UNITED NATIONS
ENVIRONMENT PROGRAMME

Chemicals

FINDING ALTERNATIVES TO PERSISTENT ORGANIC POLLUTANTS (POPs) FOR TERMITE MANAGEMENT

Prepared by members of the UNEP/FAO/Global IPM Facility Expert Group on Termite Biology and Management - established in 2000 to support international activities on Persistent Organic Pollutants (POPs) covered by the Stockholm Convention

TABLE OF CONTENTS

INTRODUCTION:

Of the 12 chemicals identified as Persistent Organic Pollutants (POPs) and addressed in the Stockholm Convention, nine are pesticides, and of these, six are currently, or have in the past, been used to control termites (aldrin, chlordane, dieldrin, endrin, heptachlor, and mirex). Three of these substances, namely chlordane, heptachlor and mirex, are the subjects of specific exemptions requested for termite control during the negotiations of the convention.

At least fourteen countries indicated during the negotiations of the Convention that they still rely on the use of POPs pesticides for termite control. Elimination of these substances is the ultimate goal of the Convention, and implementation of the provisions of the treaty will require successful transition to non-POPs alternatives for termite control. Those countries that request specific exemptions for these products for termite control will have to eliminate these uses within five years after the Convention enters into force. This deadline can only be extended through a decision by the Conference of Parties.

This document, provided in the form of web-pages, is intended to serve as a resource to assist countries as they make the transition to non-POPs termite control. It has been produced by members of the UNEP/FAO/Global IPM Facility Expert Group on Termite Biology and Management that was established in 2000 to provide guidance on alternative approaches to POPs for termite management.

I. DETERMINATION OF TERMITE PEST PROBLEMS

In countries where POPs are used to control termites, the first step in eliminating the use of these products for this use is to characterize the termite pest problem. Once properly characterized, alternative strategies for termite control can be selected, evaluated, and implemented.

Characterization of a termite pest problem is a multi-step process, that starts with identification of the termite species involved, an understanding of the basic biology and ecology of the species, and then an evaluation of the type and magnitude of the economic damage caused by termites.

Termites can cause economic loss by damaging structures such as buildings, bridges, dams, and even roads; or by damaging crops, forest trees, or rangelands. It must be recognized at the outset that termites are a part of the natural ecosystem in much of the world, and that the presence of termites is not, by itself, evidence of a termite pest problem. Termites become a pest when economic damage is caused by termite activity.

Steps in characterization of a termite pest problem:

- Identification of economic loss associated with termite activity;
- Identification of termite species associated with this activity;
- Observation by trained scientists on the activity of termites associated with the damage, and description of basic biology, including characterization as to subterranean, drywood, mound builder, or arboreal nester;
- Demonstration of economic benefit if termites are controlled;
- Identify voids in knowledge about species;
- More detailed investigation into termite species biology and ecology.

II. TERMITE BIOLOGY AND ECOLOGY

II.1 Basic Biology

Termites are small (4 to 15 mm long) and variable in color from white to tan and even black. They have three-body parts: head, thorax, abdomen, and six legs (Fig. 1). They are also social insects and live in colonies. Termites have different looking individuals (called castes) living together in the colony. The largest individual is the queen (Photo.:20 Annex:II). Her job is to lay eggs, sometimes thousands in a single day. A king (Photo.:20 Annex:II) is always by her side. Other individuals have a large head with powerful jaws, or a bulb-like head that squirts liquid. These individuals are called soldiers (Photo.:18 & 21 Annex:II). But the majority of the termites in the colony are called workers. They toil long hours tending to the queen, building and maintaining the nest, or gathering food, and feeding the young, which are called larvae. Unique among social insects, termites workers can be male or female. Some individuals develop wing buds become longer. Finally the nymphs develop into the fully winged adult (alates - Photo.:25 Annex:II), the future kings and queens. They vary in color from black to pale brown and the wings are opaque grey to black. The timing of swarming varies depending on species but usually occur after rainfall. In tropical habitats around the world termites, and the large earthen mounds they can build, are very conspicuous. These mounds are air-conditioned and may contain millions of individuals.

There are many people who think termites are white ants. They are not! Termites are an ancient insect order. Their roots go back more than 180 million years. Termites belong to the group of insects called Isoptera. This term is Latin and refers to the fact that termites have 2 sets of wings that look very much alike. Features that help to differentiate termites from ants include termites having straight, flexible antennae and a broad waist while ants have elbowed antennae and a narrow waist (Photo.:18 Annex:II).

There are more than 2,600 different species of termites now recognized. However, most of this diversity can be lumped into four distinct groups: dampwood, drywood (Photo.:27 Annex:II), subterranean, and arboreal/mound builders. Dampwood termites are very restricted in their distribution. They derive their name from the fact that they live and feed in very moist wood, especially stumps and fallen trees on the forest floor. Drywood termites are common on most continents. They do not require contact with moisture or soil. Subterranean termites are very numerous in many parts of the world and live and breed in soil, sometimes many meters deep. Some subterranean termites may construct nests in trees or other above ground locations. Lastly, some mound builders are capable of building earthen towers 8 meters or more in height. Termite mounds which from their shear site or numbers often can dominate landscapes are common in Africa, Australia, Southeast Asia, and parts of South America. Termite mounds are not found in North America or Europe.

II.2 Positive Impacts of Termites

Termites contribute significantly to most of the world's ecosystems. Termites are of greatest importance in recycling woody and other plant material. Their tunnelling efforts help to aerate soils. Termite activity results in patchy changes/improvements to soil composition and fertility. Compacted and encrusted soils cannot absorb water and hence will no longer support plant life. Termite tunnelling can help to reclaim such damaged soils as demonstrated in the African Sahel zone. Termites also contribute significantly to atmospheric gases.

II.3 Negative impacts of Termites

The negative impact of termites is often cited in economic terms as expenditures for damage, repair, and preventative treatment costs. In the United States alone estimates range between US$ 2-3 billion dollars annually. However, it can be argued that termites have little or no negative impact in environments unaffected by humans. There are over 2,600 described species of termites, but fewer than 185 are considered pests. Conflicts arise when termite societies compete for resources important to human societies. Termite species gain pest status because, as they fulfill their ecological role of recycling plant material they encounter and then endeavor to utilize the materials used in building construction or agronomic and forestry commodities. In fact, significant environmental impact results when humans use persistent organic pesticides in an attempt to protect their investment from termite activity. There is little information that allows assessment of realistic economic thresholds to justify pesticide intervention for control of termites in either urban or agricultural habitats. Therefore, to assess their negative impact a better understanding of termite ecology and the economics of termite damage are needed.

Increasing urbanization that involves building in endemic termite habitats will likely continue to result in further conflicts between human and termite societies. In addition, many termite problems in urban areas follow from the establishment of exotic species. Commercial traffic in wood products, infested solid wood packing materials, and unsupervised disposal of ship ballast has been implicated in the spread of foreign termites to distant urban centers. The potential for human-aided dispersion of termites needs to be addressed to reduce further introductions. The problems associated with native termites need to be systematically studied to provide a realistic assessment of their economic impact and the feasibility of using less pesticide for control.

Termite control in agriculture is often initiated on anecdotal information rather than on sound scientific inquiry into their true impact on certain crops. In agricultural situations the use of exotic plants and planting in previously non-agricultural areas need to be studied to understand the ecological and economic impact termites have on cropping systems. Such information should provide the basis for alternatives to the over-application and use of POPs.

The negative impact of termites is essentially a human perspective that is too often founded in apprehension rather than in fact. Understanding the biology and ecology of termites in different areas of the world would be a first step in developing realistic economic thresholds and environmentally compatible control tactics.

II.4 Termite Biology and Ecology by Continent

II.4.1 Americas

The diversity of termites in North America is low compared to other regions of the world. Less than 50 species are currently recognized. Termite diversity falls into three distinct ecological groups; dampwood, drywood, and subterranean (including arboreal nesting species). Conspicuously absent from North America are mound termites that are commonly found in other continents. Dampwood termites (genus Zootermopsis, Family Termopsidae) are very restricted in North America, confined primarily to the coniferous forests of the Pacific States. However, there is one species found along streams in the desert southwest. Drywood termites (important genera include Incisitermes, Neotermes, Family Kalotermitidae (Photos.:25 to 28 Annex:II)) occupy a band approximately 35 degrees southward latitude across the continent. In nature, they prefer hardwood forests and scrubs at elevations < 1500 meters. Subterranean termites (important genera include Reticulitermes, Heterotermes, Amitermes, and introduced species of Coptotermes, Family Rhinotermitidae (Photo.:22 Annex:II)) are the most diverse and widespread termites in North America. There are > 24 species and they occur from below sea level to ~ 3,000 m. These termites nest below ground and have large (50,000 to 500,000 individuals) and diffuse colonies. In general, all termite species in North America prefers dead or decaying wood. Native species rarely attack living plants in natural areas. Termite biomass estimates and their contributions to soil quality for various habitats for North America are underreported.

The situation in South America is quite different from North America. Over 400 termite species are recognized in South America, with many more yet to be discovered and described. Mound 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 Cryptotermes and Neotermes (Family Kalotermitidae), Coptotermes and Heterotermes (Family Rhinotermitidae), and Nasutitermes (Photo.:20 Annex:II) (Family Termitidae). Some of the highest termite densities in the world, 2 g/m2, are reported from the tropical forests of South America. 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 known on termite biology and ecology for the Caribbean. For Central America and Mexico much of the termite diversity is yet to be described and the biology and ecology are poorly understood.

II.4.2 Europe

Europe has the least termite diversity among the world's populated continents. Less than 10 species occur in natural habitats in Europe. The most important genus is Reticulitermes. This genus currently contains five species that are widespread along the Mediterranean coastline of Spain, France, Italy, Balkans, and Greece. Although native species of Reticulitermes exist in Europe, there are still questions about their origins and relatedness with species from eastern North America. In parts of Europe Reticultermes kills living trees, an unusual occurrence in North America. Research continues in Europe using insect chemistry, molecular genetics, and behavior in mapping out species distribution and describing inter-colony interactions.

II.4.3 Africa

The African continent is climatically and geographically very diverse and contains the world's largest desert and one of the greatest mountain peaks. Termite diversity also reflects this topological and climatological diversity. Termite diversity is tremendous, more than 1,000 of the > 2,600 recognized species occur on the African continent. Mound species of termites occur throughout most of the African landscape. Termite diversity for northern Africa is low, about 11 species, represented by subterranean and drywood termite groups. The important genera are Anacanthotermes (Family Hodotermitidae), Psammotermes and Reticulitermes (Family Rhinotermitidae), Amitermes, and Microcerotermes (Family Termitidae), and several species of Kalotermitidae. Termites have been transported over much of northern Africa over the millennia due to commerce and nomadic migrations. The xeric conditions throughout most of northern Africa preclude dampwood termites. However, mound termites do occur. Termite ecological groups also include straw feeders, structure infesting, and agricultural pests.

Termite diversity is great in eastern Africa, especially among the abundant Macrotermitidae. The important genera include Macrotermes (Family Termitidae), Hodotermes (Family Hodotermitidae), and Schedorhinotermes (Family Rhinotermitidae). Their biomass exceeds that of mammals in the same landscape and may exceed 50kg 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 soil, 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 illicit response across genera and families.

Termite diversity in western Africa is similar to eastern Africa; mound species dominate the landscape, although subterranean and drywood species also occur. Important genera include Ancistrotermes, Macrotermes, Odontotermes, Microtermes, and Cubitermes (Termitidae). The xeric conditions over most of the continent generate severe competition for resources for termites and other xylophagous organisms.

Termites play a role in the rehabilitation of crusted soils in the Sahel. By using mulch, soils formerly barren and unusable for agriculture or grazing have been restored within months by termite activity. Termites in the genera Macrotermes, as a result of their tunneling and foraging, are primarily responsible for positively impacting soil structure, porosity, chemistry, and organic residues. Carbon dioxide production by termites is most pronounced in savanna areas containing mound building species. Important genera include Ancistrotermes and Odontotermes. Carbon dioxide production was approximately double for areas with termite mounds versus open areas. The recycling of carbon in grassy, shrubby, and woody savannas in Africa is greatly influenced by termites.

Little information is available on the tropical forests of central Africa and savanna and deserts of southern Africa. These areas also contain much termite diversity and ecology.

II.4.4 Asia

Termite diversity in China is great, with more than 435 species described. Most termite ecological groups, subterranean, drywood, harvester, and mound builders, are found in China. Common and important genera include Coptotermes, Reticulitermes (Family Rhinotermitidae), Macrotermes and Odontotermes (Termitidae), as well as members of the Cryptotermes

(Kalotermitidae) and Hodotermitidae. Termite distribution in China is restricted to the tropical, subtropical, and milder habitats south of the Yangtze River. Termite species occur in many environmental habitats throughout the provinces of China; natural, forests, agricultural, dikes, and urban. There is much termite diversity and ecology yet to be discovered in China. Absent from the expert group's discussions were the status of termites in southeastern Asia and India.

II.4.5 Australia

More than 360 species of termites have been described from Australia. All termite ecological groups (subterranean, drywood, harvester, and mound builders) are represented in the Australian region. However, the Australian termite fauna is most known for its relict, primitive genera Mastotermes, Porotemes, and Stolotemes. 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 the ecology of 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.

III. TERMITES AS STRUCTURAL PESTS
(INCLUSIVE OF DAMS, ROADS, UTILITY POLES, & UNDERGROUND CABLES AND PIPES)

Termites become a problem when they damage structural timber and other materials in structures. Damage may extend to household furniture, paper products, many synthetic materials and food items. Each year hundreds of thousands of structures (bridges, dams, decks, homes, retaining walls, roads, utility poles, and underground cables and pipes) require treatment for the management of termites. Proper design of a building and building practices, installation of termite management systems at the time of construction and ongoing regular inspections for termite activity can greatly reduce the risk of termite damage to structures.

Internationally important termite pests include species from subterranean, arboreal, dry and wet wood feeding ecologies. Important termite genera include Mastotermes (Photo.:19 Annex:II) Family-Mastotermitidae; Cryptotermes, Incisitermes, Kalotermes, Neotermes Family-Kalotermitidae (Photos:25 to 28 Annex:II); Coptotermes (Photo.:2 Annex:II), Heterotermes, Psammotermes, Reticulitermes, Schedorhinotermes Family-Rhinotermitidae (Photo.:22 Annex:II); Macrotermes, Microtermes, Nasutitermes, Odontotermes Family-Termitidae. Many regions of the world are experiencing expansions of termite activity and/or invasions by exotic termite species.

III.1 Detection and Identification

Termite adults are sometimes confused with winged forms of ants. The adult reproductive stages of both ants and termites leave their nests in large numbers to establish new colonies. However, ants and termites can be distinguished by checking three features: antennae, wings, and abdomen (Photo.:18 Annex:II). Signs of subterranean termite infestations include evidence of soil and tunnels and swarming of winged forms; drywood termite infestations are usually obvious by the presence of characteristic dry pellets (Photo.:28 Annex:II) in wood or on horizontal surfaces beneath infested wood. Swarming of winged termites occurs seasonally and is highly variable depending on species and continent (see Basic Biology section). Darkening or blistering of wood in structures is another indication of an infestation; wood in damaged areas is typically thin and easily punctured with a knife or screwdriver. Visual searches are the most frequent means for detecting termite infestations in structures. More modern innovations for improving termite detection include odor detectors, feeding-sensitive devices (acoustic emission), fibre optics, microwave technology and infrared cameras.. However, some of these technologies are experimental, and most are expensive and have limited availability. No detection technology is 100% effective in all circumstances. Using a combination of different technologies for detecting the presence of termites is the best approach.

Once a termite infestation has been located, if there is doubt as to the nature of the infestation, a specimen of infested wood material or the termite specimens themselves, preserved in a small amount of alcohol, can be sent to a specialist for diagnosis and identification.

There are dozens products and techniques, chemical, nonchemical, and biological available to manage and prevent drywood termites. Many of the sections and tables in these web-pages are dedicated to helping the reader decide on which options to further explore.

III.2 Dampwood Termites

Species in this ecological group are composed of two families of termites, Termopsidae and Kalotermitidae. The common name “dampwood termite” is confusing because some species actually prefer drier wood. The pest status for this group is minor compared to the other termite groups listed below. If treatment is required the procedure includes local treatment with a chemical, infested wood removal, or prevention (use of chemically treated woods or keeping structural wood dry and away from sources of water and dampness).

III.3 Drywood Termites

As was mentioned when using the common name “dampwood termite,” the same applies to the use of the common name “drywood termite.” There is some variance in the ecology and biology of species in this group; however, for the most part, drywood termites infest dry, sound wood, including structural lumber, as well as dead limbs of native trees, shade and orchard trees, utility poles, posts, and lumber in storage. From these areas, winged reproductives seasonally migrate to nearby buildings and other structures, usually on sunny days during summer and/or fall. Drywood termites are most prevalent in many coastal and arid locations around the world. Drywood termites have a low moisture requirement and can tolerate dry conditions for prolonged periods. They do not connect their nests to the soil. Piles of their faecal pellets, which are distinctive in appearance, may be a clue to their presence. The faecal pellets are elongate (a mm or less long) with rounded ends and have six flattened or roundly depressed surfaces separated by six longitudinal ridges (Photo.:28 Annex:II). They vary considerably, but appear granular like multi-colored sand. There are dozens products and techniques, chemical, nonchemical, and biological available to manage and prevent drywood termites. Many of the sections and tables in these web-pages are dedicated to helping the reader decide on which options to further explore.

III.4 Subterranean Termites

Subterranean termites require a source of moisture in their environment. To satisfy this need, they usually nest in or near the soil and tend to reach their food sources from the underlying soil. They maintain some connection with the soil through tunnels in wood or through shelter tubes that they construct (Photo.:22 Annex:II). These shelter tubes are made of soil with bits of wood and termite faecal material. Termites readily chew through a number of other materials including plasterboard (drywall) and plastics. The most significant damage they cause occurs in foundation and structural support wood. Subterranean termites are very abundant in many parts of the world and sometimes have large colonies, often exceeding 1,000,000 individuals and foraging over a 10,000-m2 area.

Reproductive winged forms of subterranean termites, developing from wing-budded nymphs, vary in color from black to pale brown: their wings are opaque to gray to dark charcoal. The time of swarming varies considerably among species, but usually occurs after rain (see Basic Biology section). Soldiers have more pronounced and pigmented heads. Their long, narrow heads have no eyes. They have elongated mandibles or other defensive structures. Some species of termites have no soldiers, but in most species soldiers comprise from 1 to 25% of the colony. Workers (roughly 80% of the colony) are smaller than reproductives, wingless, and have a smaller head than soldiers. There are dozens products and techniques, chemical, nonchemical, and biological available to manage and prevent subterranean termites. Many of the sections and tables in this website are dedicated to helping the reader decide on which options to further explore.

III.5 Arboreal Nesters

Some arboreal nesting termites are important structural pests in tropical and subtropical America, from northern Argentina to Mexico, Asia, and Australia. One species has recently been introduced into Florida (USA). They usually build carton nests on trees, poles, fences, and under the roof of old buildings. Some species build a single nest, but others build multiple, interconnected nests. These termites have nasute soldiers (Photo.:18 Annex:II) with a brown to black head and a conical "nose" through which they can squirt a defensive liquid. However, some arboreal species in Asia Microcerotermes do not have nasute soldiers. Workers are larger than soldiers. They usually damage wood that is moist and decayed, but sometimes they feed on sound wood, as well as paper. Problems usually occur when a nest is present on a tree near a building. They reach the building through carton tunnels, which are easily visible on the walls and structural wood. Sometimes the nest can be inside the building, under the roof or inside the walls. Arboreal nasute termites may reach a building not necessarily by tunneling through the soil, but via galleries built over the soil surface. By doing so they are even able to circumvent chemical soil barriers, however, because their presence is relatively easy to detect, direct nest treatment is often a management option. These termites are a serious problem in historical buildings in South America.

Alates of several genera of subterranean termites (Coptotermes and Reticulitermes) are able to establish a colony in the upper parts of buildings, railway carriages and the like, without the need for contact with the soil, as long as they have a source of moisture (for example leaking roofs, gutters, and plumbing). These infestations can be treated effectively by fumigation and baiting.

III.6 Termite Pests and Management by Continent

III.6.1 Africa

The African continent is climatically and geographically diverse and contains the world's largest desert and also one of the highest mountain peaks. Termite diversity 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. Genera infesting wooden structures include Reticulitermes, Coptotermes, Psammotermes (Family Rhinotermitidae), Anacanthotermes (Hodotermitidae), and several species of Kalotermitidae. However, there are additional species with agricultural impact (see Termites in Agroecosystems section). Some species of termites have been transported over much of Africa due to commerce and nomadic migration. The tropical forests of central Africa and all of southern Africa also contain a diverse and abundant termite fauna.

Termite control on the African continent is varied. Some practices markedly differ from those in the Americas and Europe. In northern Africa, measures range from commercial services to physical removal of queens and nests by hand. Yet some control procedures are similar to those reported for the Americas and Europe, including soil applications (topical and injection) with the usual range of termiticides, as well as baiting. For drywood termites, fumigation with methyl bromide[1] and topical and subsurface chemical injections are the standard practice. Future prospects for control include improved building practices, physical barriers, and use of baits and safer chemicals. Termiticides, including organochlorines, are infrequently used due to lack of availability. In western Africa, newer termiticides are not yet available. Alternative methods for control include flooding termite nests with water.

III.6.2 Americas

The diversity of termites in North America is low compared to other regions of the world. Less than 50 species are recognized; mostly subterranean and drywood nesters (see Basic Biology section). Subterranean termites (important genera Reticulitermes, Coptotermes, Heterotermes, Family Rhinotermitidae) are the most diverse and widespread group of termites in North America. There are > 24 species and they occur from below sea level to ~ 3,000 m. Drywood termites (important genera Incisitermes, Marginitermes, Cryptotermes, Family Kalotermitidae) occupy a band approximately 35 degrees southward latitude across the continent. In nature, they prefer hardwood scrub and forests at elevations < 1500 meters. In general, all termite species in North America prefer dead or decaying wood.

In the United States, > $ 1 billion (US) is spent annually for the management of termite problems in buildings and other structures. Termite control in North America is highly regulated, both at the chemical manufacturer and service level. Thousands of firms are licensed to practice termite control in North America. Subterranean termites (Reticultermes, Coptotermes, and Heterotermes) are responsible for > 90% of the control and damage costs in the United States. Drywood termites (Incisitermes and Cryptotermes) have lesser importance as structural pests. Soil drenches with liquid termiticides dominate the control tactic for subterranean termites. However, baiting has gained a large share of control market for subterranean termites. Surveys of pest control firms reveal poor building practices are responsible for many of the subterranean termite problems. Canada and Mexico also have commercial pest control firms and associations responsible for termite control in their respective countries.

Over 400 termite species are recognized in South America, with many more yet to be described. Mound-building species and arboreal species are common in South America, in addition to subterranean and drywood termites. Important termite genera include Nasutitermes (Family Termitidae), Cryptotermes, Neotermes (Family Kalotermitidae), 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. A species of the subterranean Reticulitermes, possibly santonensis, has become an introduced pest in Chile. It now infests entire neighborhoods. The current control method involves the use of a commercially available organophosphate termiticides applied to the soil. However, a commercial bait system is now being evaluated and used in selected neighborhoods. The drywood termite Cryptotermes brevis is spreading and causing damage in the northern regions of Chile. However, Neotermes chilensis (Family Kalotermitidae) is more widespread. Its damage progresses slowly and control is rarely undertaken.

III.6.3 Asia

Most ecological groups, subterranean, drywood, harvester termites, and mound builders are found in China. Common and important pest genera include Coptotermes and Reticulitermes (Family Rhinotermitidae), and Cryptotermes (Family Kalotermitidae). Termites occur in many environments, be they natural or influenced by man.

For China, economic losses from termites exceed > $ 1 billion (US) each year. Tens of thousands of tons of pesticides have been applied in the 13 provinces of southern China. Infestation rates of buildings in Guangdong and Hainan provinces may be as high as 80%. Pest control in China is state controlled and operated. Termites also damage utility poles and the earthen walls of dams. Many different chemicals are used in China for termite control. They include fumigants (methyl bromide1 and phosphine), organophosphates, inorganic dusts, pyrethroids, wood preservatives (copper-arsenic) and a number of organochlorines. Future prospects for control include using baits, physical barriers, monitoring, improved building practices and less dependence on the use of organochlorines.

It appears Japan may be the third largest user of pesticides for structural pest control in the world. Termites can be found everywhere in Japan except for the northern half of Hokkaido Island. It is estimated that the cost of preventing and controlling termite infestations amounts to at least 800 million (US$) a year.

III.6.4 Australia

More than 360 species of termites are described from Australia. All termite ecological groups (subterranean, arboreal and mound builders, drywood, dampwood and harvester termites) occur in Australia. The Australian termite fauna is also well known for its relict primitive genera Mastotermes, Porotemes, and Stolotemes (see Basic Biology section). In-depth understanding of the biology and ecology of termites is restricted to 5 to 15% of the described species. 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 1995 ban on cyclodiene use triggered development of a diverse array of remedial and preventive termite management methods. Termite management systems available include soil drenches; physical barriers, including properly constructed concrete slabs; baits; resistant materials; and biological control. Australia is unique in the world in having developed national standards on termite management for whole-of-house protection. Regulators and the pest control industry are close to implementing a national training and licensing system for pest control operators.

III.6.5 Europe

Europe has the smallest number of termite species in comparison with the other populated continents. Fewer than 10 species have been identified in natural habitats. Reticulitermes is the most common genus encountered. It is widespread around the Mediterranean (Spain, France, Italy, Balkans, and Greece) and Black Sea (Turkey, Rumania, and Ukraine). Five species have been described so far and a sixth is being studied. Several unanswered questions remain about the origin of these termites. While some Reticulitermes are native to Europe, others may be related to species from eastern North America and the Middle East (Israel, Asian Turkey, etc.). In some parts of Europe, Reticulitermes kill living trees in urban areas. This aggressive behavior is unusual for the genus.

Termite problems in Europe are increasing. Introductions well outside the natural range have been reported from Germany and England. The pest control industry in Europe, relevant to termite management, is small (< 200 firms).

Costs for treatment and damage repairs will exceed 1 billion (Euro) within 5 years. Termiticide applications are particularly challenging in Europe due to high density of buildings, type of construction, and historic age of many buildings. Termiticides used today are primarily organophosphates and pyrethroids. Newer chemicals (e.g., compounds that affect GABA receptors, such as imidacloprid and fipronil) 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 and more environmentally friendly management methods.

III.7 Alternatives to POPs for management of Termite as Structural Pests

There are a number of disclaimers to be remembered before reading the following sections. First, the following tables and suggestions for alternatives to POPs are not exhaustive. Less than 20 experts, mostly researchers and one regulator created the following tables and suggestions. Realistically, many countries have regulatory mechanisms and local expertise pertaining to termites and their management. Local expertise within your country is very important and should be sought out when planning for alternatives to POPs. Second, there are many alternatives to POPs. However, they all are not equally effective and applicable to situations involving termites and structures. Availability of products differs greatly between countries. Remember that the perception of termites as pests is very important in deciding on management measures. Changing from one chemical to another is not a long-term solution. However, paying close attention to building design, site preparation, construction and regular building maintenance and inspections lead to long-term solutions. Terms like prevention and elimination should be used with extreme caution when referring to termites. The more appropriate and realistic terms used should be termite management systems that include regular building maintenance and inspections for signs of termites and breaches in barriers (chemical or physical). Successful termite management is a process that includes the talents of construction, pest management, and building management professionals. Lastly, termite management systems are most successful and least expensive pre-construction. Conversely, they often are less successful and more expensive post-construction. The following products and services mentioned do not represent an endorsement by UNEP or FAO.

As per treaty negotiations, use of all POPs for termite control is to be phased-out. Initially, chlordane, heptachlor and mirex can still be used as termiticides in countries that are Parties to the Convention if they register for a relevant specific exemption that is included in Annex A of the Convention. However, unless extensions are requested and approved by the Conference of the Parties, these exemptions will expire 5 years after the date of entry into force of the Convention[2]. There are many alternatives to POPs for termite management/control (Table 1 Annex I). Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available (See Process for Selecting/Testing Strategies section for information on evaluating effectiveness and determining appropriate alternative management methods.). For all termite management systems, it is critical that label instructions and other specifications are followed.

III.8 Termite Management Systems in buildings and structures

III.8.1 Design of a Building

There are many steps that can be taken to prevent termite damage/infestations, (Table 2 Annex 1) . Design the building with termite management in mind. Determine the type of management system to be used first (for example specific physical or chemical barrier or combinations thereof, use of resistant materials for all structural elements) and select the appropriate building materials and practices. In the design, allow for ease of inspection of the structural elements (for example removable skirting boards, slab-edge exposure, adequate crawl space).

Building design and construction techniques may contribute to termite invasion. Construction techniques should avoid the use of wooden or other cellulose forms, spacers, and fill materials, unless these can be removed before construction is completed. All wood (substructure, siding, doorframe, etc.) should be at least 30 cm above the soil. Other structural deficiencies that attract or promote termite infestations should be identified and corrected. Materials used for siding or cladding of buildings (such as cement, stucco, stone fascia, wood fascia, etc.) must be kept from contact with soil at the foundation to prevent termites from entering the structure undetected behind these materials. Attic and foundation areas should be kept well ventilated and dry. Use screening over attic vents and seal other openings, such as knotholes and cracks, to discourage the entry of winged drywood termites. Although screening of foundation vents or sealing other openings into the substructure helps block the entry of termites; these procedures may interfere with adequate ventilation and increase moisture problems, especially if a very fine mesh is used in the screening. Ensure that attachments to buildings do not provide shelter or a hidden point of entry for termites. Utility and service boxes may have to be sealed, downpipes and service pipes, steps, porches, ramps, trellises, air-conditions, etc., are to be separated from the building so that full inspection is possible.

Reduce chances of infestation by removing or protecting any wood in contact with the soil. Replacement of damaged wood is another remedial treatment option, (Table 3 Annex 1) However, the effectiveness of wood replacement is highly dependent on detection accuracy and extent and location of the infestation, and it may be expensive to accomplish. Structural lumber in buildings varies around the world. Some timber species are to a varying extent resistant to termites. Usually trees and termites in a given area have co-evolved. While a given species of tree may be resistant to the local termite fauna, termites from other parts of the world may be able to attack this species of tree. Hence, experiences with termite resistance of certain timber species are not necessarily transferable from one region to another.

III.8.2 Preservative-treated Timber Products

There is a wide range of panel products and structural lumber with several insecticides added that are available as a management option (Tables 1 & 3 Annex 1). Termite susceptible wood can be turned into a termite resistant material by treating it with chemical toxicants (wood preservatives) that inhibit feeding by termites, and often growth of wood-degrading microorganisms. Use of such timber can be effective and economical for some situations. A list of commercially available active ingredients is provided in (Table 3 Annex 1). Wood that has been chemically treated will be protected from damage; however some minor termite feeding might still occur. Termites, especially subterranean termites, might also build foraging tubes over or around and along cracks within the chemically treated wood to areas not so treated. For these reasons, wood treatment is most successful in preventing termite infestations when used in conjunction with other termite management strategies, especially proper site preparation (removing cellulose debris and earth-to-wood contacts) and termite-resistant-building design. Drawbacks for wood treatment include harmful effects to applicators and the environment, depending on the active ingredients and solvents used, type of application equipment and training given to applicators. Some wood treatments require the use of pressurized chambers. Disposal of treated wood during construction renovations and possible harmful effects to the public and environment are additional issues to consider when using this termite management strategy.

Historically, active ingredients for wood preservatives included creosote and pentachlorophenol. However, because of environmental persistency and toxicity, most of the uses of these chemicals have been restricted or banned in many parts of the world. Other active ingredients include chromated copper arsenate (CCA), ammoniacal copper quat compound (ACQ), and disodium octoborate tetrahydrate (DOT). Wood containing CCA is tinted green, and ACQ is brownish. The surface of wood treated with DOT or borates are clear in appearance when used in accordance with label specifications. Borates are gaining in popularity because of their low mammalian toxicity, water solubility, and ease of application. There are many variables to consider when choosing wood preservatives, most important is whether they use is interior, exterior, and in ground contact. The label on the wood preservative should be read carefully to insure proper usage.

Wood preservatives are most toxic to termites when ingested. In the case of drywood termites, treated timber may also discourage new kings and queens (alates) from establishing colonies. Pressure treatment is always favored over topical applications when using any wood preservative. Care should be taken when using wood preservatives to ensure that all exposed wood is treated. This includes spot applications at construction sites where lumber is cut and drilled for fasteners.

III.8.3 Physical Barriers

Physical barriers are made from a variety of inert materials, (Table 4 Annex 1). They may also contain other components, such as sealant and “glues” to join sheet material or woven mesh to bricks and concrete to provide a strong and durable bond.

Physical barriers fall broadly into two types: graded particles and sheet materials. Particle barriers can be produced from sand, crushed rocks such as granite and basalt or crushed glass and consist of specific particle sizes that prevent termite tunneling when installed under or around foundation elements or penetrating conduits and pipes. Barriers from sheet materials can be in the form of corrosion resistant sheets of solid metals or woven stainless steel mesh. These types of barriers can also be installed under and around foundation elements or penetrating conduits and pipes to prevent termite invasions. Concrete slabs produced to certain specifications (“engineered slabs”) that minimize shrinkage cracks, can also form a physical barrier. However, at joints and service pipe penetrations through the concrete slab, physical barriers must also be installed to prevent termite passage into the superstructure.

These physical barriers are designed to force activity of subterranean termites out into the open, where it can be detected during routine inspections of buildings and appropriate action taken. In this context, it is important to note that physical (and chemical) barriers cannot entirely exclude the possibility of termite attack as barriers may be bridged or breached. Termite activity can be detected during regular inspections and appropriate steps for managing the problem can be taken. Some of these measures can also be effective in managing problems with arboreal nesting species. These recently developed physical barriers, such as stainless steel mesh and use of particle size barriers, are gaining popularity in their use for some countries. These barriers are not appropriate for the protection from drywood termite infestations in structures.

III.8.4 Termiticide Applications to Soil and Non-soil Substrates

Termiticides applied to soil and/or wood have long been the traditional management strategy applied to subterranean, arboreal, and drywood termites for many regions of the world. Typically these treatments consist of liquid, dust, or foam formulations applied to soil, wood, or aerial and arboreal nests (Table 5 Annex 1). Treatment is aimed at creating a zone of treated soil between the wood in a structure and the termites. Rodding and reticulation systems are sometimes used (closed, perforated tubing laid underground to distribute the chemical). For drywood termites and arboreal nesters, the termiticide may be topically applied or injected via drill holes to inhabited wood or the nest

Newer application techniques include the incorporation of insecticides into fibrous matting or plastic laminates, thus avoiding direct treatment and contamination of soil with the chemicals.

Active ingredients in available termiticides can be broadly classified as repellent or nonrepellent. Pyrethroids and synthetic pyrethroids (several brands are marketed) are considered repellent. This means termites can detect the barrier before a toxic dosage is encountered. Care in application is needed to minimize breaches in the barrier. Termites that detect these materials may forage until they find a break in the barrier and "tunnel" into a structure through this break. Examples of "nonrepellant" chemicals include organophosphates, imidacloprid, fipronil, chlorphenapyr (see Table 5 Annex 1 for more listings).

Active ingredients of toxic dusts that do not act as barriers include arsenic trioxide, boron and many more (see Tables 3 & 6 Annex 1for more examples).

III.8.5 Baiting Systems

Baits for subterranean termites are commercially available in a number of countries (Table 6 Annex 1). This method of controlling termites is very appealing because it does not require extensive site preparation and uses significantly lower amounts of toxicant than soil treatment. For example, baiting systems may use 1,000-fold less pesticide than a typical soil treatment for a similarly sized structure. Key features of this treatment strategy involve the use of systems (bait stations) to aggregate termites to a few points close to the outside or inside of the structure and application of toxicants either to the food matrix in the stations or directly to the termites (dusts). Termites carry the active back to the nest where it is passed along to nestmates via mutual food exchange or grooming. Thus, bait technology targets the termite colony, although depending on circumstances, only reduction of the population may be achieved. Active ingredients have to be slow-acting, nonrepellent chemicals to allow for uptake of significant amounts of the toxicant and transfer to nestmates.

Bait systems are chiefly applied to active infestations of subterranean termites (effects for aerial and arboreal nesters are still unclear as at this time). Dusts and biological control agents (Tables 6 and 9 Annex 1) can also be used in bait systems. Research is currently focused on the use against different pest species, mixed species infestations, and varying environments.

III.8.6 Space Fumigation

Space fumigation (Table 7 Annex 1) involves the introduction of a toxic gas inside a structure sealed inside a tarpaulin, or into or around an isolated area or object infested with subterranean termite aerial nesters, arboreal nests, and drywood termites. These gases must be used with extreme care, because they are extremely toxic to humans, as well as other animals, and plants. Improper or careless use can result in death or injury. Fumigants treat all termite infestations or colonies simultaneously, and have high levels of efficacy, if correctly applied. Major issues to consider with the use of fumigants include the difficulty of installing tarpaulins to contain the gas within the structure, determining the proper dosage, the need to protect food items and certain furnishings in the structure, and the lack of residual control. Additional considerations with fumigant use are the need to vacate structures for 2 to 3 days for treatment and ventilation, and the possible damage to roofs caused by dragging tarpaulins or the activity of workmen. Methyl bromide1 is a commonly used fumigant. However, issues involving the atmospheric ozone layer, odor in some household materials after treatment, and long aeration times for fumigated structures have limited the use of this fumigant. Methyl bromide1 is scheduled for phase out for international use in several years.

III.8.7 Thermal Control

There are four thermal options available for termite management, although mostly for drywood termites (Table 8 Annex 1). They include electricity, heat from propane heaters, excessive cold from liquid nitrogen, and excessive heat from microwaves. Many questions remain on their effectiveness and safety to humans and building materials. Additional research will be needed before these methods are used on a larger international scale. All of these thermal techniques have limited availability.

III.8.8 Biological Control

Experimental efforts have been made to control termites (mostly subterranean and arboreal nesters) using biological control agents, including fungi, nematodes, and argentine ants (Table 9 Annex 1). Biological control is the use of other life forms (e.g., insects, nematodes, fungi, or microbes) to control pest insects. Although predators, parasites, and pathogens have been shown to control other insect pests, their efficacy for termites is only just beginning to be explored.

---

[1] an ozone depleting substance

[2] The Convention enters into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification

IV. TERMITES IN AGROECOSYSTEMS

Termite attacks on annual and perennial crops, especially in the semi-arid and sub-humid tropics, cause significant yield losses. In general, damage by termites is greater in rain-fed than irrigated crops, during dry periods or droughts than periods of regular rainfall, in lowland rather than highland areas, and in plants under stress (lack of moisture, disease or physical damage), rather than in healthy and vigorous plants. In particular, exotic crops are more susceptible to termite attacks than indigenous crops.

Termites causing greater losses in agriculture belong to the following families and genera: Hodotermitidae (Anacanthotermes and Hodotermes), Kalotermitidae (Neotermes), Rhinotermitidae (Copotermes, Heterotermes, and Psammotermes), and Termitidae (Amitermes, Ancistrotermes, Cornitermes, Macrotermes, Microcerotermes, Microtermes, Odontotermes, Procornitermes, and Syntermes).

The extent to which termites are a problem to agricultural crops, the nature of loss they cause and the plant species they infest are very much related to the geographic region concerned.

IV.1 Identification

Lack of taxonomic understanding has been a major impediment to the study and management of tropical termites. Species numbers are high and many of those are undescribed or poorly described. Farmers and extension personnel often lack proper training. Very few specialists are able to identify tropical termite species and many of the economically important groups lack proper taxonomic revision, resulting in a large number of incorrect, doubtful or incomplete identifications. Under these conditions it is very difficult to accurately collect information on the biology and economic importance of each species. Therefore, it is strongly recommended to establish and develop regional reference collections, identification guides and training programs for extension staff.

IV.2 Damage

Termites can attack plants at any stage of development from the seed to the mature plant.

IV.2.1 Damage to seedlings

Various species of termites build large mounds often containing many thousand of individuals. Termites construct shallow subterranean foraging galleries radiating from the nest for distance of up to 50m. The main galleries give rise to a network of small galleries from which foraging parties can exploit potential food resources over extensive areas of land. Termites forage directly on underground plant material. Seedlings are either cut just below or above the soil surface. In the latter case termites gain access from soil-covered galleries impinging on the base of the plant. Usually, the seedlings are completely severed, resulting in lowered plant populations.

IV.2.2 Damage to maturing and mature plants

Damages to maturing plants are largely caused by species that have entirely subterranean nests consisting of a diffuse network of galleries and chambers. These species enter and consume the root system, which directly kills the plant or indirectly lowers yield through decreased translocation of water and nutrients. Attack to the root system can also lead to increased susceptibility to pathogens, or lodging of mature plants. When the grain in lodged plants touches the ground, soil fungi such as Aspergillus may invade it.

IV.2.3 Damage to stored products

Termite damage to stored products generally results in invasion by Aspergillus. The fungus causes indirect yield losses and contaminates production with aflatoxins.

IV.2.4 Crop losses

In the assessment of insect pest status, injury is the effect of insect activity on the plant (usually feeding on some part), whereas damage is the measurable loss of yield quantity or quality. Injury does not necessarily cause detectable damage. Control measures should be applied only when the pest species reaches a certain density. This density is called the economic threshold, which needs to be established in terms of simple estimation protocols that can be used by agricultural technicians and farmers. Very little research in this line has been conducted for termites and in most cases control measures are applied inefficiently on a trial-and-error basis.

With regard to termites, credible information on the economic losses is difficult to obtain. Termite damage to crops is generally expressed as percentages of plants attacked or plant mortality, and degree of plant damage. However, yield loss may not necessarily be significant, but a relationship between the percentage damage by termites and yield losses has been reported in some crops.

IV.3 Termite Pests and Management by Continent

IV.3.1 Africa

In Africa, the reputation of termites as pests is coupled with the presence of large mounds in crops or close to trees. Termites are widespread in Africa, restricted mainly by desert areas and the lower temperatures found at higher altitudes. There are approximately 20-50 damaging termite species in savanna and forest ecosystems in the family Termitidae. The majority of species feed on plant material, living or dead, dung or soil rich in organic material. The greatest pest potential exists within the subfamily Macrotermitinae, which has a symbiotic association with the fungus Termitomyces. The most economically important genera throughout Africa are Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes and Microtermes. These genera differ characteristically in their biology and mode of attack. Macrotermes spp. build large epigeal nests (mounds) from which they forage outwards for distances up to 50m in galleries/runways. They attack plants at the base of the stem, ring-barking or cutting them through completely. Odontotermes spp. build both subterranean and epigeal nests. Damage is due to feeding either under soil sheeting on the outer surface of the plants or on the roots. Microtermes spp. and Ancistrotermes spp. have diffuse subterranean nests and attack plants from below ground by entering the root system and tunneling up into the stem, hollowing it out and frequently filling it with soil.

Major crops attacked by termites

(i) Groundnuts

Microtermes and Odontotermes species have always been associated with groundnuts in semi-arid tropical countries of Africa, causing yield losses between 10 and 30%. Management measures include the use of resistant groundnut varieties, cultural practices, botanical insecticides, and minimal application of synthetic insecticides either to the soil or as a seed dressing. These treatments form a barrier, which repels or kills foraging termites.

(ii) Maize

Among cereal crops, maize is the most often damaged by termites. Microtermes and Ancistrotermes attack maturing and mature maize plants, while Macrotermes spp. cause damage to seedlings. Species of Odontotermes, Allodontermes, and Pseudacanthotermes can defoliate maize seedlings or consume the entire plant. Yield losses of from 30 to 60% have been reported in some parts of Africa. Maize plants attacked early in the season can compensate damage with new growth. One of the options for farmers to manage termites is to sow at a higher rate. The other option is to dress the seeds with insecticides.

(iii) Sugarcane

The most damage to sugarcane is done by genera Amitermes, Pseudacanthotermes, Macrotermes, Odontotermes, Microtermes and Ancistrotermes. Yield losses of 18% were reported in Sudan, and 5-10% in central Africa. In Nigeria plant germination failure of up to 28% has been reported. The most common damage to sugarcane is the destruction of the setts (planting material). The usual method of prevention is to dip the setts in various formulations of chlorinated hydrocarbons before planting, or to spray them in the furrows before filling in.

(iv) Yam and Cassava

Yams and cassava are grown from tuber and stem cuttings, respectively, and are consistently attacked as seed pieces by Amitermes, a predominantly root-feeding species. Ancistrotermes, Macrotermes, Odontotermes, Microtermes and Pseudacanthotermes are also involved in damaging the maturing crops, as well by hollowing out stems at ground level. The current management strategy consists of treating setts with aldrin dust.

(v) Cotton

Termite species in the genera Allondotermes, Ancistrotermes, Hodotermes, Microtermes and Odontotermes have been reported to damage cotton especially in the drier parts of Africa. Management measures include broadscale application of chlorinated hydrocarbons or seed dressings, and baiting with chopped grass treated with insecticides. Information on other crops are provided in Table 10 Annex 1.

IV.3.2 Southeast Asia

Termite problems in agriculture in Southeast Asia largely affect perennial tree crops. The most economically important genera throughout Southeast Asia are Microtermes, Coptotermes, Odontotermes, Macrotermes, Trinevitermes and Heterotermes.

Microtermes obesi is a small, fungus-growing, subterranean termite that has a diffuse network of brood-rearing and nesting chambers in the ground. It can be very widespread where it occurs. The termite attacks freshly planted sugarcane setts in Thailand and the north of Peninsular Malaysia, resulting in poor establishment of plantations. Yield losses of 12% have been recorded in Pakistan. Species such as Heterotermes, Coptotermes, Odontotermes, Macrotermes and Trinervitermes also attack sugarcane. Current chemical control involves the use of granular insecticides, such as fipronil, applied into the soil when the setts are planted.

Coptotermes curvignathus in Southeast Asia causes damage to a number of commodity crops, as well as fruit trees (see Termites in Forestry section). Crops that appear to be rather susceptible include rubber (Hevea brasiliensis), oil palm (Elaeis guineensis), coconut (Cocos nucifera), kapok (Ceiba pentandra), mango (Mangifera spp.) and papaya (Carica papaya). In oil palm and coconut, termites usually attack the spear region of the palm. Once the spear is destroyed, the tree dies, as it is the only growing vegetative part of the palm. Some crops are rarely attacked and, therefore, appear to be more resistant. These include coffee (Coffea arabica), tea (Camellia sinensis) and a number of fruit trees such as cocoa (Theobroma cacao), durian (Durio zibethenus), mangosteen (Garcinia mangostana), rambutan (Nephelium lappaceum), nutmeg (Myristica fragrans) and cloves (Syzygium aromaticum). Information on other crops are provided in Table 10 Annex 1.

IV.3.3 Australia

In Australia, several species in the genera Mastotermes, Heterotermes, Coptotermes, Amitermes and Microcerotermes have been reported to attack a range of field crops (Table 10 Annex 1). However, most incidences are reported in the tropical areas, chiefly during the dry season or in low-rainfall areas, with Mastotermes darwiniensis as the key species. Mastotermes may cause significant damage to sugar cane and other produce, but only in areas where the crops are cultivated on other than rainforest soils (Mastotermes is absent from tropical rainforest regions.). Elsewhere in the country termite damage to field crops is sporadic, and in general associated with longer periods of dry weather or other special circumstances. For example, in southeastern Australia Coptotermes and Heterotermes can attack certain varieties of potatoes in dry summers, and in semi-arid regions cereal crops in the first year of cultivation on fallow land may be attacked by Amitermes neogermanus.

Mastotermes darwiniensis poses major problems to horticulture in the tropical Australia (Table 10 Annex 1 and Termites in Forestry section). For example, losses of cashew, mango and avocado trees to this species can be as high as 30% in the Northern Territory. In tropical Queensland, the importance of Mastotermes as a pest species in horticulture is likely to increase, as plantings of exotic fruit trees extend more and more into areas outside former rain forest. Elsewhere in Australia, localized damage, most notably by species of Coptotermes, to fruit trees, tea trees (Melaleuca) and grapevines has been recorded. But in most cases, termite attack is selective and focuses on plants that are past their prime or otherwise stressed (for example root-bound seedlings). Sources of moisture, including drip irrigation, may attract termites to some of these sites in the first place.

The main approach to dealing with the problems caused by Mastotermes to the horticultural industry in tropical Australia is a combination of plantation management and use of aggregation and baiting techniques. The POPs chemical mirex is the currently registered active ingredient in baits for Mastotermes control. (Northern Territory and Western Australia only). Alternative bait toxicants and other management strategies are under investigation.

On some islands of the South Pacific (northern Cook Islands, Tuvalu) Neotermes rainbowi hollows out the trunk of coconut palms. If attack starts in mature palms, termite activity has limited impact on yield until the palms snap off in storms at the point where the greatest damage has been done. Species of Neotermes in the South Pacific can also damage other tree crops such as Citrus and cocoa, and occasionally some annual crops. In experiments with the biological control agents Metharizium anisopliae (fungus) and Heterorhabditis sp. (nematode), colonies of Neotermes could be eliminated from palms and other trees. However, plantation management and tree care alone can be successful in preventing a build-up of Neotermes populations.

IV.3.4 South America

Termites are abundant and diverse in most parts of South America, particularly in tropical lowland forests, savannas and grasslands. Several native termite species have been reported as agricultural pests. As natural habitats are gradually replaced by urban and agricultural space, new pests are discovered, while the increasing trade with other continents facilitates the introduction of new pests. However, information on the pest status of termites in South America is still very limited. There are no estimates of the economic losses caused by termites or the relative importance of each species. Agricultural termite pests are more numerous and much less studied than urban pests. Furthermore, termite research and expertise in South America are highly concentrated in Brazil, while the fauna and termite problems of large countries, such as Colombia, are virtually unknown. A total of 53 termite species are reported as agricultural pests, and 15 species as pests of both agriculture and structure.

The main pest species belong to Rhinotermitinae (Heterotermes and Coptotermes) and Nasutitermitinae (Cornitermes, Procornitermes, Syntermes and Nasutitermes).

The most affected crops in South America are sugarcane, upland rice, maize, cotton, groundnuts, soybean, coffee, cassava, and some vegetables. Termite damage includes injury to roots, injury to leaves and stems, and injury to woody tissue by kalotermitids.

In the Amazon, the largest biome of South America (6 million km2), Nasutitermes, Coptotermes, and Heterotermes may cause variable damage to crops such as cassava, maize and fruit trees. In the Cerrado, which is savanna, termites are abundant and diverse. Because large areas of the Cerrado are being replaced by agroecosystems, termites may become a menace to some crops.

Perennial tree crops that are affected by termites in South America include several fruit trees, ornamental trees, palm trees and coffee. Damage to fruit trees is often restricted to seedlings and young trees, which may be killed by termites. Termites feed on several parts of the plant, especially the roots. Heterotermes tenuis seems to be the most important species causing these problems. Mature trees, including palms and coffee, may be attacked by drywood termites, particularly Neotermes, and by arboreal-nesting termitids Nasutitermes and Microcerotermes. However, in general, termites seem to be minor pests of tree crops in South America and, in many cases, damage is presumed based only on the presence of termites. Information on other crops are provided in Table 10 Annex 1.

IV.4 Alternative Management Systems for Termites in agroecosystems

Alternatives to POPs for control of termites in agriculture is attracting renewed interest following increasing restrictions on the use of POP's. Some progress has been made in this respect in agricultural settings involving termites.

Management of termites generally varies according to the type of termites involved and can be conceived in three ways: (IV.4.1) preventing termites gaining access to the plants, (IV.4.2) reducing termite densities in the vicinity of the plants and (IV.4.3) rendering plants less susceptible to attack by termites. The three approaches may overlap in some cases.

IV.4.1 Preventing termites gaining access to plants

Conventionally, placing persistent insecticidal barriers in the soil around the roots has prevented damage to plants by subterranean termites. Organochlorines (lindane, aldrin, dieldrin, chlordane and heptachlor) were, in the past, applied almost exclusively as seed dressing or to the soil in planting holes or as furrows treatments. Attack on crops, especially by Macrotermitinae in Africa and India, have been prevented by poisoning the mounds with organochlorines. Following increasing restrictions on the use of POPs less persistent insecticides, such as organophosphates (chlorpyrifos, iodofenphos, isofenphos), carbamates (carbosulfan, carbofuran), and pyrethroids (permethrin, decamethrin, deltamethrin), have been used as alternatives, however their low persistence often necessitates repeated applications. Recently, controlled-release formulations of some non-persistent insecticides were tried and found to be effective and long-lasting. However, these formulations are not cost-effective for the majority of low-income farmers in developing countries.

IV.4.2 Reducing termite densities in the vicinity of the crops

A number of techniques are used to reduce termite densities in the vicinity of the plants. They include cultural methods, plant insecticides and biological control.

Cultural practices

Deep plowing or hand tillage exposes termites to desiccation and to predators, thus reducing their number in the crops. Pre-planting tillage also destroys the tunnels built by termites and restricts their foraging activities and associated damage to crops. Removal of the queen and/or destruction of the nest have frequently been used by farmers as a traditional method for control of mound-building termites. Mounds are physically destroyed, flooded or burnt with straw to suffocate and kill the colony.

Crop rotation may be useful in reducing the buildup of termites since intensive monoculture for long periods makes plants more susceptible to termite attack. However, winged adults of some termite species are capable of moving in from other sites if preferred hosts are planted in the field used for rotation.

Intercropping is the most effective cultural practice used by small-scale farmers in Sub-Saharan Africa to manage insects that have specific host ranges. However, controversial results have been reported for termites. For example, intercropping maize and beans resulted in significant reduction of ground tunneling by termites but did not reduce termite damage on the plants. Intercropping groundnut with sunhemp did not affect termite abundance or damage to the groundnuts. On the other hand, intercropping in forestry has been suggested as a means of retaining termite diversity in the crop in order to prevent them from achieving pest status. Certain grasses are intercropped with different crops in western Africa to repel termites.

The removal of residues and other debris from the field may reduce potential termite food supplies and hence lead to a reduction in termite numbers and subsequent attack. On the other hand, leaving residues in the field or adding further organic matter could provide alternative food to which termites will be attracted, thereby reducing levels of attack on the main crop. However, this is not true in all cases. For example, in most parts of Sub-Saharan Africa, monocropped groundnut is cultivated after cereal crops. Post harvest debris from cereal plantings is often left behind. It serves as food for Microtermes and Macrotermes, which at the same time attack ground crops. Termite infestation of 100% was observed in groundnut crops where the plant residues were rated very high.

Mulches may either increase or decrease the incidence of termites depending on whether they have any repellent properties. Non-decomposed organic matters such as plowed weeds and green manure have been associated with termite attack on cotton in Malawi and Sudan.

Plant extracts

Various parts of plants and plant extracts are known to be either toxic or repellent to pests of agriculture, and are widely used in rural settings. However, no specific recommendations have been made for their large-scale utilization. Some of these extracts have been investigated in the laboratory and proven effective against termites. Plant extracts, such as those of neem, wild tobacco and dried chili, have been used to control termites in the field and storage warehouses.

Wood ash heaped around the base of the trunk of coffee bushes has been recorded as preventing termite infestations. Wood ash has also been reported to repel termites from date palms. Wood ash has also been used to protect stored yams, maize straw, tree seedlings, if it is mixed into plant nursery beds or applied as a layer. However, the potential benefits of using wood ash for termite management require verification.

Biological control

Many natural enemies (predators, parasites and pathogens) attack termites in nature. Biological control is the use of these natural enemies in termite management. It constitutes a more environmentally acceptable alternative to traditional chemical control measures. The US Environmental Protection Agency encourages the development and the use of biological control agents (http://www.epa/pesticides/citizens/advantages). Biological control can be accomplished in three ways:

- By introducing exotic natural enemy to pests of exotic origin (classical biological control).
- By enhancing the effects of natural enemies through manipulation of the environment.
- By augmentative or inundative application of control organisms. Natural enemy numbers may be augmented with releases of laboratory-reared organisms (microbial insecticides).

Termites have a wide variety of predators, both opportunist and specialist, but ants are the greatest enemies of termites in all regions of the world. Although ants limit termite numbers under natural conditions, their suitability for use as biological control agents for target termite management has yet to be ascertained. The practice of traditional farmers of using dead animals, meat bones and sugarcane husks to poison Macrotermes mounds was recently used to develop baits for predatory ants and tested in maize fields for termite control in Uganda. The protein-based baits attracted significant number of ants and more ants established nests near maize plants, this in turn reduced termite damage and increased grain yield.

Among the pathogens (bacteria, viruses, protozoa and fungi), entomopathogenic fungi so far offer the best prospect as termite control agents. Fungi infect their host through the cuticle and do not need to be ingested. In fact, spores of candidate fungi, such as Metarhizium, pass through the termite gut without causing any harm. Conidia of entomopathogenic fungi could be spread through the colony and the nest by contact and grooming between contaminated and uncontaminated termites. However, factors such as repellency of fungal conidia, the removal and burial of fungus-killed termites, and behavioural changes in infested termites (in the case of Metarhizium they congregate at the base of a nest where they are easier to quarantine by nest mates) may limit the spread of the disease in the colony. Application methods to overcome some of the limitations include inundating of termite nests or sites of high termite activity with formulated products, and use of low doses of the insecticide imidacloprid in combination with the fungus. The insecticide has a synergistic effect. More termites die from the combined treatment than from the combined mortality caused by each agent alone.

The entomopathogenic fungus, Metarhizium anisopliae, has recently been developed into a product for control of termites in buildings in the USA, Brazil and Australia. Colonies of some species could be killed when nests were inundated with conidia. With a similar approach it was possible to destroy colonies of Macrotermes and Ondotermes in Kenya. Successful control of Cornitermes colonies has also been achieved in pasture in South America. The effectiveness of M. anisopliae to control termites in maize cropping system was demonstrated for the first time in Kenya and Uganda. The fungus, formulated as granules and applied as seed treatment, resulted in reduction of plant lodging and a subsequent increase in maize yield comparable to that obtained with the chemical insecticide lindane.

The use of the fungus *M. anisopliae* in bait stations is under investigation in Australia, and may represent a new potential alternative for the control of termites.

IV.4.3 Rendering plants less susceptible to attack by termites

Although termites may damage healthy plants, unhealthy and stressed plants are generally more susceptible to termite attack. Therefore, cultural practices should aim at maintaining or enhancing plant vigor.

The use of good quality seed, healthy seedlings, and appropriate transplanting procedure is more likely to produce healthy plants.

Intensive cropping for long periods may reduce soil fertility and structure. This in turn may lead to reduced crop vigor and an increase in susceptibility to termite attack. Crop rotation, including fallow periods, is recommended as a measure to improve soil fertility and structure. However, in a number of cases, crop rotation can lead to greater levels of termite attack.

In general, crops showing resistance or tolerance to termites are indigenous while the susceptible crops are exotic. In Africa, sorghum and millet are more resistant to termites than maize and groundnut. Presumably indigenous crops have evolved defense mechanisms against the local termite fauna. Cultivars of a particular crop may also differ in susceptibility to termites. This has prompted research on the selection of cultivars for resistance to termites. Some varieties of groundnut and maize have been found to be resistant.

Weeds competing with crops for nutrients, light and water may lead to stress and hence increased susceptibility to termite attack. For example, higher incidence of termite attack on cotton was noted in Sudan in areas where the sedge Cyperus rotundus was abundant.

Deficiency or excess of water may stress plants and encourage termite attack. In general, attack on crops and trees is greater in drier areas and during dry periods. Overall, annual rainfall is important but the temporal distribution of rainfall through the growing season may be more significant. Various measures may be taken to reduce water stress and, therefore, maintain plant vigor. It is recommended to water nursery stock prior to planting out and to plant at the correct time to avoid drought periods.

The use of inorganic fertilizers enhances plant vigor and hence the ability to withstand pest damage. Application of nitrogen, phosphorus and potassium in wheat, barley and yam has been observed to reduce termite incidence.

V. TERMITES IN FORESTRY

Termites can have a significant impact on plantation and urban forestry, as well as on agricultural tree crops. Many other insect pest species cause damage to various parts of the tree, but often do not cause mortality. Some termite species, however, are able to kill apparently healthy trees and, therefore, have the potential to cause much greater losses. Even where termites do not cause death of the tree, they may cause damage to the bole, for example, by consuming the heartwood and, thereby, hollowing the trunk and reducing the value of the tree as a source of timber. The extent to which termites are a problem to trees and the nature of loss they cause are very much related to the geographic region concerned. There are a number of current chemical control methods employed, however, a number of alternative, traditional control methods, largely relating to silvicultural practices or plantation management, are also very important, and should be considered before chemical intervention is attempted. Some of these control strategies are also applicable to urban forestry.

V.1 Urban Forestry

In urban forestry, where trees are planted in highly populated areas along streets or in parks, special consideration needs to be given to the types of control strategies that are applicable, because of the environment the trees grow in and the proximity to human dwellings. A number of current chemical control methods are employed, but these have a relatively high environmental impact, and many governments generally refrain from these chemical control methods in urban areas. Some alternative traditional methods of control such as the use of species suitable for a region, use of resistant tree species, reduction of mechanical damage, maintenance of plant vigour and inter-planting may be applicable in some circumstances, depending on the termite pest species in the geographic region concerned. Additionally, some new and potential alternative control methods, such as baiting systems, hold a lot of promise for managing termites in urban plantings.

V.2 Termite Pests and Management by Continent

V.2.1 Southeast Asia

In southeast Asia, the termite species responsible for most losses in agricultural tree crops and forestry is the subterranean termite, Coptotermes curvignathus, which has the ability to kill healthy trees. Only one other species in the region can attack trees, Microcerotermes dubius. The latter species is only very occasionally a problem in forest plantations, because its aerial nests are more readily destroyed than the subterranean nests of the former species. Coptotermes curvignathus attacks a wide range of tree species, but some tree species are more resistant to attack than others.

Coptotermes curvignathus usually builds mud and carton sheaths around the bases of trees that it attacks, and undermines the bark beneath with numerous perforations into the living tissue, eventually killing the tree as a result of impaired food transport from the crown above to the root system below. Sometimes it may first penetrate into the heartwood before working outwards to kill the tree in the same manner.

Forest plantation tree species attacked by Coptotermes curvignathus in Southeast Asia include pines and all other species of conifers, which are particularly susceptible, rubber trees (Hevea brasiliensis), Acacia mangium, Paraserianthes falcataria and Gmelina arborea. Most species of conifers suffer high mortality when attacked by this termite species. Acacia mangium is more commonly infested within the heartwood, through pruning wounds, than killed by the termite. Nevertheless, healthy trees can still be killed, although the mortality is much lower than in conifers. Teak (Tectona grandis) is relatively resistant, but has problems with the drywood termite, Neotermes tectonae. Many native tree species of forestry importance that occur in natural forests are susceptible to the termite, for example, Koompassia malaccensis and Buchanania sessifolia. In addition, many species of trees planted in urban areas are also attacked.

V.2.2 Australia

Termites are relatively scarce in Australian rain forests. They are of negligible importance as pests of timber trees in this type of forest. In the hardwood (Eucalyptus) forests of coastal and near-coastal eastern Australia, species of Coptotermes, including C. acinaciformis and C. frenchi, very commonly infest living trees. Termite damage to forest trees mainly takes the form of a cylindrical pipe running up inside the centre of the trunk. Coptotermes spp. reach the inner heartwood through the root system. A varying and often limited number of galleries reach into surrounding wood. It is common practice to 'box out' the inner heartwood because it is often degraded not just by termites, but also by decay fungi. Thus, even a high incidence of termite infestation in trees does not necessarily translate into serious loss of marketable timber. Porotermes adamsoni and Neotermes insularis can also affect commercial timber trees. No specific measures are taken to manage any the termite problems in eucalypt forests.

Plantations of native and exotic pine trees do not experience termite damage, except in tropical areas where Mastotermes darwiniensis occurs. This species has prevented the successful establishment of some pine plantations in the Northern Territory. Planned large-scale plantations of species of Acacia in the same region will have to be protected from Mastotermes attack in order to succeed. Unique among termites, Mastotermes foragers often kill trees first by ring-barking them, before hollowing them out from the top down. In Australia, management measures for Mastotermes darwiniensis include baiting techniques with POP's, and biological control.

V.2.3 South Pacific Islands

Islands of the South Pacific with major areas of rain forest usually have a species of Neotermes, to which a number of native tree species are susceptible, while others are resistant. Damage in native trees is, as a rule, restricted to the central heartwood ('piping'). Where rainforest is cleared to grow exotic hardwoods, Neotermes may attack any susceptible species. The most notable example is the plantings of American mahogany (Swietenia macrophylla) on Fiji. Up to 10% of trees, and possibly even more, have been lost due to termite damage. Incidences of attack vary between sites. Trees are vulnerable to attack from about two years of age onwards. Termites enter the trees via the root system and spread through both inner and outer heartwood over the full length of the bole and into the main branches. Control of Neotermes in the South Pacific islands can be achieved using biological control.

In New Guinea plantations of native and exotic pines (Araucaria, Pinus) are prone to attack by Coptotermes elisae. This species attacks trees in a manner very similar to Coptotermes curvignathus, and is managed in the same way.

V.2.4 Europe

In Europe, subterranean termites attack living trees in urban areas, besides infesting wood in buildings. The termite species generally responsible for this is Reticulitermes santonensis, which causes an estimated several million euros worth of damage to street trees in the city of Paris alone, where there are about 90,000 trees worth around 2500 euros each. This species attacks deciduous trees indiscriminately, regardless of age and species. Among tree species attacked are the plane tree, chestnut tree, ash tree, wingnut (Pterocarya spp.), poplar, etc. Infested trees are generally found near buildings that are infested. Heat and moisture generated in urban areas promote the spread of the termite. Baiting systems are currently being explored as a method of managing this termite problem.

V.2.5 South America

Forestry in South America is dominated by several species of Eucalyptus and Pinus, which are widely cultivated as a source of timber or wood fiber. Termites are important pests of Eucalyptus, but cause limited damage to Pinus trees. In Eucalyptus, damage is most significant to seedlings and young trees, which may suffer severe attack in some areas, often causing high mortality. The most important termite pests belong to the genera Syntermes, Procornitermes, Cornitermes, and Heterotermes. The most important species seems to be Syntermes nanus, which has caused severe mortality of up to 70% in some areas. Coptotermes, which hollows the trunk, may also attack adult trees but this kind of damage is not common. Many other termites are common in the Eucalyptus and

Pinus plantations, but most of them are harmless. Some urban, ornamental trees have been infested by Coptotermes havilandi, which hollows the trunk and may cause the tree to fall and cause accidents. C. havilandi is restricted to the coastal region of Brazil, where it has become established since its introduction in the 1920s.

V.3 Alternative Management Systems of Termites in Forestry

V.3.1 Current chemical control

A number of chemical control methods are currently used to protect trees against attack by termites. These methods have remained largely the same over the years, although the chemicals used have changed to reduce the environmental impact of these treatments. Many, or all, of the organochlorines, which are persistent organic pollutants, are no longer registered for use in most countries. Current chemical control methods employed are soil treatment, treatment of seedlings before transplanting and baiting techniques.

V.3.1.1 Soil treatment

Soil treatment to protect trees from attack by termites involves the application of chemicals to the soil surrounding the base of the tree. This may be done at the time of transplanting seedlings from the nurseries into the field, or it can be done to trees already in-ground. In the former, granular formulations of insecticides (e.g. fipronil) are usually used, since they are easy to carry into the field, and they are applied into the planting hole. In the latter, the soil at the base of the tree is removed to form a cavity or trench around the tree, and liquid-based chemicals are poured in and allowed to seep into the ground by gravity and capillary action. The cavity or trench is then filled over with the soil originally excavated from around the tree, and treated as well. Chemicals currently used include chlorpyrifos, imidacloprid and fipronil.

V.3.1.2 Treatment of seedlings before transplanting

Treating seedlings before transplanting reduces the labour involved in field-based treatments, but provides less protection to the seedlings. The seedlings are usually prepared with granular insecticide mixed into the soil at the time of planting in the nursery.

V.3.1.3 Baiting techniques

Aggregation and baiting techniques, using the POP chemical mirex as the active ingredient, are used primarily in Australia as a management measure for Mastotermes darwiniensis (Australia, Termites in Agroecosystems section).

V.3.2 Alternative control: traditional methods

Many traditional methods of control of termites in forest plantations have a sound basis in the principles of ecology. They are often simple and cost effective means of minimising termite problems through silvicultural practices that involve thoughtful planning before establishing a plantation and suitable practices following establishment. These, some of which are inter-related, are listed below:

- Selecting Low-Risk Sites
- Use of Species Suitable for a Region
- Resistant Tree Species
- Reduction of Mechanical Damage
- Maintenance of Plant Vigour
- Removal of Nests
- Increasing Biodiversity
- Inter-Planting

V.3.2.1 Selecting low risk sites

Termite pest species have their own native habitats in which they are most abundant. For example, in Southeast Asia, the tree-killing termite species, Coptotermes curvignathus, is abundant in peat swamps. The abundance of termite species in particular plantation sites is often, therefore, reflective of the history of the site. Plantations established in areas once occupied by peat swamps in Southeast Asia often have a relatively high incidence of attack by Coptotermes curvignathus. One way of avoiding the problem of termites in forest plantations is not to plant susceptible species of trees on sites known to be high-risk.

V.3.2.2 Use of species suitable for a region

Tree species-site matching is an important aspect of termite management. Trees grown in regions to which they are not suited may be more stressed and, hence, more prone to attack by termites. Acacia mangium for example, which is widely planted in parts of Southeast Asia, does better in a climate with a marked season, such as a wet and dry season. In other areas, it tends to develop a bushy growth form, which requires more pruning and predisposes the trees to attack as a result of mechanical injury to the trees. Terrain, climate and soil properties (physical and chemical) should be suitable for the tree species chosen, bearing in mind its native habitat and its degree of tolerance outside the conditions in which it naturally grows.

V.3.2.3 Resistant tree species

Some tree species are naturally resistant to certain termites. However, a tree species that is resistant to one termite species may not be resistant to another. Thus, it is important to identify the termite pest species that is a problem in the geographic area concerned. In southeast Asia, Coptotermes curvignathus is the primary species that kills trees in plantations, and it has a wide host range.

V.3.2.4 Reduction of mechanical damage

Reducing mechanical damage to trees can minimise damage by termites. Such mechanical damage can occur from pruning wounds, or during weed control or thinning operations, especially where heavy machinery is used. Wounds and scars on tree trunks or branches serve as entry points for termites into the heartwood of the tree, sometimes after fungal infections of the wounds. Termite species that kill trees, such as Coptotermes curvignathus in Southeast Asia, may also preferentially attack trees with wounds, and may locate trees by the exudates that flow from such wounds or dissolve in rainwater. All wounds should be treated with a wound dressing, but minimising any form of mechanical damage to trees is advisable, as wound dressings do not adequately prevent fungal and termite infestations. Besides mechanical injury, it is thought that stress also predisposes trees to attack, therefore, maintaining plant vigour is an important means of minimising damage by termites.

V.3.2.5 Maintenance of plant vigour

Healthy trees are likely to be less readily attacked by termites. Trees under water or nutrient stress, or deprived of sufficient light, due to overly high planting densities or lack of thinning, may be more prone to attack. At the extremes of such conditions, termites that are not normally pests of plantation trees may cause damage or even accelerate death of the trees. But it is also likely that termites that have the ability to kill healthy living trees may preferentially attack stressed trees growing under poor conditions. For similar reasons, reduction of mechanical damage to trees due to silvicultural practices is also important. Selecting trees that are suited to the region in which they are planted is also an integral part of ensuring that plant vigour is maintained.

V.3.2.6 Removal of nests

Nests of pest termite species that are easily visible can be removed manually, thus reducing their population. This has been used in South America to control arboreal nesting species, particularly Nasutitermes, which may occur in high densities on fruit trees. It is also applicable to Microcerotermes dubius in Southeast Asia, which may occur very occasionally in forest plantations.

Likewise, drywood termites, such as Neotermes tectonae on teak, can also be controlled by removal of affected branches.

V.3.2.7 Increasing biodiversity

Taking measures to increase biodiversity may increase competition from non-pest termite species and, thereby, reduce populations of pest termite species. For example, in southeast Asia established colonies of the pest termite species, Coptotermes curvignathus, have a competitive edge over other termite species in plantations of susceptible tree species because of its ability to kill trees. However, encouraging a diversity of termite species in forest floor wood litter may reduce nesting opportunities for new founding colonies and, in the long term, reduce the population of the pest termite species. In addition to providing increased competition against termite pest species, increasing biodiversity can also increase natural enemies of termites, such as ants. Measures that can be taken to encourage biodiversity in forest plantations include inter-planting, retaining a litter layer, retaining ground cover, encouraging rapid canopy closure and reducing pesticide usage.

V.3.2.8 Inter-planting

When tree species susceptible to termite attack are to be used, inter-planting them with resistant species may help reduce the overall incidence of attack in the plantation and, consequently, limit the build-up of the termite pest population. Inter-planting may also help reduce attack on susceptible tree by making it more difficult for the termites to locate them. It also helps increase biodiversity in the plantation, which may help reduce populations of termite pest species.

V.3.3 Alternative control: new and potential methods

A number of novel methods of termite control have been recently introduced, or may be introduced in the future. These are:

- Resistant Tree Varieties & Genetic Engineering
- Biological Control
- Baiting Systems
- Treatment of Soil and Seedling with New Generation Insecticides

V.3.3.1 Resistant Tree Varieties & Genetic Engineering

The development of resistant tree varieties through breeding programmes and genetic engineering is still at an early, exploratory stage, and is hampered by the long rotation periods of forest plantation trees in comparison to annual agricultural crops. However, it may become an important means of protection against termites in the future. Genetic engineering for resistance usually involves the introduction of genes from insect pathogens, such as bacteria, into the tree, which then expresses pathogenic characteristics towards insects. The environmental implications of such genetically modified organisms in agriculture and forestry are controversial and still largely unstudied. Some studies indicate that they may carry a set of environmental problems of their own.

V.3.3.2 Biological Control

Biological control of termites has largely focussed on the use of fungi (e.g., Metarhizium) and nematodes. It is not easily achieved in the field because of the tendency of termite colonies to cut off and avoid infected areas as soon as disease sets in. Nevertheless, such biological control agents can be a substitute for chemicals when they are used to control local infestations. The use of these agents against termites is an area of active research and, in the future, methods may be developed for colony elimination using biological control agents. Trials using the entomopathogenic nematode, Heterorhabditis sp., have given encouraging results for the control of Mastotermes darwinensis in Australia. Also, initial studies indicate that Neotermes colonies attacking Mahogany in the South Pacific Islands can be eliminated by both the fungus Metarhizium anisopliae and the nematode Heterorhabditis sp. However, because Mahogany in Fiji is planted in single rows, separated by strips of undisturbed forest, recolonisation of trees over a plantation lifetime of about 30 years is possible.

V.3.3.3 Baiting Systems

Baiting systems using active ingredients such as moult (chitin synthesis) inhibitors, have become widely used in the control of termites affecting housing. They are effective in eliminating colonies when used consistently over an extended period of time. However, their application against termite pests in agriculture and plantation or urban forestry has not yet been widely developed or specifically tailored for the purpose. They would almost certainly prove to be effective against subterranean pest species from among the lower termites, such as Reticulitermes and Coptotermes. Systems specifically designed for the treatment of termites on trees will probably become available in the future, and will be a low-environmental-risk chemical method of control, because the chemicals can be targeted specifically at pest species of termites in baiting receptacles. Bait systems have already been tested and have shown promising results against Reticulitermes santonensis in Paris, where city officials are also co-operating with the Centre National de la Recherche Scientifique (CNRS) in a pilot study to investigate colony and population structure using molecular and chemical markers. Hopefully this knowledge will lead to a better understanding of the pest's invasion strategies and allow development of effective targeted control measures for Paris and other big cities.

V.3.3.4 Treatment of Soil and Seedlings with New Generation Insecticides

Soil treatment and the treatment of seedlings before transplanting have been used as classical methods of control and prevention of termite attack in forest plantations for many years. These methods of control have a high environmental impact because of the large amounts of insecticides that have to be applied in open areas that are exposed to leaching. In recent years, new generation insecticides that are active at very low doses have become available. These chemicals generally also have a low toxicity to other life forms. When chemical treatment is deemed necessary, such chemicals provide an environmentally preferable alternative to traditional chemicals. Examples of these new generation insecticides are imidacloprid and fipronil. However, before adopting a chemical means of control, alternative, traditional methods of control should be considered.

VI. PROCESS FOR SELECTING/TESTING STRATEGIES

In order to select the best alternatives to POPs for the management of termites, an evaluation of the available alternatives must be conducted. This evaluation should include the following considerations:

- Economic viability of the POPs alternative . –The strategy must be affordable for the target population. Although initial costs will often be higher, on a long-term basis the costs of the alternative strategy must be acceptable.
- Efficacy of the POPs alternative in its intended area of use. – Assessment of the efficacy must be conducted against local or similar pest species of termite and under local or similar environmental conditions to be relevant.
- Environmental acceptability of the POPs alternative. – The alternative must not cause environmental problems, such as contamination of water or food crops, toxic effects on non-target organisms, or cause the creation of hazardous waste.
- Availability of the alternative. – The alternative must be available in commercially significant quantities.
- Safety of the alternative to applicators and consumers. – The alternative must be safe for the workers who will be applying it or otherwise implementing the management measure, and safe for the general public when used in or around the protected agricultural crops or structures.
- Resources for evaluation of the alternative. – Resources may be available for conducting such evaluations. Information on some of these sources can be obtained through UNEP Chemicals.

Each of these areas for consideration is discussed in more detail below.

VI.1 Economic viability.

A change to alternatives to POPs is likely to require higher economic investments than if the use of POPs is continued, and there is likely to be an economic incentive to continue to procure the POP material. However, if potential damages to the environment and health, costs for regulatory controls and waste management and other indirect costs are taken into account, the real long-term cost of continuing the use of POPs is likely to be much higher than if counting only the direct costs. Comparisons made in Thailand, Germany and the USA have demonstrated indirect costs that are equal to, or even higher than, the direct costs of pesticides.

Providers of termite protective services and users of these services can be informed that, although the alternatives may cost more than the POPs they are replacing, they can still be affordable and are still a good investment when compared to the cost of replacing structural components or crop-loss. Governments may want to consider seeking temporary financial supports for POPs alternatives to encourage their adoption and familiarization of the termite protection providers or users with these alternatives.

An evaluation of the direct costs of a commercially available alternative can be readily conducted by determining the cost of the alternative in areas where it is currently in use and extrapolating those costs to the area of interest. Consideration must be given to relevant trade or import policies that might increase the cost. It is also very important to make certain that any materials imported can be properly used so that, in a case of an alternative pesticide, environmental and health problems can be avoided.

In many circumstances, changes to building design and practice, the use of physical barriers, or the combination of different termite management systems may provide cost effective alternatives.

VI.2 Efficacy of the POPs alternative in its intended area of use.

Determination of the efficacy of the alternative strategy may be an involved process. It should not be assumed that a particular management tool may be efficacious in a given area because it is efficacious in another area. Determination of efficacy for a specific application is best done using a controlled scientific experiment under the application conditions, i.e. in the environment (climate, soil), against the species, and on structures or crops representative of the area of intended use. Conduct of these experiments requires an investment of adequate personnel and funds. Demonstration of efficacy necessitates tests that cannot be accomplished in a short period of time and may have to run for several years. Preferably, efficacy testing of a number of alternatives should be established as an ongoing project, not necessarily on a country-by-country basis, but on a regional basis. The size of the region will be determined by the communality of pest problems and environmental conditions. A couple of funds have been established for the implementation of the Stockholm Convention and may be approached for support.

Prior to conducting region or country-specific efficacy assessments, existing efficacy data should be reviewed. Such data are available in a number of countries. A partial list, with links to data sources is given below. It should be noted that these data are generated under differing study conditions, using differing methods, and standards for acceptance. Most of the existing data are developed for efficacy against structure destroying termite species.

Sources of efficacy data on termite management materials and strategies can be found at:

- US - contact http://www.epa.gov/pesticides/
- Australia (National Registration Authority for Agricultural and Veterinary Chemicals, Standards Australia, Australian Building Codes Board)

The design and conduct of efficacy studies requires consideration of multiple factors, including:

- termite species of concern
- type of termite management system or material
- environmental conditions (climate incl. seasonal changes; soil type)
- time duration for test
- frequency of inspections and measures for the maintenance of termite pressure over the experimental period
- criteria for demonstration of efficacy.

Demonstration of efficacy depends on the establishment of an agreed upon end-point for the efficacy study. For example, in the United States, before soil-applied termiticides for management of subterranean termites (Reticulitermes, Heterotermes, Coptotermes) can be registered for use, it has to be demonstrated that they provide 100% protection of test blocks of wood in surrogate concrete slab test units for five years in four geographically separate test areas.

Another example, in Australia, is that termite resistant and physical barriers are required to keep termites out of structures for at least 3 years. For baiting systems, Australian Standard AS3660.3 (Assessment Criteria for Termite Management Systems) states:

"For systems that claim colony eradication, field assessments shall demonstrate the system's ability to eradicate infestation, define performance in terms of time to eradication and define the mode of action, where there is a known central nest. Eradication shall only be claimed if there is physical evidence of the irrecoverable collapse of the termite colony and where no central nest can be located. In addition, eradication shall only be claimed if there is a complete cessation of termite activity by the target colony at the sites of known infestation and at monitoring baits, for an appropriate period. An appropriate period shall not be less than 9 months for slow-acting toxicants such as insect growth regulators and not less than 3 months for conventional insecticides. Mature and vigorous colonies, representative of real world infestations, shall be used for all field assessments. At least half of the data shall be derived from tests against colonies infesting structures."

Governments or regional organizations considering adoption of a POPs alternative should establish an efficacy standard for each type of alternative – e.g. baiting systems, wood treatments, or biologicals prior to testing.

VI.3 Environmental acceptability of the POPs alternative

Determination of the environmental acceptability of some alternative strategies can be done by evaluating data developed during registration of commercially available pesticides. Tables 1 to 9 Annex 1 lists those materials for which this information should be available, either through the relevant government agency or through the product manufacturer.

Very important issues to be addressed when considering environmental acceptability of pesticides are:

- Persistence
- Biodegradability
- Non-target effects/species specificity

Information on these properties can be obtained for many of the alternatives from the countries where these materials and products have already been evaluated and registered for use. This information should be made available and could be utilized to also evaluate their environmental acceptability in the context of termite management.

VI.4 Availability of the alternative.

Any viable alternatives to POPs must be available in commercially significant quantities if it is to compete with currently available POPs. Assessment of availability can be made by surveying suppliers or manufacturers of alternative materials. In some cases concerns about intellectual property rights will have to be resolved prior to introduction of alternatives to new areas. Other issues may include the business environment and regulatory requirements in a given country.

VI.5 Safety of the alternative to applicators and consumers

When choosing an alternative it is necessary to consider the safety of the workers who will be applying the alternative or otherwise implementing the management measure, as well as the safety of the general public when an alternative is used in and around the agricultural crops or protected structures. As with environmental acceptability data, safety information can be obtained for many of the alternatives from the countries where these materials and products have already been evaluated and registered for use. In most cases the same contacts for the environmental data can be used for safety information.

VI.6 Resources for evaluation of the alternatives

The Stockholm Convention recognizes that developing countries and countries with economies in transition will require access to funding and technical assistance to meet their obligations under the Convention. Arrangements will be put in place to promote the transfer and adoption of technologies. An internal mechanism is defined and the Global Environment Facility (GEF) is the principal entity on an interim basis (see www.pops.int). Countries under the Convention are required to develop and implement national plans for implementation of its obligations and can get assistance through GEF to develop such plans. The Canada POPs Fund administered jointly by the The World Bank and UNEP also supports projects aimed at the phase-out of the use of POPs. Further information on there and other sources can be found at www.chem.unep.ch/pops.

ANNEX I
TABLES

TABLE 1. Availability of Alternative Termite Management Strategies to POPs for Subterranean, Arboreal and Drywood Termites.

Management Strategy	Termite Type by Nesting			Time of Application of Management Strategy	
	Subterranean	Arboreal Nesters and Subterranean Aerial	Drywood	Pre-/During Construction	Post-Construction
Building Design & Site Preparation	Yes	Yes	Yes	Yes (best)	Yes (repairs)
Termite Resistant Construction and use of Preservative-treated Timber Products	Yes	Yes	Yes	Yes (best)	Yes (repairs)
Physical Barriers	Yes	Yes, but limited	Yes	Yes (best)	Yes (repairs)
Termiticides to soil and topical and subsurface applications to wood.	Yes	Yes, but limited	Yes	Yes (best)	Yes
Baiting Systems	Yes	(insufficient data available for arboreal nesters)	No	No	Yes
Space Fumigation	No	Yes	Yes	No	Yes
Thermal Control	No	Yes	Yes	No	Yes
Biological Control	Experimental	Experimental	No	No	Yes

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality, and effectiveness and safety information may not be available.

TABLE 2. Termite Management POPs Alternative: Building Design and Site Preparation

Requirement	Activity	Considerations
Building Design (in reference to termite prevention)	Choice of building materials	Soil contact and whether physical or chemical barriers will be used beneath the building material.
	Ease of inspection of structural components	Concrete slab edge exposure; removable skirting boards
Building Site Preparation	Remove obvious nests of pest species of termite from site	Difficult to accomplish and can be expensive, but best for long-term prevention.
	Remove tree stumps and logs and prune vegetation in and around building site.	Difficult to accomplish and can be expensive, but best for long-term prevention.
	Remove all construction and building debris from the building site	Doable and should be done for all new construction sites.
	Consider water drainage at site.	Fill or grade around building. Adding gutters for appropriate drainage away from building.
	Landscape with termite resistant materials.	Limit mulches to thin layers around the outside perimeter of buildings.
Progressive Inspection of Building Work	Ensure compliance with local building codes and regular termite inspections.	Inspections by competent, independent personnel

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 3. Termite Management POPs Alternative: Termite Resistant Construction and use of Preservative-treated Timber Products

Types	Specifics/Mode of Action	Considerations
Masonry	Clay and concrete bricks, concrete blocks and stone, not a barrier to subterranean attack.	Termites may be able to penetrate mortar joints or use the hollow areas in the bricks and blocks
Concrete elements	Not a barrier to subterranean termite attack.	Produced with certain specifications that vary. Cracks commonly occur allowing termite entry.
Steel, aluminium and other metals	Exclusion for subterranean termites.	Limited availability
Naturally resistant timbers	Toxic/repellent for subterranean, arboreal and drywood termites.	Limited availability
Preservative-treated timbers		
Ammoniacal Copper Quat (ACQ)	Metabolic poison	Apply to subterranean, arboreal, and drywood termites.
Chrommated copper arsenate (CCA)	Metabolic poison	Apply to subterranean, arboreal, and drywood termites
Copper Naphthenate	Metabolic poison	Apply to subterranean, arboreal, and drywood termites
Zinc Napthenate	Metabolic poison	Apply to subterranean, arboreal, and drywood termites
Copper Azole	Metabolic poison	Little published data.
Creosote Oil	Metabolic poison	Being phased out
Disodium Octaborate tetrahydrate (DOT)	Metabolic poison	Apply to subterranean, arboreal, and drywood termites
Extract of Azidirachtin	Repellant, Metabolic poison	Published information limited.
Neem Oil	Repellant, Metabolic poison	Published information limited.
Silica Gel	Repellant, very toxic metabolic poison	Environmentally very persistent, being phased out.
Cresote	Repellant and very toxic metabolic poison	Being phased out.
Construction practices		
No wood-soil contact	Exclusion	Apply to subterranean and arboreal nesters.
Seal foundation cracks	Exclusion	Apply to subterranean and arboreal nesters.
Fill hollow-block construction	Exclusion	Apply to subterranean and arboreal nesters.
No exterior sliding in soil contact	Exclusion	Apply to subterranean and arboreal nesters.
Damaged wood removal	Exclusion	Apply to subterranean, arboreal, and drywood termites

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 4: Termite Management POPs Alternative: Physical Barriers

Active Ingredient	Mode of Action	Application/ Considerations
Concrete Slab	Exclusion	Has to be produced to certain specifications; joints and penetrations require additional protective measures. Wide range of materials and systems used, see below.
Graded Particles		
Sand	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
crushed rock, granites and basalts	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
Glass	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
Solid Sheet Material		
high grade stainless steel	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
marine grade aluminium	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
certain plastics	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.
Woven Stainless Steel Mesh		
high grade stainless steel	Exclusion	These barriers can be breached and bridged over by foraging mud tunnels.

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. All physical barriers in this table apply to subterranean termites. The above barriers do not apply to drywood termites. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 5. Termite Management POPs Alternative: Termiticides in Soil or Other Carriers

Active Ingredient	Mode of Action	Application/Considerations
Chemical Applied to Soil or Foam		
Repellant		
Bifenthrin	Repellant and toxic, sodium ion channel inhibitor	Applied as sprays or via reticulation systems (enclosed tubing). Termites can detect chemical and move from treated areas. Lethal effects are not passed among colony members.
Cyfluthrin	Repellant and toxic, sodium ion channel inhibitor	
Cypernethrin	Repellant and toxic, sodium ion channel inhibitor	
Fenitrothion	Toxicant, cholinesterase inhibitor	
Fenvalerate	Repellant and toxic, sodium ion channel inhibitor	
Phenthioate	Toxicant, cholinesterase inhibitor	
Permethrin	Repellant and toxic, sodium ion channel inhibitor	
Silafluofen	Repellant and toxic, sodium ion channel inhibitor	
Triazophos	Toxicant, cholinesterase inhibitor	
Tralomethrin	Repellant and toxic, sodium ion channel inhibitor	
Zeta-cypermethrin	Repellant and toxic, sodium ion channel inhibitor	
Nonrepellant		
Chlorpyrifos	Toxicant, cholinesterase inhibitor	Application as above. Termites unable to detect chemical. Lethal effects are delayed and may be passed among colony members.
Imidacloprid	Toxicant, non-repllent; nicotinamide inhibitor	
Fipronil	Toxicant, non-repellent; GABA inhibitor	
Chlorphenapyr	Toxicant	
Thiome	Toxicant	
Chemicals Applied as foams to soil or wood.	Many of the same active ingredients mentioned above.	Apply to subterranean, arboreal nesters, and drywood termites
Chemicals Applied as Synthetic Fibre Matting or Plastic Laminate Sheets		
Deltamethrin	Repellant and toxic, sodium ion channel inhibitor	Acts as more chemical than physical barrier. Apply to subterranean termites.

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Soil treatments can be breached and bridged over by subterranean termite foraging mud tunnels. For drywood termites, the toxixant must be applied to tunnels used by foragers to be effective; if missed, the termites will not die. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 6. Termite Management POPs Alternative: Bait technology

Active Ingredient	Mode of Action	Application/ Considerations
Diflubenzuron	Chitin synthesis inhibitor	In food matrix
Chlorflurazuron	Chitin synthesis inhibitor	In food matrix
Hexaflumuron	Chitin synthesis inhibitor	In food matrix
Triflumuron	Chitin synthesis inhibitor	Dust
Disodium octoborate tetrahydrate	Metabolic toxin	In food matrix/dust
Arsenic trioxide	Metabolic toxin	Dust
Hydramethylnon	Metabolic inhibitor	In food matrix
Sulfluramid	Metabolic Inhibitor	In food matrix
Biocontrol Agents		
Fungus: spores, mycelium.	Grows through cuticle and utilizes entire termite body	Also biocontrol system (see Table 9). Use as bait and soil treatment is experimental.
Nematodes: infective stages	Invade; carry bacterium which produces lethal toxins	Bait system is experimental

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. There are no commercially available baits for drywood termites. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 7. Termite Management POPs Alternative: Fumigants
(This strategy is employed to deal with drywood termites, aerial colonies of subterranean termites and cases where arboreal species nest inside structures.)

Active Ingredient	Mode of Action	Application/ Considerations
Carbon Dioxide	Asphyxiant	All of these gases are very toxic and require evacuation of structure prior to treatment.
Methyl bromide	Metabolic poison	
Phosphine	Metabolic poison	
Sulfuryl fluoride	Metabolic poison	

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 8. Termite Management POPs Alternative: Thermal Treatment.
(Apply mostly to drywood and arboreal nesting termites.)

Active Ingredient	Mode of Action	Application/ Considerations
Electricity	Electric shock is best guess.	All have limited effectiveness and safety data and also limited in use.
Heat	Denature proteins using high temperatures via propane heaters.	
Liquid Nitrogen	Disruption of cellular membranes using very low temperatures.	
Microwave	Denature proteins using high temperatures via microwaves.	

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 9. Termite Management POPs Alternative: Biocontrol
(Apply mostly to subterranean and arboreal nesting termites.)

Active Ingredient	Mode of Action	Application/ Considerations
Fungus: spores, mycelium.	Grows through cuticle and utilize entire termite body	Bait systems (see Table 6); soil treatments; experimental and limited commercial
Nematodes: infective stages	Invade; carry bacterium which produces lethal toxins	Bait systems; experimental
Ants	Predator	Opportunistic; not suitable for targeted applications

Determination of the termite pest (subterranean, arboreal or drywood) is necessary before proceeding on with the information in this table. Many of the management methods mentioned may not be commercially available for your country/locality and effectiveness and safety information also may not be available.

TABLE 10. Crops Attacked by Termites

Crop	Country
A. ANNUAL CROPS	
1. Cereals	
Maize	Argentina, Benin, Brazil, Democratic Republic of Congo, Ethiopia, India, Kenya, Malawi, Nigeria, Paraguay, South Africa, Saudi Arabian Peninsula, Swaziland, Tanzania, Uganda, Uruguay, Zambia, Zimbabwe, Yemen Ethiopia, India, Malawi
Sorghum	Argentina, Brazil, India, Paraguay, Uruguay
Rice	India
Barley	China, Ethiopia, India, Yemen
Millet	India, Yemen
Wheat	
2. Pulse crops	
Beans	India, Malawi
Cowpea	India, Malawi
Pigeon pea [= chich pea??]	India [Chick pea], Malawi
3. Oil crops	
Groundnut	Australia, Botswana, Brazil, Burkina Faso, China, Ethiopia, Gambia, Guyana, India, Malawi, Mali, Niger, Nigeria, Senegal, Sudan, Zambia, Zimbabwe
Sunflower	India, Yemen
Soybean	India, Brazil, Guyana
4. Sugarcane	Argentina, Australia, Bolivia, Brazil, Caribbean, Central Africa Republic, China, Colombia, Cuba, Dominican Republic, Guyana, India, Jamaica, Kenya, Mexico, Nicaragua, Nigeria, Pakistan, Panama, Paraguay, Philippines, Uruguay, Somalia, South Africa, Sudan, Venezuela
5. Root crops	
Sweet potatoes	India, Jamaica
Potatoes	Australia, India
Yam	Ghana, Nigeria
Cassava	Brazil, Guyana, West Africa, Malawi
6. Vegetables	
Tomato	Saudi Arabian Peninsula, Yemen
Okra	Saudi Arabian Peninsula, Yemen
Pepper	Saudi Arabian Peninsula, Yemen
Egg plant	Saudi Arabian Peninsula
Cabbage	India
B. PERENNIAL CROPS	
1. Fruit trees	
Guava	India, Saudi Arabian Peninsula
Tea	India, Malawi, Pakistan, Peru
Coffee	Argentina, Brazil, Bolivia, Kenya
Citrus	Afghanistan, Algeria, Australia, Egypt, India, Iran, Iraq, Israel
Cocoa	Ghana
Passion fruit	Colombia, Trinidad, Venezuela
Banana	Malawi
Mango	Australia, India, Saudi Arabian Peninsula
Papaya	Saudi Arabian Peninsula
Grapes	Australia, India

2. Palm trees	
Oil palml	Ghana, Nigeria, South Asia, Pacific Island
Date palm	Afghanistan, Algeria, Egypt, Iran, Iraq, Israel, Jordan, Libya, Morocco, Sudan, Tunisia
Coconut	India, Malaysia, Nigeria, some South Pacific Island
3. Field crop	
Pineapple	Argentina, Australia, Brazil, Kenya, Paraguay, Uruguay
Cotton	Central Africa Republic, India, Malawi, Sudan, Tanzania, Uganda, Yemen
4. Forestry plantations	
Rubber Trees	Southeast Asia
Pine plantations	Australia, Southeast Asia
Hardwood plantations	Mahogany in south Pacific islands, Eucalyptus South America, street trees France,

ANNEX II
PHOTOGRAPHS

Photo: 1 - Reticulitermes sp. attacking an urban tree in the city of Paris
Photo: Dr. Anne-Geneviève Bagneres

Photo: 2 - Soldiers of Coptotermes curvignathus, a termite species that kills trees in Southeast Asia
Photo: Dr. Laurence G. Kirton

Photo: 3 - Soil and carton layer on the trunk of a buttressed forest tree in Southeast Asia, typical symptoms of attack by Coptotermes curvignathus
Photo: Dr. Laurence G. Kirton

Photo: 4 - Pine tree killed by Coptotermes curvignathus
Photo: Dr. Laurence G. Kirton

Photo: 5 - Syntermes nanus, a harvester mandibulate nasute which is an important pest of sugar-cane, Eucalyptus and other crops in South America
Photo: Dr. Reginaldo Constantino

Photo: 6 - Damage to crops caused by subterranean termites
Photo: Mr.Jean Nguya Kalemba Maniania

Photo: 7 - Among cereal crops, maize is the most often damaged by termites
Photo: Mr.Jean Nguya Kalemba Maniania

Photo: 8 - Credible information is difficult to obtain with regard to termite damage to crops.
Photo: Mr.Jean Nguya Kalemba Maniania

Photo: 9 - Mahogany neotermes
Photo: Dr Michael Lenz

Photo: 10 - Mahogany neotermes cross section
Photo: Dr Michael Lenz

Photo: 11 - Coconut palm attacked by Neotermes rainbowi
Photo: Dr Michael Lenz

Photo: 12 - A tree(right side) killed by Mastotermes and fallen over
Photo: Dr Michael Lenz

Photo: 13 - Cross section of a coconut palm attacked by Neotermes rainbowi
Photo: Dr Michael Lenz

Photo: 14 - Native rain forest trees "piped" by Neoterms
Photo: Dr Michael Lenz

Photo: 15 - Coconut palm attacked
by Neotermes rainbowi
Photo: Dr Michael Lenz

Photo: 16 - Stolotermes Group
Dr. Barbara L. Thorne

Photo: 17 - Arboreal nest and
foraging pathways
Dr. Barbara L. Thorne

Photo: 18 - Nasute soldier
Dr. Barbara L. Thorne

Photo: 19 - Mastotermes:
A soldier and neotenic plus some workers
Dr. Barbara L. Thorne

Photo: 20 - Queen, King and Workers
Dr. Barbara L. Thorne

Photo: 21 - Soldiers
Dr. Barbara L. Thorne

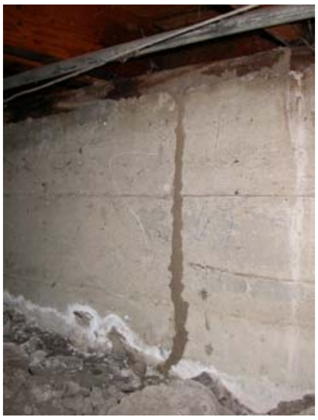

Photo: 22 - Subterranean termite foraging tube,
Reticulitermes, family Rhinotermitidae
Photo: Dr. Vernard R. Lewis

Photo: 23 - Subterranean termite swamers,
Reticulitermes, family Rhinotermitidae
Photo: Dr. Vernard R. Lewis

Photo: 24 - Subterranean termite swamers,
Reticulitermes, family Rhinotermitidae
Photo: Dr. Vernard R. Lewis

Photo: 25 - Drywood termite swamers,
Incisitermes, family Kalotermitidae
Photo: Dr. Vernard R. Lewis

Photo: 26 - Drywood termite damage,
Incisitermes, family Kalotermitidae
Photo: Dr. Vernard R. Lewis

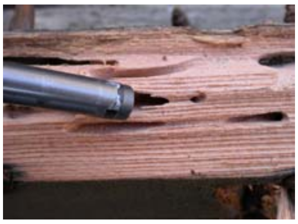

Photo: 27 - Drywood termite damage,
Incisitermes, family Kalotermitidae
Photo: Dr. Vernard R. Lewis

Photo: 28 - Drywood termite pellets,
Incisitermes, family Kalotermitidae
Photo: Dr. Vernard R. Lewis

ANNEX III
List of Contributors:

Dr Michael Lenz
Project Coordinator, Termite Research
CSIRO Entomology
GPO Box 1700, Canberra ACT 2601
Australia
Tel.: +61-(0)2-6246 4143
Fax: +61-(0)2-6246 4000
E-mail: Michael.Lenz@csiro.au

some agriculture, urban forestry, biology; final editor; photos

Dr. Abdoulaye Mando
Ecologie des sols, Ecologie de la Restauration
Gestion des Ressources Naturelles au INERA
01 B.P. 5385
Ouagadougou 01
Burkina Faso
Tel. : +226-36 31 08/09
Fax : + 226-36 31 10/34 02 71
E-mail : abdoulayem@hotmail.com

Prof. Reginaldo Constantino
Departamento de Zoologia
Instituto de Ciencias Biológicas
Universidade de Brasília
Campus Universitário - ICC Sul
70910-900 Brasília, DF
Brazil
Tel.: +5561-307-2265
Fax: +5561-274-1141
E-mail: constant@unb.br

agriculture and urban trees; photos

Mr. Renato Ripa S.
Centro Experimental de Entomologia La Cruz
Instituto de Investigaciones Agropecuarias.
Chorrillos 86, La Cruz, CHILE
Tel.: +5633-31 23 66
Fax: +5633-31 23 66
Email rripa@lacruz.inia.cl

Dr. Junhong Zhong
Guangdong Institute of Entomology
105 Xingang Road West
Guangdong, Guangzhou 510260
Peoples Republic of China

Tel.: + 86 20-8419 1989
Fax: + 86 20-8418 3704/8418 9165
E-mail: zhong@gdei.gis.sti.gd.cn

Prof. Souleymane Konate
Associate Professor, Director
Tropical Ecology Station of LAMTO
Center for Ecological Research
Université d'Abobo Adjamé
BP 28 N' douci, Cote D' Ivoire
Tel. : +225 30-62 90 95/ 0560 23 80
Fax : +225 30-62 92 20/21 25 73 76
E-mail : skonate@caramail.com

Prof. Samia Ibrahim M. Moein
Plant Protection Research Institute
Sabahia Research Station
608 El-Horria Road, Apt. 43
Zezenia, Alexandria
Egypt
Tel.: +583-6886
Fax: +583-6142
E-mail: smoein2001@yahoo.com

agriculture and urban control; photos

Dr. Abdurahman Abdulahi
Desert Locust Control Organization for Eastern Africa
P.O.Box 48
Dire Dawa,
Ethiopia
Tel. : + 251 5-111-115

Dr. Anne-Geneviève Bagneres
Institut de Recherch sur la Biologie
de l'Insecte - UMR CNRS 6035
Faculté des Sciences et Techniques
Université de Tours
Parc de Grandmont
37200 Tours
France
Tel.: +33 2-47367378
Fax: +33 2-47367356
E-mail: bagneres@univ-tours.fr

biology

Prof. Manfred Kaib
Department of Animal Physiology
University of Bayreuth
D-95440 Bayreuth,
Germany
Tel.: +49 921-552 482
Fax: +49 921-552 794
E-mail: Manfred.Kaib@uni-bayreuth.de

Dr. Kunio Tsunoda
Associate professor
Wood Research Institute
Kyoto University
Gokasho, Uji, Kyoto 611-0011
Japan
Tel: +81-774-38-3661
Fax: +81-774-38-3664
E-mail: tsunoda@termite.kuwri.kyoto-u.ac.jp

chemical control

Jean Nguya Kalemba Maniania
Insect Pathologist
International Centre of Insect Physiology and Ecology (ICIPE)
P.O. Box 30772 Nyayo Stadium
Nairobi
Kenya
Tel.: +254-2-802501/3/9
Fax: +254-2-803360/860110
E-mail: nmaniania@icipe.org

agriculture; photos

Dr. Laurence G. Kirton
Forest Research Institute Malaysia
Kepong, 52109 Kuala Lumpur
Malaysia
Tel. +60-03-62797109
Fax. +60-03-62797858
E-mail: laurence@frim.gov.my

urban forestry and some agriculture; photos

Ms. Agnéta Sunden-Bylehn
Scientific Affairs Officer
UNEP Chemicals
11-13 Chemin des Anémones
CH-1219 Châtelaine, Geneva
Switzerland
Tel.: +4122 917 8193
Fax: +4122 797 3460
E-mail: asunden@unep.ch

final editor

Dr. Barbara L. Thorne
Professor
Department of Entomology
4112 Plant Sciences Building
University of Maryland
College Park, Maryland 20742-4454
USA
Tel.: +301-405-7947
Fax: +301-314-9290
E-mail: bt24@umail.umd.edu

biology, general editor; photos

Mr. Stephen E. Dwinell
Assistant Director
Division of Agricultural Environment Services
Dept. of Agriculture and Consumer Services
3125 Conner Boulevard
Mailstop C-16
Tallahassee, Florida 32399 - 1650
USA
Tel.: +1850-488 7447
Fax: +1850-488 2164
E-mail: dwinels@doacs.state.fl.us

regulatory sections

Prof. Nan-Yao Su
Ft. Lauderdale Research & Education Center
University of Florida
3205 College Ave.
Ft. Lauderdale, Florida 33314
Tel: 954-475-8990
Fax: 954-475-4125
E-mail: nysu@ufl.edu

Dr. Vernard R. Lewis
Associate Extension Specialist
Cooperative Extension
Insect Biology
University of California
201 Wellman Hall
Berkeley, CA 94720-3112
USA
Tel.: +1510-643 0733
Fax: +1510-642 7428
E-mail: vlewis@uclink2.berkeley.edu

biology and management for urban termite sections; photos; final editor

Prof. Brian T. Forschler
Department of Entomology
University of Georgia
Athens, GA 30602
USA
Tel.: +1706-542-4282
Fax: +1706-542-2279
E-mail: bfor@arches.uga.edu

biology and control

Dr. Michael Haverty
Chemical Ecology of Forest Insects
Pacific Southwest Research Station
USDA Forest Service
P.O. Box 245
Berkeley, CA 94701
USA
Tel.: +1510-559-6471
Fax: +1510-559-6499
E-mail: mhaverty@fs.fed.us

biology; final editor