps quadrisetus,*** which prefers eggs and larvae of its scolytid phoront, ***Ips paraconfusus*** (Kinn 1967,197 1). ***Trichouropoda lamellosa*** which is phoretic on cerambycid beetles fed on the pinewood nematode (Kinn 1987).

Nematodes are also phoretic with the mites on flying bark beetles and cerambycids. In Japan, deutonymphs of at least one phoretic mite, ***Dendrolaelaps unispinatus*** has been recorded to feed on the pinewood nematode phoretic on cerambycids (Enda and Tamura 1977; Tamura and Enda 1980). This behavior should be watched for in the U.S. where the pinewood nematode is native.

BIODATA.CRB; 10/25/94

BIOGRAPHICAL DATA
John Conrad Moser

Address:
Permanent employment: Retired.
Degrees: 1951 B.S. Entomology, Ohio State University
1954 M.S. Entomology, Ohio State University
1958 Ph.D. Insect Ecology, Cornell University
Permanent Employment: 1958 - 1989. Research Entomologist, GM-14, USDA Forest Service, Forest Insect Research Work Unit 4501, Pineville, LA.
Volunteer Work: 1990 - present. RWU-4501, USDA Forest Service, Pineville, LA 71360.
Summary of Research Accomplishments:

Dr. Moser's entire professional career has been devoted to basic research on the biology and biodiversity of forest insects and mites. Six of his 100 papers have been published by the journals SCIENCE and NATURE. These dealt with new discoveries of ant pheromones as well as insect-mite-fungus interactions and hyperphoresy.

Dr. Moser is the leading authority on mites associated with forest insects, and possesses the world's largest collection (over 30,000 specimens) of these mites. Among his many discoveries was the finding that certain Tarsonemus mites are not only major vectors of bluestain disease of pine, but that these phoretic mites also carry the ascospore stage of certain bark beetle mycangial fungi. The mites carry these spores in special pouches (similar to bark beetle mycangia) called sporothecae. Another discovery was his concept of phoretomorphy, which revolutionized the systematics of certain groups of the Acarina. This concept has been a basic addition to all textbooks on acarology published since 1975. Basic to ongoing research efforts and the modeling of bark beetle dispersal, was his plotting of the range of temperatures at which the southern pine beetle is known to fly. His observed minimum, 6.7°C, documents that the southern pine beetle flies at lower temperatures than any other bark beetle, and for this reason it is capable of doing tremendous damage in winter.

Dr. Moser is also the prime authority for leafcutting ants in the United States. In the early 1970's, he was an author and the driving force behind two important breakthroughs in chemical ecology, and published in the journals SCIENCE and NATURE -- the discovery and synthesis of "attalure" the first ant trail pheromone, as well as the splitting and demonstrating of the first pheromone enantiomere activity for any invertebrate.