Resistance of polyamide and polyethylene cable sheathings to termites in Australia, Thailand, USA, Malaysia and Japan: a comparison of four field assessment methods

Michael Lenz[a,*], James W. Creffield[b], Theodore A. Evans[c], Brad Kard[d], Charunee Vongkaluang[e], Yupaporn Sornnuwat[e], Chow-Yang Lee[f], Tsuyoshi Yoshimura[g], Kunio Tsunoda[g]

[a] *CSIRO Ecosystem Sciences, GPO Box 1700, Canberra, ACT 2601, Australia*
[b] *Onwood Entomology Pty Ltd, 22 Davis Drive, Mt. Eliza, VIC 3930, Australia (formerly CSIRO Forestry and Forest Products, Australia)*
[c] *Department of Biological Sciences, National University of Singapore, 21 Lower Kent Ridge Road, Singapore 119077 (formerly CSIRO Ecosystem Sciences, Australia)*
[d] *Department of Entomology and Plant Pathology, 127 Noble Research Center, Oklahoma State University, Stillwater, Oklahoma 74078-3033 USA*
[e] *Royal Forest Department, Bangkok 10900, Thailand*
[f] *Urban Entomology Laboratory, Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia, 11800 Penang, Malaysia*
[g] *Research Institute of Sustainable Humanosphere, Kyoto University, Uji, Kyoto 611-0011, Japan*

[*] Corresponding author, Tel.: +61 2 6246 4143; fax: +61 2 6246 4000.
E-mail address: Michael.Lenz@csiro.au

A B S T R A C T

Cables sheathed with medium density polyethylene or polyamide were exposed together with highly palatable bait wood to termite faunas in south-eastern and northern Australia, Thailand and southern USA using three methods: below-ground exposure, samples buried horizontally at a depth of 15 to 30 cm; graveyard method, samples inserted vertically 25 cm deep into the ground; ground-contact method, samples placed horizontally on the ground surface, covered with soil and a plastic sheet. Samples were inspected for damage and bait wood replaced annually for six years. No polyamide sample was attacked. Damage to polyethylene was most severe at the two Australian sites (across all methods) and in the graveyard method (across all sites), although in Australia in the below-ground method samples experienced greatest damage. Exposing samples together with bait wood within containers for one year, and replenishing bait wood up to three times, i.e. an 'accelerated' test method' compared to the standard procedure of providing new bait wood only once a year, resulted in only very limited damage to cables at other Asian sites (Macrotermitinae and *Coptotermes* spp., Malaysia; *Coptotermes formosanus,* southern Japan), matching the earlier results for Thailand. But 73% of samples were destroyed by *C. acinaciformis* in northern Australia.

Keywords: Plastics, Cable sheathings, Termite resistance, Accelerated assessment, *Coptotermes,* Macrotermitinae*, Reticulitermes*

1. Introduction

Subterranean termites can damage a wide range of materials including many plastic products. The susceptibility of plastics to termite attack varies with their chemical structure, hardness and surface finish. Resistance of plastics to termites can be improved through physical and chemical manipulations, such as varying the amount of plasticisers, adding inert fillers or insecticides, or enclosing them in a physical barrier (Gay and Wetherly 1962, 1969; Beal et al. 1973; Beal and Bultman 1978; Unger 1978; Watson et al. 1984; Ruddell 1985, Boes et al. 1992). The economic implications of termite damage to plastics such as plastic-sheathed underground communication and power cables and pipes can often be considerable (Ruddell 1985). For example, relatively low-priced polyvinyl chloride (PVC) products may, even after a range of measures to improve their resistance to termites have been taken, still not provide adequate protection (Beal et al. 1973). In many applications more costly alternatives such as polyamides (Nylon), have to be used (Ruddell 1985). Further, a given material may prove resistant to one species of termite but not to another (Beal et al. 1973; Beal and Bultman 1978; Watson et al. 1984).

Many studies on the resistance of plastics to termites were conducted under both laboratory and field conditions during the 1960s through the 1980s (see references above), but few if any have been published since. Some commercial-in-confidence experiments were conducted in Australia until quite recently but were not published for proprietary reasons. Therefore only limited information is available on the termite susceptibility of plastics currently used in contact with soil. This is in part due to inadequate information on suitable assessment methods for both field and laboratory (Tsunoda et al. 2010).

This paper provides results from a six-year field study (the main trial) conducted in Australia, Thailand and the southern USA. The trial evaluated the performance of two reference materials, a polyamide and a polyethylene, with known resistance levels against termites in Australia based on previous CSIRO laboratory and field trials

(Watson et al. 1984, unpubl.; Lenz unpubl.). Three methods of exposing the materials to subterranean termites were compared.

Following on from results of this field study, the specific question of the resistance of these materials to termites at other sites in southern Asia was addressed in a one-year trial conducted in Malaysia, Japan and for comparison also in Australia, employing an ‘accelerated test’ method.

2. Materials and methods

In the main trial, resistance of the plastic cable sheathings against termite attack was evaluated in the field through three methods of exposure each year for six years. The cable samples were placed with bait wood and other samples, which were part of another trial (Lenz et al. in prep). The arrangement of all samples was randomised.

2.1. Experimental plastic materials

Cables sheathed individually with one of two common plastic formulations were exposed to foraging termites. Both cable types were supplied by the former Telecom Australia Research Laboratories, Melbourne, Australia. They have served as standard reference materials in CSIRO field trials in Australia for many years (Watson et al. 1984, unpubl.; Lenz unpubl.).

Plastic cable specifications were as follows:

Polyamide jacketed cable (“Grilamid”, Nylon 12); product of Emser Werke Ag., Ems, Switzerland; compound density 1020 kg/m^3; 2.0 ± 0.3% carbon black; several proprietary stabilisers; Shore D hardness of 63. This product is considered resistant to termite attack (Ruddell 1985).

Polyethylene sheathed cable (“Alkathene”, medium density polyethylene (MDPE)); product of ICI Australia Ltd.; with 5% butyl rubber; compound density 932 kg/m^3; 2.5 ± 0.5% carbon black; antioxidant – Lowinox WSP at 0.09% level; Shore D hardness of 47. This product is considered susceptible to termite attack.

Cylindrical cable samples were 30 cm long with a 1.4 cm outside diameter, including the 0.2 cm thick outer plastic sheathing. The ends of each sample were covered with a cylindrical 0.5 cm deep metal cap, leaving a 29 cm length of cable with a surface area of ≈131 cm^2 exposed to foraging termites. Thus, the trial evaluated the ability of termites to attack the smooth surface of the two types of cables without access to their end edges that possibly could be damaged if left exposed.

2.2. Bait wood

The plastic samples have no inherent food value for termites. Hence, in any field trial assessing their resistance to termite attack they must be placed side-by-side in direct contact with highly palatable and preferred wood (bait wood) to attract and sustain termite activity adjacent to the plastic samples.

Bait wood stakes (2.5 x 5.0 x 30.0 cm) of *P. radiata* sapwood from New Zealand were used in Thailand and the USA, and locally grown *P. radiata* stakes with the same dimensions and of similar quality in Australia. Two of the installation methods (see Sect. 2.5) required the use of additional wooden “feeder” strips (10 cm wide x 0.5 cm thick). These were sourced from locally available timber, *P. radiata* in Australia, rubberwood [*Hevea brasiliensis* (Willd. ex Adr. de Juss) Muell. et Arg.] in Thailand, and southern yellow pine (*Pinus* spp.) in the USA.

2.3. Methods of exposure in the main trial

The termite resistance of the plastics was evaluated using three published methods of exposing plastic or timber samples in contact with the soil to subterranean termites.

2.3.1. Below-ground (horizontal) exposure method

Key features of this method are that samples are installed horizontally on the base of a trench at a set but variable target species-specific distance below the soil surface, and are in contact with a significant supply of bait wood, thus producing conditions favourable for a build-up in termite numbers and sustained presence of termites at the experimental samples (Lenz et al. 1992).

The samples were oriented perpendicular to the long axis of the flat-bottomed trench, and parallel to each other at a depth of 15 cm (Thailand, USA), and 30 cm (Australia). The depth of the trenches depended on the preferred foraging range below the soil surface of the termite fauna at a given site and specifically the depth in the soil at which termites are still active even during dry conditions (*e.g.* Lenz et al. 1992; Sornnuwat et al. 2003).

The base of each trench was first lined with feeder strips. Experimental samples were then laid in random linear sequence on top of the feeder strips. Each sample was sandwiched between two *P. radiata* bait wood stakes, *i.e.* two bait wood stakes separated the experimental samples from each other. Cables, treated wood samples and bait wood were placed contiguously. This arrangement was covered with a layer of feeder strips. By moving along the feeder strips underneath and on top of the arrangement of samples and bait wood, termites could readily access the materials in the entire trench (Fig. 1).

Next, heavy-gage wire mesh with wide openings was laid over the top feeder strips. The mesh did not impede termite foraging but protected samples against mechanical damage from digging tools when the trenches were re-opened for inspection. Finally the trench was back-filled with soil up to the level of the surrounding soil surface.

The inspection procedure involved removing any soil from the trench down to the wire mesh, then the mesh and remains of the top feeder strip. Samples were taken out next. The plastic samples were cleaned with a soft brush under water and then evaluated visually for damage by termites. Next, any wood debris and loose soil in the trench were removed and the base was clad with new feeder strips. The cleaned specimens and new bait wood stakes were re-positioned in their assigned sequence on top of the feeder strips, and as in the initial installation, covered with another layer of feeder strips, protective mesh and soil.

2.3.2. Graveyard (in-ground vertical) exposure method

With this method, used commonly world-wide for the evaluation of wood products for in-ground use for many decades (see e.g. Snyder 1924; Gay et al. 1957; Butterworth et al. 1966; Becker 1972, Beesley 1985), and also for plastic materials, samples are inserted vertically for most of their length into the soil, and spaced evenly along parallel rows. Samples within a row and rows at their ends are connected to each other with wooden feeder strips that are buried into the ground with their flat broad sides vertical to a depth just below the soil surface and connecting with all samples (Fig. 2). This increases the likelihood of contact with and potential attack on samples as foraging termites can move more readily along the feeder strips (Beesley 1985).

Plastic samples were oriented lengthwise and attached with rubber bands to a bait wood stake on one of its broad faces, and along with the samples of treated timber, installed vertically into the soil to about 25 cm of their length in random sequence in four ≈3 m long rows with spacing of 25 cm between specimens and 1.0 m between rows. The opposite broad side of each bait wood stake was in direct contact with the feeder strip.

During each inspection, the plastic samples were carefully removed from the soil, detached from any wooden debris, cleaned with a soft brush under water, evaluated for termite damage and fastened to a new bait wood stake. Each plastic sample and bait wood arrangement was then re-inserted into its original position. Feeder strips were not disturbed or replaced.

2.3.3. Ground-contact (soil surface) method

In this method, samples are laid on a vegetation-free soil surface and then covered with loose soil followed by a sheet of plastic. The plastic sheet creates moister conditions that favour termite activity.

Our protocol was adapted from a South African assessment method that uses much smaller samples (‘pencil’ stakes) for rapid screening of termite resistance at sites with a high termite hazard (Conradie and Jansen 1983). A 2.5 x 3.5 m area of ground was first cleared of vegetation. Then plastic samples were attached to wooden bait stakes as described in Section 2.3.2 and, along with the samples of treated timber, were placed in random sequence with one of their broad faces flat on the soil surface, in four parallel rows of 10 (Fig. 3). The distance between samples as well as the rows was ≈20 cm. Samples were then covered with a ≈3 to 4 cm layer of soil and a plastic sheet. The sheet was ‘camouflaged’ with soil and tree branches to reduce disturbance from animals and human activities as well as to hold it in place.

With this method retrieval and re-installation of samples during an annual inspection was faster and simpler than with the other two methods. Each plastic sample was attached to a new bait wood stake before placing it back in its original position.

2.4. Replication rate in the main trial

Three replicate sets each of polyamide and polyethylene samples were installed for each of the three exposure methods on each of the main test sites (except Darwin, Australia which received six replicate sets – see 2.6.2), with five replicates of each material in each set. A total of 15 replicates per site for each of the three test methods were exposed to termites.

2.5. Inspection procedure

Samples were inspected annually for six years. Termite presence on or contact with samples and bait wood was recorded. When possible the species or genus of termite responsible for damage or plastering on samples was identified (see Sect. 2.6) either from live termites or their characteristic building activity (pattern of deposited faecal material, galleries and coating on and around samples.

Following the clean-up of removed samples, the entire surface area of a cable sample was inspected carefully with the naked eye and any damaged areas further with a 10x magnifying hand lens by either the first author alone or together with another person. In same instances, damage was highly variable and could occur in more than one position on a cable sample. Therefore, the damage was categorised into four ratings for simplicity and ease of analysis. The four damage ratings were: ‘undamaged (OK)’, ‘nibbled’ (N), ‘attacked’ (A) and ‘destroyed’ (D) (Table 1). Only the most severe damage rating found on each sample was used in the analyses.

2.6. *Main sites and their subterranean termite faunas*

Sites are listed by latitude from South to North

2.6.1. Australia, New South Wales, Griffith, Conapaira South State Forest

This open eucalypt forest (32^{o} 54'S, 146^{o} 14'E) near Griffith, New South Wales, is situated in the south eastern part of the continent. The climate is semi-arid with mean annual rainfall of 400 mm and a mean annual temperature of 16.3 ^{o}C. Tree-nesting *Coptotermes acinaciformis* (Froggatt) and *C. frenchi* (Hill) are the dominant species on this site. Other more common wood-feeding species include *Heterotermes brevicatena* Watson & Miller, *H. ferox* (Froggatt), *Schedorhinotermes reticulatus* (Froggatt), and *Nasutitermes exitiosus* (Hill). Species in the genera *Amitermes, Microcerotermes, Occasitermes* and *Ephelotermes* (Termitidae) are also encountered. The trial commenced in April 1996.

2.6.2. Australia, Northern Territory, Darwin, Humpty Doo Naval Station

The naval station (12°36'S, 131°16'E) lies close to Darwin, Northern Territory, within the wet and dry tropics of coastal northern Australia. Annual mean rainfall is 1666 mm and the mean temperature is 27.6 °C. On this site the mound-building form of *C. acinaciformis* is common in the eucalypt woodlands. In more open areas the Giant Northern Termite, *Mastotermes darwiniensis* Froggatt, dominates. In addition, other wood-feeding genera such as *Heterotermes, Schedorhinotermes* and *Microcerotermes* are represented with several species. In June 1996, three sets of samples were installed against each of the two economically most important target species, *i.e.* three sets adjacent to mounds of *C. acinaciformis*, and three sets within active foraging territories of *M. darwiniensis.*

2.6.3. Thailand, Phuket Province, Bang Kanoon Forest Plantation

The Bang Khanoon Forest Plantation (Department of Natural Resources and Environment) on Phuket Island (8°00'N, 98°22'E), is located in SW Thailand. The island lies in the humid tropics and experiences a mean annual rainfall of 2518 mm and a mean annual temperature of 27.4 °C. A partly cleared section of the plantation was used for the trial. The termite fauna is dominated by species of fungus-culturing termites (Macrotermitinae) with the key genera *Macrotermes, Microtermes* and *Odontotermes* represented by one or more species each, plus *Hypotermes makhamensis* Ahmad. Other main target species on site are *Coptotermes gestroi* (Wasmann), *Globitermes sulphureus* (Hagen) and *Nasutitermes* sp. (Sornnuwat et al. 2003; Vongkaluang et al. 2005). The trial commenced in November 1997.

2.6.4. USA, Mississippi, Gulfport, Harrison Experimental Forest

The Harrison Experimental Forest (30°37'N, 89°08'W) with mixed deciduous trees and *Pinus* spp. plantations lies within the Desoto National Forest 20 km north of the city of Gulfport and the coastline of the Gulf of Mexico in southern central Mississippi (Lenz et al. 2009). The region experiences a humid, subtropical climate with mean annual rainfall of 1830 mm and mean annual temperature of 16.7 °C. The termite fauna of the site is comprised of three species of *Reticulitermes* [*R. flavipes* (Kollar), *R. virginicus* (Banks) and *R. malletei* Clément et al.] with *R. flavipes* as the dominant species. The trial commenced in May 1996.

2.7. Analysis of results from main trial

Since termite damage would develop over a period, the number of cable samples for each damage rating behaved differently over time. All cables commenced the experiment with an 'undamaged' rating; the number of 'undamaged' cables could either remain the same or decrease over time. The number of 'nibbled' cable samples could remain the same or increase, but also decrease, as greater damage occurred and cables were re-rated to the more severe 'attacked'. The same situation applied for 'attacked' cables as they could be re-rated as 'destroyed'. The total number of 'destroyed' cable samples could only remain the same or increase over time. These complications necessitated that only 'undamaged' cable samples were analysed statistically.

The data (number of 'undamaged' cable samples) were analysed by repeated measures, two-way ANOVA, with method of exposure and location as the two factors, and year as the repeated measure. There was a significant three-way interaction, therefore data from each year were separately analysed with two-way ANOVA. The later years showed a significant interaction between the two factors (method of exposure and location); data from these years were analysed for each method of exposure with one way ANOVA using location as the factor. All posthoc-pairwise comparisons were Bonferroni-corrected (Sokal and Rohlf 1995).

The *Mastotermes* sites in Darwin had the species present only a few times; other species, mostly *C. acinaciformis* and *Schedorhinotermes* spp. dominated. Hence the data from the *Mastotermes* and *Coptotermes* sites were pooled.

2.8. Container method for 'accelerated' assessment in Malaysia, Japan and Australia

Overall low incidences of termite attack on the plastic cable samples by the diverse termite fauna in Thailand, including the economically most destructive SE Asian *Coptotermes gestroi* (Sornnuwat 1996; Lee 2002; Kirton and Azmi 2005), raised the question whether this was a phenomenon restricted to Thailand or whether in other regions in southern Asia species of *Coptotermes* and other genera would similarly leave the plastic samples largely unscathed. A limited trial was therefore established that exposed cable samples within containers to termite attack for just one year in Penang, Malaysia, against several species of *Coptotermes*, including *C. gestroi*, and Macrotermitidae (see Section 2.8.1.1) and in southern Japan to *C. formosanus* (see section 2.8.1.2). For comparison, a similar trial was also conducted in Darwin, Australia, with the mound-building form of *C. acinaciformis* (see Section 2.6.2) and compared with the below-ground exposure method (see Section 2.3.1). On all sites the containers were placed within areas of known high termite activity

The primary difference between this method and that of the main experiment was the frequency of cleaning samples and replacing bait wood. The usual termite response to the areas of non-edible materials they explore and are not attacking is to cover them with a mixture of their ‘plastering’, a combination of faeces, partly digested wood and mud. This would often happen to varying extent to the cable samples in all experiments and locations. Plastered sections of a cable sample are presumably not attacked at later times. Therefore during the year of the experiment, the cable samples were removed, cleaned of plaster, and returned with new bait wood several times. However samples were evaluated for termite damage only after the completion of the trial. This process exposes the cable samples to multiple incursions of termites (C-Y Lee unpubl.), and thus was considered to be an ‘accelerated’ test relative to the main experiment.

On the Malaysian site (a patch of rainforest), installation of plastic samples by any of the three exposure methods used in the main trial proved not practical due to the large number of shallow tree roots and dense vegetation. Hence, samples together with bait wood were placed within containers with access holes for termite entry. The containers were buried to a depth into the soil so that their lids were flush with the soil surface. Lids were covered with a plastic sheet and a ≈5 cm thick layer of soil.

A similar approach was then used at the site in southern Japan, and for comparison also in Darwin, Australia. Although details of container type and bait wood species differed between sites, the principal of placing samples together with a larger supply of bait wood within a container applied to all sites. Details for the three sites were as follows:

Penang, Malaysia: Five rectangular plastic boxes (40 x 30 x 15 cm; 18 L), with a removable lid and several entry holes through the base and the sides were installed. The boxes were filled with boards of rubber bait wood, and five replicate samples of both types of plastic per box were placed at random horizontally amongst the wood. The samples were removed, cleaned and re-installed together with fresh bait wood every three months.

Kagoshima, Japan: Three plastic buckets (28 cm deep, diameter at the top 28.5 cm, at base 22.5 cm, lid raised by 2 cm, ≈16 L), with entry holes at the sides and the base cut out (to accommodate fully the 30 cm long cable samples and the 35 cm long bait wood), were installed. Five replicate samples of both types of plastic per bucket were positioned at random vertically between boards of the bait wood *Pinus thunbergia* Parl. Each bucket was located next to a different colony of *C. formosanus.* Samples were removed, cleaned and re-installed with fresh bait wood after six months.

Darwin, Australia: Three steel drums (32 cm high x 30 cm diameter; 22 L, flat lid), with entry holes at the base and the sides, were installed. Five replicate samples of both types of plastic per drum were installed at random vertically between boards (27 cm long) of the bait wood *Eucalyptus regnans* F. Muell. For comparison, the same number of samples was installed in a trench using the below-ground exposure method as described in Section 2.3.1, but using stakes of *E. regnans* as the bait wood. One drum and one trench each were installed on opposite sides of three mounds of *C. acinaciformis.* Samples were removed, cleaned and re-installed together with fresh bait wood every three months.

2.8.1. Additional sites for the container trial and their termite faunas

2.8.1.1. Malaysia, Penang, Universiti Sains Malaysia, Minden Campus

The Minden Campus (5°21’N, 100°18’E) of the Universiti Sains Malaysia is located on Penang Island on the north-eastern coast of Peninsular Malaysia. The climate is equatorial. The mean annual rainfall of 2670 mm is generally evenly distributed throughout the year. The mean annual temperature reaches 27.3 °C. The trial was installed in 2001 on a 2.5 ha patch of rain forest with an abundant termite fauna with *Microcerotermes crassus* Snyder, *Coptotermes gestroi* and *C. curvignathus* Holmgren, and several species of fungus-culturing termites, including *Microtermes pakistanicus* Ahmed, *Macrotermes gilvus* (Hagen), *M. carbonarius* (Hagen) and species of *Odontotermes*, (Lee 2009).

2.8.1.2. Japan, Kagoshima Prefecture, Government Forest, Kyoto University experimental site

The "Living Sphere Simulation Field (LSF)" of the Research Institute for Sustainable Humanosphere (RISH) of Kyoto University is located in Fukiage-Cho (31°00'N, 130°23'E), Hioki-city in the Kagoshima Prefecture in the SW of Kyushu Island of southern Japan. The region has a warm temperate climate with a mean annual rainfall of 2265 mm and a mean annual temperature of 18 °C. *C. formosanus* is abundant in the forest of largely *Pinus thunbergia* Parl.. *Reticulitermes speratus* (Kolbe) is also present at high density. The one-year trial commenced in 2004.

3. Results for the main trial

With few exceptions, all plastic samples were contacted by termites within the first year of exposure. However, judging by the extent of plastering material on the cable surfaces, termite activity was often restricted to a narrow strip along the line of contact between the curve of the cylindrical cable and the flat surface of the bait wood stake in the graveyard and ground contact methods (see Sections 2.3.2 and 2.3.3). In general, plastering was far more extensive, often covering the entire cable surface of samples, in the below-ground exposure method where they were completely surrounded by wood from the combination of bait wood stakes and feeder strips (see Section 2.3.1).

All samples of polyamide remained 'undamaged' throughout the six-year trial irrespective of the exposure method and termite fauna. Hence, all results mentioned and discussed below refer only to the samples of medium-density polyethylene (Table 2).

At Australian sites *C. acinaciformis*, both the tree-nesting form in Griffith and the mound-builder in Darwin, caused most of the damage to the samples. Species of *Schedorhinotermes* and *Heterotermes* were also commonly encountered. In Phuket *C. gestroi* and *Macrotermes* spp. were the termites most frequently contacting samples. In Gulfport it was *R.. flavipes*.

3.1. Main trends

Results (Table 2) showed three broad trends: (**1**) damage ratings were most severe in Darwin, followed by Griffith and least severe in Gulfport and Phuket; (**2**) damage ratings were most severe in the graveyard method of exposure; and (**3**) the number of 'undamaged' cable samples decreased over time. However, within these broad trends there was important variation as shown by the significant interaction effect in the repeated measures two-way ANOVA (Year x Location x Method interaction $F_{30,155}$ = 1.863, p = 0.008; Table 3).

3.1.1. Location

The trend of declining damage from Darwin to Phuket is apparent from the number of 'undamaged' cables, which decreased from five replicates per set to around 1.5 in Darwin and 2.5 in Griffith during the first year, whereas this number remained close to 5 in Gulfport and Phuket. The number of 'undamaged' cables declined consistently over six years in all sites, to almost zero in Darwin and Griffith, down to 2.5 in Gulfport and 3 in Phuket (Fig. 4a).

The number of 'nibbled' cables decreased from ≈2 to 1.5 over six years in Darwin, but increased from 2.5 to 3 by the third year in Griffith, then declined to 2.5 by the sixth year, increased from 0.0 to 2.0 over the six years in Gulfport, and from 0.0 to 1.5 in Phuket (Fig. 4b).

The number of 'attacked' cables increased in all locations over the six years, and was always higher in Darwin (from 1.0 to 2.8), although the number in Griffith rose more rapidly (zero to 2). The number of 'attacked' cables reached one over the six years in Gulfport and Phuket (Fig. 4c).

The number of 'destroyed' cables increased in Darwin from zero to 0.5 by the sixth year. The only other location to record a destroyed cable (one) was Griffith, which occurred in the fifth year (Fig. 4d).

3.1.2. Exposure method

The number of 'undamaged' cables declined from five replicates per set to approximately 2.5 in graveyard sets, and to approximately 3.5 in surface and below-ground sets during the first year. By the sixth year, the number of 'undamaged' cables had declined to almost zero in graveyard sets, and around two in both surface and below-ground sets (Fig. 5a).

The number of 'nibbled' cables ranged from one to two over six years, without clear differences between methods (Fig. 5b). The number of 'attacked' cables increased in all methods over six years, but was always higher in graveyard sets (from around 0.5 to 3.5), compared with around 0.3 to 1 for both surface and below-ground sets (Fig. 5c). Few cable samples were 'destroyed', most of these in the below-ground sets (Fig. 5d).

3.2 Statistical analysis by year

There was a significant three-way interaction in the repeated measures two-way analysis of variance (p = 0.008; Table 3), interpreted as significant variation in how the number of 'undamaged' cables changed between the methods of exposure and locations over time. The simplest factor to interpret was time, as this effect was a simple decrease in the number of 'undamaged' cables over time. Therefore the data were separated into years, and data from each year were analysed separately using two-way ANOVA.

Year 1 – 1997

There was only one significant effect during the first year, *i.e.* location. There were significantly fewer 'undamaged' cables in Darwin and Griffith compared with Gulfport and Phuket; within a location pair numbers of 'undamaged' cables were not significantly different (Table 4).

Year 2 – 1998

There were significant effects for location and method of exposure during the second year. As seen in the first year, there were significantly fewer 'undamaged' cables in Darwin and Griffith compared to Gulfport and Phuket; within these two pairs of sites numbers were not significantly different from each other. There were significantly fewer 'undamaged' cables in sets of the graveyard method compared with sets from the surface and below-ground exposure method, with results from the latter two not significantly different from each other (Table 4).

Year 3 – 1999

The results for the third year of test were the same as for the second. There were significantly fewer 'undamaged' cables in Darwin and Griffith compared with Gulfport and Phuket; within these two pairs of sites numbers were not significantly different from each other. There were significantly fewer 'undamaged' cables in graveyard method sets compared with ones from the surface and below-ground exposure methods, with the latter two methods not significantly different (Table 4).

Year 4 – 2000

There was a significant interaction between location and method of exposure during the fourth year of the trial. Therefore, one-way ANOVAs were performed on each method of exposure. For the below-ground exposure method, the interaction for the Darwin and Griffith sites was the same, but significantly less compared with Gulfport, which in turn was significantly lower than for Phuket. For the graveyard method, Darwin, Griffith and Gulfport location and method interactions were the same and all were significantly lower than for Phuket. For surface exposure, the location and method interaction was significantly less for Darwin compared with Phuket. All other comparisons were not significantly different (Table 5).

Year 5 – 2001

Similar to year 4, there was a significant interaction between location and method of exposure during the fifth year of testing. Therefore, one-way ANOVAs were performed on each method of exposure. For below-ground exposure, Darwin and Griffith were the same, but were significantly less compared with Gulfport, which was the same as Phuket. For graveyard exposure, there were no significant differences. For surface exposure, Darwin was significantly lower than Phuket; all other comparisons were not significantly different (Table 6).

Year 6 – 2002

As for the years 4 and 5, there was a significant interaction between location and method of exposure during the sixth year. Therefore, one-way ANOVAs were performed on each method of exposure. For below-ground exposure, Darwin and Griffith were the same, but were significantly less compared with Gulfport, which was the same as Phuket. For graveyard exposure, there were no significant differences. For surface exposure, Darwin was significantly less compared with Phuket. All other comparisons were not significantly different. (Table 7)

4. Results for the container trial

All polyamide samples remained intact. Neither the mixed fauna of *Coptotermes* spp. and Macrotermitinae in Penang nor *C. formosanus* in Kagoshima caused much damage to the medium density polyethylene cables despite repeated offers of cleaned surfaces and replenishment of the surrounding bait wood destroyed by termites. Between the two sites only one 'nibble' and one 'attack' was observed among a total of 40 samples (Table 8).

In contrast, the plastic layer of 73% of samples (n = 15) exposed in the container method in Darwin, was fully penetrated, i.e. destroyed (Table 8). In many cases termites also removed a considerable amount of the plastic sheathing from the cables (Fig. 6). These differences were significant (χ^2 = 49.693, d.f. = 6, $p < 0.001$); with the difference due to Darwin as Penang and Kagoshima did not differ significantly (χ^2 = 0.853, d.f. = 3, p = 0.837). The black plastic material was incorporated into some of their constructions of galleries and seals along gaps between bait wood boards.

In the below-ground exposure method, run simultaneously in Darwin, 20% of samples were destroyed. Termites chewed through the plastic but did not remove large amounts of it. Interestingly, there was a significant difference between the damage levels in containers and the below-ground exposure methods (χ^2 = 14.905, d.f. = 3, p = 0.002), with greater damage observed in the containers.

5. Discussion.

The three factors tested in the main experiment all showed significant differences. Perhaps most obviously, time was important for the level of attack on polyethylene; the longer these cable samples were under test the more they were damaged. The next most predictable difference may have been location, with the expectation that cable samples in tropical locations, with more consistently hotter temperatures and greater termite diversity and abundance, would experience greater damage. There were differences between locations, however, the differences did not hold to this trend. Instead, the cable samples in the two Australian locations, Darwin (tropical) and Griffith (temperate), suffered the highest levels of damage. Perhaps the least clear predictions could be made for method of exposure. The graveyard exposure method showed the most consistently high level of damage, however, it was the below-ground method that had the highest number of destroyed cables – in Australian locations.

Significant interactions were found between the three factors. For the interaction between location and exposure methods, perhaps the local climatic conditions determined the best method of assessment. Soil moisture was most likely lowest in plots of the ground contact method and highest for the below-ground method. In the drier habitats in Australia, termites may well have experienced the driest conditions in the ground contact method, whereas in the wetter habitats of Phuket and Mississippi conditions may have been too wet in the below-ground method. For these reasons it may well be that the graveyard method proved overall to be best. With cable samples being inserted vertically in the soil, they traversed the full span of exposure depths and soil moisture ranges of all three exposure methods. Consequently, this allowed termites to shift position between depth levels and aggregate where conditions were most suitable for them at any given time whilst still having full access to the bait wood and hence contact with cable samples.

The polyamide samples proved again resistant to termite attack, thus confirming earlier work (Watson et al. 1984; Boes et al. 1992; Rosenblatt et al. 2005). However, this does not mean that this material is completely immune from termite attack. Mechanical damage to the smooth surface (scratches, creases, e.g. Ruddell 1985), which can happen *e.g.* during the laying of a cable, will provide access points for termite mandibles, and damage by termites can follow. It is for such a reason that some nylon-jacketed cable products are fitted with an outer sleeve of sacrificial soft PVC. It ensures that the polyamide surface of the cable remains intact during installation. Termites will readily penetrate the PVC sleeve, however, were never shown to extend attack to the nylon surface in both laboratory and field trials (M. Lenz, CSIRO, unpubl.).

One of the unexpected results was the low incidence of attack on plastic samples from the multi-species termite fauna, including several major pest species (Sornnuwat 1966; Sornnuwat et al. 2003) in Phuket, Thailand. This result gave the idea to the additional trial of investigating the potential for attack by of the termite faunas at other Asian sites with an accelerated test method (container method), including two of the pest species of termite considered to be among the most aggressive species towards wood-based and other materials in the built environment around the world, *C. formosanus* and *C. gestroi* (Tsunoda 2005; Chutibhapakorn and Vongkaluang 2006; Lee et al. 2007; Scheffrahn and Su 2008; Li et al. 2009; Yeap et al. 2009; Su and Scheffrahn 2010). Yet despite providing conditions for a repeated build-up of termite numbers at the cleaned samples within a short assessment period, and all the bait wood repeatedly being destroyed as an indicator of high termite activity around the samples, the results did not differ in Malaysia and southern Japan from those obtained earlier in Thailand. In contrast, the Australian *C. acinaciformis* caused significantly more damage in the container method than in the below-ground exposure method although in both bait wood was changed and a cleaned sample surface exposed repeatedly. Perhaps, the more confined space within the containers, resembling more closely the feeding situation within trees and allowing termites to better control the microclimate, may have focused termite foraging at the bait wood and the plastic samples.

Australian *Coptotermes* attacked and damaged the plastics cable samples far more than any other termite species intercepted in these trials. We have no explanation why that may be the case. Perhaps some chemical additives in the plastics, *e.g.* plasticisers, were attractive to the Australian species, but not or less so to their counter parts of Asian origin. Of course, Asian species of *Coptotermes* are able to attack plastic materials. There is enough anecdotal evidence showing that they can. Rosenblat et al. (2005) and Tsunoda et al. (2010) have demonstrated in well-designed laboratory experiments that *C. formosanus* will damage various plastic materials. However, under field conditions, using established and novel assessment methods, termites only slightly damaged a few of the polyethylene plastic samples despite completely destroying all surrounding bait wood.

One of the practical implications is that one cannot necessarily rely on proof of termite-resistance of a plastic material based on trials with species outside Australia for this continent. Any candidate materials will have to be re-evaluated against *C. acinaciformis* and *Mastotermes darwiniensis*, Australia's key pest species of termite (Gay and Calaby 1970).

Acknowledgements

We thank for excellent support in the field: Messrs. Silvano Runko, Patrick Gleeson, Aaron Barrett (Australia), Mss. Suchi Chutippakorn, Suwanna Umpeurk, Krisna Chaikruad and Mr Khwanchai Chareonkrung (Thailand), Messrs. J. Larry Etheridge, Eldon J. Mallette and Craig D. Bell (USA), Ms Boon-Hoi Yeoh and Messrs. Peng-Soon Ngee, Kong-Meng Lee, Edwin Teo, Kean-Teik Koay, all formerly of Universiti Sains Malaysia (Malaysia), and Mr Akio Adachi (Japan). Permission for access to field sites was provided by State Forests NSW (for Griffith), United Group Real Estate Services (NT) Pty. Ltd for Australian Department of Defence (Darwin), Chief of Bang Khanoon Forest Plantation (Phuket Province), USDA-Forest Service, Southern Institute of Forest Genetics Gulfport (Gulfport).The project was partly funded by Dr Alan Preston (Viance LLC, Charlotte, NC, USA).

References

Beal, R.H., Bultman, J.D., 1978. Resistance of polymeric cable coverings to subterranean termite attack after eight years of field testing in the tropics. International Biodeterioration Bulletin 14, 123-127.

Beal, R.H., Bultman, J.D., Southwell, C.R., 1973. Resistance of polymeric cable coverings to subterranean termite attack. International Biodeterioration Bulletin 9, 28-34.

Beesley, J., 1985. Field testing of wood preservatives in tropical countries. In: Findley, W.P.K., (Ed.), Preservation of timber in the tropics. Nijhoff, Dordrecht, pp. 205-231.

Becker, G., 1972. Suggested standard method for field tests with wooden stakes. PANS 18, Suppl., 137-142.

Boes, P., Latoszynski, P., Rachcoff, J., Styzinski, M., 1992. Development of co-extruded polyethylene/polyamide 12 insect resistant telecommunications cable. In: Proceedings 41st International Wire & Cable Symposium, Reno, pp. 285-292.

Butterworth, D., Mac Nulty, B. J., 1966. Testing materials for resistance to termite attack. Part 1. A quantitative field test. Materials and Organismens 1: 173-84

Chutibhapakorn, S., Vongkaluang, C., 2006. Termite diversity and some important wood destroying termites in Thailand. In: Proceedings of the 3rd Conference of the Pacific Rim Termite Research Group, Guangzhou, P.R. China, pp.20-25.

Conradie, W., Jansen, A., 1983. A new accelerated field test for termites. IRG/WP/1178. The International Research Group on Wood Preservation, Stockholm.

Eaton, R.A., Hale, M.D.C., 1993. Wood - decay, pests and protection. Chapman and Hall, London.

Gay, F.J., Calaby, J.H., 1970. Termites of the Australian region. In: Krishna, K., Weesner, F.M., (Eds.), Biology of termites, Vol. 2, Academic Press, New York, pp. 393-448.

Gay, F.J., Wetherly, A.H., 1962. Laboratory studies of termite resistance. IV. The termite resistance of plastics. Division of Entomology (CSIRO Melbourne, Australia) Technical Paper No. 5, 31 pp.

Gay, F.J., Wetherly, A.H., 1969. Laboratory studies of termite resistance. V. The termite resistance of plastics. Division of Entomology (CSIRO Melbourne, Australia) Technical Paper No. 10, 49 pp.

Gay, F. J, Greaves, T., Holdaway, F. G., Wetherly, A. H., 1957. The development and use of field testing techniques with termites in Australia. CSIRO Bull. No. 288: 1-3 1.

Kirton, L.G., Brown, V.K., 2005. The taxonomic status of pest species of *Coptotermes* in Southeast Asia: resolving the paradox in the pest status of the termites, *Coptotermes gestroi*, *C. havilandi* and *C. travians* (Isoptera: Rhinotermitdae). Sociobiology 42, 43-63.

Lee, C.-Y. 2002. Subterranean termite pests and their control in the urban environment in Malaysia. Sociobiology 40, 3-9.

Lee, C.-Y., 2009. Subterranean termites of Universiti Sains Malaysia. In: A. Ismail, M. Mansor, K. Yahya, M.H. Baharuddin, C. Y. Lee, (Eds.), The ecosystem, landscape and heritage of Universiti Sains Malaysia. Division of Research & Innovation, Universiti Sains Malaysia, Penang, Malaysia, pp. 33-42.

Lee, C.-Y, Vongkaluang, C., Lenz, M. 2007. Challenges to subterranean termite management in multi-genera faunas in South East Asia and Australia. Sociobiology 50, 213 – 221.

Lenz, M., Creffield, J.W., Barrett, R.A., 1992. An improved field method for assessing the resistance of woody and non-woody materials to attack by subterranean termites. Material und Organismen 27, 89-115.

Lenz, M., Kard, B., Evans T.A., Mauldin, J.K., Etheridge, L.A., Abbey, H.M., 2009. Differential use of identical food resources by *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) in two types of habitats. Environmental Entomology 38, 35-42.

Li, H.-F., Ye, W., Su, N.-Y., Kanzaki, N., 2009. Phylogeography of *Coptotermes gestroi* and *Coptotermes formosanus* in Taiwan. Annals of the Entomological Society of America 102, 684-693.

Rosenblat, G., Hwang, Won-Joung, Tsunoda, K., 2005. Laboratory evaluation of the resistance of polyamide. In: Proceedings of the 2nd Conference of the Pacific Rim Termite Research Group, Bangkok, pp. 61-64.

Ruddel, H.J., 1985. Development of an insect resistant telecommunication cable for the Australian environment. Telecommunication Journal of Australia 35, 59-73.

Scheffrahn, R.H., Su, N.-Y., 2008. Asian subterranean termite, *Coptotermes gestroi* (= *havilandi*) (Wasmann) (Insecta: Isoptera: Rhinotermitidae). EENY-128 University of Florida, Institute of Food and Agricultural Sciences, Gainesville, FL, USA (published 2000, reviewed 2008, online at http://edis.ifas.ufl.edu/pdffiles/IN/IN28500.pdf.

Snyder, T.E., 1924. Test methods of protecting woods against termites or white ants. USDA Department Bulletin No. 1231 (Washington), pp. 1-16.

Sokal, R.R., Rohlf, 1995. Biometry. 3rd ed. Freeman, New York.

Sornnuwat, Y., 1996. Studies on damage of constructions caused by subterranean termites and its control in Thailand. Wood Research: Bulletin of the Wood Research Institute Kyoto University 83, 59-139.

Sornnuwat, Y., Vongkaluang, C., Chutibhapakorn, S., 2003. Foraging patterns of termite species in the living complex of Bangkanoon forest plantation, Phuket Province, southern Thailand. The International Research Group on Wood Preservation, Document IRG/WP 03-10481, 10pp.

Sornnuwat, Y., Vongkaluang, C., Takematsu, Y., 2004. A systematic key to termites of Thailand. Kasetsart Journal (Nat. Sci.) 38, 349-368.

Su, N.-Y., Scheffrahn, R.H., 2010. Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Insecta: Isoptera: Rhinotermitidae). EENY-121 University of Florida, Institute of Food and Agricultural Sciences, Gainesville, FL, USA (published 2000, reviewed 2010, online at http://edis.ifas.ufl.edu/pdffiles/IN/IN27800.pdf.

Tsunoda, K., 2005. Improved management of termites to protect Japanese homes. In: Lee, C.-Y., Robinson, W.H., (Eds.), Proceedings of the Fifth International Conference on Urban Pests, Singapore, pp. 33-37.

Tsunoda, K., Rosenblat, G., Dohi, K., 2010. Laboratory evaluation of the resistance of plastics to the subterranean termite *Coptotermes formosanus* (Blattodea: Rhinotermitidae). International Biodeterioration & Biodegradation 64, 232-237.

Unger, W., 1978. Termitenschäden an Materialien und Möglichkeiten ihrer Verhütung. Holztechnologie 19, 195-199.

Vongkaluang, C., Sornnuwat, Y., Chareonkrung, K, Chitibhapakorn, S., 2005. Termite diversity in Thailand. Forest Economic and Forest Products Research Office, Royal Forest Department, Bangkok, 48pp.

Watson, J.A.L., Dai Zi-Rong, Barrett, R.A., 1984. Comparative studies on the resistance of materials to species of *Coptotermes* (Isoptera:Rhinotermitidae). I. The susceptibilities of various plastics to *C. acinaciformis* (Froggatt) from Australia and *C. formosanus* Shiraki from China. Bulletin of Entomological Research 74, 495-503.

Yeap, B-K., Othman, A.S., Lee, C.-Y., 2009. Molecular systematics of *Coptotermes* (Isoptera: Rhinotermitidae) from East Asia and Australia. Annals of the Entomological Society of America 102, 1077-1090.

Table 1
Rating system for damage to cable samples.

Damage rating	Abbreviation	Definition
Undamaged	OK	No damage
Nibbled	N	Surface roughened or pitted very shallowly (less than 0.5 mm), and only in a few, restricted regions ≤100mm^2 (≤1% surface area of sample)
Attack	A	Surface shallowly or deeply pitted, over extensive areas (>100 mm^2), but material not penetrated.
Destroyed	D	Material penetrated so that metal core is exposed, allowing corrosion and thus loss of data or electrical conductivity and capacity.

Table 2
Termite damage to polyethylene cables from four locations using three methods of exposure. Data are average (± standard error) number of cables for each damage rating.

Location[a]	Method[b]	Rating[c]	Years after installation 1	2	3	4	5	6
Griffith	below	OK	2.3 ± 0.7	1.7 ± 0.3	0.7 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
		N	2.7 ±0.7	3.3 ± 0.3	4.0 ± 0.6	3.7 ± 0.9	3.0 ± 0.6	1.7 ± 0.9
		A	0.0 ±0.0	0.0 ± 0.0	0.3 ± 0.3	1.3 ± 0.9	1.7 ± 0.3	3.0 ± 0.6
		D	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.3 ± 0.3
	grave	OK	2.0 ±1.2	1.7 ± 1.2	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
		N	3.0 ±1.2	2.3 ± 1.5	3.0 ± 0.6	2.0 ± 1.2	1.7 ± 1.2	1.7 ± 1.2
		A	0.0 ±0.0	1.0 ± 0.6	1.3 ± 0.3	3.0 ± 1.2	3.3 ± 1.2	3.3 ± 1.2
		D	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	contact	OK	3.3 ±0.9	2.0 ± 0.0	2.0 ± 0.0	1.5 ± 0.4	1.0 ± 0.0	0.5 ± 0.4
		N	1.7 ±0.9	3.0 ± 0.0	3.0 ± 0.0	3.5 ± 0.4	4.0 ± 0.0	4.0 ± 0.0
		A	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.4
		D	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Darwin	below	OK	2.7 ±0.7	1.8 ± 0.6	1.2 ± 0.6	0.5 ± 0.5	0.3 ± 0.3	0.3 ± 0.3
		N	1.2 ±0.3	1.3 ± 0.3	1.7 ± 0.7	1.8 ± 0.7	1.5 ± 0.5	1.0 ± 0.4
		A	0.8 ±0.7	1.3 ± 0.6	1.3 ± 0.5	1.7 ± 0.5	1.8 ± 0.5	2.2 ± 0.7
		D	0.3 ±0.3	0.5 ± 0.3	0.8 ± 0.5	1.0 ± 0.7	1.3 ± 0.8	1.5 ± 0.8
	grave	OK	0.5 ±0.3	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
		N	3.2 ±0.4	2.2 ± 0.7	1.5 ± 0.6	1.0 ± 0.4	0.8 ± 0.4	0.8 ± 0.4
		A	1.3 ±0.5	2.7 ± 0.6	3.3 ± 0.5	3.8 ± 0.4	4.0 ± 0.4	3.8 ± 0.3
		D	0.0 ±0.0	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.3 ± 0.2
	contact	OK	1.8 ±0.7	1.0 ± 0.4	0.3 ± 0.3	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
		N	2.3 ±0.3	2.7 ± 0.3	2.3 ± 0.6	2.2 ± 0.7	2.0 ± 0.6	2.0 ± 0.6
		A	0.8 ±0.4	1.3 ± 0.6	2.3 ± 0.7	2.3 ± 0.7	2.8 ± 0.5	2.8 ± 0.5
		D	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2
Phuket	below	OK	5.0 ±0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	4.3 ± 0.3	3.7 ± 0.3
		N	0.0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.3	1.0 ± 0.0
		A	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
		D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	grave	OK	5.0 ± 0.0	3.7 ± 0.9	3.5 ± 1.2	2.0 ± 0.8	1.5 ± 1.2	1.5 ± 1.2
		N	0.0 ± 0.0	1.0 ± 0.6	1.0 ± 0.8	1.0 ± 0.0	0.5 ± 0.4	0.0 ± 0.0
		A	0.0 ± 0.0	0.3 ± 0.3	0.5 ± 0.4	2.0 ± 0.8	3.0 ± 0.8	3.5 ± 1.2
		D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	contact	OK	5.0 ± 0.0	5.0 ± 0.0	4.3 ± 0.7	3.7 ± 1.3	3.7 ± 1.3	3.3 ± 1.2
		N	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.7	1.0 ± 1.0	0.7 ± 0.7	0.7 ± 0.3
		A	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.7 ± 0.7	1.0 ± 1.0
		D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Gulfport	below	OK	5.0 ± 0.0	5.0 ± 0.0	4.0 ± 0.6	4.0 ± 0.6	4.0 ± 0.6	3.3 ± 0.9
		N	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.6	1.0 ± 0.6	1.0 ± 0.6	1.7 ± 0.9
		A	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

	D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
grave	OK	4.3 ± 0.7	2.7 ± 1.5	1.0 ± 0.6	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
	N	0.0 ± 0.0	1.0 ± 0.6	1.7 ± 0.9	2.3 ± 1.2	2.3 ± 0.7	2.0 ± 1.0
	A	0.7 ± 0.7	1.3 ± 0.9	2.3 ± 1.3	2.3 ± 1.3	2.7 ± 0.7	3.0 ± 1.0
	D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
contact	OK	5.0 ± 0.0	4.7 ± 0.3	3.7 ± 0.9	2.7 ± 1.2	2.7 ± 1.2	2.3 ± 0.9
	N	0.0 ± 0.0	0.3 ± 0.3	1.0 ± 1.0	2.0 ± 1.2	2.0 ± 1.2	2.3 ± 0.9
	A	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.3
	D	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

[a] Location: Griffith, New South Wales, Australia (33°S), Darwin, Northern Territory, Australia (13°S), Phuket, Thailand (8°N) and Gulfport, Mississippi, USA (31°N).

[b] Method: ‘below’ = the below-ground exposure method with samples buried 15-30cm; ‘grave’ = the graveyard method with samples placed vertically 25cm deep in the ground with 5cm protruding out of the ground; ‘contact’ = on-ground contact method with samples placed on the surface of the ground and covered with soil and a plastic sheet.

[c] Rating: see Table 1 for details.

Table 3
Results of the two-way repeated ANOVA comparing number of undamaged cables (rated ‘OK’) from all locations, methods and years.

Source	SS	df	MS	F	*P*
Undamaged (OK)					
Location	459.179	3	153.060	37.542	<0.001
Method	91.150	2	45.575	11.178	<0.001
Location x Method interaction	48.332	6	8.055	1.976	0.100
Error	126.389	31	4.077		
Year	149.691	5	29.938	53.372	<0.001
Year x Location interaction	13.829	15	0.922	1.644	0.068
Year x Method interaction	4.499	10	0.450	0.802	0.627
Year x Location x Method interaction	31.355	30	1.045	1.863	0.008
Error	86.944	155	0.561		

Table 4

Results of the two-way ANOVAs comparing number of ‘undamaged’ cables from all locations and methods for years 1 – 3. For paired comparisons, DAR=Darwin, Australia, GRI=Griffith, Australia, GUL=Gulfport, USA, and PHU=Phuket, Thailand.

Source	SS	df	MS	F	*p*	Paired comparisons
Year 1 – 1997						
Location	97.422	3	32.474	22.482	<0.001	GRI=DAR<PHU=GUL
Method	6.048	2	3.024	2.093	0.139	–
Location x Method interactn	7.978	6	1.330	0.921	0.493	–
Error	47.667	33	1.444			
Year 2 – 1998						
Location	106.578	3	35.526	27.264	<0.001	GRI=DAR<PHU=GUL
Method	14.111	2	7.056	5.415	0.009	grave<below=contact
Location x Method interactn	5.622	6	0.937	0.719	0.637	–
Error	43.000	33	1.303			
Year 3 – 1999						
Location	92.712	3	30.904	29.668	<0.001	GRI=DAR<PHU=GUL
Method	15.415	2	7.708	7.399	0.002	grave<below=contact
Location x Method interactn	11.753	6	1.959	1.881	0.115	–
Error	33.333	32	1.042			

Table 5

Results of the two-way and one way ANOVAs comparing number of undamaged cables (rated ‘OK’) from all locations and methods for year 4. Abbreviations as for Table 4.

Source		SS	df	MS	F	*p*	Paired comparisons
Year 4 – 2000							
Location		72.496	3	24.165	21.202	<0.001	
Method		22.613	2	11.306	9.920	<0.001	
Location x Method interaction		18.624	6	3.104	2.723	0.030	*see one way ANOVAs*
Error		35.333	31	1.140			
below	Location	64.500	3	21.500	24.895	<0.001	GRI=DAR<PHU=GUL
	Error	9.500	11	0.864			
grave	Location	6.548	3	2.183	8.185	0.005	GRI=DAR=GUL<PHU
	Error	2.667	10	0.267			
contact	Location	25.690	3	8.563	3.696	0.050	DAR<PHU
	Error	23.167	10	2.317			

Table 6

Results of the two-way and one way ANOVAs comparing number of undamaged cables (rated ‘OK’) from all locations and methods for year 5. Abbreviations as for Table 4.

Source		SS	df	MS	F	*p*	Paired comparison
Year 5 – 2001							
Location		66.292	3	22.097	22.961	<0.001	
Method		22.613	2	11.306	11.748	<0.001	
Location x Method interaction		20.974	6	3.496	3.632	0.008	*see one way ANOVAs*
Error		29.833	31	0.962			
below	Location	56.400	3	18.800	34.467	<0.001	GRI=DAR<PHU=GUL
	Error	6.000	11	0.545			
grave	Location	3.857	3	1.286	2.857	0.091	GRI=DAR=GUL=PHU
	Error	4.500	10	0.450			
contact	Location	32.167	3	10.722	5.546	0.017	DAR<PHU
	Error	19.333	10	1.933			

Table 7
Results of the two-way and one way ANOVAs comparing number of undamaged cables (rated ‘OK’) from all locations and methods for year 6. Abbreviations as for Table 4.

Source		SS	df	MS	F	*p*	Paired comparison
Year 6 – 2002							
Location		52.617	3	17.539	20.137	<0.001	
Method		14.848	2	7.424	8.524	0.001	
Location x Method interaction		13.791	6	2.298	2.639	0.035	*see one way ANOVAs*
Error		27.000	31	0.871			
below	Location	39.067	3	13.022	16.528	<0.001	GRI=DAR<PHU=GUL
	Error	8.667	11	0.788			
grave	Location	3.857	3	1.286	2.857	0.091	GRI=DAR=GUL=PHU
	Error	4.500	10	0.450			
contact	Location	27.024	3	9.008	6.512	0.010	DAR<PHU
	Error	13.833	10	1.383			

Table 8
Damage ratings for medium density polyethylene cables after exposure to termites for 12 months inside a container or trench with repeated change of bait wood (see Section 2.8).

Location	Method	Total no. samples	Damage rating/ No. samples			
			OK	N	A	D
Penang, Malaysia	Container	25	24	1	---	---
Kagoshima, Japan	Container	15	14	---	1	----
Darwin, Australia	Container	15	---	1	3	11
Darwin, Australia	Trench	15	9	2	1	3

Figure captions

Fig. 1. Example of an installation with the below-ground exposure method, showing a trench with samples and bait wood arranged on top of a layer of feeder strips and covered with a layer of feeder strips (the latter not complete to expose the samples) and heavy gage wire mesh. Finally the trench is backfilled with soil.

Fig. 2. Example of an installation of a graveyard trial, showing samples in final position (front) and others being connected with feeder strips.

Fig. 3. Example of an installation with the ground-contact method, showing samples arranged on a vegetation free soil surface. Samples are then covered with soil and a sheet of plastic.

Fig. 4. Average number of medium density polyethylene cables (n = 45; for Darwin n = 90) at each damage rating for each of the four experimental sites (values combined for all three exposure methods).
N.B. OK = ‘undamaged’; N = ‘nibbles’; A = ‘attack’; D = ‘destroyed’ (see Table 1 for more detail).

Fig. 5. Average number of medium density polyethylene cables (n = 60; for Darwin n = 120) at each damage rating for each of the three exposure methods (values combined for the four experimental sites).
N.B. OK = ‘undamaged’; N = ‘nibbles’; A = ‘attack’; D = ‘destroyed’ (see Table 1 for more detail).

Fig. 6. Examples of cable samples ‘destroyed’, i.e. penetrated, by *Coptotermes acinaciformis* at the Darwin site: sample from the trial with the accelerated container method. Note that the sample has not only been penetrated but large amounts of the polyethylene have been removed.