CWPA Proceedings, 2006, pp 27-38

TERMITE TRENDS WORLDWIDE

J. Kenneth Grace

Department of Plant and Environmental Protection Sciences
University of Hawaii at Manoa
3050 Maile Way, Room 310
Honolulu, HI 96822, USA
(email: kennethg@hawaii.edu)

I appreciate the opportunity to address the membership of the Canadian Wood Preservation Association at the 27th annual meeting, and discuss current trends in (1) termite biology, (2) termite research, and (3) termite control. This is, in some respects, an update to a paper I delivered at the seventh annual meeting of the CWPA on "The Challenge of Wood Destroying Insects" (Grace 1987). During the past 20 years, we have done much to meet the challenges described in that paper. However, wood destroying insects, particularly termites, are constantly presenting us with new questions and new challenges. For example, our increasingly mobile society has facilitated a rapid increase in the rate of introduction of invasive termites to new regions. Fortunately, scientific tools that were in their infancy 20 years ago, such as DNA fingerprinting, and pest control methods that were dreams in the minds of researchers, such as the use of termite baits (e.g., LaFage 1984), are now available to help us answer these questions and address these challenges.

Trends in Termite Biology

Increasing distribution of cosmopolitan pests. Increased societal mobility during the latter half of the 20th century has had an enormous impact on the distribution of pestiferous insects around the globe. Termites have always been moved by human travel and commerce, but the frequency of such movements (that is, the rate of invasion) has dramatically increased.

Although it is not particularly easy for subterranean termites to become established in new regions, increased frequency of introduction obviously leads to increased rates of success in establishment. Fewer than 10% of the approximately 2,500 species of termites in the world (90% of which occur in the tropics) are considered pests to man, but these species are being distributed by travel, commerce and military traffic more frequently, and as a result are increasingly found in regions outside of their climatic comfort zone. Tropical species, such as *Coptotermes vastator*, have become established in the subtropics (Cabrera et al. 2006, Grace 2006); and subtropical species such as *Coptotermes formosanus* are expanding their range northward into more temperate areas (Jenkins et al. 2002).

The Hawaiian Islands offer an example of the increasing frequency of exotic termite establishment. Prior to the late 19th century, only three species of drywood termites (Family Kalotermitidae) were found in the islands. One of these species, *Cryptotermes brevis*, inhabits seasoned wood almost exclusively, and is easily spread in man-made wooden materials. Thus, it would have easily been introduced by Polynesian traffic. The other two species, *Neotermes connexus* and *Incisitermes immigrans*, generally inhabit dead wood in living trees or wood on the forest floor, and are thought to have either been introduced by the Polynesians or perhaps on floating logs. With the introduction of the voracious Formosan subterranean termite, *C. formosanus*, in the late 1800s, the number of termites considered to be established in Hawaii increased to four, and this number remained stable into the 1990s. However, during the single decade of the 1990s, the number of termites known to be established in Hawaii doubled to eight species (Grace et al. 2002). One of these termites, *Coptotermes vastator*, is a more tropical species and the major termite pest in Guam and the Philippines (Woodrow 2001). This species was very likely introduced to Hawaii by military traffic; while two of the other species (*Incisitermes minor* and *Zootermopsis angusticollis*) were apparently introduced by commercial shipment of infested materials from the western United States, and the final species (*Cryptotermes cynocephalis*) most likely by shipment of household effects from the Philippines to Hawaii.

The increasing spread of the Formosan subterranean termite, *C. formosanus*, in the southern United States is a particularly well documented example of a largely man-made termite distribution, with this pest now found in 11 states. Movement of infested materials, particularly used rail-road ties for use in landscaping (Jenkins et al. 2002) is thought to be the major factor in this spread. Movement of household effects from Hawaii is considered to be the source of a continuing infestation near San Diego, California (Atkinson et al. 1990).

Emergence of new pest problems. A second trend in termite biology is the emergence of new pest problems, either due to increasing urbanization encroaching on termite habitats (Rust 2004), or pest control applications creating opportunities for lesser pest termites to move into niches formerly occupied by more common pests (Lee et al. 2006). These phenomena represent an interesting counterpoint to the more widely discussed trend of increasing movement of invasive insect species around the world. Rather, native termites that had not previously been considered threats are no becoming so, as a result of human actions.

As urban areas expand and housing developments are erected in previously uninhabited areas, native termites are presented with new food resources in the form of structural lumber. In Hawaii, incidences of the drywood termite *Incisitermes immigrans*, a species generally found in trees, in structural lumber have increased over the past two decades. The rotten wood termite *Zootermposis angusticollis* usually infests stumps and logs in wooded areas in western North America (and in Kula, Maui, Hawaii), but it will also attack wooden steps, decks, and even lower wall framing when homes are built in its proximity and there is sufficient moisture present.

The use of baits to eliminate subterranean termite colonies in and around buildings in the past decade, although very effective, has also raised the possibility of secondary pest outbreaks. In the southern United States, native *Reticulitermes* spp. are often found in soil monitoring stations following successful baiting for the Formosan subterranean termite. This stands to reason, since a high density of small native termite colonies is characteristic of the southern woods, in contrast to the single large *C. formosanus* colonies that are often found around buildings. Baiting has the unique effect of killing the exposed termite colony, but leaving their gallery structure in the soil intact. Adjacent termite colonies tunneling into this existing gallery structure will use its channels to rapidly explore the area and begin to feed on the wood placed in the monitoring stations (Grace and Su 2001).

This emphasizes the need for continued monitoring of the bait stations to detect these new foragers. In North America, when *Reticulitermes* spp. are detected, they can also be controlled by subsequent bait applications. However, in Southeast Asia, the situation is more complex, since the secondary pest species often found after elimination of *Coptotermes* spp. are higher termites (Family Termitidae) and do not respond well to paper-based bait matrices (Lee et al. 2006). With these secondary termite pests, different control measures may be necessary.

Trends in Termite Research

Proliferation of researchers and research contributions. The greatly reduced availability and use of chlorinated cyclodiene insecticides for termite control in the latter half of the 1980s triggered a new global interest in research on termite control, and a strong interest on the part of both government and industry in funding these research efforts. Since a basic principle of pest control is that one must understand the organism in order to effectively control it, the interest in termite control also triggered an upsurge of interest in research on termite biology and behavior. I recall attending a symposium on termite research at a national entomology conference in the early 1980s where perhaps six people were present in addition to the symposium speakers. However, multiple symposia on termites are now the norm at such professional meetings, with the speakers more often than not addressing standing-room-only crowds. It is no exaggeration to state that more scientific papers on termite biology, ecology, behavior and control are now issued each month than were typically published in a decade in the period prior to 1980.

Along with this increase in knowledge has come an increasingly sophisticated approach to termite control research. New insecticides and baits are vetted much more broadly by a much greater number of researchers than was the case prior to 1980, when pesticide manufacturers in North America looked almost exclusively to a limited number of field tests performed by the USDA Forest Service. Although research by this agency is still important, active university-based research programs also now exist across North America, and in major population centers around the world. Beneficial outcomes of this "researcher proliferation" have been a much more comprehensive and accurate understanding of the distribution of termite species around the world, and pest control techniques tuned to particular local conditions and issues.

With a broader base of termite researchers and new graduate students, novel approaches that may very well represent termite control in the future are now receiving research attention. Scientists are naturally competitive, and this competition propelled the field forward in the 1990s, establishing new molecular techniques and illuminating termite foraging behavior on the research side, and creating the framework for the introduction of both baits and non-repellent soil insecticides on the industrial side. As the number of researchers has continued to increase and the technology required for molecular genetics has matured, however, networks have formed among these researchers; and the theme for further advancement in the 21st century will certainly be collaboration rather than individual competition.

Focus on the use of molecular genetics. A key trend in termite research is the use of the tools of molecular genetics to study species identification and distribution, differentiation of populations, colony social structure, and feeding behavior (Husseneder et al. 2003, Jenkins 2006, Szalanski 2003, Vargo 2004). At the beginning of the 21st century, molecular genetics offered a way to finally explore the secret world of these cryptic insects; insects that not only hide under the soil or inside wood, but also offer very few morphological characters to differentiate species, populations, or individuals.

Our early attempts to use molecular tools to examine the spread of the Formosan subterranean termite were frustrated by the low resolution of the methods available at the time (Broughton and Grace 1994, Strong and Grace 1993). However, technology advances exponentially, and we moved rapidly from early experiments with cellulose acetate gel electrophoresis (Strong and Grace 1993) to successful application of polyacrylamide gel electrophoresis to differentiate *Coptotermes* populations (Wang and Grace 2000a, 2000b), and on to the use of DNA fingerprinting to study population structure (Husseneder and Grace 2001) and microsatellites to study not only population structure, but also social relationships within the termite colony (Husseneder et al. 2002, 2005c). Genetic markers are now used routinely to identify individual termite colonies in field studies of termite bait efficacy (Vargo 2003, 2004; Messenger et al. 2005).

Molecular tools are an enormous help in answering the key termite research questions, "Who are they, where did they come from, and how is their colony organized?" These questions are virtually impossible to answer on the basis of morphology or behavior alone.

Focus on drywood termite detection. Better methods of termite detection have been of major interest with drywood termites (Family Kalotermitidae). These termites initiate their colonies in dry wood above ground, and the entire colony is contained within a single piece of wood. Usually, the only evidence of termite infestation (prior to obvious damage) is the presence of sand-like fecal pellets, pushed out of small holes in the wood as the termites clean their galleries. The most common recommendation for control is to fumigate the structure with a lethal gas, since one can almost never be sure how many termite colonies actually exist within a building, or the extent of each of these individual colonies. Although local treatments of the infested wood by insecticide injection or application of heat, microwaves, or electricity are possible, their efficacy is limited by this basic problem of detection. Breakthroughs have come slowly, but current research efforts focus on detection by acoustics, infrared, x-rays, or microwaves. At this point, each of these is an aid in problem-solving, but none are definitive. The next step is likely to be integration of several different detection modalities via a microprocessor and effective programing.

An area of research in Hawaii has been the development of better methods of termite detection in order to improve survey efforts to find new invaders to the islands. We have used the quantitative and qualitative patterns of hydrocarbons (lipids) on the insects' cuticle as a means to authoritatively identify insects collected in surveys (Haverty et al. 2001). This same cuticle lines the hindgut of the termites, and fecal pellets passing through the hindgut pick up the same pattern of hydrocarbons found on the cuticle. Thus, one can actually identify the species of a cryptic drywood termite by analysis of the fecal pellets pushed to the outside of the wood (Haverty et al. 2005).

Focus on subterranean termite foraging behavior. In the early 1990s, research on subterranean tunneling and food location behavior was stimulated by the successful introduction of baits, particularly the Sentricon Colony Elimination System (Dow AgroSciences) for termite control. At the end of this decade, such research received additional stimulation from the commercial interest in non-repellent and slow-acting soil insecticides, as alternatives to the repellent pyrethroids or the more immediately toxic organophosphates. Finally, research in Hawaii has been further stimulated by the desire to understand how preservative-treated wood impacts termite foraging.

The patterns by which termites tunnel through the soil differ among species (Grace et al. 2004, Puche and Su 2004), and are likely influenced by their ancestral habitat and the distribution of woody resources (food) in that habitat. For example, *Coptotermes formosanus* is a subtropical species and excavates fairly wide and straight tunnels in the soil, with limited branching occuring. In contrast, the tropical termite *C. vastator* excavates a mosaic-like matrix of thinner and interconnected tunnels. These differences may relate to the more clumped distribution of wood on the soil in less tropical areas, and the general prevalence of woody materials in the tropics. Thus, *C. vastator* may be programmed for intensive local search, while *C. formosanus* must move a fair distance between food sources (Grace et al. 2004). On the other hand, once *C. formosanus* locates a food source, multiple tunnel branches outward from that resource are immediately established in order to search the immediate area effectively (Campora and Grace 2001, Grace and Campora 2005). Once a gallery system is established throughout the soil, movement within that system by individual termites appears to largely be a random process (Su and Bardunias 2005).

We investigated Formosan subterranean termite foraging behavior in order to understand how borate wood treatments, which are not repellent to the insects, protect structural lumber. Foraging arenas in which a thin layer of sand is sandwiched between two sheets of plastic, similar to a horizontal “ant farm,” were constructed both in the laboratory and at a field site in Waimanalo, Hawaii. Small pieces of wood treated to the commercial retention of disodium octaborate tetrahydrate (DOT) were placed on one side of each arena, and untreated wood was placed on the other side. Termites were allowed to enter the arena from the center, and by observing their pattern of tunneling and movement through established tunnels, we were able to observe their response to the treated wood. By switching the locations of the treated and untreated wood, we were also able to determine whether the insects learn to recognize the borate treatment.

The results of these studies (Grace and Campora 2005, Campora and Grace 2007) indicated that foraging termites gradually begin to avoid the locations of the borate-treated wood. This was not a response to an accumulation of dead termites around the treated wood (necrophobia), since the delayed nature of borate toxicity does not result in such accumulation; nor did termites learn from experience to recognize the borate treatment. When borate-treated samples were moved to new locations, termites initially visited them without hesitation. However, when an untreated wood piece was substituted for a borate-treated sample, there was a several day delay before termites began to investigate and feed on the new wood. Thus, termite foragers appear to respond to the location of the borate-treated wood samples within their foraging network (i.e., they are able to map the resources within their gallery network).

Trends in Termite Control

External drivers. A major driving force behind the current direction in termite control has been the phase-out of organocholorine insecticides, such as chlordane, aldrin, dieldrin, and heptachlor. These insecticides were largely removed from the North American market in the late 1980s, and have now been drastically reduced worldwide as undesirable Persistent Organic Pollutants (POPs). In North America, the past decade has seen a less drastic, but quite significant, reduction in the use of organophosphate insecticides, of which chlorpyrifos (Dursban, Dow AgroSciences) was a primary insecticide for termite control. It is likely that this will be followed by governmental pressure (normally through the re-registration process in the United States) on carbamates and then pyrethroids.

In 2004, the wood preservation industry experienced an event comparable to the loss of the organochlorine insecticides for termite control: the phase-out of chromated copper arsenate (CCA) for most building materials. Just as the loss of chlordane and related compounds stimulated new research and new directions in termite control (such as the use of baits), the loss of CCA has stimulated new research on alternative wood treatments and engineered wood products, as well as being a boon to the steel framing industry. For protected, above-ground uses, borates have proven to be effective alternatives in many markets, such as Hawaii (Grace 2002). However, there is a very real danger that they will be used inappropriately since alternative treatments are often not readily available to consumers. Cost and corrosiveness to metal fasteners are the largest drawbacks of other currently available treatments.

Baits for termite control. The introduction of the Sentricon Colony Elimination System (Dow AgroSciences) for subterranean termite control in the mid-1990s constituted a true paradigm shift in termite control. One could argue that its development was driven largely by the scientific elegance of using baits for social insect control, and by researcher and industry concerns over increasing pressure to limit broadcast applications of broad-spectrum insecticides. However, its success was certainly due to the efficacy of this baiting technique in comparison to the reduced expectations for efficacy with the soil insecticides then available. The fact that this was not a wholesale paradigm shift was demonstrated six years later when the non-repellent soil insecticide fipronil (Termidor, BASF) was introduced and rapidly reclaimed a good portion of the market that had moved from soil insecticides to baits. Since there is indeed a strong, albeit long term, regulatory trend to reduce pesticide applications, however, the longevity of fipronil for termite control will probably depend upon how “bait-like” it can become (i.e., whether it can be incorporated into application techniques that greatly limit pesticide exposure).

As previously mentioned, variation among termite species in their response to bait stations, matrices, and toxicants, and the possibility of secondary termite pest occurrences pose challenges to researchers and the pest control industry. Standardization of bait efficacy studies and registration requirements have been of major concern in the United States, as has the role of baits in termite prevention as opposed to their use in remedial control. At present, a great deal of research effort is focused on reducing the time required to control termites with baits (by increasing the rate of bait discovery and consumption), and reducing the cost of control by extending monitoring cycles (through the use of more durable baits, for example) and improving methods of automating monitoring of termite activity.

Non-repellent termiticides. Rapid industry adoption of the non-repellent soil insecticide fipronil demonstrated that baits had not entirely changed the face of termite control. Although its ability to kill termites rather than repel them, due to its non-repellent nature, is the major focus of interest in fipronil, its efficacy in termite control is in no small measure due to its longevity and stability in the environment. Currently, fipronil is applied in the same fashion as earlier soil insecticides, with a low concentration but relatively high volume of insecticide solution applied to the soil around the perimeter and beneath the structure. As mentioned, the long term regulatory trend is to reduce pesticide exposure, and research with fipronil and other non-repellent insecticides is focusing on how “bait-like” liquid insecticide treatments can become. The importance of transfer of insecticide from one individual to another is a particularly active area of research. With some research results suggesting that this effect is real, but perhaps not too significant in current practice (Shelton and Grace 2003), the logical extension of this line of research will be to attempt to improve and enhance insecticide transfer.

Microbial termite control. Due to their cryptic nature (hidden in soil or wood), termites are apparently subject to virtually no pressure from parasites, and little from predators (Culliney and Grace 2000). However, they are certainly subject to disease. Unfortunately, although both fungi and nematodes are quite effective at killing termites in the laboratory, none of these naturally-occuring disease organisms have proven to be very effective under field conditions (Culliney and Grace 2000, Grace 2003). A possible exception is the use of fungal pathogens against mound-building termites (Lenz 2005), but even here no commercial products have surfaced despite years of research. After many years of research on microbial agents for termite control, this state of affairs led me to conclude several years ago that nature is simply not good enough (Grace 2003). The difficulty comes in delivering a naturally-occurring pathogen to the termite colony in adequate concentration to induce a disease epidemic.

Two viable areas of research have emerged in the past few years. The first is to investigate why termites appear to be less susceptible than other insects to some pathogenic organisms, in hopes of manipulating their susceptibility to enhance efficacy. For example, the ability of termites to resist nematode infection seems to be largely due to their social mutual grooming behavior, in which the nematodes are manually removed before infection can occur. However, the infectivity of nematodes differs among nematode species, among different termite species, and even among the different castes in the termite colony (Mankowsky 2005), suggesting that factors could be identified and possibly manipulated to enhance their efficacy.

A second line of research is to modify naturally occurring micro-organisms in order to create a novel pathogenic agent. Research has focused on the bacteria and protozoa found within the termite intestinal track. Using a technique termed “paratransgenesis” (Husseneder et al. 2006), gut bacteria naturally associated with termites may be isolated and transformed to express a toxin or lethal gene. The goal of such research is a self-perpetuating bait, that will replicate within the termite gut, and be spread by social interactions throughout the colony (Hussender et al. 2005a). Using plasmid-facilitated transformation of bacteria associated with the Formosan subterranean termite to express green flourescent protein (GFP) and ampicillin resistance, we have demonstrated the practicality of this concept. Transformed bacteria are easily introduced to the termites by feeding, are stable in the gut over 6 weeks (but rapidly deteriorate outside of the insect), are transferred quickly within the colony, and are self-perpetuating due to their constant replication (Husseneder and Grace 2005, Husseneder et al. 2005b). To avoid any undesirable impact on non-target insects, this process can be fine-tuned to use bacteria found only in the termite gut (Higashiguchi et al. 2006); or, conversely, broadened to address multiple pest complexes.

Conclusions

In conclusion, the future is both bright and challenging for termite researchers and those concerned with protecting structures from termite attack. As societal mobility and ease of international commerce increase, so does the distribution of hitch hiking termite pests. As urbanization increases, so do threats by previously passive termite species. However, the number of researchers in the area is also increasing, and providing the answers needed to develop and apply novel termite control strategies effectively around the globe. In some cases, the very success of these strategies (e.g., termite baits) has opened up niches for secondary pests, and thus a need for new research answers. Our knowledge of termite food location and feeding behaviors is rapidly increasing; the tools of molecular genetics now allow us to dissect population differences and the complex network of social interactions within the termite colony; and research-intensive control techniques such as the combination of genetic engineering with microbial control have become very real options for the future. Although the regulatory environment of the past 20 years may have closed some doors with respect to termite control, the windows that have opened offer great promise for the future.

Acknowledgments

I am grateful to Dr. Paul I. Morris and the members of the Canadian Wood Preservation Association for the opportunity to present this paper at the 27th Annual Meeting of the CWPA, in Vancouver on 7-8 November 2006. Research discussed in this paper and performed at the University of Hawaii was partially supported by McIntire-Stennis funds for forestry research administered by the College of Tropical Agriculture and Human Resources, by contributions from industrial cooperators, and by USDA-ARS Specific Cooperative Agreements 58-6615-9-018 and 58-6615-4-237.

References

Atkinson, T.H., M.K. Rust and J.L. Smith. 1993. The Formosan subterranean termite, *Coptotermes formosanus*, established in California. Pan-Pacific Entomologist 69: 111-113.

Broughton, R.E. and J.K. Grace. 1994. Lack of mitochondrial DNA variation in an introduced population of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Sociobiology 24: 121-126.

Cabrera, B.J., R.H. Scheffrahn, N.-Y. Su and W.H. Kern, Jr. 2006. Status of two invasive termite species, *Nasutitermes corniger* and *Coptotermes gestroi,* in southeast Florida. Proceedings of the 2006 National Conference on Urban Entomology. Raleigh-Durham, North Carolina; 21-24 May, 2006. Pp. 98-99.

Campora, C.E. and J.K. Grace. 2001. Tunnel orientation and search pattern sequence of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Journal of Economic Entomology 94: 1193-1199.

Culliney, T.W. and J.K. Grace. 2000. Prospects for the biological control of subterranean termites (Isoptera: Rhinotermitidae), with special reference to *Coptotermes formosanus*. Bulletin of Entomological Research 90: 9-21.

Grace, J.K. and C.E. Campora. 2005. Food location and discrimination by subterranean termites (Isoptera: Rhinotermitidae). Pp. 437-441 *in* Lee, C.-Y. and W.H. Robinson [eds.], Proceedings of the Fifth International Conference on Urban Pests, Executive Committee of the International Conference on Urban Pests, Singapore.

Grace, J.K. 1987. The challenge of wood destroying insects. Proceedings of the Canadian Wood Preservation Association 7: 3-12.

Grace, J.K. 1999. Termite penetration of construction elements. Shiroari 115: 18-23.

Grace, J.K. 2002. Hawaiian experience with treated building components. Enhancing the Durability of Lumber and Engineered Wood Products. Forest Products Society, Madison, Wisconsin. Pp. 305-309.

Grace, J.K. 2003. Approaches to biological control of termites. Sociobiology.41: 115-121.

Grace, J.K. 2006. When invasives meet: *Coptotermes formosanus* and *Coptotermes vastator* in the Pacific. Proceedings of the 2006 National Conference on Urban Entomology. Raleigh-Durham, North Carolina; 21-24 May, 2006. Pp. 92-94.

Grace, J.K. and N.-Y. Su. 2001. Evidence supporting the use of termite baiting systems for long-term structural protection. Sociobiology 37: 301-310.

Grace, J.K., R.J. Woodrow and J.R. Yates. 2002. Distribution and management of termites in Hawaii. Sociobiology 40: 87-93.

Haverty, M.H., R.J. Woodrow, L.J. Nelson and J.K. Grace. 2000. Cuticular hydrocarbons of the termites (Isoptera: Rhinotermitidae) of Hawaii. Journal of Chemical Ecology 26: 1167-1191.

Haverty, M.I., R.J. Woodrow, L.J. Nelson and J.K. Grace. 2005. Identification of termite species by the hydrocarbons in their feces. Journal of Chemical Ecology 31: 2119 - 2151.

Higashiguchi, D.T., C. Husseneder, J.K. Grace and J.M. Berestecky. 2006. *Pilibacter termitis* gen. nov. sp. nov., a novel lactic acid bacterium from the hindgut of the Formosan subterranean termite (*Coptotermes formosanus*). International Journal of Systematic and Evolutionary Microbiology 56: 15-20.

Husseneder, C., R.E. Collier and B.R. Wise. 2006. Paratransgenesis in termites.

Proceedings of the 2006 National Conference on Urban Entomology. Raleigh-Durham, North Carolina; 21-24 May, 2006. Pp. 144-146.

Husseneder, C. and J.K. Grace. 2001. Similarity is relative: hierarchy of genetic similarities in the Formosan subterranean termite (Isoptera: Rhinotermitidae) in Hawaii. Environmental Entomology 30: 262-266.

Husseneder, C. and J.K. Grace. 2005. Genetically engineered termite gut bacteria (*Enterobacter cloacae*) deliver and spread foreign genes in termite colonies. Applied Microbiology and Biotechnology 68: 360-367.

Husseneder, C., J.K. Grace and D.E. Oishi. 2005a (August 9). Recombinant Bacteria for Insect Control. U.S. Patent No. 6,926,889.

Husseneder, C., J.K. Grace and D.E. Oishi. 2005b. Use of genetically engineered *Escherichia coli* to monitor ingestion, loss, and transfer of bacteria in termites. Current Microbiology 50: 119-123.

Husseneder, C., M. T. Messenger, N.-Y. Su, J. K. Grace and E. L. Vargo. 2005c. Colony social organization and population genetic structure of an introduced population of the Formosan subterranean termite from New Orleans, Louisiana. Journal of Economic Entomology 98: 1421-1434.

Husseneder, C., E.L. Vargo and J.K. Grace. 2002. Multilocus DNA fingerprinting and microsatellite genotyping: complementary molecular approaches to investigating colony and population genetic structure in subterranean termites. Sociobiology 40: 217-226.

Husseneder, C., E.L. Vargo and J.K. Grace. 2003. Molecular genetic methods: new approaches to termite biology. *In:* Wood Deterioration and Preservation: Advances in Our Changing World (B. Goodell, D.D. Nicholas, and T.P. Schultz, eds.). American Chemical Society Symposium Series 845: 358-370.

Jenkins, T.M. 2006. Termite population structure revealed by DNA marker technology. Proceedings of the 2006 National Conference on Urban Entomology. Raleigh-Durham, North Carolina; 21-24 May, 2006. Pp. 139-143.

Jenkins, T.M., R.E. Dean and B.T. Forschler. 2002. DNA technology, interstate commerce, and the likely origin of Formosan subterranean termite (Isoptera: Rhinotermitidae) infestations in Atlanta, Georgia. Journal of Economic Entomology 95: 381-389.

LaFage, J.P. 1984. A review of the bait-toxicant method of termite control: In search of the holy grail. Proceedings of the Canadian Wood Preservation Association 5: 77-81.

Lee, C.-Y., C. Vongkaluang and M. Lenz. 2006. Challenges to termite management of multi-fauna genera in South East Asia. Proceedings of the 2006 National Conference on Urban Entomology. Raleigh-Durham, North Carolina; 21-24 May, 2006. Pp. 79-80.

Mankowski, M.E., H.K. Kaya, J.K. Grace and B. Sipes. 2005. Differential susceptibility of subterranean termite castes to entomopathogenic nematodes. Biocontrol Science and Technology 15: 367-377.

Messenger, M.T., N.-Y. Su, C. Husseneder and J.K. Grace. 2005. Elimination and reinvasion studies with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Louisiana. Journal of Economic Entomology 98: 916-929.

Puche, H. and N.-Y. Su. 2001. Tunnel formation by *Reticulitermes flavipes* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in response to wood in sand. Journal of Economic Entomology 94: 1398-1404.

Rust, M.K. 2004. The ffect of urbanization on the distribution of drywood termites of the southwest. Proceedings of the 2004 National Conference on Urban Entomology. Phoenix, Arizona; 20-22 May, 2004. Pp. 27-31.

Shelton, T.G. and J.K. Grace. 2003. Effects of exposure duration on transfer of nonrepellent termiticides among workers of *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Journal of Economic Entomology 96: 456-460.

Strong, K.L. and J.K. Grace. 1993. Low allozyme variation in Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), colonies in Hawaii. Pan-Pacific Entomologist 69: 51-56.

Su , N.-Y. and P. Bardunias. 2005. Foraging behavior of subterranean termites (Isoptera: Rhinotermitidae): Food discovery and movement of termites within established galleries. Pp. 443-445 *in* Lee, C.-Y. and W.H. Robinson [eds.], Proceedings of the Fifth International Conference on Urban Pests, Executive Committee of the International Conference on Urban Pests, Singapore.

Szalanski, A.L., J.W. Austin and C.B. Owens. 2003 Identification of *Reticulitermes* sp. (Isoptera: Reticulitermatidae (sic)) from South Central United States by PCR-RFLP. Journal of Economic Entomology 96: 1514-1519.

Vargo, E.L. 2003. Genetic structure of *Reticulitermes flavipes* and *R. virginicus* (Isoptera: Rhinotermitidae) colonies in an urban habitat and trackif of colonies following treatment with hexaflumuron bait. Environmental Entomology 32: 1271-1282.

Vargo, E.L. 2004. Windows on the underworld: DNA markers present new vistas for termite biology and management. Proceedings of the 2004 National Conference on Urban Entomology. Phoenix, Arizona; 20-22 May, 2004. Pp. 55-57.

Wang, J. and J.K. Grace. 2000. Esterase differences among *Coptotermes formosanus* (Isoptera: Rhinotermitidae) populations. Sociobiology 36: 1-6.

Wang, J. and J.K. Grace 2000. Genetic relationship of *Coptotermes formosanus* (Isoptera: Rhinotermitidae) populations from the United States and China. Sociobiology 36: 7-19

Woodrow, R.J., J.K. Grace and S.Y. Higa. 2001. Occurrence of *Coptotermes vastator* Light (Isoptera: Rhinotermitidae) on the Island of Oahu, Hawaii. Sociobiology 38: 667-673.