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International Field Trials of Pyrethroid-Treated Wood Exposed to *Coptotermes acinaciformis* in Australia and *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in China and the United States

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ABSTRACT *Coptotermes* Wasmann is one of the most important genera of wood-destroying insect pests, both in its native and introduced countries. Pyrethroids are among the most widely used insecticides in wood preservation around the world. Consequently, they have often been evaluated against different species of *Coptotermes*. However, because various test methods have been used between countries, comparing results is problematic. These field trials, using a single aboveground method of exposure, assessed a range of retentions of two pyrethroids (bifenthrin and permethrin) in *Pinus radiata* D. Don sapwood against two species of *Coptotermes* in three countries to provide directly comparable results. *Coptotermes acinaciformis* (Froggatt) in Australia consumed the most nontreated wood, followed by *Coptotermes formosanus* Shiraki in China, then *C. formosanus* in the United States, although these data were not significantly different. Both termite species demonstrated a dose–response to wood treated with the two pyrethroids; less wood was consumed as retention increased. Overall, *C. acinaciformis* consumed relatively little of the treated wood. In comparison, *C. formosanus* consumed 20–90% of the wood treated at the lowest retentions of the pyrethroids evaluated. Results indicated that *C. acinaciformis* was more sensitive to pyrethroid toxicity/repellency compared with *C. formosanus*. Factors that may have influenced the results are discussed. However, using a single aboveground method of exposure across three countries, that suited both species of *Coptotermes*, made it possible to determine unambiguously the actual differences between the species in their tolerances to the two pyrethroid insecticides.

KEY WORDS bifenthrin, *Coptotermes acinaciformis*, *Coptotermes formosanus*, permethrin, pyrethroid

Coptotermes is a pan-tropical to warm-temperate genus of wood-eating termites. Over 40 species are described, with four native to Africa, 21 to Asia, 16 to Australia and nearby Melanesian Islands, and 3 to Central and South America (Snyder 1949), although the taxonomy is under revision (Kirton and Brown 2005). Several species have been spread, presumably by international trade, to new habitats, in particular, *Coptotermes acinaciformis* (Froggatt) to New Zealand, Fiji, and other Pacific islands; *Coptotermes formosanus* Shiraki to Japan, Hawaii, other Pacific islands, and the southern continental United States; and *Coptotermes gestroi* (Wasmann) to Taiwan, Hawaii, several Pacific islands, Brazil, and the Caribbean Islands (Howick 1999, Jenkins et al. 2007, Evans 2010, Evans et al. 2013).

Species of *Coptotermes* are among the most important pests of wood and wood products. They commonly infest live trees, consuming both sapwood and heartwood (Hill 1942, Gay and Calaby 1970, Cowie et al. 1989, Watson and Gay 1991, Creffield 1996). There is considerable variation in the natural termite resistance between the sapwood and heartwood of timbers (Ruyooka and Groves 1980, Eaton and Hale 1993, Kennedy et al. 1996, Peters and Fitzgerald 2004). In addition, to prevent or minimize damage to many susceptible timbers by termites, a wide range of wood preservative formulations is available. Currently, py-

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rethroids are among the most widely used insecticides in wood preservation, used either alone or in combination with other biocides (Evans 2003, Schultz et al. 2007). Pyrethroids were initially developed for wood preservation >30-yr ago, in the 1970s and 1980s (Berry 1977, Shires et al. 1996, Creffield and Watson 2002). Efficacy evaluations of pyrethroids are typically conducted on a country-by-country basis. However, there is a question that is often asked by scientists, government regulators, and the wood preservation industry: is it possible to compare performance data against one species of termite from one location/country with those from another species in a different location/country?

The only previous attempts to compare the response of different *Coptotermes* species to pyrethroids were laboratory bioassays in which *C. acinaciformis* in Australia and *C. formosanus* in China were exposed to duplicate sets of insecticide-treated 'wood specimens' (specimens; J.W.C. and J.-H.Z., unpublished data.). However, the results were difficult to interpret because of differences in testing protocols between laboratories, such as termite group size, holding matrix, bioassay duration, and maintenance conditions (e.g., temperature, light, and humidity). Accordingly, we decided to adopt an established field test method for this comparative study (Scown and Creffield 2009) that was considered suitable for both *C. acinaciformis* and *C. formosanus.* The identical protocol was followed at all field locations. Respective consumption rates of softwood specimens treated to several retentions with each of two pyrethroids were used to compare responses of *C. acinaciformis* and *C. formosanus.*

Materials and Methods

Treated Specimens. Rectangular sapwood specimens (25 × 25 × 100 mm) were cut from matched sections of fast-grown *P. radiata* D. Don from Tasmania, Australia (mean air-dry density ≈490 kg/m^3; mean oven-dried density ≈450 kg/m^3). Specimens were then randomly allocated into groups before treatment. Treatments were nontreated controls, solvent (white spirit) controls, bifenthrin (Biflex SFR, FMC Corp., Ewing, NJ), and permethrin (LCWR Trussguard, Osmose Australia Pty Ltd., Mt. Gambier, Australia). Both Biflex SFR and LCWR Trussguard formulations were diluted using white spirit (a common, kerosene-derived clear organic solvent). Sapwood specimens were treated at the Clayton (Victoria) laboratories of Commonwealth Scientific and Industrial Research Organization in Australia. Specimens were impregnated using a full-cell Bethell treatment process (University of Minnesota 1998, Hiziroglu 2004). The treatment schedule used an initial vacuum of −95 kPa for 45 min, then introduction of the treatment solution followed by an air pressure of 650 kPa for 45 min. After treatment, excess solution was wiped from the surfaces of the specimens and then the latter were weighed to determine pyrethroid active ingredient (AI) retentions (nominal target and actual retentions, Table 1).

Table 1. Mean (range) of actual retentions of bifenthrin and permethrin AI in specimens (N = 22)

Preservative	Nominal retention, g AI/m^3	Actual retention, g AI/m^3	Actual retention, % wt:wt ($\times 10^{-3}$), OD[a]
Bifenthrin	0.5	0.49 (0.35–0.55)	0.11 (0.08–0.14)
	1.0	1.01 (0.91–1.09)	0.23 (0.20–0.26)
	2.0	1.99 (1.82–2.19)	0.45 (0.36–0.54)
	5.0	5.03 (4.46–5.60)	1.26 (0.94–2.40)
	10.0	9.99 (9.12–10.77)	2.25 (1.88–2.48)
	20.0	20.17 (18.44–21.59)	4.66 (4.04–5.17)
Permethrin	2.5	2.48 (2.29–2.72)	0.57 (0.50–0.75)
	5.0	4.79 (4.53–5.48)	1.08 (0.96–1.35)
	10.0	10.30 (9.39–10.94)	2.46 (1.96–2.79)
	20.0	19.86 (18.33–21.78)	4.69 (3.94–5.41)
	45.0	46.05 (44.10–48.34)	10.75 (9.54–11.80)
	90.0	88.34 (80.31–94.79)	19.57 (17.30–22.10)

[a] OD, oven dried.

Specimens were subsequently air-dried for 4 wk, after which time they were artificially weathered to satisfy aboveground and protected exposure conditions (Australian Hazard class 2; H2) by vacuum oven drying for 5 d at 40°C and 0.04 mBar (as specified for H2 in the Australasian Wood Preservation Committee Protocols for Assessment of Wood Preservatives; AWPC 2007). H2 exposure conditions are equivalent to American use categories UC1 and UC2 (AWPA 2011a). The artificial aging procedure also removed residual solvents and volatiles from the specimens. After removal from the vacuum ovens, specimens were cooled in desiccators before being weighed to obtain initial weights. Specimens of different treatments were always separated from each other to minimize the possibility of cross-contamination.

Field Test Method. The established Commonwealth Scientific and Industrial Research Organization aboveground field method for exposing treated wood specimens to termites in an H2 situation was used (Scown and Creffield 2009). The target species of *Coptotermes* was aggregated before installation of the field trials to ensure rapid discovery of the replicate sets of specimens confined within exposure containers. The aggregation sites were prepared by burying two to four layers of wooden slats of a palatable Australian timber (*Eucalyptus regnans* F. Muell; 15 × 75 × 1,000-mm long) adjacent to active foraging sites so that the upper surface of the top layer was ≈50-mm below the soil surface. The buried wooden slats were then covered with plastic sheeting (750 × 750 mm) and soil. Infestation of the aggregation wood typically occurred within 4 wk. Once the slats became infested, the previously backfilled soil and plastic sheeting were removed to allow easy placement of the exposure containers on top of the slats.

Exposure Containers. The rectangular exposure containers had stainless steel sides (300 × 300 × 450-mm high, 20-liter volume) and a stainless steel mesh floor (25 × 25 mm square apertures) located 80-mm above the base of the container (to allow termite ingress). The 80-mm cavity below the mesh floor allowed for additional palatable wood (*P. radiata*

Fig. 1. Rectangular stainless steel exposure container (300 × 300 × 450-mm high, 20-liter volume) containing pyrethroid-, solvent-, and nontreated specimens with *P. radiata* sapwood strips and blocks (Fig. 2) in a *C. formosanus*-infested site, Guangzhou, China.

sapwood; rectangular, 35 × 95 × 300 mm) to be placed in contact with the top of the buried aggregation wood, which sustained the presence of termites throughout the duration of the field trial. Vented stainless steel lids sealed the containers (Fig. 1). Each container enclosed one replicate set of specimens (i.e., one from each treatment, for a total of 14 specimens per container). Specimens were arranged in three parallel horizontal tiers consisting of five, five, and four specimens from bottom to top that were separated by wooden strips (10 × 45 × 215 mm) of *P. radiata* sapwood between tiers, with solid wood blocks (15 × 25 × 100 mm) also of *P. radiata* sapwood separating each specimen horizontally on each tier (Fig. 2). This arrangement of wooden strips and blocks minimized potential neighbor cross-contamination effects. Wooden sheets of *P. radiata* sapwood (2.5-mm thick) were inserted completely around and in contact with the specimens inside each container, thereby encasing the entire arrangement of specimens.

Field Sites. The trials were installed at four locations each for *C. acinaciformis* and *C. formosanus.* All *C. acinaciformis* sites were in Australia. Three sites were in tropical Australia near Darwin (12° 14′ S, 131° 04′ E) in the Northern Territory, where this termite builds mounds (sites 1, 2, and 3). The fourth site was near Griffith (32° 54′ S, 146° 14′ E) in New South Wales, where this termite either nests in tree trunks or underground. Three of the *C. formosanus* sites were in the United States, in Baton Rouge (30° 27′ N, 91° 08′ W) and New Orleans (29° 57′ N, 90° 03′ W), both in Louisiana, and within the grounds of the Stennis Space Center near Poplarville (30° 50′ N, 89° 32′ W) in Mississippi. The fourth site was near Guangzhou in Guangdong Province (23° 05′ N, 113° 17′ E) in southern China. At all sites, three exposure containers were installed. One container was destroyed by Hurricane Katrina (August 2005) in Baton Rouge, and one container failed to effectively establish in China (i.e., 12 and 10 replications of specimens exposed to *C. acinaciformis* and *C. formosanus*, respectively). For each location, the exposure containers were placed >100 m apart to target different termite colonies, as this is greater than maximum known foraging distances of ≈80 m (Greaves 1962, King and Spink 1969, Evans and Gleeson 2001, Evans 2002). Field trials commenced when the exposure containers were placed on top of the aggregation wood.

Assessment. The field trials were designed to allow termites ad libitum consumption of food, therefore they continued until the termites vacated the exposure containers, which usually occurred after all palatable wood had been more or less completely consumed. Termites vacated containers after approximate durations of 3–4 mo (Darwin, China, and the United States sites) and 6 mo (Griffith site). At the conclusion of the trials, specimens were removed from the containers and returned to the laboratory for examination. Specimens were then cleaned, vacuum oven dried for 5 d at 40°C and 0.04 mBar and cooled in desiccators before obtaining final weights.

Statistical Analysis. Percentage weight loss data (wood consumption) were analyzed initially in a three-factor analysis of covariance (ANCOVA). The three factors used were species, location nested in species, and treatment (nontreated control, solvent control, bifenthrin, and permethrin), with retention (dose) and initial specimen weight (oven dry) as the

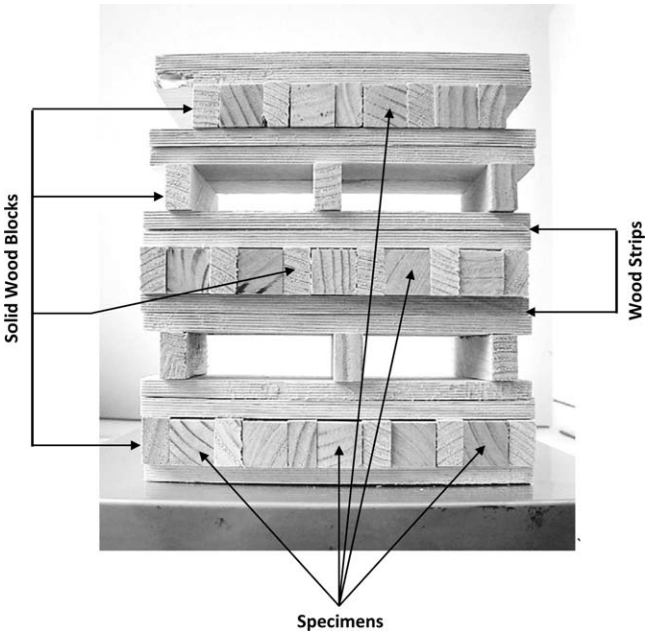

Fig. 2. Arrangement of pyrethroid-, solvent-, and nontreated specimens (25 × 25 × 100 mm) in three parallel horizontal tiers, separated by two double-layer wood strips (each strip 10 × 45 × 215 mm) between tiers, with solid wood blocks (15 × 25 × 100 mm) of *P. radiata* sapwood adjacent to specimens within each exposure container.

covariates. There was a significant interaction between species and treatment, therefore treatments were analyzed separately. The two controls were analyzed in a three-factor ANCOVA, and the insecticides were analyzed with ANCOVAs, with planned post hoc Bonferroni corrected pair-wise comparisons (Sokal and Rohlf 1995). Analyses were performed using Systat 9 (SPSS 1998).

Results

A summary of mean wood consumption (grams) for all treatments (including both nontreated and solvent controls) at the conclusion of the field trials is given in Table 2. When averaged over species and locations, termites consumed more control wood, 24.47 ± 0.03 g of nontreated and 26.45 ± 0.55 g of solvent-only, compared with pyrethroid-treated wood, 4.02 ± 0.66 g of bifenthrin-treated and 3.11 ± 0.67 g of permethrin-treated, as was expected. For nontreated control wood, *C. acinaciformis* consumed more than *C. formosanus*, 25.73 ± 1.19 g and 22.96 ± 0.93 g, respectively (although not significantly different). For solvent control wood, *C. acinaciformis* consumed a similar amount compared with *C. formosanus*, 26.90 ± 0.81 g and 25.90 ± 0.72 g, respectively, as the latter had increased its consumption. For bifenthrin-treated wood, *C. acinaciformis* consumed almost no wood, 0.48 ± 0.06 g, whereas *C. formosanus* consumed approximately one-third of the available wood, 8.26 ± 1.26 g. A similar, if less extreme, trend was observed for permethrin, with *C. acinaciformis* and *C. formosanus* consuming 1.45 ± 0.49 g and 5.09 ± 1.03 g, respectively.

ANCOVA on percentage of wood consumed found that two factors (treatment $F_{3,292} = 181.371$, $P < 0.001$; species $F_{1,292} = 16.689$, $P < 0.001$) and both covariates (dose $F_{1,292} = 38.412$, $P < 0.001$; initial mass $F_{1,292} = 7.850$, $P = 0.005$) were significant, and that location was not significant ($F_{6,292} = 1.319$; $P = 0.248$). The analysis explained approximately 74% of the variation observed ($r^2 = 0.737$). The relative size of the F ratios indicates that treatment was more important than dose, which was more important than species, which was more important than initial mass. The difference in treatments and dose were expected, as pyrethroids are widely known insecticidal actives and their dose–responses are well-documented (Berry 1977, Shires et

Table 2. Mean ± SEM, wt of specimens consumed by both *Coptotermes* species in field trials (*N* = 12 for *C. acinaciformis*, 10 for *C. formosanus*)

Treatment	Retention, g AI/m^3	Weight loss, g	
		C. acinaciformis	*C. formosanus*
Nontreated control	0.0	25.7 ± 1.2	23.0 ± 0.9
Solvent control	0.0	26.9 ± 0.8	25.9 ± 0.7
Bifenthrin	0.5	1.2 ± 0.2	23.0 ± 1.7
	1.0	0.5 ± 0.1	16.5 ± 1.9
	2.0	0.4 ± 0.1	8.3 ± 2.2
	5.0	0.3 ± 0.1	1.1 ± 0.4
	10.0	0.2 ± 0.1	0.4 ± 0.0
	20.0	0.2 ± 0.1	0.4 ± 0.0
Permethrin	2.5	6.6 ± 2.5	17.8 ± 2.0
	5.0	0.6 ± 0.2	9.8 ± 2.8
	10.0	0.5 ± 0.1	1.8 ± 0.8
	20.0	0.4 ± 0.1	0.4 ± 0.1
	45.0	0.3 ± 0.1	0.4 ± 0.0
	90.0	0.3 ± 0.1	0.4 ± 0.0

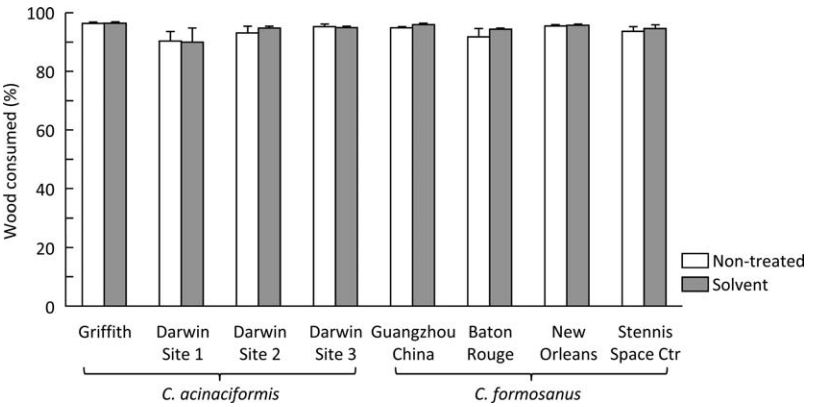

Fig. 3. Mean percentage wood consumption of nontreated and solvent-treated control specimens after exposure to *C. acinaciformis* and *C. formosanus* at field test sites in Australia, China, and the United States.

al. 1996, Creffield and Watson 2002). In addition, the effect of initial weight was also expected, as termites are known to increase consumption when more food is available (Lenz 1994). However, there was a significant interaction between species and treatment ($F_{3,293} = 6.064$; $P = 0.001$), necessitating separate analysis.

ANCOVA on the percentage of control wood consumed (both nontreated and solvent-treated controls) found no significant differences for factors, although location was nearly significant (treatment $F_{1,33} = 0.605$, $P = 0.442$; species $F_{1,33} = 0.235$, $P = 0.631$; location $F_{6,33} = 2.273$, $P = 0.060$). The analyses also showed no significant differences for the covariate (initial mass $F_{1,33} = 0.102$, $P = 0.752$), or the interaction between species and treatment ($F_{3,33} = 0.335$, $P = 0.567$; Figs. 3 and 4). One location had slightly lower consumption for each species (Darwin site 1 for *C. acinaciformis* and Baton Rouge for *C. formosanus*). The r^2 was low at 0.382.

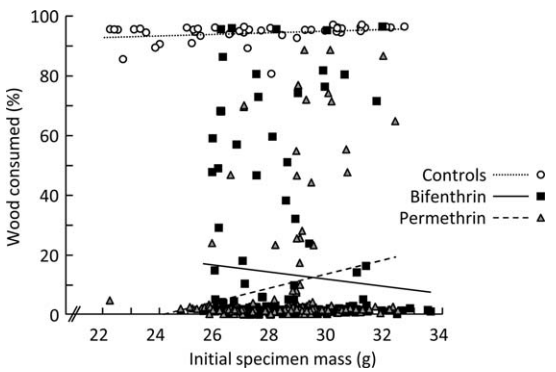

Fig. 4. Percentage wood consumption plotted against initial mass for each test specimen exposed to *C. acinaciformis* and *C. formosanus.* The regression equations for percentage wood consumed against initial mass of specimen are: controls, y = 0.867 + 0.003x ($r^2 = 0.079$; $F = 3.592$; df = 1,42; $P = 0.065$); bifenthrin, y = 0.468–0.011x ($r^2 = 0.007$; $F = 0.877$; df = 1,130; $P = 0.351$); and permethrin, y = −0.511 + 0.022x ($r^2 = 0.046$; $F = 6.238$; df = 1,130; $P = 0.014$).

ANCOVA on the percentage bifenthrin-treated wood consumed found significant differences between species ($F_{1,122} = 54.706$; $P < 0.001$) as *C. formosanus* consumed more than *C. acinaciformis*, and between doses ($F_{1,122} = 33.434$; $P < 0.001$) as less wood was consumed at higher retentions. Differences were not significant for location ($F_{6,122} = 0.892$; $P = 0.503$) or for initial mass ($F_{1,122} = 0.068$, $P = 0.795$; Figs. 4 and 5). The r^2 was relatively low at 0.443.

ANCOVA on the percentage of permethrin-treated wood consumed found significant differences between both species ($F_{1,122} = 24.034$; $P < 0.001$), as *C. formosanus* consumed more than *C. acinaciformis*, and dose ($F_{1,122} = 31.929$; $P < 0.001$), as less wood was consumed at higher retentions. Initial weight was also significant ($F_{1,122} = 18.609$; $P < 0.001$); consumption of higher density specimens was greater than that of lower density specimens. Location was not significant ($F_{6,122} = 1.000$, $P = 0.428$; Figs. 4 and 6). The r^2 was low at 0.358.

Discussion

The results of these field trials showed that all populations of *Coptotermes* consumed >90% of the control wood specimens, but considerably less of the pyrethroid-treated wood specimens. However, consumption of the latter differed between species. These data demonstrate that native and introduced field populations of *C. formosanus* are more tolerant of low retentions of pyrethroids in wood compared with native field populations of *C. acinaciformis.* These results have a number of possible implications, foremost 1) inferring outcomes from one species compared with another, and 2) efficacy of existing standards.

1. Inferring Outcomes Between Species. Results from these field trials suggest that specific retentions of pyrethroids in wood (*P. radiata* sapwood) that demonstrate efficacy against *C. formosanus* are also most likely to be equally efficacious against *C. acinaciformis.* However, the reverse may not necessarily be true, particularly at lower pyrethroid retentions. There is one possible caveat for this conclusion. Hab-

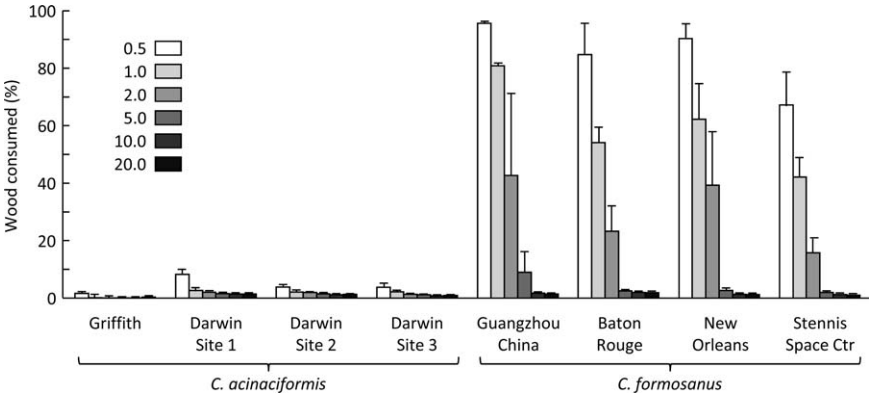

Fig. 5. Mean percentage wood consumption of bifenthrin-treated specimens after exposure to *C. acinaciformis* and *C. formosanus* at field test sites in Australia, China, and the United States. Bifenthrin retentions (g AI/m^3) indicated in the legend.

itat type may also be important, as alternative food availability affects termite foraging decisions (e.g., choice cf., no-choice laboratory tests: Smythe and Carter 1970, Morales–Ramos and Rojas 2001, Kard et al. 2007, Gautam and Henderson 2011; food volumes: Lenz et al. 2009). All sites in Australia used for *C. acinaciformis* were in native forest with an abundance and diversity of alternative food, while all those for *C. formosanus* were in urban settings. The one exception was the site location on Stennis Space Center (mostly cleared, previously forested land), which also had the lowest mean consumption of treated wood (although not significant). Furthermore, termites are known to use food resources differentially dependent on alternative supplies (Lenz et al. 2009), thus treated wood, which is a less valuable resource either because of distastefulness or toxicity, could become more valuable in habitats containing less overall food. However, both species of *Coptotermes* consumed similar amounts of nontreated and solvent control wood. This suggests that the observed differences in consumption of insecticide-treated wood primarily reflected actual differences between the two species of *Coptotermes* in their tolerance to the lower retentions of the two pyrethroids and less so the effect of habitat. While both species showed dose–responses to the pyrethroid-treatments (Figs. 5 and 6), *C. formosanus* was clearly more tolerant of the lower retentions of the pyrethroids than was *C. acinaciformis.*

It is not possible to infer the relative responses of others within the genus *Coptotermes* (e.g., the widespread invasive pest *C. gestroi* and other Asian species such as *C. curvignathus* Holmgren and *C. intermedius* Silvestri from Africa) from the data presented here. Several studies have found large differences in tolerances to a range of insecticides, that is, up to 16 times greater survival between colonies of the same species and between different pest species of termites (Sands 1962, Lenz and Zi-Rong 1985, Osbrink et al. 2001, Delgarde and Rouland–Lefèvre 2002). Neither is it possible to consider the effect of these pyrethroids (bifenthrin and permethrin) against other termite species. Although *Coptotermes* is one of the most important genera in urban habitats in economic terms, it is only one genus of several damaging termites. Other pest termite species found in Australia, southern Asia, and the United States include drywood termites in the genera *Cryptotermes* and *Incisitermes*,

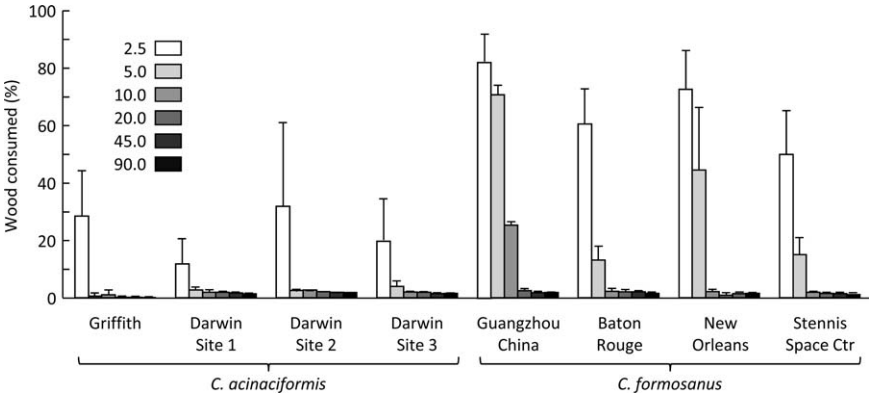

Fig. 6. Mean percentage wood consumption of permethrin-treated specimens after exposure to *C. acinaciformis* and *C. formosanus* at field test sites in Australia, China, and the United States. Permethrin retentions (g AI/m^3) indicated in the legend.

and the subterranean genera *Globitermes*, *Heterotermes*, *Macrotermes*, *Mastotermes*, *Microcerotermes*, *Nasutitermes*, *Odontotermes*, *Reticulitermes*, and *Schedorhinotermes*, which cause significant problems and exhibit different responses to termite management systems (Lee et al. 2007). However, one can still characterize multiple species of *Coptotermes* by inherent differences in their ability to tolerate toxic or repellent compounds. Such information is important when assessing the economic impact of a given species. For example, while *C. acinaciformis* appears to be less tolerant to the pyrethroids bifenthrin and permethrin, this species is known to be far more damaging to plastics than *C. formosanus* and *C. gestroi* and for that matter representatives of other genera in southern Asia (Lenz et al. 2012).

2. Efficacy of Existing Standards. The Australasian Wood Preservation Committee Protocols for Assessment of Wood Preservatives (AWPC 2007) state that a given preservative or insecticidal formulation may be considered to have successfully prevented damage to wood by a given termite species if the mean weight loss of treated specimens does not exceed 5%. Using this performance criterion for our study, bifenthrin was rated effective in preventing damage to *P. radiata* specimens at a retention of 1 g/m^3 for *C. acinaciformis* and at 5 g/m^3 for *C. formosanus* (Fig. 5). A similar trend was observed for permethrin, with effective protection provided by a 5 g/m^3 retention for *C. acinaciformis* and a 10 g/m^3 retention for *C. formosanus* in the United States, but 25 g/m^3 in China (Fig. 6).

The pyrethroid retentions that prevented damage by termites in this study are considerably lower than the required minimum retentions approved for the treatment of solid wood for use in Australia. For bifenthrin, this is 0.0047% wt:wt in oven-dried (OD) wood; $\approx$20 g/m^3 (Standards Australia 2010). For permethrin, this is 0.02% wt:wt in OD wood (90 g/m^3) (Standards Australia 2010). The approved retentions for bifenthrin and permethrin were determined from both laboratory- and field-derived efficacy data using *P. radiata* sapwood as one of the wood substrates (Creffield and Howick 1984a,b; Creffield and Watson 2002). In all instances, specimens treated with the pyrethroids were artificially weathered before laboratory and field testing against termites (*Mastotermes darwiniensis* Froggatt, *C. acinaciformis* and/or *Nasutitermes exitiosus* (Hill), the latter species only being subjected to hardwood specimens treated with permethrin). Considering only data obtained for *C. acinaciformis*, bifenthrin was effective in preventing damage to *P. radiata* specimens at a retention of $<$2.5 g/m^3 in a laboratory bioassay that was subsequently confirmed in the field to be $<$5 g/m^3 (Creffield and Watson 2002). Likewise, permethrin was effective in preventing damage to *P. radiata* specimens at a retention of 40 g/m^3 in the laboratory (Creffield and Howick 1984a,b). Bifenthrin and permethrin are not approved as stand-alone insecticidal actives in the United States (AWPA 2011a,b). In addition, the minimum approved retentions set for these pyrethroids in Australia were not just based upon their efficacy against *C. acinaciformis* but also other species of termites including the more voracious *M. darwiniensis*. Furthermore, higher retentions were required to offset the effects of chemical loss over time and to compensate for any potential under-treatment because of substrate variability, as is known for insecticides in treated soil (e.g., chemical type, initial concentration, soil type, soil pH, and soil moisture content) (Harris 1972; El Beit et al. 1981; Racke et al. 1994, 1996; Baskaran et al. 1999a,b; Standards Australia 2000).

The strength of this entire study comes from the fact that a single method of field exposure, suitable for both target species of *Coptotermes*, was used, thereby allowing valid comparison of efficacy data. As shown in our study, once differences in methodology as a potential factor for differing results between species can be excluded, inherent responses of a given species of termite (e.g., tolerance to insecticides and/or level of aggressiveness toward different materials) can be more readily determined.

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