



**UNITED NATIONS FOOD AND
AGRICULTURE ORGANIZATION**

**UNITED NATIONS
ENVIRONMENT PROGRAMME**



**Report of the
UNEP/FAO/Global IPM Facility
Termite Biology and Management Workshop
February 1-3, 2000, Geneva, Switzerland**



IOMC

INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS
A cooperative agreement among UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD



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This publication is produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC)

The Inter-Organization Programme for the Sound Management of Chemicals (IOMC), was established in 1995 by UNEP, ILO, FAO, WHO, UNIDO and OECD (Participating Organizations), following recommendations made by the 1992 UN Conference on Environment and Development to strengthen cooperation and increase coordination in the field of chemical safety. In January 1998, UNITAR formally joined the IOMC as a Participating Organization. The purpose of the IOMC is to promote coordination of the policies and activities pursued by the Participating Organizations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

**UNEP
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Preface

Persistent Organic Pollutants (POPs) are chemicals that persist for several years in the environment, are accumulated to high concentrations in fatty tissues and that are magnified through the food-chain, and hence constitute a serious risk of causing long term damage to human health and the environment. POPs chemicals can cause cancer, reproductive, immune, as well as developmental and other disorders bringing infants and children at particular risk if exposed to high levels through breast-milk and food. In 1997, UNEP's Governing Council authorized negotiations of global treaty on 12 POPs and requested that UNEP also initiate a number of immediate actions to promote the reduction and / or elimination of these POPs into the environment.

Of the 12 POPs aldrin, chlordane, dieldrin, heptachlor and mirex have been used to control termites and ants, and data indicate that the following uses may be on-going:

- chlordane for use as a termiticide in buildings and constructions,
- dieldrin for use in wood,
- heptachlor for wood treatment and existing use in cable boxes and
- mirex as a termiticide.

The Expert Meeting on Termite Biology and Management was organized jointly by UNEP and FAO with support from the Global IPM Facility. The meeting was to provide useful and constructive expert advice with regard to alternative management strategies for termites, including control to protect constructions and agricultural crops. The outcome of the meeting, including the establishment of the FAO/UNEP termite expert group and subsequent products that will be produced, is meant to serve both donor and recipient countries in understanding the biology of termites, especially the roles of termites in rural and urban ecosystems, and from this understanding identifying sustainable management strategies to strengthen national action plans and projects. Implementation of such alternative management strategies will also be promoted through regional training workshops, pilot studies and support to develop and implement national action plans.

This document forms part of a package of products provided by UNEP to facilitate and support the development of national, regional and other initiatives to reduce / eliminate releases of POPs. Those products are all available through the POPs Homepage at <http://www.chem.unep.ch/pops/>.

Thanks are given to all participating experts listed in Annex I for their valuable contributions to the meeting discussions and the report. Special thanks are extended to Dr Vernard Lewis who chaired the meeting and was the main drafter of the report, to Dr Michael Lenz and Dr Michael Haverty for their special efforts and to Ms Marjon Fredrix (consultant to UNEP) who contributed substantially to the organization of the meeting and the preparation of the report. Dr Peter Kenmore (FAO), and Ms Agneta Sundén Byléhn (UNEP) were the responsible officers in the secretariats. UNEP would also like to extend specific thanks to FAO and the Global IPM Facility for supporting via this workshop, the international actions on POPs. Financial support from the Government of the United States of America for immediate actions on POPs also contributed to the workshop.

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I. WORKSHOP BACKGROUND

UNEP Chemicals, FAO Plant Protection Services, and the Global IPM Facility organized the Expert Workshop on Termite Biology and Management from 1-3 February 2000 in Geneva. Termite researchers and pesticide regulators from around the world gathered for three days to discuss termite biology, ecology, and management.

The objectives of the Termite Biology and Management Workshop were:

- to assess the present situation on termite biology and their management worldwide and
- to formulate recommendations on approaches and future activities for termite management that would allow reduction/elimination of the pesticides known as Persistent Organic Pollutants (POPs).

Persistent Organic Pollutants (POPs) are toxic compounds that are persistent, bio-accumulate, and are transported globally in air and water. At present, POPs can be found everywhere, including places where they were neither used nor produced. They pose a threat to human health and the environment at the global level.

UNEP's Governing Council, at its nineteenth session in 1997, concluded that international action, including a global treaty, is required to reduce the risks to human health and the environment arising from the release of POPs. The Governing Council requested that UNEP prepare for, and convene by early 1998, an intergovernmental negotiation committee (INC). The INC has a mandate to prepare an international treaty. Twelve POPs were selected initially: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene (9 pesticides), PCBs, dioxins and furans (industrial chemicals and unwanted chemicals). The treaty text is expected to be agreed upon by the end of 2000 and the convention adopted and opened for signature in May 2001 in Stockholm.

In the draft treaty text Article D, paragraphs 1 and 2 addresses measures to eliminate and restrict intentionally produced POPs and possible exemptions to such measures. The treaty text can be accessed through Internet: (<http://www.chem.unep.ch/pops/>). As can be seen in the convention text, most POPs pesticides are scheduled for elimination..

Of the 9 POPs pesticides aldrin, chlordane, dieldrin, heptachlor, and mirex have been used to manage termites and ants. In the elimination annex (A) of the draft treaty text special country exemptions had by mid 2000 been requested for uses relevant to termite control for:

- chlordane for use as a termiticide in buildings and constructions,
- dieldrin for use in wood,
- heptachlor for wood treatment and existing use in cable boxes and,

- mirex as a termiticide.

The Expert Meeting on Termite Biology and Management was organized to provide advice with regard to alternative management strategies for termites leading to the elimination of POPs.

The ongoing negotiations and the future POPs treaty have created momentum to review present termite management strategies and to search for more sustainable management in the future. The outcomes of the workshop are expected to make information on termites available for the further development of the treaty, to educate stakeholders, and to help develop a decision making process to reduce the World's reliance on POPs pesticides.

II. TERMITE BIOLOGY AND ECOLOGY

In the first ever attempt to globally discuss the impact termites have on natural and man-made habitats, termite experts convened from all major continents (see Annex I for list of participants). Although the focus of the workshop was to identify alternative management strategies to replace or eliminate POPs, the organizers felt that a global understanding of termites and their role in the environment was a necessary first step. Workshop presentation abstracts on termite biology and ecology are contained in Annex II.

A. Background on Termites

Termites are small white to tan, sometimes black, colored insects that live in social groups or colonies and are composed of very different looking individuals called castes. Termites also have overlapping generations and a sterile caste that does not reproduce. Tasks are shared among colony members. Certain individuals have developed special features enabling them to carry out special tasks. The largest colony member is the queen. She lays eggs, sometimes thousands in a single day. A king, or reproductive male, is always nearby. Soldiers have large heads with powerful jaws, or a bulb-like head that squirts a deterrent liquid. The vast majority of the termites in a colony are workers. They tend the queen and brood, build and repair the nest, and gather food. Unique among social insects, termite workers can be male or female. Nymphs make up another significant part of the population. They resemble workers, but have wing buds. The nymphs develop into the adult termites (alates). They leave the nest at certain times of year, fly away from the colony, pair up, and found new colonies. Nymphs are the future kings and queens.

Many people confuse termites with ants, hence termites are often called "white ants". A closer look at both groups of insects, apart from a difference in color, reveals two easily observed distinguishing features: termites have straight antennae and a broad waist, while ants have elbowed antennae and a narrow waist. Termites are an ancient insect group whose ancestry goes back more than 100 million years. Termites belong to the group of insects called Isoptera, a Latin term referring to the fact that adult termites have two pairs of wings that look very much alike.

1. Termites as social insects and ecology groupings

There are more than 2,600 recognized species of termites. However, most of this diversity can be assigned to three distinct groups based on feeding and nesting habits: dampwood, drywood, and subterranean termites. Dampwood termites are largely restricted to cooler and wetter forest regions in different parts of the world. They derive their name from the fact that they live and feed in very moist standing or fallen trees. Drywood termites are common on most continents and can survive in very dry conditions, even dead wood in deserts. They do not require direct contact with a source of moisture and do not make any connections to the soil. Both dampwood and drywood termites nest within their food source. Once all suitable wood is consumed, a colony of dampwood or drywood termites declines, producing one last group of alates or the colony eventually perishes. These termites are as a rule not able to move from one food source to another. In subterranean termites on the other hand, nesting and feeding sites are well separated but linked through a system of underground tunnels. These termites maintain foraging territories and can utilize a variety of food sources simultaneously. They reach their food sources by moving through the soil and meet their requirements for water by tunneling in the ground, often to great depth, to reach the water table. This group can be further subdivided, based on nesting biology. Some species have a rather open, ill-defined nest system of a series of chambers and galleries in the ground or in fallen timber, while others build well-defined nests either below ground, within trees, on the outside of trees (arboreal nests) or construct above-ground mounds. The mounds may tower 8 meters or more in height. These mounds can be a significant feature of the landscape, most notably in the tropical zones of Africa, Australia, Southeast Asia, and parts of South America. Mound-building termites are not found in North America or Europe (see Annex III, Biology and Ecology of Termites). Subterranean termites are very numerous in many parts of the world.

2. Positive impacts of termites

Termites contribute significantly to most of the world's ecosystems. Of greatest importance is the role they play in recycling wood and other plant material. Their tunneling efforts help to ensure soils are porous, aerated and enriched in minerals and nutrients to support better plant growth. For example, termite activity in the desert areas of North Africa helps to reclaim soils damaged by overgrazing. Termites are an important food source for many other animals including many reptiles, birds and mammals. Termite mounds and trees hollowed out by termites provide shelter and breeding sites for many other creatures.

3. Negative impacts of termites

Some termites are destructive feeders and consume homes and agricultural crops. Termites that are most destructive to wooden buildings include the subterranean *Reticulitermes* and *Coptotermes*. These two groups appear to be increasing in importance worldwide, due to growing international commerce and exchange of people and goods. Many regions of the world are currently experiencing expansions and/or invasions of subterranean termites. In some areas, termites constitute a

significant pest problem in agriculture. In general, plants exotic to the specific area and stressed plants are most prone to attack by termites.

4. Evolution

The origins of termites probably go back as far as the Upper Jurassic. All known fossils are from the Cretaceous Period and appear to be relatively primitive. However, the distribution of modern termite families suggest evolution and dispersion before the break up and drifting of continents in the Cretaceous Period about 130 million years ago. The current thinking is that there was an explosive radiation and dispersion of termites during the Tertiary Period and not early evolution or drifting continents that produced their current distribution and dominance as primary herbivores on plant material. Today, they continue to move among the continents, but this time their dispersion mechanism appears to be international commerce. Their success in many habitats around the world is due in part to many factors including cryptic habits, social structure, broad diet, breeding strategies, and their ability to efficiently exploit resources.

5. Biological species concept

The earliest naming systems relied on biologists viewing specimens and naming them based only on appearance. Darwin's views on evolution and the discovery of wide variance within and among species led to the Biological Species Concept (BSC), as a system for naming species. This concept emphasizes the actual or potential interbreeding of populations for species inclusion. However, hybrid zones and difficulties in knowing for certain if isolation mechanisms for preventing interbreeding exist under field conditions are impediments to accepting the BSC. Currently, a combination of genetic and chemical techniques are being used to improve character definition for naming termites. This more comprehensive system will be particularly useful for naming subterranean termite species (*Reticulitermes*) and fungus-growing species (e.g., *Odontotermes* and *Microtermes*), traditionally difficult groups to define taxonomically.

B. BIOLOGY AND ECOLOGY

1. Characteristics of a termite colony

Termites appear to be highly variable in number and foraging range depending on species, season, and geographic locality. Some species (subterranean) appear to have very large colonies of several million individuals and forage over an area > 10,000m². Other species have much smaller colonies and forage within areas of only a few square meters.

2. Review of termite biology and ecology by continent

North/Central/South America

The diversity of termites in North America is low compared to other regions of the world. Less than 50 dampwood, drywood, and subterranean species are recognized. Conspicuously absent from North America are mound-building and arboreal termites that are commonly found in other continents. Dampwood termites (genus *Zootermopsis*, Family Termopsidae) are confined to coniferous forests of the Western United States, Canada and Mexico; one species, however, is found in the southwestern desert region. Drywood termites (important genera *Cryptotermes*, *Incisitermes*, *Kaloterme*s, *Neotermes*, Family Kalotermitidae) occupy a band approximately 35 degrees southward latitude across North America. In nature, they prefer hardwood forests and scrubs at elevations < 500 meters. Subterranean termites (important genera *Reticulitermes*, *Heterotermes*, Family Rhinotermitidae; *Amitermes*, Family Termitidae) are the most diverse and widespread group of termites in North America. There are > 24 species and they occur from below sea level to > 2,000 m. These termites nest below ground and can have large populations that travel through a diffuse network of tunnels connecting numerous feeding sites. In general, all termite species in North America prefer dead or decaying wood. Native species rarely attack living plants in natural areas. Termite biomass estimates and their contributions to soils for various habitats of North America are under-reported.

Over 400 termite species are recognized from South America. However, many more are yet to be described. Mound-building species and arboreal species are common in South America. Termites in South America occupy many ecological zones; Amazon, Cerrado Atlantic Forest, Pampa, and Chaco. Important termite genera include *Nasutitermes* (Family Termitidae), *Cryptotermes* and *Neotermes* (Family Kalotermitidae), and *Coptotermes* and *Heterotermes* (Family Rhinotermitidae). In part because of the tremendous diversity and lack of experts, taxonomy remains a critical impediment to understanding termite biology and ecology in South America

Only cursory information is available on termite biology and ecology for the Caribbean Basin. The termite expert group also acknowledged the limited expertise among those present at the workshop for Central America and Mexico where much of the termite fauna is yet to be described and the biology and ecology are poorly understood.

Europe

Europe has the smallest number of termite species among the world's continents. The important genus is *Reticulitermes* which is widespread along the Mediterranean coastline of Spain, France, Italy, the Balkans countries, and Greece. Currently five species are recognized. Although native species of *Reticulitermes* exist in Europe, there are still questions on their origins and relationship to species from eastern North America. In parts of Europe *Reticulitermes* kills living trees, an unusual trait for the genus. Research continues in Europe using cuticular hydrocarbons,

molecular genetics, soldier defensive secretions, and antagonistic behavior in mapping out species distribution and describing colony interactions.

Africa

The African continent is climatically and geographically very diverse, contains the world's largest desert, and also one of the highest mountain peaks. Termite diversity also reflects this topological and climatological diversity. More than 1,000 of the > 2,600 recognized species are found on the African continent. Mound-building species of termites occur throughout most of the African landscape.

Termite diversity in North Africa is low, with about 11 species, comprised of subterranean and drywood termites. The important genera are *Anacanthotermes* (Family Hodotermitidae), *Psamotermes* and *Reticulitermes* (Family Rhinotermitidae), *Amitermes*, and *Microcerotermes* (Family Termitidae), and several species of Kalotermitidae. Termites have been transported over much of North Africa over the millennia due to commerce and nomadic migrations. The xeric (dry) conditions throughout most of North Africa preclude dampwood termites. However, mound-building termites do occur.

East Africa, has a rich termite fauna with a notable abundance of species in the Macrotermitinae. The important genera in the forests include *Schedorhinotermes* and *Cubitermes*. In the savanna areas, Macrotermitinae, Termitiane, Amitermitinae and Nasutitermitinae are important taxa. Their biomass exceeds that of mammals in the same landscape and may exceed 50 kg (dry weight) per hectare. The distribution of mounds in the savannas appears highly dependent on resources more than competition from nearest neighbors. Grass-feeding and harvester species play an important role in decomposition of organic matter and turning over as much as 2000 kg of soil per hectare per year. Pheromones, cuticular hydrocarbons, and genetics all play an important role in maintaining colony and species uniqueness. A number of chemicals used by termites to communicate foraging information elicit responses across genera and families.

Termite diversity in West Africa is similar to that in East Africa: mound-building species dominate the landscape, although other subterranean and drywood termite species also occur. Important genera include *Ancistrotermes*, *Macrotermes*, *Odontotermes* (Family Termitidae, Subfamily Macrotermitinae), and *Microtermes* and *Cubitermes* (Termitidae: Termitinae). The xeric conditions over most of the continent pose severe competition for resources for termites.

Results were presented at the workshop on the role that termites play in the rehabilitation of crusted soils in the Sahel and carbon dioxide gas production. By using mulch, soils formerly barren and unusable for agriculture or grazing were restored within months by termite activity. Because of their tunneling and foraging activity, termites in the genera *Macrotermes* are primarily responsible for positively impacting soil structure, porosity, chemical status, and organic residue. Carbon dioxide gas production by termites is most abundant in savanna areas containing mound building species. Important genera included *Ancistrotermes* and *Odontotermes*. The recycling

of carbon in grassy, shrubby, and woody savannas in Africa is greatly influenced by termites.

The group's discussions on termites for the continent did not cover the tropical forests of Central Africa or all of southern Africa. These areas also contain a diverse and abundant termite fauna.

Asia

The information for this continent was restricted to presentations from China. More than 435 termite species are described from China. Most ecological groups, subterranean, drywood, harvester termites, and mound builders, are found. Common and important genera include *Coptotermes*, *Reticulitermes* (Family Rhinotermitidae), *Macrotermes* and *Odontotermes* (Macrotermitidae), and *Cryptotermes* (Kalotermitidae). Termite distribution in China is restricted to the tropical, subtropical, and milder climatic regions south of the Yangtze River. Termites occur in many environments; be they natural or influenced by man. Overall, the knowledge of the Chinese and Asian termite fauna and its biology and ecology is still rather limited.

Australia

More than 360 species of termites have been described from Australia. Most termite ecological groups (subterranean [including mound builders], drywood, dampwood and harvester termites) are represented in Australia. However, the Australian termite fauna is most known for its relict, primitive genera *Mastotermes*, *Porotermes*, and *Stolotermes*. In-depth understanding of the biology and ecology of termites is restricted to 5 to 15% of the described species. Termites in Australia significantly contribute to soils, air, carbon cycles, as well as invertebrate and vertebrate ecologies. Large-scale studies have described, or are attempting to describe, intra- and inter-colony interactions. Comparisons of direct counts of termites in colonies of mound-building species with estimates from mark - release - recapture studies have identified the limitations of the latter method in obtaining reliable population estimates.

III. MANAGEMENT OF TERMITES

Nine presentations gave a global view of the pest status of termites as structural pests and their management. The presentations are listed geographically by continent. One presentation was given on termites as agricultural pests. (Management practices from around the world are contained in Annex IV-Table Management of Termites in Urban Ecosystems). Presentation abstracts on termite management are available in Annex II.

A. Termite management in urban ecosystems

Americas

In the United States, > 1 billion (US\$) is spent annually for the management of termite problems in buildings and other structures. Termite management in North America is highly regulated, both at the chemical manufacturer's level and service provider level. Thousands of firms are licensed to practice termite management in North America. Subterranean termites (*Reticulitermes*, *Coptotermes*, and *Heterotermes*) are responsible for >90% of the management and damage costs in the United States. Drywood termites (*Incisitermes* and *Cryptotermes*) have lesser importance as structural pests. Soil drenches with liquid termiticides use to dominate the management tactic for subterranean termites. However, baiting is gaining acceptance. Surveys of pest management firms reveal poor building practices are responsible for many of the subterranean termite problems. Although not discussed at the workshop, Canada and Mexico also have commercial pest management firms and association responsible for termite management in their respective countries.

Discussion on termite management in South America focussed primarily on Chile. Dampwood, drywood, and subterranean termites can be found in Chile. A subterranean termite, *Reticulitermes* has recently become an introduced pest. It now infests at least 70,000 homes. The pest management industry is not very large in Chile. The current management method involves the use of a commercially available organophosphate termiticides applied to the soil. However, a commercial bait system is now being used in selected neighborhoods.

Europe

Termite problems in Europe are increasing. Traditionally the pest genus *Reticulitermes*, occurs in France and the Mediterranean (Portugal, Spain, Italy, and Greece). Spread into neighboring countries is considered a possibility. Introductions well outside the natural range have been reported from Germany and England. The pest management industry in Europe, relevant to termites, is small compared to the United States (< 200 firms). The costs for treatment and damage repairs will exceed 1 billion (Euro) within 5 years. Average cost for subterranean termite management per residence is expensive in Europe, three-fold more expensive per m² compared to North America (60 Euro/m² versus 20 Euro/m², respectively). Termiticide applications are particularly challenging in Europe due to high density of buildings, type of constructions, and historic age of many buildings. Termiticides used today are

primarily organophosphates and pyrethroids. Newer chemicals (e.g., compounds that affect GABA receptors) and baits are gaining acceptance. There are considerable differences between termite species in behavior and susceptibility to chemical barrier treatments. The challenges pest control operators face will be in identifying which species are causing the problem and selecting safer management methods.

Africa

Termite management on the African continents is varied and differs markedly from the Americas and Europe. In North Africa measures range from commercial services to physical removal of queens and nests by hand. In Egypt, drywood and subterranean termites pose the greatest threat to structures. Management practices are similar to those reported for the Americas and Europe, including soil applications with the usual range of termiticides and baiting. For drywood termites, fumigation with methyl bromide is the standard practice. Surface application (brushing or spraying) and injection into wood of organophosphates, pyrethroids, and inorganic materials are also conducted. Future prospects for management includes improved building practices, physical barriers, and use of safer chemicals, and development of other alternative management methods. In Ethiopia, much of the pest management is done by local residents, removing nests and queens by hand although the key pest species (*Microtermes*) nest below ground out of the farmers' direct reach. Termiticides, including organochlorines are infrequently used due to lack of availability. In West Africa, newer termiticides are also not available. Alternative methods for management include used motor oil and flooding termite nests with water.

Asia

Again, comments are restricted to China. Economic losses from termites exceed

>1 billion (US\$) each year. Tens of thousands of tons of pesticides, mostly organochlorines, have been applied in the 13 provinces of Southern China. *Coptotermes*, *Cryptotermes*, and *Reticulitermes* are the primary termite pests of structures. Infestations rates of buildings in Guangdong and Hainan provinces may be as high as 80%. Pest management in China is state controlled and operated. As many as 17 special companies conduct soil treatments for termites in Guangdong province alone. Termites also damage utility poles and the earthen walls of dams. Many different chemicals are currently used in China for termite management. They include fumigants (methyl bromide and phosphine), organophosphates, inorganic dusts, pyrethroids, wood preservatives (copper-arsenic and penta compounds) and a number of organochlorines. Future prospects for management include using baits, physical barriers, monitoring, improved building practices and less dependence on the use of organochlorines.

Unfortunately other experts from Asia were not represented at the workshop. However, it appears Japan may be the third largest user of pesticides for structural pest management in the world. Other areas of Southeast Asia and India also may use large volumes of pesticides for termite management. Representatives from these regions will be sought to attend future workshops.

Australia

There are 16 key pest species of subterranean termites in Australia. The cost for management and damage repairs for termites is estimated at > \$ 100 million (Australian) each year. The ban on cyclodiene use in 1995 triggered the development of a diverse array of remedial and preventive termite management methods. Termite management systems currently available include soil drenches with modern chemicals, physical barriers (including properly constructed concrete slabs), baits, resistant materials, and biological control. Australia is unique in the world in having developed a national standard on termite management for whole-of-house protection. Regulators and the pest management industry are getting close to having a national training and licensing system in place.

B. Regulatory Issues

Two pesticide regulators were in attendance at the workshop (USA and China). Commercial pest management in the USA is highly regulated. For public safety and efficacy assurance, pesticide registration is an expensive and time-consuming process. There are many national and state laws pertaining to the safe use of pesticides. The use of chlordane and aldrin for termite management has been prohibited since 1989, and substantial experience with the use of alternatives to POPs has been developed in North America. A regulatory concern is assuring consumers that alternatives to POPs are effective and that these alternatives protect wooden structures from termite attack and will not require excessive re-treatments with pesticides. Countries that are adopting alternatives to POPs may experience problems with ineffective treatment methods during the transition.

Pest management in The People's Republic of China (PRC) is state operated. Certification and training are required for pesticide applicators. Many chemicals manufactured and used in the PRC for termite management are also listed as POPs. At least 200 tons of chlordane are used annually for termite management. However, PRC is exploring the use of alternatives to POPs.

C. Termites as Agricultural Pests

Termites as agricultural pests are confined primarily to Asia, Africa, South America, and Australia. The major pest species belong to the genera *Macrotermes*, *Microcerotermes*, *Microtermes*, *Psamotermes*, and *Odontotermes* in Africa and Indo-Malaysia. *Mastotermes* is an important horticultural pest in tropical Australia, while *Cornitermes* and *Procornitermes* cause significant crop problems in South America. Damage varies from superficial to death of the plant. However, most damage appears restricted to exotic plants which are often stressed when grown at suboptimal sites. Healthy plants can often tolerate some termite damage. It was stressed that most termite species in agricultural fields do not damage native crops. Management over the decades has relied on persistent low-cost organic pesticides. Agricultural practices of today do not stress the use of POPs as compared to management practices in urban areas. Alternatives used include baits and non-chemical methods, such as providing alternative food material to termites between rows of crops. Access to and

affordability of termiticides and aspects of the biology of some pest species limit the success of control measures, notably in poorer countries.

IV. TERMITE WORKGROUPS (Definition and Membership)

1. Nasute termites

Nasute termites live in most tropical and subtropical regions of the world, being particularly abundant and diverse in South America. They live in all kinds of habitats and have diverse feeding habits. Food items, range from wood to humus to leaf-litter and even lichens. There are about 600 known species of nasute termites. In some parts of South America they may be economically more important than all other groups of termites. There are reports of structural damage by nasute termites in tropical America and Australia. In South America, *Nasutitermes corniger* became an urban pest, with records of damage from Venezuela, various parts of Brazil, and Argentina. A study on the wood pests in the city of Belém, Brazil, showed *N. corniger* to be the single most important structural pest. This species occurs in natural habitats from southern Mexico to northern Argentina. In Australia, *Nasutitermes exitiosus* has been reported as an important structural pest. Several nasute termites are also important pests in agriculture and forestry. Damaged crops include sugar-cane, rice, soybean, cotton, maize and peanut. In South America, the most often damaged crop is sugar-cane, which is attacked by *Nasutitermes* and the mandibulate nasutes *Syntermes*, *Procornitermes* and *Cornitermes*. Nasutes of the genus *Trinervitermes* have been reported as agricultural pest in some parts of Africa and India. Mandibulate nasutes, especially *Syntermes*, cause important damage to *Eucalyptus* in Brazil.

Experts: Reginaldo Constantino and Barbara Thorne (Group Spokesman, Reginaldo Constantino.)

2. Urban subterranean termites-Rhinotermitidae

Subterranean termites are globally one of the dominant life forms that inhabit soils. Their presence can be obvious (mound-builders), or cryptic and hidden below ground; for example species in the family Rhinotermitidae. Many species have been reported as pests of buildings, agricultural crops, and trees. Subterranean termite problems are increasing in many continents. The function of this workshop expert group will be to centralize information on the biology, detection, and management of subterranean termites. This information will be a resource for UNEP and FAO as they prepare negotiators for upcoming treaty deliberations on POPs reduction/elimination

Experts: Nan-Yao Su, Barbara Thorne, Jean-Luc Clément, Brian Forschler, Michael Haverty, Michael Lenz, Steven Dwinell (Group spokesmen; *Coptotermes*, Nan-Yao Su; *Reticulitermes*, Brian Forschler).

3. Fungus growing termites-*Microtermes*, *Macrotermes* and *Odontotermes*

Microtermes, *Odontotermes*, and *Macrotermes* with their conspicuous earthen mounds are the major genera of the fungus-growing termites. This group of termites is renowned for their ability to maintain fungus gardens. First, fungi are an important factor in the food chain of the termites; fungus enable termites to live on food of low quality not utilised by mammals. Second, fungus gardens are an important medium for maintaining a constant microclimate in a termite nest. Finally, fungi are a nutritional buffer so that colonies can survive harsh conditions, such as draught (Sahelian Zone), or fluctuating environmental conditions, such as extended periods of heavy seasonal rains (savannahs). The number of fungus growing termite species is questionable. Two genera, *Microtermes* and *Odontotermes*, urgently require taxonomic revision. Nevertheless, their ecological role is significant, particularly in arid and semi-arid ecosystems that dominate Africa south of the Sahara. In these habitats the biomass of fungus growing termites exceeds that of domestic livestock and other vertebrates. Their beneficial impact on soil rehabilitation is notable due to their role in decomposition of organic matter and turning over soil, which is particularly important in the Sahelian Zone with its crusted soils. Therefore, these termites help to fertilize and to aerate soil especially in arid and overgrazed regions. *Microtermes* and *Odontotermes* are important pests in agriculture; they attack predominantly introduced crops like wheat, groundnuts, or other legumes rather than indigenous plants. As damage seems to be restricted to the root system, damage is greater in seedlings than in mature crops. *Macrotermes* and *Odontotermes* cause damage to pastures, particularly during draught periods, but damage is mostly associated with overgrazing. The majority of fungus growing termite species do not feed on wood, and thus their damage to rural housing seems to be of little economic significance.

Experts: Manfred Kaib, Abdoulaye Mando, Souleymane Konate, Thomas Wood, Abdurahman Abdulahi (Group Spokesman, Manfred Kaib).

4. Drywood termites-Kalotermitidae

Drywood termites are common on all continents. The unique characteristic of this termite group is that they do not require soil contact for survival. There are hundreds of species worldwide. The important pest species belong to the family Kalotermitidae and genera *Cryptotermes*, *Incisitermes*, *Kalotermes*, and *Neotermes*. Drywood termites are serious structural pests around the world. Some can also be agricultural pests. The function of this workshop expert group is to gather information on the ecology, biology, and management of drywood termites. This group will also serve as a resource for UNEP and FAO as they prepare negotiators for upcoming treaty deliberations on POPs reduction/elimination.

Experts: Vernard Lewis, Michael Lenz, Samia Moein (Group Spokesman, Vernard Lewis).

5. Alternative management for termites

Realistically, alternatives to POPs for termite management exist around the world. However, the identification, categorization, and efficacy testing for many POPs alternative management methods are incomplete. The function of this workshop expert group will be to identify alternatives to POPs and centralize them in a database for UNEP and FAO as they prepare negotiators for future treaty deliberations.

This subgroup membership and committee charge still needs resolution
Experts (so far): Vernard Lewis, Group Spokesman Michael Lenz.

V. APPROACHES AND STRATEGIES FOR SUSTAINABLE TERMITE MANAGEMENT

After the technical presentations, the meeting broke up into three smaller groups to discuss the Ecology and biology of termites, Population monitoring and damage assessment, and Alternative management.

A. Ecology and biology of termites

This group noted that the concern about POPs and pest management has put a welcome spotlight on termites and their beneficial role in many habitats around the world. The groups also acknowledged the exciting work on termites that includes their taxonomy, physiology, population genetics, combating desertification (habitats becoming deserts), and many more areas of biology and ecology. Termites are also important as ecosystem engineers in soils. Their tunneling and foraging activities help soil aeration, soil fragmentation, and nutrient recycling. The group would especially like to see work on the ecosystem links continue, and incorporate plant, invertebrate, vertebrate, and other metazoan (all animals except the protozoa) communities.

B. Population monitoring and damage assessment

This group focussed on termite monitoring and damage assessment for agricultural and urban ecosystems. The damage termites cause is vastly different between urban and agricultural habitats. While termites do attack agricultural crops, this does not necessarily mean notable economic losses. For urban habitats, the perception and fear of termites are greater than should be the case, given the damage they cause. The discussion also included the need for tools for species determination and a better means for assessing termite numbers and damage.

C. Alternative management

This group tried to define just which species should be classed as subterranean termites, as well as delineating urban, natural, and agricultural habitats. They felt that the first step in reducing or eliminating POPs was to define the termite problem and its scope. Documentation was needed for alternatives to POPs, as well as a clear set of descriptions and criteria for evaluation and adoption of these alternatives. Testing of

alternative management methods should be based on sound biology and ecology of termites, including interactions with invertebrates, vertebrates, plants, and other metazoans. Adoption of these alternative methods should also take into account their accessibility, and cultural differences between regions in the decision-making processes leading to adoption of alternative technology. Decentralization and accessibility of information to a broad public base was very important. This group also recommended more information on termites be provided to the public at large and more targeted to negotiators during the remaining INCs, and other stakeholders. Wide dissemination of such information should result in less reliance on POPs pesticides.

VI. FUTURE ACTIONS

Creation of key points on termite biology (Chairman's Report) for policy makers for INC. Completed March 2000. The information is now available through the POPs Homepage Website.

Creation of five termite functional groups (letters of invite sent out from UNEP May 2000).

Creation of 2 to 3 web pages of essential information for each termite functional group. Work is ongoing.

Creation of in-depth booklets containing 20-25 pages of text, illustrations, and photographs for each termite functional group. Time frame for completion of booklets in several languages is in time for the Stockholm INC meeting in May 2001.

Create web pages and short fact sheets on alternatives to POPs and link to other regulatory and environmental sources of information. Work is ongoing.

Continuation of the expert group, creation of chat groups at the POPs homepage, and identifying other relevant expertise for other world regions. Work is ongoing.

Possible pilot studies on alternative management strategies. Work to be developed.

Annex I. List of participating experts and affiliations (alphabetical order last name)

Dr. Abdurahman Abdulahi, FAO, Addis Ababa, Ethiopia;
Dr. Jean-Luc Clément, Lab. de Neurobiologie du CNRS, Marseille, France;
Dr. Reginaldo Constantino, Dept. of Zoology, Univ. Brasilia, Brasilia, Brazil;
Steven Dwinell, Bureau of Entomology & Pest Control, Depart. of Agriculture & Consumer Services, Tallahassee, Florida, U.S.A.;
Dr. Brian Forschler, Dept. of Entomology, Univ. of Georgia, Athens, Georgia U.S.A.;
Dr. Michael Haverty, Pacific Southwest Research Station, Forest Service, USDA, Albany, California U.S.A.;
Hui Jiang, Bioassay Division, Ministry of Agriculture, The People's Republic of China;
Dr. Manfred Kaib, Dept. of Animal Physiology, Univ. of Bayreuth, Germany;
Dr. Michael Lenz, Division of Entomology, CSIRO, Canberra, Australia;
Dr. Vernard Lewis, Insect Biology, Univ. of California, Berkeley, California, U.S.A.;
Dr. Abdoulaye Mando, University Ouagadougou, Burkina Faso;
Dr. Samia Ibrahim M. Moein, Plant Protection Research Inst., Alexandria, Egypt;
Dr. Renato Ripa, Centro Experimental de Entomología La Cruz, La Cruz, Chile;
Dr. Konate Souleymane, Director Lamto Ecological Station, Ivory Coast;
Dr. Nan-Yao Su, Ft. Lauderdale Research & Education Center, Univ. of Florida, Ft. Lauderdale, Florida U.S.A.;
Dr. Thomas Wood, Natural Resources Institute Kent, United Kingdom;
Dr. Barbara Thorne, Dept. of Entomology, Univ. of Maryland, College Park, Maryland, U.S.A.;
Dr. Jianhua Zhang, Guangdong Entomological Institute, Guangzhou, The People's Republic of China.

Annex II. Presentation Abstracts

Termites as Structural Pests in Ethiopia

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Termites are very serious Pests in several parts of Ethiopia, particularly in the Western parts of the country. They cause considerable damage on agricultural crops, rangelands, forestry seedlings, and wooden structures such as rural houses, stores, fences and bridges crossing streams. According to the studies conducted in western Ethiopia, thatched roof huts are destroyed in less than five years and corrugated iron roof houses in less than eight years.

Many of the wooden structures in the western parts of the country require maintenance every year.

As a result, trees are cut frequently to replace the structures destroyed by termites. This would in turn lead to deforestation, erosion and environmental degradation.

About 61 species of termites belonging to 2.5 genera and four families have been recorded in the country.

Only very few of these are important pests of agricultural crops, forestry seedlings, rangelands and wooden structures. The rest are harmless feeding either on dead plant materials, herbivore dung or soil organic matter.

The major termite species that cause damage on wooden structures belong to the fungus- growing subfamilies and to the genera *Macrotermes*, *Odontotermes*, *Pseudacanthotermes*, *Microtermes* and *Ancistrotermes*. The fungus-growing termites depend for the digestion of their food on the fungus cultivated within the nest.

The termite Control methods currently practiced in the country include mound treatment using aldrin 40% WP or heptachlor 40% WP, queen removal, mound flooding and to some extent use of botanicals.

Trench treatment using persistent organochlorine is hardly used due to lack of their availability in the market and lack of donor support to fund their procurement.

Although termites are important structural pests in the country research on the development of alternative pesticides and methods of control has not yet received the necessary attention. Therefore, research in these areas and IPM requires special consideration.

NATURAL BIOLOGY AND ECOLOGY OF TERMITES IN EUROPE

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Termites are useful natural components of European woodland ecosystems. They feed mainly on decaying *Pinus* trees. Two termite genera are found living naturally in Europe, i.e., *Calotermes* and *Reticulitermes*. *Calotermes* is represented by a single species, namely: *C. flavicollis*, a dry-wood termite living along the entire Mediterranean coastline. *Reticulitermes* is represented by five species, namely: *R. santonensis* in western France, *R. grassei* in southwestern France, northern and southern Spain and Portugal, *R. banyulensis* in northeastern Spain and southwestern France, *R. lucifugus* in Italy and southeastern France and *R. balkanensis* in the Balkans. *R. santonensis* is closely kin to the American species *R. flavipes*. *R. grassei*, *R. banyulensis*, *R. lucifugus* and *R. balkanensis* belong to the same super species. Discrimination of these closely similar species was achieved on the basis morphological, chemical (cuticular hydrocarbons and soldier defensive secretions) and molecular (DNA) features. New colonies can be formed by two methods. The first involves the flight of winged sexual alates from the parent colony. This is called swarming. The second involves subterranean gallery building. When workers become cut off from the parent colony, some can molt and become neotenic reproducers. The mechanisms of specific isolation have been extensively studied including the swarming period and interspecific aggression between workers preventing neotenic hybridization. Ethological and molecular studies have provided much data on the genetic structure of nests which varies according to species and location. All colonies of *R. banyulensis* and colonies of *R. grassei* in southern areas are closed families with a single couple of reproducers. Colonies of *R. grassei* in northern areas are open in the summer and closed in the winter. Sixty percent of *R. grassei* nests are interrelated. Nests in the area extending from Royan to Santiago da Compostel can be considered as a vast supernest forming a chain with genetic exchanges and communicating galleries between neighboring colonies. In *R. lucifugus* and *R. santonensis*, colonies remain open year round. Half of the nest can be considered as a family descending from the same couple of reproducers (sexual alates or neotenics). In all termite societies, nestmate recognition depends on chemical signatures formed by variation in the relative proportion of cuticular hydrocarbons.

TERMITES AS STRUCTURAL PESTS IN EUROPE

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Termite species of the *Reticulitermes* genus cause extensive property damage in Europe. France is the only country with accurate statistics on this problem. The estimated cost of termite treatment is 200 million Euros per year. The termite control sector includes 180 Pest Control Operator (PCO) companies with 400 technicians. Over 8000 job sites are treated each year. The mean price per site is around 6700 Euros per 100 m². This amount would probably double if added with the cost of repairs, replacement or destruction of structures, furniture, walls, and other woodwork. Including fees charged for mandatory inspection before all real estate sales, the annual cost in France alone would be around 500 million Euros a year. In southern Europe (Italy, Spain, Portugal, and Greece) where a variety of termite species can be found and building infestation is considerable, government officials have only recently given serious attention to this problem. Many historic buildings have been severely damaged. With growing income, economic harmonization, and new regulations in Europe, the situation can be expected to change rapidly in the next 10 years. Within 5 years, the yearly turnover of termite control companies in the European Community will reach at least 1 billion Euros. Over two-thirds of PCOs use traditional chemical barrier control techniques involving injection of hazardous pesticides (organochlorates and pyrethroids) into walls, ground, or structural elements. In the last 5 years, substantial progress has been made in control technology thanks to initiatives from the industry in co-operation with consumer groups and governmental agencies (Universities and CNRS). A number of safer agents are now available such as growth regulators and molecules that target newly discovered functions or biochemical receptors (e.g. GABA receptors, monoamino oxydases, ...). These breakthroughs have enabled the development of more sophisticated technologies such as baits and treatment with pathogenic agents. However widespread implementation of these sophisticated technologies still faces numerous obstacles. The 5 species of termites found in Europe differ widely in behavior and resistance to control techniques. Colonies show various types genetic structure including closed families, consanguineous tribes, and vast populations. Diffusion of the toxin varies depending on the mechanism of new colony formation and genetic structure. Some species may be so closely related that they cannot be distinguished by morphological criteria. Pest control techniques must be constantly taking into account whether or not the species are naturally present in the area. Current PCOs are not equipped with chemical or biological techniques necessary to identify species and plan adequate control strategy. It should also be noted that human endeavor in recent years has resulted in a displacement of species outside of natural habitats in southern regions to northern regions. A variety of highly destructive species have been identified in a wide range of locations including towns like Paris, Rouen, Nantes, Bourges, and Domene (near Grenoble) in France, Bagniacavalo in Italy, and Hamburg in Germany as well as in villages in southern England. By confounding the conventional borders between species, this man-made migration has greatly complicated the task of PCO. As a result of importation,

Marseille now has two foreign species in addition to the one naturally occurring species. Similarly in southwestern France, three imported species can be found in addition to one natural woodland species. Since species react differently to new control techniques and agents, identification systems must be developed to allow PCO to customize control strategy. Spreading will likely continue and infestation will probably appear in areas that have been unaffected up to now in northern France, England, Belgium, Germany, and Switzerland. A greater understanding of the mechanisms of new colony formation in cities is needed so that local officials can choose and implement adequate preventive strategies. Traditional techniques using chemical barriers and hazardous chemicals such as organochlorates or pyrethroids can and must be replaced with more environmentally friendly, specifically targeted techniques. Interesting results have been obtained in pilot areas such as Paris and Bourges.

Natural Biology and Ecology of Termites in South America

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Termites are abundant and diverse in most parts of South America, particularly in tropical lowland forests, savannas and grasslands. The number of known species is currently 400, six of them introduced from other regions as urban pests. Five families are present: Kalotermitidae (53 species), Rhinotermitidae (20), Serritermitidae (1), Termitidae (325). Nasute termites (Nasutitermitinae) are dominant both in abundance and diversity, comprising 54% of all species. The proportion of Rhinotermitidae is low compared to other regions, but some species, particularly *Heterotermes spp.*, are abundant in most parts. The taxonomy, biology and geographical distribution of most species are poorly known, and the number of undescribed species is high. The termite faunas of large areas remain totally unknown. Colombia, for example, a large country with diverse habitats, has only 28 species recorded in the literature. Biological data is available only for a few species. The original taxonomic description is the only information available for 150 species, and for most of the rest, there are only some additional locality records or minor biological notes.

Some of most important urban pests are introduced species: the dry-wood termites *Cryptotermes brevis*, *C. domesticus*, *C. dudleyi*, *C. havilandi*, and the subterranean termites *Coptotermes havilandi* and *Reticulitermes lucifugus*. *C. brevis* is widespread, and probably already present in most cities. *Coptotermes havilandi* is currently the major termite pest in the coastal region of Brazil, which is also the most populated area. *Reticulitermes lucifugus* became an important pest in Uruguay, and is likely to be introduced in neighbor countries in the future.

More or less distinct termite faunas can be recognized in the major biomes of South America. None of these is uniform and limits are not precise.

1. Amazon. The Amazon region, with the largest extension of tropical forest in the World, has a diverse and abundant termite fauna, with 240 known species. Wood-feeders are dominant in the forest, especially nasute termites of genus *Nasutitermes*. Termite biomass has been estimated as about 2 g/m², which corresponds to nearly 20% of the total animal biomass. There are also savannas in the Amazon, some of them with a distinct fauna and high density of epigeic mounds. The most important termite pests in the Amazon are *Nasutitermes spp.*, *Coptotermes testaceus*, and *Heterotermes tenuis*. Dry-wood termites are also present in larger cities.
2. Cerrado. The second largest biome is the Cerrado, a savanna vegetation that covers 12% of South America. Termites are extremely abundant in the Cerrado, with 120 species recorded. Termite mounds are a conspicuous part of the landscape, reaching densities between 300-750/ha. Dry-wood termites are rare, with a few records. Litter-feeding termites are dominant. Many of them forage on the surface during the night in large numbers. Termites can be agricultural pests in this region, attacking *Eucalyptus*, sugar cane and other crops. Mound-building *Cornitermes* can reach impressive densities in pastures, being considered pests.
3. Atlantic Forest. There are about 50 species recorded from the Brazilian Atlantic

forest. *Nasutitermes* spp. are dominant, and their arboreal nests common. Dry-wood termites are also abundant. Most data on termites come from the southern portion of the Atlantic forest. The fauna of the northern portion is clearly more diverse and apparently there are many undescribed species. Some native termites of this region have become urban pests, even some undescribed species. For example, a new *Heterotermes* has been reported causing damage in several cities.

4. Caatinga (xerophytic open forest or savanna). The termite fauna of the Caatinga is poorly known. There are only some 20 species recorded for the entire region, but a recent survey shows the presence of at least 138 species, 60% of them undescribed. At least in some areas, mounds are rare, just a few per hectare. The most common genera are *Nasutitermes* and *Heterotermes*.

5. Pampa. The Pampa of Argentina, Uruguay and southern Brazil is mostly open grassland, which is used as pasture. There are about 32 species recorded for this region, but many seem to be restricted to patches of forest. Apparently there are few endemic species, most being present also in the Atlantic forest, Chaco or Cerrado. Typical species are *Cortaritermes fulviceps* (= *Nasutitermes fulviceps*), *Procornitermes striatus* and *Termes saltans*. *Nasutitermes corniger* has been reported as an important urban pest at Corrientes, Argentina.

6. Chaco. The Chaco region, a large extension of xerophytic open forest of Bolivia, Paraguay and northern Argentina is expected to have a diverse termite fauna, possibly with many endemic species. However, there is virtually no information on its termite fauna, with only 17 species recorded. Species records show that its fauna may be similar to that of the Cerrado.

7. Other regions. Information about the termite fauna of other regions is very limited. Forests of northeastern Colombia are connected to those of Panama, with similar termite fauna. Forests of northern Venezuela seem also to be similar. Typical species are *Nasutitermes corniger*, *N. ephratae*, *Obtusitermes* spp., *Microcerotermes exiguus* and *Heterotermes convexinotatus*. Mounds are absent and the only visible nests are those of arboreal *Nasutitermes*. The termite fauna of the Llanos (grassland) of Venezuela seems to be composed mainly of mound-building *Nasutitermes* and *Velocitermes*, which feed on grass-litter and may reach high densities. The temperate forests of southern Chile bear two endemic species: the dry-wood termite *Neotermes chilensis* and the damp-wood termite *Porotermes quadricollis*. There is only one termite record for Patagonia: *Synhamitermes brevicorniger*, at 42°34'S, which is also the southernmost record of termites in South America. Termites are absent in the Atacama desert and mountain regions at high elevation.

In conclusion, termites are abundant and diverse in South America, but there is a serious lack of basic information about them. Nearly 150 species are still known only from their original taxonomic descriptions. The absence of a solid taxonomic work is a major impediment for sound biological and ecological studies. The most important taxonomic problems are the genus *Nasutitermes* and the soldierless termites (Apicotermatinae). *Nasutitermes* spp. are the most abundant termites in most natural habitats and some species are also important structural and agricultural pests. The Apicotermatinae, on the other hand, are among the most abundant termites in the soil, being important members of the decomposer fauna. Some of them have also been reported as agricultural pests. Without proper taxonomy, it is impossible to reliably store and retrieve information on biology, ecology and economic importance of the various species. The number of termite specialists in South America is very limited, and most countries have no Regulatory Agency Role in termite control

Regulatory Agency Role in Termite Control

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Regulatory agencies (local, regional, and national) perform two basic functions relative to the control of termites that are structural pests. These are the assurance of proper use of pesticides used to control termites, and the assurance that purchasers of structural protection receive the protection for which they have contracted. In countries complying with provisions of the Persistent Organic Pollutants (POPs) treaty, these regulatory functions can play an important role in the transition from the use of insecticides such as chlordane, heptachlor, etc. for control of termites as structural pests to alternative methods. The Southeastern United States, which comprises a region of ten states and approximately 60 million people, and where structures have a high probability of termite damage, has undergone just such a transition over the last eleven years, from pre-1988 when chlordane and heptachlor were the primary means of termite control.

Assurance of proper pesticide use includes regulation of pesticide applicator safety provisions such as personal protective equipment (PPE), training of applicators, and certification and verification of training. It also includes regulation of application procedures. In the Southeast United States, ensuring application of the proper amount of insecticide has been a problem. Insecticides that replaced chlordane and heptachlor are more expensive, and there is an economic incentive to apply less than the recommended amount. Costs for the most commonly used insecticides (chlorpyrifos, permethrin, cypermethrin, imidocloprid) range from \$0.09 to \$0.35 per treated square foot of foundation. Of 122 preventative treatments observed in Florida from March 1998 to June 1999, 34% were deficient applications (defined as less than 75% of the required amount).

The regulatory agency plays an important role in making certain that consumers receive the protection against structural damage that they pay for. In the United States this takes the form of enforcing contract provisions and responding to consumer complaints regarding failure to perform contracted services or to repair damage that occurred after a contract guaranteed repair. Another important facet of consumer protection is educating the builder community that structures must be built to keep termites out. Construction practices that were acceptable when relying on chlordane are no longer adequate when relying on less efficacious materials. Practices such as terminating siding 6-8 inches above final grade, extending overhangs to 12-24", diverting water lines and rain gutters, and avoiding wood to soil contact are critically important in preventing termite damage. Use of wood treated before use or after installation with disodium octaborate tetrahydrate (DOT) is also helpful as a second line of defense in wooden structures. Building codes must also be revised to ensure that poor practices are eliminated.

TERMITES AS STRUCTURAL PESTS IN NORTH AMERICA

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Termites are considered major economic insect pests in North America. In the United States alone, most estimates place the annual monetary expenditures for termite control and damage-repair costs at over 1 billion dollars (U.S). This presentation will focus on four criteria that pertain to termites as pests. Those criteria are the, species of termite, area of the continent (or habitat), building construction, and control options. Basically, I believe a termite species gains pest status according to the frequency and intensity of encounters resulting from that termite's pursuit of sustenance and human society's dislike for cohabitation with insects. To address the topic of termites as structural pests in North America I will briefly outline each of the aforementioned criterions in reference to conferring pest status to these small, cryptic, eusocial insects.

I. Species and Distribution

By most estimates there are approximately 50, scientifically recognized, species of termites in North America that are represented by four families, Termitidae, Termopsidae, Kalotermitidae and Rhinotermitidae. The pest status of each of these species is determined, in part, by their geographic distribution, food preference(s), and colony structure.

The Termitidae include a dozen species all found only in the southwestern desert habitat. None of the species in the family Termitidae are considered structural pests because of their small colony size and distribution in areas unaffected by urban development. A single genus, *Zootermopsis*, represents the family Termopsidae in North America. The Termopsidae inhabit areas west of the Rocky Mountains along the Pacific Coast and are also not considered economic pests largely because of small colony size and preference for moist, decayed wood. The third family, Kalotermitidae, is represented by four genera in North America and only two genera contain species considered economically important structural pests, *Cryptotermes* and *Incisitermes* because their food preference includes wood used in building and furniture construction. Although these drywood termites are occasionally reported from all regions of North America, (a result of human commercial transport) they are considered economic pests only along the Pacific, Gulf of Mexico and south Atlantic Coastal areas where atmospheric humidity assists maintaining the moisture conditions they require. The fourth family, Rhinotermitidae, is represented in North America by three genera, *Coptotermes*, *Heterotermes*, and *Reticulitermes*. Also called subterranean termites this group contains the most economically important termite pests. The genus *Heterotermes* contains one, *Coptotermes* two, and the *Reticulitermes* six pest species that together are responsible for 90-95% of the annual control and damage-repair costs mentioned earlier. These three genera are usually found in areas of urban expansion, display a wide range in their food preference, lead a cryptic lifestyle, and have a social structure that permits multiple reproductives and coalescence of colonies that can result in populations numbering in the millions of

individuals. The aforementioned subterranean termites, therefore, display many of the qualities needed for pest status.

Traditionally, the potential for termite infestation in different regions of North America was attributed to the distribution of Rhinotermitid or Kalotermitid termites. The coastal distribution of the Kalotermitidae was mentioned above. The distribution of the Rhinotermitidae is continuous across the United States with some exceptions in mountainous or desert regions. The highest population densities are found in the southeastern states, as well as California and Hawaii. Indicators of termite population pressure are often gathered from the records kept by pest control firms (PCF's). The records of one PCF with offices throughout North America indicate that phone calls requesting termite services were highest in California followed by Florida, Georgia and Texas and that re-treatment rates were highest in Florida, Texas and Georgia, respectively.

The northern distribution of termites in North America appears delimited by urban development and human commercial traffic. Only two cities in Canada are known to support active subterranean termite (*Reticulitermes*) populations, Toronto and Winnipeg. The Canadian termite populations highlight the transport into and subsequent establishment of Rhinotermitid termites in non-endemic habitats. Another reminder of the introduction and establishment of subterranean termite pests in North America are provided by an introduced subterranean termite *Coptotermes formosanus*. *C. formosanus* currently has established populations in California, South Carolina, Georgia, Alabama, Mississippi, Tennessee, North Carolina, Florida, Louisiana, Hawaii and Texas.

II. Construction Practices

One of the most important considerations in assigning pest status to a particular termite species is the construction practice(s) used in building a structure. Any construction practice that provides termites with access to wooden structural, or non-structural, components and that provides adequate moisture can incur and sustain a termite infestation. Building construction practices in North America present tremendous variability in materials and designs. It is therefore a topic too broad to cover in this brief overview of termite pest problems. In general, single-family homes use wood for all structural components whereas commercial and multi-family dwellings employ steel and/or concrete.

Any termite technician working for a PCF can identify the three or four areas where termites are likely to be found infesting a particular construction type. The records of a PCF from Florida for the last decade (1989-1999) show that most termite problems occur in homes with slab construction (89%). Twenty-eight percent of the termite claims, (settlements to pay for termite damage) mentioned in that PCF data-set, occurred in bathrooms and adjacent bedrooms, which in slab construction would have utility-access holes through the concrete slab foundation. The next highest percentage (20%) was associated with garages/carports and porches/patios that would have expansion or cold joints in association with the various concrete slabs used in that construction practice. Therefore, approximately half of the termite infestations encountered by this firm in Florida can be traced to construction elements that provide a crack, crevice or break in the building foundation.

The aforementioned figures will vary by region yet it appears that most termite infestations are repeatedly associated with particular construction practices. This is probably related to the proclivity subterranean termites display for following physical and chemical guidelines in their search for food resources. A better understanding of the mechanics of gallery construction and maintenance, as well as the chemical communication used by termites in their search for food and subsequent recruitment to an identified food resource would help illuminate those aspects of a particular construction practice that predispose a building to infestation. This knowledge could then be used to design and build structures that would be less prone to infestation by subterranean termites or, at least, provide inspection of all structural components to assist in directed application of treatment options.

III. Control Options

Urbanization and changing land-use patterns has increased encounters between human and termite societies. Attempts to limit those encounters defines what we call termite control. Termite control is essentially any attempt to disrupt the flow of information termites use to locate and exploit food resources. An entire industry is currently operating in North America whose sole purpose is reducing encounters between termites and humans. Chemical-based exclusionary methods were the mainstay of termite control for most of the last fifty years. Population management-based control tactics have recently been introduced and are changing the mindset of the pest control industry.

The termite control industry in the United States is regulated by Federal legislation outlining the approval process for registration and use of products. State legislation can supersede but not reduce those requirements. States assume the majority of the burden for oversight in enforcing industry compliance with most legislative mandates. Canada has a similarly rigorous regulatory climate. However, regulation has not hindered development and implementation of new termite control technologies. The termite control industry in North America has more options for detection, treatment tactics, chemistries, formulations, and application technologies today than at any other time in the past 50 years. The treatment tactics used would include:

- termite resistant building materials
- wood treated prior to construction
- physical barriers
- chemistries for soil treatment
- chemistries for wood treatment within existing structures
- fumigation
- baits

Within each of the aforementioned control tactics, the number of registered products change, often from year to year, and existing tactics are continually refined by innovations in equipment, application techniques and detection technologies. The following list of technologies registered for termite control should be considered partial but is provided to give the reader some background information on current registrations and treatment use patterns. Formulations vary from wettable powders, water-dispersible granules, emulsifiable concentrates, flowables, fumigants, and bait.

Dust formulations are not used for termite control in North America. There are one organophosphate (chlorpyrifos), three synthetic pyrethroids (cypermethrin, permethrin, deltamethrin, cyfluthrin, fenvalerate), one phenyl pyroazole (fipronil), and one nitromethylene (imidacloprid) insecticide registered for application to soil or for wood injection into infested lumber. Application techniques for soil treatments and wood injection include trenching and/or rodding with liquids or foam. There are two fumigants (methyl bromide and sulfuryl fluoride), several chemistries for wood treatment prior to construction (CCA and DOT), several physical barriers (crushed rock, steel mesh and insecticide-impregnated plastic), and at least three bait active ingredients (diflubenzuron, hexaflumuron and sulfluramid) currently registered.

Of the structure-based control tactics, fumigation is used, principally, against drywood termite infestations. Fumigations are, occasionally, conducted against *Coptotermes* to affect above ground carton nests and their attendant termite populations but fumigation is not used against soil-borne termite populations. Physical barriers are most often employed as a pre-construction, exclusionary control tactic although occasional retrofitting is attempted. Wood treatments can be applied before, during or after construction as a preventative treatment. The former is usually accomplished as pressure treated lumber and the latter two by surface application. Injection of wood or wall voids with insecticides is gaining popularity within the pest control industry for control of active termite infestations. Bait applications can also be structure-based but are currently used only at the site of active infestations inside structures, not incorporated into construction elements.

Soil-based treatment tactics would include soil-insecticide treatments and baits. Both are used to remove (remedial treatment) and/or prevent (preventative treatment) infestation. 'Whole-house treatments' are the regulatory standard for remedial and preventative soil-based treatments. This is defined for soil insecticides as drenching the soil surrounding all foundation elements with at label-mandated application rates, in addition to 'critical areas' such as utility access points through a slab foundation. Likewise, with baits, termite detection devices are usually placed around the entire perimeter of the structure, again following label directions.

A detailed summary of all the available control options, chemistries and equipment is beyond the scope of this outline yet it should be noted that the termite control community in North America is a dynamic entity involving scientists, regulators, manufacturers, pest control operators and property owners. In addition, it is important to realize that termite control is a process - not an event. The process of termite control requires an ongoing inspection program to detect termites, assess risk and recommend and implement additional or continue control tactics. Development of detection devices that would enable the pest control technician to observe termite activity without disturbance to the termite population or damage to the structure would simplify termite control attempts. In addition, understanding the behavior of termites in response to a particular control measure is important in predicting, with a reasonable degree of certainty, the probability of consistent control, as well as highlight the best application technique for each control tactic.

IV. The Future

My wish list for the future of termite control in North America would include increased implementation of directed application and, when necessary, use of multiple control tactics. This would require choosing a set or series of tactics based on the site-specific characteristics present and directing application of control tactics rather than the current practice of “whole-house” treatment. Following identification of site characters conducive to termite infestation, recommendations would be made regarding the most practical and affordable treatment option(s). Inclusion of architects and builders in the termite control community is being encouraged and should increase. Construction practices that incorporate design details with regard to prevention of infestations or that provides inspection-ports of potential termite entry points will assist in timely detection and implementation of directed application of control methodologies. There also will be new detection technologies that will enable the termite control professional to more accurately locate infestations, and/or termite populations that present a threat to infestation, without destructive sampling, and allow directed placement of treatment options. Finally, implementation of control tactics will account for the biology and behavior of a targeted pest species and identify ‘weak-links’ that exploit termite life history and provide environmentally sound management practices. Therefore, I believe the termite control industry in North America will eventually develop termite population management strategies and structural protection methodologies that could allow cohabitation between termite and human societies.

What Does the Biological Species Concept Mean for Termites?

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There are approximately 2200 species of termites recognized worldwide. Many definitions of “species” have been proposed, but the one used must accurately characterize the concept or object of discussion, and be correctly applied. At first, species were named categories to which early biologists assigned specimens, largely on the basis of appearance. They held a “Typological” or “Essentialist” notion of species. Individuals were members of a given species if they sufficiently conformed to that “type,” or ideal, in certain characters that were “essential” fixed properties. The typological concept of species was based on morphological characteristics, yet contained another criterion, common descent. This concept led to the idea that organisms are the same species if they can produce fertile offspring, and are different species if they cannot. It caused biologists to recognize that morphologically different individuals may well be members of the same species. The abundance of variation within and among populations, together with the adoption of Darwin’s view that all characteristics can vary and evolve, eventually led to the abandonment of the typological species concept. Also abandoned was the concept that species could be defined by degree of morphological difference.

A new concept of species evolved: the Biological Species Concept (BSC). Mayr defined the BSC in 1942 as Groups of actually or potentially interbreeding populations, which are reproductively isolated from other such groups. The BSC cannot be applied to entirely asexual organisms. The definition is phrased in terms of populations, not individuals. The criterion is gene exchange among populations in nature, not fertility or sterility. Clearly this attribute could not have been used in the 18th century because there was no knowledge of genes and genetics. The BSC refers to actually or potentially interbreeding populations. There have been several recent, alternative definitions of species that emphasize phylogenetic history, not the present properties of organisms (such as gene exchange) or their hypothetical future. However, the biological species concept is still more widely used, and most biologists continue to use the biological species concept to define species.

The problem of how species multiply could not be solved until it was understood that the evolution of reproductive discontinuity is the key event. The buildup of local diversity depends largely on the existence of reproductive isolation. Interbreeding vs. reproductive isolation is not an either/or, all-or-nothing distinction. Graded levels of gene exchange exist among some parapatric populations, and sometimes between sympatric populations. Narrow hybrid zones are geographic areas in which genetically distinct populations meet and interbreed to a limited extent. Sympatric hybridization occurs when partial, but not completely free, interbreeding occurs between populations that are rather broadly sympatric. Human alteration of habitat has been implicated in many cases of sympatric hybridization.

The greatest practical limitation of the BSC surely lies in determining whether or not allopatric populations belong to the same species, because application of the BSC requires us to assess whether or not they would potentially interbreed. There is no simple way to judge whether allopatric populations are conspecific. The most common criterion for classifying allopatric populations as different species has been the existence of morphological or other phenotypic differences that are as great as

those usually displayed by other species in the same genus that are sympatric. These phenotypic differences could be morphological, chemical, behavioral, ecological, or even genetic.

According to the biological species concept, populations or groups of populations are different species if gene flow between them is mostly or entirely prevented by biological differences: reproductive barriers or barriers to gene flow. Thus speciation consists of the evolution of biological barriers to gene flow. These biological barriers can be divided into prezygotic and postzygotic barriers. Prezygotic barriers include temporal isolation, habitat or resource isolation, ethological isolation, mechanical isolation, and gametic incompatibility. Postzygotic barriers include hybrid inviability, hybrid sterility, and reduced fertility in F2 populations or backcrosses.

In addition to features that affect reproductive isolation, related species also display presumably nonadaptive features. Assuming that many or most species are formed by genetic divergence of geographically segregated populations, both kinds of differences, those that contribute to reproductive isolation and those that do not, accumulate before, during and after speciation. Allele frequencies are most similar among conspecific populations and least similar among nonsibling species. There is substantial evidence that “genetic distance” increases fairly linearly with the time since gene flow between populations was curtailed

Biological species are defined as reproductively isolated populations, but diagnosing species in practice is seldom done by directly testing their propensity to interbreed. Species are not defined by their degree of phenotypic difference, yet phenotypic characters are the usual evidence used for diagnosing species. This is not a contradiction, because morphological and other phenotypic characters, judiciously interpreted, can serve as markers for reproductive isolation among sympatric populations. There is a complete difference between basing one’s species concept on morphology and using morphological evidence as inference for the application of the biological species concept.

If we were to sample termites from a single locality, and we found that a particular feature shows two distinct states, but no intermediates, we might suspect that the sample contains two species. Still, this might be a simple single-locus polymorphism of a single species. If however, the two morphs differ in a number of other features so that each feature is bimodally distributed, and the characters are correlated, our suspicion that these are two species grows stronger as the number of such distinguishing features increases. Morphological distinctiveness is a good, but not infallible, indicator of separate species. Sibling species may remain undetected unless allozymes, molecular markers, or other phenotypic characteristics are studied.

If we were to begin basic or applied studies of termites, we would likely begin by consulting a source that lists the species in the geographic area of interest. These sources generally have keys to the species for both the imago (alate) and soldier castes. These keys are usually based on morphological characters such as shape, position, measurement(s), or even color of various structures. Many of these lists and keys are based on explorations or surveys that were conducted in the beginning of the 20th century. These early species determinations and keys to species were developed when the predominant concept governing taxonomic work was the Typological Species Concept. The ideas of gene flow and reproductive isolation were not considered. Specimens were sorted and grouped on the basis of morphology.

We are often frustrated by our inability to identify the termites we are studying.

Morphology of soldiers and alates is quite variable. Keys based on these features often provide equivocal determinations. Alternative phenotypic and genotypic characters are now being used to sort termites we are studying. One technique that is gaining acceptance is the use of cuticular hydrocarbon mixtures as taxonomic characters. Lending credibility to this technique is the correlation of these hydrocarbons with other phenotypic and genotypic features. Papers are beginning to appear in the literature in which the authors are sorting termite collections on the basis of their cuticular hydrocarbon mixtures, then examining these sorted groups to look for morphological features that can be used to make species identifications.

We have been studying the cuticular hydrocarbon mixtures of *Reticulitermes* in throughout much of the United States. To date, we have found what we think are 27 distinct phenotypes. These phenotypes fall into 3 main groups or lineages: those with abundant internally branched methyl alkanes, those with abundant 5-methyl or 5,17-dimethylalkanes, and those with an abundance of unsaturated compounds. There are 8 phenotypes in the first group, 8 in the second, and 11 in the third. Correlation of cuticular hydrocarbon (CHC) phenotypes with genotypes is just beginning; preliminary evidence demonstrates a good correlation between CHC phenotypes and haplotypes of the *Reticulitermes* in Georgia, USA. We have also found a strong correlation between CHC phenotypes and soldier defense secretion (SDS) phenotypes in *Reticulitermes* from North America; some SDS phenotypes correlate with more than one CHC phenotype, however, with 2 exceptions each CHC phenotype is correlated with one SDS phenotype.

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Ecology and Biology of Termites in East Africa- Diversity and Communication -

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Parallel to ants, termites dominate the terrestrial ecosystems in the tropics. Termite diversity is distinct for Asia, South America and Africa as generic richness is highest in Africa. This richness is mainly due to the high abundance of Macrotermitidae among which particularly the fungus-growing genera are well adapted to habitats with low annual rainfall. They play an important role in agro-ecosystems, particularly in African semi-arid areas and rangelands by promoting essential ecological processes such as (1) facilitating germination by braking crusted soil, (2) soil comminution and turnover making nutrients available to the vegetation, (3) facilitating carbon and nitrogen fluxes in the soil by decomposing organic matter, (4) recycling plant particles at various soil depths (humus production). Grass-feeding *Macrotermes* reach biomass densities equal to that of large mammals. However, these termites, together with the harvester termite *Hodotermes*, consume about twice as much plant litter as the herbivorous livestock and may thus achieve pest status, especially in drought periods or in situations with too much livestock.

The termites' success and dominance can be easiest explained by the evolution and maintenance of sociality, which - in some species - led to insect colonies with over one million nestmates. The social organization in such colonies depends on an efficient recognition and communication system resulting in collective activities that can cause complex spatial and temporal patterns. Termites primarily rely for chemical signals, and in particular they employ pheromones produced by different glands. Two types of pheromones can be distinguished. Primer pheromones cause long-term physiological changes in nestmates and are usually dispersed by only one or a few individuals, e.g. the queen(s), and may regulate sexuality and caste expression. In contrast, chemical signals that cause immediate behavioral changes in conspecifics are defined as releaser pheromones and are emitted by numerous nestmates. Releaser pheromones are produced in different exocrine glands and may be volatile and act as airborne signal (e.g. for alarm) or they might be deposited onto the substrate (e.g. to mark trails).

When not being constantly reinforced, such volatile signals vane over time. Such signals are typically employed in modifying highly dynamic behavioral patterns like foraging or colony defense. Alternatively, signals might be non-volatile and thus persistent over time (e.g. marking of food sources).

Four major exocrine glands (cuticle, sternal gland, frontal gland, and labial gland) as well as their role in nestmate recognition, trail following, alarm/defense, and food exploitation will be discussed. It also will be shown that signals from different glands may interact. During e.g. the exploitation of a food source two major behaviors can be observed: gnawing and commuting. The frequencies of both behaviors are balanced by the significant difference in the volatility of the two pheromones involved.

In contrast to the highly volatile trail pheromone from the sternal gland used on commuting trails, at the gnawing zones the aggregation pheromone from the labial gland is non-volatile and thus persists over long periods of time. This difference in the

evaporation rate leads to a constant shift between the gnawing zones and the commuting zones. When the process of food exploitation proceeds individual gnawing aggregations, initially separated by zones for commuting, will finally merge and the food source will be completely used up. Foraging for food and exploitation of a food source is thus a dynamic process governed by different pheromone systems with different volatility. This allows both, individuals and a colony as a whole to rapidly respond to changing extrinsic conditions.

Biological and Ecology of Australian Termites

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The Australian termite fauna has 360 described species. Notable are the relict primitive genera *Mastotermes*, *Porotermes*, and *Stolotermes*. In depth understanding of the biology and ecology of termites is restricted to 5 to 15% of described species, composed mainly of wood-feeding (pest) species and some mound-building harvesters/detritus feeders.

In addition to being key decomposers, termites have other major roles in Australian ecosystems. For example, they contribute to soil formation and modification (especially mound-building species) and interact in complex ways with microbial carbon mineralizing populations (negatively correlated distribution patterns, mounds as sites of high microbial decomposer activity). Mounds and tree hollows created from an interaction of termites, fungal decay and wind provide significant shelter and breeding sites for the large component of hollow-dependent Australian vertebrates.

Studies, largely with wood-feeding subterranean termites, have focussed on:

- (1) Delineating developmental pathways (“who’s who” in a colony) as a basis from which to: study caste and age-specific allocations of tasks in a colony; determine the origin of secondary (supplementary or replacement) reproductives); and monitor the impact of control measures on all castes and stages in a colony.
- (2) Reproductive strategies - notably the ability of orphaned colonies to re-establish themselves as fully functional colonies.

Control strategies have to take account of the capacity of remnant populations of different species to produce secondary reproductives, that is, the ability of a given species to ‘bounce back’ if only population reduction and not colony elimination was achieved. The different scenarios are described for *Cryptotermes*, *Mastotermes*, *Heterotermes*, *Coptotermes*, *Nasutitermes*, and *Schedorhinotermes*.

Foraging biology at the population and the colony level:

- (1) Investigations of seasonal patterns of activity and the dynamics of species interactions in a tropical wood-feeding termite community of 15 species, revealed that the number of bait stakes attacked was not very variable over time, but that patterns of attack (“which species is where”) were very variable (rainfall, temperature, species interactions). This means, for example, that a decline in forager numbers of a given species at a monitoring station may not necessarily reflect the impact of an applied bait toxin but a normal seasonal decline.
- (2) Mark/release/recapture methods (MR) are used worldwide to determine the size of the forager population in a colony. Comparisons of MR population estimates with direct counts of termites using Australian mound-building species, indicated that MR estimates varied widely and could be up to two orders of

magnitude larger than direct counts. Several pre-conditions for indicative MR estimates are, in fact, violated: for example, marked individuals did not mix randomly or evenly with unmarked foragers in space and time, termites displayed site fidelity and avoided disturbed sites. Although the MR method does not provide reliable colony population estimates, it is most valuable for delineating the foraging territories of many subterranean termites species and for gaining insights into the behavior of marked castes and stages.

Management of Australian Termites in the Built Environment and in Horticulture

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The cost of termite damage, caused by about 16 pest species of termite, and for managing termites in the built environment is estimated at Aus\$ 80-100 million/year. The ban on the use of cyclodienes in 1995 has triggered the development of diverse and novel termite management systems. Much research on termite control in Australia focuses on non-chemical preventive measures, on methods permitting safer application of chemical barriers, and on control of infestations in existing buildings through 'trap-and-treat' and bait-systems.

Guidance for the protection of new buildings is provided by the Building Code (structural elements) and the Australian Standard AS 3660 (whole of house). The latter also covers the control of infestations in existing buildings. Insurance against termite attack is now obtainable in conjunction with the use of certain barrier systems and inspection/maintenance schedules.

The following range of termite management systems is currently available:

(A). Protective measures, singly or in combination, incorporated at the design and construction stage of a building include:

(1). Physical barriers: stainless steel mesh (Termi-Mesh); solid sheet metal (Termite Tite, Alterm); graded stones (Granitgard); concrete slab designed and produced in accordance with AS2870 with associated protection of slab penetrations ('pipe seals') and joints.

(2). Chemical barriers: dursban and clones; bifenthrin or imidacloprid applied either directly to the soil or via a reticulation system for slab-on-ground constructions (3 systems); chemical (deltamethrin) in a carrier other than soil: fibrous 'blanket' (Kordon TMB);

(3). Termite resistant materials (inclusive preservative-treated timber);

(4). Building design (for example, site preparation, exposure of slab edge, removable skirting boards etc.), i.e. 'building-out' of termites.

(B). Treatment of infestations in existing buildings:

(1). Restoration or the establishment of physical or chemical soil barriers, can be combined with use of nematodes (*Steinernema carpocapsae*);

(2). Location and direct treatment of colonies;

(3). Dusting (stand-alone or with 'trap-and-treat' systems): arsenic trioxide, triflumuron (possibly *Metarhizium anisopliae*);

(4). Bait-systems (Sentricon and various devices for termite aggregation and detection)

(C). Termite problems in horticulture are largely restricted to attack of crop trees (mango, Citrus, cashew) by *Mastotermes darwiniensis* in the wet/dry tropics. They can be dealt with through site management, planting of the indicator crop

Cassava, aggregation of termites and use of bait toxins (currently mirex).

The following general issues on termite management (TM) are flagged:

- (1). Legislative and regulatory framework covering requirements for the assessment of the efficacy/claims of any TM system.
- (2). Can a given TM system, proven successful in a certain country be recommended for use in another country without prior assessment there?
- (3). Rationalization of assessment requirements, harmonization of assessment protocols
- (4). Many TM systems are proprietary (patents) and tied to quality control.
- (5). Termites in the ecology and productivity of soils with special reference to the Sahelian conditions

Geneva Termite Workshop-Geneva
Natural Biology and Ecology of Termite for North America
February 1-3, 2000

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Termites represent less than 1% of the total insect diversity found in North America. Approximately, 45 species are recognized. Termite diversity is represented in three ecological groups, dampwood, drywood, and subterranean. Subterranean termites are our most diverse termite group. There are more than 20 named species. Subterranean termites occur from Atlantic to Pacific oceans and from sea level to > 1600 m. As their name imply, they nest below ground. However, nests can be widely dispersed and difficult to find. In body size, subterranean termites are smallest found in North American. Their forager population and foraging range, is varied and dependent on many factors including species, locality, and season. Subterranean termite biology and ecology has recently been reviewed for the genus *Reticulitermes* in North America (Thorne and Forschler 1998). Drywood termites have nest located above the soil level. Their colonies are reported to be much smaller than subterranean termites. Drywood termites prefer the lower elevations and warmer areas of the southwestern and southeastern United States and Mexico. They are intermediate in size compared to subterranean and dampwood termites. Little is known on the forager number and foraging range for drywood termites colonies in natural settings. Classical information on drywood termites is best found in a website (Urban Entomology, Walter Ebeling, entmuseum9.ucr.edu/ent133/ebeling). Dampwood termites are the largest species of termites found in North America. There are three species and one variant now recognized and they are restricted to the Pacific West Coast and Southwest regions of the United States. They also appear more frequent at higher elevations in conifers. Dampwood termite forager numbers are more similar to drywood termite forager numbers. The biology and ecology of dampwood termites has recently been reported (Thorne et al. 1993).

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Termites in the ecology and productivity of soils with special reference to the Sahelian conditions

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Abstract

Termites are the most important soil fauna in the Sahelian zone of Africa, intensely interacting with the soil. Both the biotic and abiotic state of the soil affect the termite population and activity. The construction by termites of nests, gallery systems or sheetings from soil or from a mixture of soil and other material within the soil horizons or on the soil surface affect the physical and chemical status of both the material used for the construction and the surrounding soil from which the materials were taken. In fact, structure, structure stability, porosity, chemical status of the soil and the decomposition of organic residues are to a large extent altered by termite activity. This presentation focuses on the contribution of termite activity triggered by the use of various types of mulch to the rehabilitation of crusted soils in the Sahelo-Soudanian zone.

It appeared that mulch, when placed on a crusted and bare soil, can trigger termite activity within a few months.

Termite activity results in a change in soil structure. Many burrows are opened through the sealed surface of the soil due to the burrowing activity of the termites. Throughout the soil profile, macropores with irregular shapes and with different diameter sizes are created. The aggregation of the soil by termites through their building systems is also observed. As a result of changes in soil structure, other soil physical properties are also improved. Soil resistance to cone penetration is reduced from a critical to a suitable level for vegetation growth. Bulk density is decreased and soil hydraulic conductivity is greatly increased. Water infiltration and drainage are also greatly improved. The combination of the increase of porosity and infiltration and the cover effect of mulch results in an increase of soil water availability in the soil profile during the growing season.

Termite activity enhanced the decomposition of the mulch and hence nutrient release in the soil.

The crown was the spectacular response of both the natural vegetation and a cowpea crop which both showed an increase from virtually nothing to a lush vegetation. This was indicated in the natural vegetation by a highly significantly increased percentage of cover, aboveground biomass, number of native plant species and rainfall use efficiency.

It was concluded that termite activity can create conditions necessary for natural vegetation and crop growth and therefore, termite in the Sahel could change from being an enemy to a friend.

Distribution, danger and some habits of the termites in Egypt and North Africa

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Through the wide desert and steppe of North Africa, four families of the Isoptera occurred: Kalotermitidae, Hodotermitidae, Rhinotermitidae and Termitidae. Termites in Egypt have been in existence since time immemorial. They include 11 species, as follows: 1-Subterranean termites:

(1) *Anacanthotermes ochraceus* Burs (Hodotermitidae): It occurs in Libya, Algeria and continues to the Arabian Peninsula as far as the Persian Gulf. It is mostly found in Lower Egypt, on either side of the Delta. It feeds mainly on wheat or rice straw from green bricks of which rural houses are made. It attacks timbers, or any cellulosic material. It is restricted to soils with clay or alluvium and low moisture content.

(2) *Psamotermes fuscofemorales* Sjoested (Rhinotermitidae)

(3) *Psamotermes asswanensis* Sjoestedi (Rhinotermitidae).

(4) *Psamotermes hypostoma* Sjoestedi (Rhinotermitidae). The above mentioned three species are synonymous.

(5) *Psamotermes allocerus* Sjoestedi. The *Psamotermes* occurs in Upper Egypt to Aswan. It is found in Sudan, Arabian Peninsula, Libya and Algeria. It destroys rural and urban buildings in Egypt. As, it attacks trees as tamaris, date palm, acacia. It prefers loamy soil of clay and sand and low moisture.

(6) *Amitermes desertorum* Desneux (Termitidae). This mound building termite occurs in Egypt as it is found in Algeria. Many trees in Giza to Aswan, as in the Eastern Desert are severely attacked with this species, as date Palm, acacia, tamaris, Egyptian small lime, sisso, bombax and entolobium, emeri tree. Damage by this termite mostly results in breakdown or death of the infested trees.

(7) *Microcerotermes eugnathus* Silv. (Termitidae). It was reported in the Western Desert, attacking human dwellings and fences. Then, it was recorded at the Northern Western Coast of Egypt, damaging human dwellings and attacking trees as gum Arabic, sisso, olive, fig, coast she oak, Ethel, and vine. Workers forage through covered passages on infested surfaces, as within the stems of plants.

(8) *Reticulitermes Lucifugus* Rossi (Rhinotermitidae). Driven only from Snyder's record

(1949) 2-Dry- wood termites:

(1) *Cryptotermes brevis* Walker (Kalotermitidae): This species is exotic, as it is termed West Indian termites. It was recorded in Giza -Egypt, and spread gradually by furniture exchange, where it has reported from other several Governorates. They are

very destructive for woods and dry cellulytic materials. Intensive swarming occurs 15-21th of June. Flights occur about 90 m.of the sunset.

(2) *Kaloterme flavicollis* Fabricius (Kalotermitidae): It is found only in the more humid parts of the Mediterranean Zone as Tunis, along the coast of Algeria and Morocco. It inhabits a variety of trees and shrubs. It is widely distributed in Lower Egypt, attacking casuarina, Egyptian willow, ficus, and mulberry previously infested with other borers. Swarming takes place in July-October intervally.

(3) *Kaloterme sinaicus* Kemner (Kalotermitidae): This termite was recorded in 1932 attacking railway sleepers on the Mediterranean coast of Sinai- Egypt. It occurs in Sinai Peninsula and Ismaelia Governorate attacking shrubs and tree stumps as casuarina; the redwood fig; acacia and tamaris trees.

Methods of controlling the structural termites in Egypt - Conventional and prospect of the future management

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Conventional methods of prevention and control could be summarized as follows:

1- The control of the dry-wood termite: A-Pretreatment: using brushing with preservatives as phosphorous compounds (chloropyrophos, phenthoate, triazophos), Pyrethroids (fenvalerate and permethrin) or inorganic materials like copper and fluoride salts. Chlorinated hydrocarbons were used until the seventeenth, where people and the Government were concerned of its disadvantages. The Egyptian Government, seeking for the safety of the environment, restricted most of these hazardous materials since three decades, where the rest have been forbidden since 1996 according to the guiding topics of EPA. B-Treatment: Brushing, spraying by pressure or non-pressure processes injection and fumigation are methods of treating the dry-wood termites. Emulsions of organic compounds in Kerosene should be injected accurately in infested woods as wood-works, furniture, floors, then brushing or spraying all the exposed surfaces with the solution, For accurate treatment of floors, holes should be drilled at 1 m in between. Fumigation is run on, using Bromide methyl, at closed cylinders, mostly for lumber woods(Plant Quarantine) or under airtight nylon or Polyvinyl chloride coverings (Authorized companies). 2- The control of the Subterranean termite: A-Pretreatment: (1) Chemical barriers around buildings, as 30 cm. depth. X 30 cm. width, treated with 4L/m of termiticide, to protect such buildings in an infested area from the termite attack. (2) Chemical barriers or spraying could be applied before construction. In concrete constructions, basics should be treated with termiticides to avoid infestation. (3) Protection of woods, used in construction indoors as windows, doors, ceilings, or woodworks, could be accomplished by brushing or spraying with emulsion of termiticides in Kerosene. B-Treatment: (1) Chemical barriers as mentioned above are applied around infested buildings. (2)For treatment of the infested soil, trenches of 30-cm deep. X 30-cm dim. at 2m. in-between can be dug, where amount of the termiticide(4 L) is poured per trench. For safe treatment, toxic baits could be inserted in each trench as recommended since 1991. (3)Infested floors are drilled and treated as abovementioned. Precautions on treatment:(1)Walls and floors should not be sprayed with hazardous termiticides. (2)Nochemical treatments should be made near the water sources.(3) Termiticides mixed with concrete, should stand the degradation after mixing. Necessary building practices should include: (1)Controlling the water sources at the building site, to avoid accumulation of humidity nearby. (2) Removing cellulytic sources as wood debris and roots. (3)Avoiding holes or cracks in concrete or mortar left by incomplete compaction, which permit penetration by termites. (4)Removing infested materials as woods or

plants from the area. (5) Good aeration of buildings, using wire on openings. (6) Baits should be employed for indicating or monitoring the infestation. Prospect of the future management of termites: 1- Information must be developed for planning accurate management. 2- Integrated control is the hopeful procedure for the ultimate management. 3- Associated insects should be studied to determine its role as a biological control agent. 4- Employing the Quarantine laws accurately. 5- Serious guidance of the safe and effective alternative methods of control. 6- Replacing brushing or spraying of infested woods in buildings with injection by non-toxic termiticides or baits. 7- Methyl bromide should be changed for the ozone layer safety. 8- Developing and applying the slow acting non-toxic termiticides and the physical barriers.

TERMITES AS STRUCTURAL PESTS IN CHILE

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Termites are important structural pests in Chile.

Termite species.

Several termite species are present in Chile:

Family Kalotermitidae:

Cryptotermes brevis (Walker), present in the north (Arica, Iquique, Antofagasta, etc)

Neotermes chilensis (Burmeister) Coquimbo to Chiloe.

Family Termopsidae:

Porotermis quadricollis (Rambur) south of Chile

Family Rhinotermitidae:

Coptotermes testaceus (Linnaeus) Valparaiso?

Reticulitermes sp Santiago, Quillota, Limache.

This last species was detected in Santiago in 1986, however considering the spread of the termite and the sizes of the colonies it was probably introduced much earlier.

Pest Status.

The economic importance of only three (3) species of termites is known in our country: *Neotermes chilensis* and *Cryptotermes brevis*. These are dry wood termites present in an important proportion of wooden structures of houses and other buildings that are over 4 to 6 years old. Its damage progresses relatively slowly and they debilitate wooden structures of their physical properties. Detection and identification of the problem is often difficult. Damaged wood replacement work and treatment is not common. When possible, tent fumigations are done with Methyl Bromide or Hydrogen Phosphide. If it is assumed that only 5% of the homes (70,000 houses from a total of about 1,400,000 houses in central Chile) are damaged by these termites and the replacement cost of the damaged structures is on average is \$1,000 US, the total damage would amount to 70,000,000 \$US.

Damage to houses from *Reticulitermes* in Santiago was stratified into three types: low, medium and high-income houses. Assuming 1.5 % of the houses with present subterranean termite damage, the following calculations were made:

House Type	No. of homes	No. infested	Repair Costs & Treatment	Total Costs
Low	500,000	7,500	1,000	7,500,000
Medium	300,000	4,500	3,000	13,500,000
High	100,000	1,500	5,000	7,500,000
			Total cost	28,500,000

It is also important to state that owners of high-income houses have decided to sell the house without giving notice of this problem. Others prefer not to treat, so as to avoid the suspicion of neighbors on the presence of this pest that may reduce the property value.

Control practices.

Several pest control companies are offering control mostly for the subterranean termite, due to the high damage potential of this termite. Probably the most common product being used is Dursban TC* applied as a barrier treatment. During the last two years 7,000 liters of the product have been used in pre-construction, while only 500 liters in post-construction. Other liquid termiticides include Baythion and PREMISE. Also homeowners apply to the damaged areas a range of products available off the shelf in supermarkets. New developments: The Sentricon Bait is being tested for control in poor to upper-class neighborhoods. Some construction companies are using treated wood as a measure to protect structural components from termite attack, since the Chilean law enforces a guarantee against defects for a period of five years after the construction of new homes.

Effect of underground fungus-growing termites on carbon dioxide emission from soils at the chamber- and landscape-scales in a humid savanna of Côte d'Ivoire.

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ABSTRACT

It has been suggested that termites could have a significant effect on carbon cycling at the ecosystem- and landscape-scales in the tropics, but the actual importance of this effect is still controversial. We studied the rate of CO₂ emission by two major termite species (*Ancistrotermes cavithorax* and *Odontotermes* sp.) of a West African humid savanna (Lamto, Ivory Coast). Both species are underground fungus-growing termites. Firstly, in three major savanna types (grassy, shrubby and woody savannas), CO₂ evolution from the soil surface was measured using a close chamber system. Three zones were sampled in each savanna type: control soil without termite chambers, and soil of eroded termite mound with or without *Odontotermes* chambers.

Secondly, the mass-specific respiration rate of the different components of termite fungus chambers (i.e. workers, soldiers, fungus comb, and chamber walls) was measured under laboratory conditions. Published data on the mass of each component of typical individual termite chamber were used to compute the CO₂ emission rate per chamber for each species. At least, published estimates of the density of termite chambers in the different savanna types in Lamto were used to assess the CO₂ emission rate due to the two termite species at the landscape scale. Whatever the savanna type, CO₂ evolution from the soil surface was not different between control soil and soil of eroded termite mound without chambers, but was higher in areas with chambers than in areas without chambers (10 to 19 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ vs. 5 to 10 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). The mass-specific respiration rates were higher for individuals of *Odontotermes* sp. than for individuals of *A. cavithorax*. Total respiration rate from an individual chamber was around 49 and 82 $\mu\text{mol CO}_2 \text{ h}^{-1}$ for *A. cavithorax* and *Odontotermes* sp., respectively. Despite a low mass-specific respiration rate, fungus comb accounted for around 90% of the total respiration flux from whole chambers in both species. The laboratory-derived respiration rate from individual *Odontotermes* chambers was consistent with the field estimates (from 49 to 108 $\mu\text{mol CO}_2 \text{ h}^{-1}$). At the landscape-scale, the CO₂ emission due to *A. cavithorax* and *Odontotermes* sp. was 0.015 and 0.017 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, respectively. This value was very low when compared to bulk soil respiration rate, and represented 12.5 gC $\text{m}^{-2} \text{ year}^{-1}$. Implications for the role of termites on the carbon dynamics in humid savannas and on the regional carbon budget in West Africa are discussed.

Colony Ecology and Control of Subterranean Termites

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I. History

A. Observation, Excavation & Monitoring

- (1) Erhorn (1934) - Foraging gallery of *C. formosanus*, 50 m long and 0.3 – 3 m deep, (report by the Oahu Sugar Co., Ltd., 1928).
- (2) Ratcliffe & Greaves (1940) – Excavated *C. lacteus* foraging galleries. Ca. 50 m from the mound, covering 1.5 acres.
- (3) Greaves (1962) - Excavated *C. acinaciformis* foraging galleries. Ca. 50 m from the mound, covering 0.4 acres.
- (4) King & Spink (1969) - Excavated *C. formosanus* foraging galleries. Over 140 m covering 1.4 acres, 5 – 117 cm deep.
- (5) La Fage et al. (1973) - Spatial distribution of surface foraging behavior of *Heterotermes aureus* and *Gnathamitermes perplexus*. Using toilet paper rolls placed on soil surface. Different foraging and feeding pattern between 2 spp.
- (6) Tamashiro et al. (1973) - Developed an on-the-ground monitoring station for *C. formosanus*.

B. Food Location and Marking

- (1) Beard (1974) - Location of food by *R. flavipes*: only random foraging and chance foraging.
- (2) Spragg & Paton (1974, 1980) – Used radioactive ^{140}La to study foraging territory and trophallaxis of *M. darwinensis*.
- (3) Li et al. (1976) - Foraging activity and range of *C. formosanus*. Using radioactive ^{131}I mixed in food. Foraging distance extending up to 100 m.

C. Marking, Population Estimate & Food Location

- (1) Lai (1976) - First to use a dye marker, Sudan Red 7B, and the mark-recapture technique (Lincoln index). Foraging distance extending up to 100 m. > 1,000,000 termites per colony for *C. formosanus*.
- (2) Ettershank et al. (1980) - Food location by desert subterranean termites, *Gnathamitermes tubiformans* and *Amitermes wheeleri*, using surface thermal shadow.

D. Population Estimate & Feeding Site Selection

- (1) Howard et al. (1982) - Excavation of colonies of *Reticulitermes* spp. ca. 100,000 termites per colony.
- (2) Su et al. (1984) - Using the dye marker, Sudan Red 7B, and the monitoring stations. To study foraging pattern of *C. formosanus*. Selection of established feeding sites appeared random _ Colony elimination by baiting is possible.

E. Monitoring Stations and Mark-Recapture with Dye Markers

- (1) Su & Scheffrahn (1986) - Developed an in-ground monitoring station after Tamashiro et al. (1973) for use in residential areas.
- (2) Su & Scheffrahn (1988) - Triple mark-recapture technique for population estimate and foraging territory studies for *C. formosanus* near structures. 1-7 million foragers per colony. Foraging distance > 100 m.
- (3) Grace (1989) - Developed an in-ground monitoring station for *R. flavipes*, after Tamashiro (1973), La Fage et al. (1983), and Su & Scheffrahn (1986).
- (4) Grace et al. (1989) - Using Sudan Red 7B and Lincoln index for *R. flavipes* in Toronto. ca. 1,000,000 foragers per colony. Foraging distance up to 50 m.
- (5) Su et al. (1991) - Discovered a new dye marker, Nile Blue A, for *R. flavipes* and *C. formosanus*.
- (6) Su et al. (1993) - Using Nile Blue A and triple mark-recapture, estimated foraging populations of *R. flavipes* at 0.2-5.0 million foragers per colony. Foraging distance up to 70 m.
- (7) Sornnuwat et al. (1996) - Using Nile Blue A and triple mark-recapture, estimated foraging populations of *C. gestroi* in Thailand at 1-2 million foragers per colony.

II. Foraging Studies and and Population Control Studies

A. Su et al. (1984) - Random selection of established foraging sites. Subterranean termite colonies can be eliminated by baiting.

B. For evaluation of baiting programs.

- (1) Simple mark-recapture (Lincoln index)
 - a. Hydramethylnon (Su et al. 1982).
- (2) Tripe mark-recapture
 - a. A-9248 (Su et al. 1991).
 - b. Sulfluramid (Su et al. 1995).
 - c. Hexaflumuron (Su 1994, 1996, Su et al. 1995, Chambers, et al. 1995, DeMark et al. 1995, Forschler & Ryder 1996, Grace et al. 1996, Su et al. 1997).

III. Subterranean Termite Control Options

- Objectives for termite control: structure protection

A. Barrier techniques

- Objectives: exclusion of soil-borne termites from structures

a. Liquid termiticides

Pros: less expensive, readily available and acceptable (both pre- and post-construction), built-in procedure during pre-construction, quick result for remedial treatment.

Cons: more pesticide use, more environmental concern, intangible (difficult to regulate), and intrusive (post-construction treatment).

b. Physical barriers

Pros: semi-permanent, non-chemical, and no environmental concern, tangible.

Cons: labor intensive, only pre-construction, industry acceptance.

c. Termiticide-impregnated polymer barrier

Pros: can control the longevity, AI is restricted, less environmental impact, built-in procedure during pre-construction, tangible, double function.

Cons: unknown installation problem, industry acceptance (PCOs or construction industry?), and unknown efficacy for post-construction treatment.

B. Population management approach

- Objectives: impact colony populations of subterranean termites near structures

a. Elimination (Sentricon®)

Pros: target specific (insects deliver the AIs), minimal pesticide use, and less insecticide exposure, less intrusive, long-term efficacy.

Cons: labor intensive, more knowledge intensive, and slow acting.

b. Suppression (FirstLine®)

Termite Evolution: The Fossil Record, Biogeography, and Relevance to Pest Species

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1. Termites probably evolved no earlier than the Upper Jurassic
 - All known fossil termites from the Cretaceous appear to be relatively primitive
 - The fossil record and morphology infer evolution of many modern families and subfamilies *later* than the Cretaceous, however the distribution of modern termite families and subfamilies suggests evolution and dispersion *before* the fragmentation of Gondwanaland in the Cretaceous.
 - Hypothesis to reconcile these contrasting lines of evidence:
The forces behind modern termite biogeographic distributions were not early evolution and continental drift, but rather an explosive Tertiary radiation followed by rapid dispersal as termites became ecologically dominant detritivores (Thorne, Grimaldi, & Krishna 2000, in press).

⇒ Termites are very capable dispersers; countries must be alert to introduction via international commerce
2. A small minority of termite species worldwide are significant pests; termites that nest in wood and forage away from the nest are a particular challenge for control (Abe's "intermediate life type" group, including *Mastotermes*, most *Rhinotermitidae*, and some *Termitidae*) [Abe, T. 1987. Evolution of life types in termites. In: Kawano, S., J.H. Connell & T. Hidaka *Evolution and Coadaptation in Biotic Communities* pp. 125-148, University of Tokyo Press]
3. Termite Life History Attributes That Make Them Ecologically Successful and Challenging to Control:
 - Cryptic habits
 - Individuals are expendable
 - Broad diet (typically)
 - Spatially diffuse colonies (except for one-piece nesters)
 - Dispersal of winged reproductives
 - Local expansion by colony budding
 - Ability to differentiate replacement reproductives
 - Efficient exploitation of resources
 - Efficient colony dynamics (due to division of labor)
4. Termite Life History Attributes That Could Potentially Be Exploited For Control:
 - Nutritionally poor diet (typically)
 - Physiology, including symbionts
 - Trophallaxis, grooming, and social behavior
 - Slow to evolve pesticide resistance

Termites as Agricultural Pests

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Damage to Crops by Termites

Some general principles can be derived from published work (Wood, 1996). The likelihood of damage is greater in exotic rather than indigenous crops, in rain-fed rather than irrigated crops and in crops under stress rather than healthy, vigorous crops. Damage occurs from seedling to maturity in annual and perennial crops and forestry trees. Losses occur throughout the Tropics but particularly in Africa and Indo- Malaysia where the major pest species belong to the Macrotermitinae ("fungus- growing termites"), particularly *Microtermes*, *Macrotermes* and *Odontotermes*. These species have semi-permanent nest-systems throughout farmers fields and are a potential threat every year .Damage varies from superficial damage to dead parts of the plant (eg. outer bark) to penetration of root systems, stems and death of the plant. Yield losses of up to 20 % are common and localised losses can exceed 50 % .Crops suffering greatest losses are wheat, maize, sugar cane, groundnuts, cotton, some vegetables and locally in West Africa and South America, cassava and yam. Some perennial crops such as cocoa, coconut and rubber suffer low-level, localised damage but throughout the Tropics tea is infested by a wide range of Kalotermitidae, particularly *Kalotermites* in South America and Asia. It should be emphasised that the majority of termite species in farmers fields do not damage crops.

Exotic forestry trees have been increasingly incorporated into agricultural enterprises and there are widespread losses to *Eucalyptus* in South America, Africa and India and to *Pinus* in South America and northern Australia. The termites causing greatest losses are Macrotermitinae in Africa and Indo-Malaysia, *Mastotermes* in Australia and *Comitermes* and *Procomitermes* in South America.

Termite Control

The most commonly practiced method of control has been by the use of persistent organic pesticides and the persistence, toxicity and low cost of the cyclodiene insecticides has over the last 50 years, has made them the most widely used and effective compounds. They have been used as seed dressings, furrow treatments, or even broadcast or applied to irrigation water and have often produced markedly increased yields (over 100 %). The advent of restrictions on their use has resulted in testing of alternative compounds eg. diazinon, phoxim, imidicloprid, chlorfenvinphos, isofenphos and chlorpyrifos. All have been shown to be less effective and more expensive as has the use of controlled release (cR) formulations (Cowie *et al*, 1989). Currently formulations based on chlorpyrifos and permethrin are recommended. "Baiting" techniques (eg. using Mirex or Amdro) are not effective in the vast areas of tropical agriculture and non-chemical methods have appeared to be unsuccessful although there has been little critical evaluation of their effectiveness (Logan *et al*, 1990). Finally it should be noted that in comparison with the construction industry only small quantities of persistent organic pesticides are used in the agricultural sector.

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Major termite problems and termiticides in China

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Termites are economic important pests in China, and widely distributed throughout the country, but especially in the 13 provinces of southern China. In agricultural lands, buildings, dykes and dams, forestry, telecommunication and transportation utilities, termites caused great economic losses, thousands million US dollars annually. For the recent half century, many scientists have taken research into the termite problems and many companies have applied tens of thousands tons of pesticides to control termites, saving great money for many fields.

1. Termite distribution in China

Termites are very diverse in China. According to the latest statistics of December, 1988, there are 4 families representing 44 genera and 435 species, which have been recorded and described by the foreign and Chinese scientists. Kalotermitidae contains 6 genera 55 species; Hodotermitidae contains 1 genus 5 species; Rhinotermitidae contains 8 genera 169 species; Termitidae contains 29 genera 195 species.

Termite distribution in China is mainly restricted to the tropical and subtropical monsoon and milder regions in the southeastern part of the country, including 25 provinces and autonomous regions of China except Heilongjiang, Jilin, Qinhai province and the Inner Mongolia, Ningxia and Xingjiang autonomous region. The Yangtze river is an important mark line for their distribution. To the north of Yangtze river, the termite species number is few and their distribution density is low; but the reverse occurs as one goes south. Among them the most widely distributed termite species are *Coptotermes formosanus* Shiraki, *Odontotermes formosanus* Shiraki, *Reticulitermes chinensis* Snyder, *R. grandis* Hsia et Fan, *R. tricolorus* Ping et Li.

2. Termite damage in China

Among 44 genera and 435 termite species, there are 5 economic important genera: *Coptotermes*, *Cryptotermes*, *Macrotermes*, *Odontotermes* and *Reticulitermes*, containing

more than 10 most destructive termite species (see Table 1), which give great damage to agricultural and forestry crops, buildings, dykes, reservoir dams, telecommunication and transportation utilities.

Table 1. The list of the most destructive termite species in China

Genera

Species

Coptotermes

Cryptotermes

Macrotermes

Odontotermes

Reticulitermes
 C. formosanus Shiraki
 C. declivis Tsai & Chen; C. domesticus
 Haviland;
 M. annandale Silvestri; M. barneyi
 Light
 O. formosanus Shiraki; O. hainanensis
 Light
 R.. chinensis Synder; R.. flaviceps
 Oshima;
 R.. speratus Kolbe;

2.1 Termites as the structural pest in China

Coptotermes, Cryptotermes and Reticulitermes are the dominated termite groups attacking buildings. In the farm land of China, most houses are made of brick walls and wooden roofs, which are easily infested by termites. Sometimes house collapsed by termites can be seen in the hilly regions. In the urban areas most buildings are made by steel and concrete floors with the brick walls (without the wooden roofs), only bathroom and kitchen doors, wooden decorated materials and ground floors are commonly found to be attacked by termites.

For the building infestation, different termite pests are found from regions to regions. To the north of Yangtze river, it is commonly found that 3-10% buildings are attacked by Reticulitermes; 40-50% buildings by Coptotermes and Reticulitermes along the Yangtze basin; 60-70% buildings by Coptotermes with few Reticulitermes to the south of Yangtze river and over 80% buildings by Coptotermes and Cryptotermes with few Reticulitermes in Guangdong and Hainan provinces.

After 1980, with the increase of the steel and concrete structure application, termite damage has become much less for the new buildings. In 1990's soil treatments were adopted in the 13 provinces of south China. Today in Guangzhou alone, there are more than 17 companies specialised in carrying out the soil treatment for the new buildings and reconstruction of the old buildings, so maybe the termite damage will not be a big problems in the urban areas of south China in the future.

2.2 Termites as other pests in China

Agricultural and forestry crop: Sugarcane, cassava, groundnuts, camphor tree, China fir, eucalypt seedlings, plum and rubber tree are commonly attacked by Coptotermes, Macrotermes, Odontotermes, Reticulitermes and other termite groups. In the hilly regions of south China, 30-50% of eucalypt seedlings, camphor trees and sugarcanes are ruined by termites in the worst case.

River dykes and reservoir dams: Odontotermes is the dominated termite group to damage the dykes and dams, followed by Macrotermes. To the south of Yangtze river, 80-90% of river dykes are damaged by Odonotermes, which resulted in 20% pipe-leaks of dykes and dams in worse case. In Fujian, Guangdong and Hubei province, some obvious evidences show that the collapses of dykes and dams are strongly related to the termite activities. Moreover the termite damage can become more serious for the dykes and dams of more than 10 years old.

Telecommunication and transportation utilities: Coptotermes is commonly found to attack the underground plastic cables, accounting for over 50% of the communication problems. Untreated wooden bridges, transmission poles, railway sleepers, train carriage, boats and ships in the Pearl river and South China sea are also infested by

termites.

3. Termite control measures

Building infestation control: 1. *Coptotermes* control. *Coptotermes* is the most common species to infest buildings in China. People take great attention to its control and have developed many ways for its control. Most research is aimed to tackle with its problem. Now there are four common ways for its control: bait systems with the aid of the termite traps; digging out the termite nests; soil treatment; spraying termiticide powders; 2. *Cryptotermes* control. It is a common termite group in the tropical area. The control way is fumigation, high temperature and injecting liquid termiticides into timbers. 3. *Reticulitermes* control. There are three ways to control their damage: bait system; spraying liquid termiticides and spraying termiticide powders.

Other infestation control: 1. Agriculture crop: In south China, for the sugarcane and other crops, the common ways to control termite damages are: a. bait systems; b. excavation of the termite nests and colonies in fields; c. seed treatment (seed soaking); d. spraying liquid termiticides into the roots; and e. water immersion of fields or crop rotation for rice. 2. Forestry crop: For the forestry plantation and urban afforestation, the general termite control ways are following: a. bait systems; b. painting lime with insecticides around the main stem; c. root soil treatment; d. spraying liquid termiticides or termiticide powders. 3. River dykes and reservoir dams: The control way is divided into three steps: first killing termites with the toxic baits and other ways; secondly finding out the locations of the dead nests by the indicator of *Xylaria*; finally grouting with the toxic mud into the tunnel and nest cavities. Sometimes digging out the termite nests is also used. For the telecommunication and transportation utilities, some of the above ways are applied for the termite attack.

4. Chemicals for the termite control

Fumigants: In China, methyle bromide (40 g/m³) and phosphine (8-10 g/m³) are commonly used for the fumigation of the warehouse pests, but rarely for termites.

Spraying liquid termiticides: For the termite control as the agricultural and forest pests, some chemicals such as chlorpyrifos, phenothrin and phoxim are sprayed into the root soil or termite tunnels and nests.

Spraying termiticide powders: Based on the termite grooming behavior and trophallaxis, arsenic trioxide and mirex are used to control termites as the main constituents of the termiticide powders. It is a traditional way for Chinese people to control termites.

The bait system: The cyclodiene mirex is still the active ingredient for the bait systems in China. Its slow toxic characteristic can provide a good success for the control of *Coptotermes* and *Odontotermes*.

The dyke and dam treatment: In some places of south China, the chemicals are benzene hexachloride, chlordane or dichlorvos solution for the base treatment of the new dykes and dams, and 6% benzene hexachloride or 1-2% pentachlorophenol sodium for the surface soil treatment of them, but these ways are not very popular.

The plastic cable treatment: Some stable cyclodiene chemicals are tested for the plastic cable treatment such as aldrin, chlordane, dieldrin and heptachlor, but their applications are very limited.

The soil treatment: In south China, for the building foundations and plastic cable ditches, 5-10% arsenic trioxide powder, 5-10% sodium arsenic solution and 1%

chlordane emulsion are widely used for the soil treatment before 1993, later only chlordane is the legal chemical for the soil treatment in the 13 provinces of south China. In recent years, the government has given great concern on the environmental and human health and prepared to phase out these chemicals, chlorpyrifos, pyrethroid (Sumialfa 5FL) and silafluofen have very good potentials as their alternatives. For the root soil treatment of agricultural and forestry crops, 0.3% chlordane, 0.1% chlorpyrifos, 0.02% phenothrin and 0.1% phoxim are the common choices.

Wood preservatives: In China the common preservatives are formulation of borax/boric acid/pentachlorophenol at 5%, copper/chrome/arsenic (CCA) at 5% loading, pentachlorophenol (1%) with lindane (5%) in diesel oil for the wooden spraying, soaking and pressure treatment. However there is no wide application of the wood preservatives in the artificial timber manufacture to prevent attacks from termites.

5. The future of the termite control in China

For a long time termite control and prevention are the traditional ways to solve the termite problems in China, also they have achieved great success on the management of the economic losses. During recent years the termite IPM emerged in the termite control business. Termite IPM is still in its young stage, monitoring-bait system with the assistance of the ecological measures, physical approaches and topical application of chemicals are the future choice for its development.

For the new buildings and campuses, the pre-plan for termite damage and control is a very important programme in their construction, which can greatly reduce the cost for the termite control.

Annex III
Biology and Ecology of Termites

Region	Subregion/country	Number of termite species present	Ecological groups present	Distribution	Comments
Americas	North America	<50	dampwood drywood subterranean	limited, forests in Pacific states, 1 species in desert from 35 degrees southward on continent; hardwood forests, scrubs at <500m most diverse and widespread group, from sea level to 2000 m	native species rarely attack living plants in natural area
	South America	>400 (Brazil)	subterranean, including mound builders and arboreal nesting species common drywood dampwood	occupy many ecological zones: Amazon, Cerrado, Pampa, Chaca	some of the highest termite densities in the world in tropical forests

	Central America, Caribbean Basin	limited information in workshop; many species to be described			
Europe		less than 5 from natural habitats	<i>Reticulitermes</i> and <i>Kalotermes</i>	Mediterranean, also South 47° N and big cities (Paris, Nantes, Hamburg)	
Africa	North Africa	11 species natural and imported species	subterranean, including mound- builders drywood no dampwood	distribution extended by man over the millennia through commerce and nomadic migrations	
	East Africa	great diversity	mound-builders	savannas -- highly dependent on resources	decomposing organic matter and turning soil
	West Africa	similar to East Africa	subterranean, mound-builders dominate landscape drywood		xeric conditions: severe competition for resources between termites and xylophages Sahel: rehabilitate crusted soils CO ² production
	tropical forests Central Africa and savannas/deserts	not enough information in this meeting			

	Southern Africa				
Asia	China	>435	subterranean, including mound- builders and harvesters drywood	tropical, subtropical and milder climatic regions south of Yangtze River	
	other Asian countries	not enough information			
Australia		>360	subterranean, including mound- builders, harvesters dampwood drywood	indepth understanding ecology/biology limited to 5-15% of species significant contribution to ecology of soils, vegetation and other fauna	significant contribution to ecology of soils, air etc.

Annex IV
Management of Termites in Urban Ecosystems

Region	Subregion/country	Estimated expenditures, losses	Regulation of termite management services	Groups and damage	Methods of management
Americas	North America	>1 billion US\$/year spent on termite control	highly regulated control and services thousands of pest control firms	drywood and subterranean termites:>90% of management costs	soil drenching with liquid termiticides and baits dominates subterranean management, poor building practices responsible for significant portion of problems
	Chile		small pest control industry	drywood subterranean-introduced species 70,000 houses infested	organophosphates as soil termiticides baiting being tried
Europe		termites spreading in Europe, estimated: >1 billion Euro in next 5 years	<200 pest management operators involved with termite work, highly regulated	subterranean	termiticides used: organophosphates, pyrethroids newer chemicals and baits gaining acceptance
Africa			varies from commercial services to physical removal		

			of queens and nests		
	Egypt			drywood subterranean	fumigation with MBr, wood surface and injection applications of organophosphates, pyrethroids, and inorganic materials soil application with termiticides and baiting
	Ethiopia		local residents	village housing	removing nests and queens by hand
	Ivory Coast				infrequent use of termiticides, including organochlorines, newer chemicals not available, motor oil, flooding with water
Asia	China	> 1 billion (US\$)/year	pest management state controlled and operated	mainly subterranean: structures and earthen dams of reservoirs drywood	POPs (organochlorines), organophosphates, pyrethroids fumigants, dust,

					wood preservatives
Australia	Australia	> 100 million (Aus\$)/year	strong regulatory framework, nationwide standard on termite management (whole-of-house): assessment criteria for termite management systems	drywood dampwood mainly subterranean	fumigation chemical barriers, physical barriers, properly designed concrete slabs, baits, dusting, building-out termites, insect pathogens



