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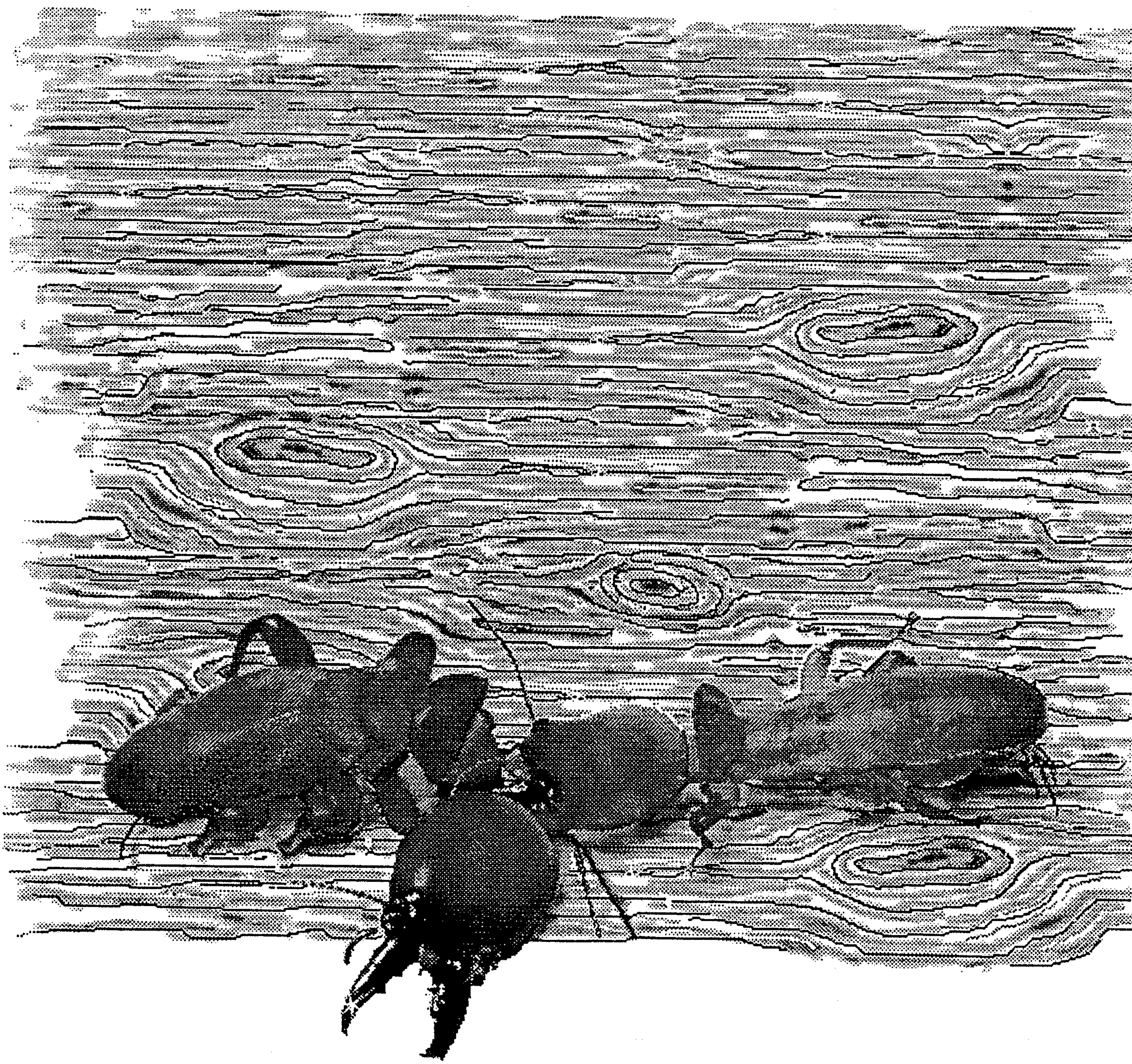

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In 1989 the Western International Forest Disease Work Conference and the Western Forest Insect Work Conference met jointly in Bend, Oregon, during the week of September 11-15, 1989. One of the 90-minute, concurrent workshops scheduled during this period was a discussion of the biology and present and future control strategies of wood-destroying organisms. This subject area has not traditionally been of concern to these two organizations, either as it might relate to protection of wood in use or to the degradation of wood in a forest environment. It was felt that many of the professionals attending the meeting would be interested in a discussion of current research in the general area of wood-destroying organisms and the future for protection of wood in service. To ensure sufficient participation by knowledgeable pathologists and entomologists, the technical coordinators organized a day-long technical session on wood-destroying organisms, which emphasized state-of-the-art and future research needs and control practices. The subjects presented included: research on wood decay by the USDA Forest Service, new developments in wood-deterioration research from the International Research Group on Wood Preservation, methods for nondestructive evaluation of infestations and infections of wood-destroying insects and decay in structures, role of termites in forest management in Australia, chemotaxonomy of termites, agonistic behavior of termites, tunneling behavior of subterranean termites, bait/toxicant strategies for control of subterranean termites, and training of the pest control industry to utilize the new technologies.

Retrieval Terms: wood biodeterioration, decay mechanisms, fungi, biosystematics, nondestructive evaluation, acoustic emission, termites, Australian forests, cuticular hydrocarbons, agonistic behavior, semiochemicals, tunneling behavior, foraging behavior, termiticides, bait toxicants.

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Behavioral Ecology of Subterranean Termites and Implications for Control[1]

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Abstract: Subterranean termites are important structural pests in much of North America, and worldwide. Recent studies of eastern subterranean termite (*Reticulitermes flavipes* [Kollar]) colonies in Ontario, Canada, indicate that these colonies contain greater foraging populations and forage over larger territories than was previously thought to be the case. These results are consistent with those obtained elsewhere with *Coptotermes formosanus* Shiraki and *Heterotermes aureus* (Snyder). Implications for the development of baiting techniques for termite control are discussed, and several laboratory investigations of potential bait toxicants and insecticidal dusts are reviewed. Behavioral chemicals are also potentially useful in termite control, and bioassays with tree extractives indicate that semiochemicals affecting termite orientation offer an explanation for the observed pattern of *R. flavipes* infestation in street trees in Toronto.

The eastern subterranean termite (*Reticulitermes flavipes* [Kollar]) (Isoptera: Rhinotermitidae) has a broad distribution in North America, extending from the southeastern United States to the Great Lakes (Weesner 1970). At the northern edge of this distribution, *R. flavipes* was first reported at Point Pelee, Ontario, in 1929, and was apparently introduced to Toronto in infested materials brought by ship from the United States about 1935 (Kirby 1965; Urquhart 1953). To date, infestations have been reported from thirty municipalities in southern Ontario, with Kincardine (44°11'N, 81°38'W) representing the northernmost site of established *R. flavipes* infestations. Outside of buildings, flights of *R. flavipes* alates are rare in Ontario, and the disjunct distribution of termites in the province results from movement of infested wood (firewood or used lumber). In 1987, a *Reticulitermes* infestation of several years standing was also discovered in a block of homes in Winnipeg, Manitoba, indicating the potential for further northern distribution of this genus.

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TERMITE TERRITORIES AND BAITING STRATEGIES

Grace and others (1989) recently evaluated the size of *R. flavipes* foraging territories and populations at two sites in metropolitan Toronto. These mark-release-recapture studies employed the dye Sudan (Fat) Red 7B (Grace and Abdallay 1989) with methodology similar to that of Su and Scheffrahn (1988) with *Coptotermes formosanus* Shiraki and Jones (1987) with *Heterotermes aureus* (Snyder). As was the case with these latter two species, eastern subterranean termite colonies were found to cover larger areas and contain greater foraging populations than previously suspected. At one site, the foraging population was estimated at 3.2 million termites, moving over a territory of 1,091 m^2 (Grace and others 1989). Continuing studies at these two field sites and at other locations in Ontario have confirmed the general applicability of these results (Grace 1990*a*). Additional dyes (Grace and Abdallay 1990*a*) would be useful in improving the precision of population estimates.

It is interesting to note that the mark-release-recapture studies with *R. flavipes* were conducted around buildings chemically treated for subterranean termite control, emphasizing that the "chemical barrier" around treated structures has little effect on termite populations outside that narrow band of pesticide-treated soil. As is mentioned elsewhere in these proceedings, the use of toxic baits appears to be the most reasonable method of attacking these populations. In regions where subterranean termites are ubiquitous, such baits would likely be employed to extend the protected area outward from the structures at risk. Baits would have to remain in place following the death of colonies in the baited zone to intercept foragers entering the area from expanding colonies in adjacent areas, as well as foragers from any new alate-founded colonies. However, in northern regions with a disjunct pattern of *Reticulitermes* infestation and limited occurrence of alate flights, it should be possible to eradicate isolated infestations, with a low probability of re-introduction. Active foraging by colony groups over large areas implies that bait placement is perhaps less critical than would be the case with localized foraging parties, and that a few baits could affect a large termite population impinging upon multiple buildings.

Toxicants intended for use in baits should be nonrepellent and slow-acting (Su and others 1987). Certain borate compounds (Grace 1990*b*) fit these criteria, although rather high dietary concentrations are required to kill termites. An alternative, although more labor intensive, approach may be to apply borate (or other insecticidal) dusts in a toxic variation of mark-release-recapture methodology. Grace and Abdallay

(1990*b*) demonstrated in laboratory assays that coating 5-10 percent of the individuals in groups of 20-40 *R. flavipes* workers with boric acid or barium metaborate dusts resulted in 28-100 percent mortality within 16 days. Subterranean termite foragers collected in traps such as those described by Grace (1989) and Su and Scheffrahn (1986) could be coated with such toxic dusts and released back into the traps to poison other colony members through mutual grooming behaviors. Collections from multiple traps at each site and multiple capture and release cycles could be employed to treat a sufficiently large proportion of the population to kill the entire colony.

An alternative to the use of chemical insecticides in termite baiting systems is the use of microbial biological control agents, such as nematodes or fungi. In Ontario, and other areas of subterranean termite introductions, surveys of the mycoflora associated with termites may reveal potential pathogens. Zoberi and Grace (1990*a*) isolated 40 fungal species from *R flavipes* and associated materials. Several of these fungi have been previously reported to be facultative insect pathogens, and a number (e.g., *Arthrobothrys oligospora* Fresenius, *Cunninghamella echinulata* Thaxter, and *Rhizopus stolonifer* Ehrenb. ex Fr.) appear to be detrimental to termite survival in preliminary bioassays. The well-known pathogenic fungus *Beauveria bassiana* [Balsamo] Vuillemin was also recently isolated from *R. flavipes* workers infesting a street tree in Toronto (Zoberi and Grace 1990b).

Although attractant or arrestant semiochemicals would be useful in masking otherwise repellent bait toxicants, the high level of foraging activity of *R. flavipes* at field sites in Ontario indicates that neither decayed wood nor attractant chemicals are necessary prerequisites to implementation of baiting techniques, so long as the feeding substrate or bait toxicant within the collection unit is not repellent. Use of a collection trap is certainly more labor intensive than placement of the toxicant-impregnated decayed-wood blocks originally used to control termites in this manner (Ostaff and Gray 1975). However, it also offers more control possibilities (such as incorporating dusts) and a means of quantifying the decline in the termite population by post-treatment monitoring and mark-release-recapture methods. Post-treatment bait units, supplemented by wooden stakes, could remain in place both to confirm the efficacy of the control method and as an aid in subsequent inspections of the property for new termite infestations.

SEMIOCHEMICALS IN ORIENTATION AND FEEDING

Eastern subterranean termite responses to behavioral chemicals (semiochemicals) may help to explain observed patterns of termite foraging, and may also be useful adjuncts to baiting systems. Low concentrations of the microbicide TCMTB, for example, are repellent to *R. flavipes,* and might protect wood from termite attack more effectively than toxic but nonrepellent preservatives (Grace 1988). Attractants and arrestant semiochemicals, on the other hand, might be used to enhance feeding on baits and to direct foragers towards baits or toxicant-treated soil. *Reticulitermes* workers are able to orient to chemical gradients, both on two-dimensional trails (Grace and others 1988) and diffused through the soil (Clement and others 1988).

In Toronto and other northern locales, *R. flavipes* infests living trees as well as cellulosic debris and wood in service. Shelter tubes are constructed in bark fissures upward from the base of the tree stem, and termites are active between the inner and outer bark. Although feeding is limited to dead portions of the tree, such as the heartwood and fungus-decayed limbs, some scarring of the bark and sapwood surfaces is also apparent.

In 1980, an inspection of 17,800 street and park trees in metropolitan Toronto revealed termite shelter tubing on 4 percent of those trees (Cooper and Grace 1987). Subsequently, two tree species commonly occurring in Toronto were selected to determine whether chemical factors were involved in the pattern of differential infestation of street trees observed in the 1980 survey. Subterranean termite tubing was found on 19.3 percent of the horsechestnuts (*Aesculus hippocastanum* L.) (Hippocastanaceae) inspected, ranking it as a frequently infested tree species. On tree of heaven (*Ailanthus altissima* [Mill.] Swingle) (Simaroubaceae), however, shelter tubing was noted on only 0.7 percent of the trees inspected, suggesting that it is rarely infested (Cooper 1981).

The bark, sapwood, and heartwood of these two tree species were each extracted in a series of solvents (chloroform:acetone, methanol, acetone, hexane), and the resulting extracts applied to filter paper and exposed to *R. flavipes* workers in no-choice laboratory assays (Grace, in preparation).[4] All extracts were assayed at 4 percent (weight/weight) concentrations, although the yields from extraction ranged from 0.3-10.2 percent (wt./wt.). Only the hexane extract of *A. altissima* heartwood caused significant termite mortality within 15 days. However, the yield of hexane extractives from *A. altissima* heartwood was only 0.3 percent (wt./wt.). Since it was assayed at a 4 percent concentration, this suggests that less mortality might be expected from termite feeding on the natural substrate.

The orientation responses of individual *R. flavipes* workers to these extracts were evaluated in behavioral assays (Grace, in preparation).[4] In these assays, a single worker was placed between a 23 mm diameter paper disk treated with 4 percent (wt./wt) extractives and a second solvent-treated control disk in a small glass petri dish. The position of the worker (in contact with either or neither paper disk) was recorded every 30 seconds over a 20-minute interval. This assay was repeated with 50 workers exposed to each of the 12 extracts from the two tree species, and the proportions in contact with the extract-treated and the control disks compared (paired-comparisons *t* test). Seven of the 12 horsechestnut extracts elicited significant ($p \leq 0.05$) positive orientation responses, and 3 elicited significant negative responses. The opposite trend

[4]Data on file, Department of Entomology, University of Hawaii, Honolulu, Hawaii.

was observed with tree of heaven, for which 7 of the solvent extracts elicited negative responses, and only two elicited positive responses. In addition, the *A. hippocastanum* extractives eliciting the strongest positive orientation responses and the *A. altissima* extractives eliciting the strongest negative responses were present in high concentration in their respective wood matrices. Thus, semiochemical-mediated orientation behavior and initiation of feeding on a particular tree species may explain differential infestation of otherwise equally suitable substrates.

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