



# Detection and Control of Subterranean Termites Using In-Ground Termite Monitoring Stations and Chitin Synthesis Inhibitor Baiting for Singapore Urban Trees

By Jaren Wong Kak Leong and Derrick Nguyen Hoang Danh

**Abstract.** Background: This study demonstrated the potential of in-ground (IG) termite monitoring stations coupled with chitin synthesis inhibitor (CSI) baiting as a complementary solution to visual inspection for tree termite detection and control in Singapore. Methods: Using lure wood pieces collected from activated IG stations to serve as a basis for comparison, we evaluated the destructiveness of detected termite species and reported their unique feeding patterns. Chitin synthesis inhibitor (CSI) baiting with chlorfluazuron was used for termite control. Results: A total of 6 termite species were detected: *Coptotermes gestroi* (Wasmann), *Coptotermes curvignathus* (Holmgren), *Schedorhinotermes medioobscurus* (Holmgren), *Macrotermes gilvus* (Hagen), *Macrotermes carbonarius* (Hagen), and *Microcerotermes crassus* (Snyder). However, the detection capability varied depending on site conditions such as intermittent flooding events, high soil salinity, and reduced foraging behavior after nesting within or near a host tree. This behavior of reduced foraging, in part, could be affected when heavily infested trees are removed, forcing termites to migrate and search for new food sources, leading to activation of nearby IG stations. In terms of termite control, CSI baiting with chlorfluazuron could effectively eliminate termite colonies for 3 species: *C. gestroi*, *C. curvignathus*, and *S. medioobscurus*. Colony elimination time ranged from 3 to 6 weeks and 24 weeks, respectively. Conclusion: Considering the effectiveness of IG stations coupled with CSI bait in detection and control of subterranean termite species, large-scale application of this system in an urban tree context is discussed.

**Keywords.** Chitin-Synthesis Inhibitor; Coptotermes; In-Ground Termite Monitoring; Subterranean Termite; Termite Baiting.

## INTRODUCTION

The Greenery Movement in Singapore envisions increasing the number of trees from the current 7 million to more than 8 million by 2030 (TreesSG 2020). Considering the large volume of trees, efficient and effective large-scale tree monitoring is essential to allow timely detection of tree health problems, especially those that compromise structural integrity and lead to tree failure. Similar to many well-documented problems in tropical urban forestry, subterranean termite infestation is one of the most common contributors to tree structural failures in Singapore. Among subterranean termite species that can infest trees, *Coptotermes gestroi* (Wasmann) and *Coptotermes curvignathus* (Holmgren)[Blattodea: Rhinotermitidae] are the most destructive (Cowie et

al. 1989; Scheffrahn and Su 2000; Zorzenon and Campos 2015). This species damages the heartwood (Greaves 1962; King and Spink 1969; Lai et al. 1983; Chouvenec and Foley 2018) and infests tree trunks from below the ground (Cowie et al. 1989; Lee 2014). Typically, infested trees do not show apparent symptoms during early infestation stage. Prominent above-ground symptoms often only emerge when a subterranean termite population within a tree is well established (Osbrink et al. 1999). Other subterranean termite species, such as *Globitermes sulphureus* (Haviland) and *Microcerotermes serrula* (Desneux), nest arboreally on tree trunks. However, their nesting behavior does not pose damage to the trees directly. Instead, they are often associated with secondary infections caused by basal stem rot (Cheng et al. 2008).

Termite detection and control are the two major components of termite management in trees. For termite detection, visual tree assessment is a common and highly valuable method used to examine subterranean termite infestations in urban trees by searching for aboveground symptoms such as termite mud trails or apparent tree wounds (Osbrink et al. 1999; Lestari et al. 2021). However, the ease of visual detection varies depending on the host tree species and local environments, as subterranean termites like genus *Coptotermes* exhibit cryptic behaviors and easily elude the naked eye. *Coptotermes* have been reported to hide underneath the superficial outer bark of pine trees or deep in the xylem tissues of oak trees, leaving no aboveground symptoms and making visual inspection particularly challenging (Chouvenc and Foley 2018). As technology has continued to progress, advanced inspection methods have been employed. Resistance drilling determines internal cavities of trees by recording the drill penetration resistance when inserted through a trunk along a linear path (Osbrink and Lax 2002; Linhares et al. 2021). Sonic tomography produces an image of internal cross-sectional structures of a tree by recording differences in the speed of sound wave transmission (Karlinasari et al. 2018). Although these technologies offer useful insights into tree internal structure and allow accurate internal defect detection, complex setup as well as high operation and maintenance costs associated with these devices make them unsuitable as large-scale monitoring tools for subterranean termites.

For termite control, the application of liquid termiticides remains the conventional approach (Sajap et al. 2000; Lee 2014; Ahmad et al. 2021). As reviewed by Lee and Neoh (2023), liquid termiticides are broadly classified into repellent and nonrepellent compounds. Repellent termiticides are primarily used to establish exclusion barriers in preconstruction treatments, deterring termites from entering treated soil. In contrast, nonrepellent termiticides such as imidacloprid and fipronil are typically applied post-infestation by introducing them directly into the soil to suppress or eliminate active termite colonies. Alternatively, fipronil and imidacloprid (Ring et al. 2002), as well as thiamethoxam (Zorzenon and Campos 2015), can be injected into the tree trunk to treat infestations internally. When termites forage through treated soil or feed on contaminated tree tissues, their bodies become exposed to the toxicants, which are

then transferred to unexposed nestmates, ultimately resulting in colony collapse (Thorne and Breisch 2001; Parman and Vargo 2010; Acda 2014).

Despite the widespread use of liquid termiticides, Lee and Neoh (2023) highlight that their efficacy remains inconsistent, with limited field evidence supporting broad-scale colony elimination. Several factors have been identified as influencing treatment outcomes, including soil characteristics (e.g., clay and organic matter content), the physicochemical properties of the active ingredient (e.g., adsorption, persistence, solubility), and environmental conditions such as flooding. Moreover, treatments often suffer from high reinfestation rates. The rapid-acting nature of some termiticides leads to quick mortality upon contact, prompting termites to alter their foraging routes and avoid treated areas altogether (Randall and Doody 1934; Hu 2011; Su 2019).

Given these limitations and growing concerns over the potential adverse effects of chemical residues on human health and environmental quality, reliance on liquid termiticides as a standalone control method has declined. Instead, there has been a shift towards integrated approaches, with termite baiting systems—particularly those using chitin synthesis inhibitors (CSI)—increasingly adopted as complementary strategies (Ahmed et al. 2015; Lee and Neoh 2023).

In brief, termite baiting systems include a non-toxic lure wood piece placed within an in-ground (IG) station to attract surrounding termites. Once lure wood is attacked by termites, a termite bait matrix consisting of cellulose powder impregnated with CSI will be added to IG stations as termite control. Baiting with CSI exploits termite foraging behaviors and food transfer systems (trophallaxis), whereby CSI will be shared throughout the colony through mutual grooming and cannibalism (Dhang 2011; Gautam and Henderson 2014; Umar and Ab Majid 2020b). The mode of action of CSI is molting inhibition (Su and Monteagudo 2017), which interrupts termites ecdysis process and prevents normal formation of peritrophic membrane (Zimmermann and Peters 1987), causing termites to be more susceptible towards microorganism infection (Arakawa et al. 2002) and eventually leading to colony elimination. Compared to conventional methods in monitoring and control for subterranean termites, IG-CSI systems do not rely on spotting aboveground symptoms but directly lure the foraging termites below ground to allow

quick detection through inspecting the stations. Since this system has been readily commercialized at a relatively competitive cost, large scale implementation of IG-CSI systems has been widely adopted for long term monitoring (Smith et al. 2006; Getty et al. 2007; Shults et al. 2021). More importantly, because CSI bait as a toxicant will be shared throughout the entire colony via social grooming, determining the precise location of actual termite nests is not necessary as long as workers still feed on CSI baits. Chitin synthesis inhibitor (CSI) baits as an effective subterranean termite control have been tested in different countries and regions, including the United States (Su 1994), Malaysia (Umar and Ab Majid 2020b), and Thailand (Ngampongsai et al. 2020). Furthermore, to eliminate the entire colony, only a small amount of CSI is required, satisfying the requirements of population management with reduced pesticide reliance (Su 2011).

When termite activity is detected on trees during visual inspection, IG-CSI systems can be supplemented with aboveground termite baiting as a remedial control measure (Su et al. 2023). An aboveground station is placed directly on active subterranean termite foraging trails, allowing termites to readily and consistently feed on the bait, ultimately leading to colony elimination (Su et al. 2023). However, two operational challenges exist with this approach: (1) the irregular tree trunk surfaces and conventional cartridge box design of aboveground stations makes secure anchoring difficult (Yates and Grace 2000), and (2) aboveground systems are more visually noticeable than IG systems, potentially attracting unwanted public attention and disturbance in urban areas and compromising treatment effectiveness.

Despite the rich body of research existing on IG-CSI systems, much of the published data have been restricted to infestation of buildings and structures. There are limited studies focusing on the application of discussed techniques in urban trees. To bridge this gap, the present study aimed to evaluate IG-CSI system capability: (1) to detect subterranean termites for different species of urban trees, and (2) to control the detected subterranean termites. To achieve these objectives, IG termite monitoring stations were installed for 145 associated trees from 14 tree species at 15 different sites in Singapore (Table 1) from June 2023 to July 2024. The activation time of the IG termite monitoring stations, lure wood feeding rate and pattern, and elimination efficacy of chlorfluazuron bait were assessed.

## MATERIALS AND METHODS

### Study Sites

In this study, a total of 145 trees from 14 species were assessed at 15 different study sites in Singapore from June 2023 to July 2024 (Table 1). Selected locations either had a recent history of or ongoing termite infestation based on visual assessment of signs and symptoms of termite infestation. These sites were broadly categorized into two main groups based on soil type: coastal areas (sandy and saline soil) and inland areas (loamy and nonsaline soil).

### Inland Areas

*Gardens by the Bay.* At sites A, B, and C (Figure 1A), *Phoenix sylvestris* (L.) Roxb., *Enterolobium cyclocarpum* (Jacq.) Griseb., and *Syzygium aromaticum* (L.) Merr. & L. M. Perry trees were reported to have had termite infestations with aboveground symptoms in the past. Termite control by chemical treatment was applied about 6 months before the installation of IG termite monitoring stations. There were no aboveground signs and symptoms of termite infestations upon installation of the IG stations for sites A through C. At site D (Figure 1A), *Araucaria columnaris* (G. Forst.) Hook in this area had termite mud trails spotted during tree inspection in May 2023 with 2 trees showing extensive damage to central wood column. Due to proximity to a nearby freshwater lake, chemical application was not feasible, leading to removal of the 2 heavily damaged *A. columnaris*.

*Hort Park.* Site E contained a standalone *Ceiba pentandra* (L.) Gaertn. (Figure 1A). In 2022 termite infestation was detected with aboveground symptoms. Chemical application was carried out, and no termite activity or aboveground symptoms were observed after the chemical treatment.

*Singapore Botanic Garden.* Site F consisted of 8 trees: 5 *Araucaria cunninghamii* W. T. Aiton ex D. Don. individuals and 3 *Agathis borneensis* Warb. individuals. Chemical application via spraying was applied to all trees one month before the installation of IG termite monitoring stations (Figure 1A). Site G was located near a carpark with a total of 17 *A. cunninghamii* trees showing neither signs nor symptoms of termite infestation (Figure 1B). This site also had no past history of infestation.

*Bidadari Park.* This park (Figure 1B) was developed with the concept of rustic aesthetic design with several dead wood logs and trees as display pieces. Living trees at Site H showed active termite activities

**Table 1.** List of study sites, their corresponding coordinates, associated tree species, and number of trees in which IG stations were installed. IG (in-ground); GB (Gardens by the Bay); HP (Hort Park); SBG (Singapore Botanic Garden); BP (Bidadari Park); ECPSR (East Coast Park Service Road); ECP (East Coast Park); CBP (Changi Beach Park); CCR (Changi Coast Road).

Location	Type	Site	Coordinates	Associated tree species	No. of trees assessed
GB	Inland	A	1.279747, 103.860548	<i>Phoenix sylvestris</i>	5
		B	1.279721, 103.861681	<i>Enterolobium cyclocarpum</i>	7
		C	1.277776, 103.862271	<i>Syzygium aromaticum</i>	5
		D	1.284024, 103.866604	<i>Araucaria columnaris</i>	4
HP		E	1.279498, 103.798199	<i>Ceiba pentandra</i>	1
SBG		F	1.313480, 103.814514	<i>A. cunninghamii</i>	5
				<i>Agathis borneensis</i>	3
BP		G	1.316170, 103.816188	<i>A. cunninghamii</i>	17
		H	1.340916, 103.875128	<i>Plumeria</i> spp.	1
				<i>Samanea saman</i>	1
<i>Buchanania arborescens</i>	1				
ECPSR	I	1.294864, 103.891266	<i>S. saman</i>	5	
			<i>Caryota mitis</i>	10	
ECP	Coastal	J	1.294864, 103.891266	<i>Casuarina equisetifolia</i>	9
		K	1.295757, 103.897229	<i>Cerbera odollam</i>	10
		L	1.297612, 103.903915	<i>C. equisetifolia</i>	8
CBP		M	1.382801, 104.002361	<i>C. equisetifolia</i>	22
		N	1.375008, 104.005502	<i>C. equisetifolia</i>	10
CCR		O	1.380527, 104.002158	<i>C. equisetifolia</i>	4
				<i>Xanthostemon chrysanthus</i>	13
<b>Total</b>					145

with several mud trails spotted during visual inspection. No chemical treatment had been applied for termite control in this location.

*East Coast Park Service Road.* Despite the proximity of this location to the sea, the soil was non-saline and loamy, so the location was categorized as inland. The 5 *Samanea saman* (Jacq.) Merr were planted as a single row along the road while the 10 *Caryota mitis* Lour. individuals existed as a cluster within a forested patch opposite the *S. saman* trees (Figure 1B). No chemical treatment had been applied for termite control in this location.

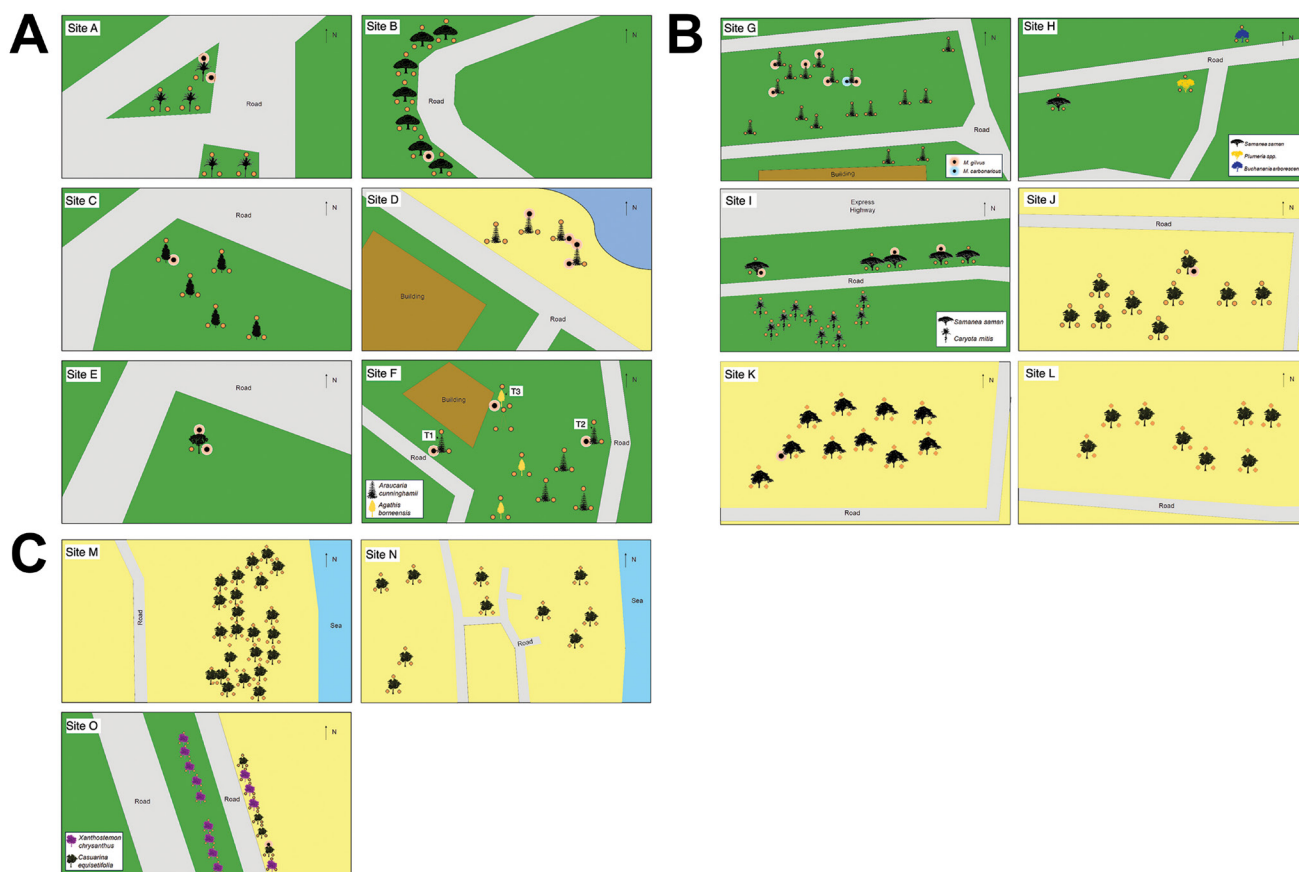
### Coastal Areas

*East Coast Park.* Sites J and K within this location (Figure 1B) were subjected to intermittent flooding due to sustained heavy rain or rising water tables

leading to waterlogged conditions. All trees within the 3 sites showed visible signs and symptoms of termite infestation. No chemical treatment had been applied for termite control in this location.

*Changi Beach Park.* *Casuarina equisetifolia* L. was the main tree species planted in this park (Figure 1C). *Casuarina equisetifolia* trees in both Sites M and N showed visible signs and symptoms of termite infestations. No chemical treatment had been applied for termite control in this location.

*Changi Coast Road.* *Casuarina equisetifolia* and *Xanthostemon chrysanthus* (F.Muell.) Benth. trees were located as a single row along the main road (Figure 1C). They showed visible signs and symptoms of termite infestation. No chemical treatment had been applied for termite control in this location.



**Figure 1.** (A) Maps of different sites in which IG stations (depicted as orange circles) were installed. Sites A through D, Site E, and Site F are located in Gardens by the Bay, Hort Park, and Singapore Botanic Garden, respectively. Activated stations are depicted as black circles with an outer glow. For Site F, T1 and T2 stations were first activated by *C. curvignathus* before being taken over by *Schedorhinotermes medioobscurus* after the colonies were eliminated, while T3 station was activated by *S. medioobscurus*. (B) Maps of different sites in which IG stations (depicted as orange circles) were installed. Sites G, H, I, and J through L are located in Singapore Botanic Garden, Bidadari Park, East Coast Park Service Road, and East Coast Park, respectively. Activated stations are depicted as black circles with an outer glow. (C) Maps of different sites in which IG stations (depicted as orange circles) were installed. Sites M through N and O are located in Changi Beach Park and Changi Coast Road, respectively. Activated stations are depicted as black circles with an outer glow.

### IG Termite Monitoring Station

In this study, we used IG stations and CSI baits produced by Exterminex (Agro Technic Ltd Pte, Singapore). A piece of preweighted lure wood (10.5 cm × 4.5 cm × 2.0 cm) made from pine was placed at the center of the station. The lure wood within the station served as a nontoxic food source for termite consumption when discovered by foraging termites and also served to evaluate the termite consumption rate and feeding behavior (Su and Scheffrahn 1986). For each tree, 3 stations were installed within intervals of 3 m at 3 directions (North, Southwest, and Southeast) as demonstrated in Figure 2. After installation, the stations were monitored weekly for termite activity. When the lure pine wood within the station was

attacked by termites, stations were said to be activated. Lure wood pieces were then replaced with a new piece. The old wood piece was collected for weighing to obtain the baseline termite consumption rate for 2 to 4 weeks prior to set up of auxiliary monitoring stations and baiting. The described step aimed to ensure that the termites were continuously foraging within the same station and to ascertain that there was no feeding aversion to the food source given. After installation of the auxiliary station and addition of CSI bait to the auxiliary station, the consumption rate on the lure wood piece of the primary station was tracked weekly until 4 weeks after no more termite activity or presence were observed in both primary and auxiliary stations. To obtain lure wood consumption

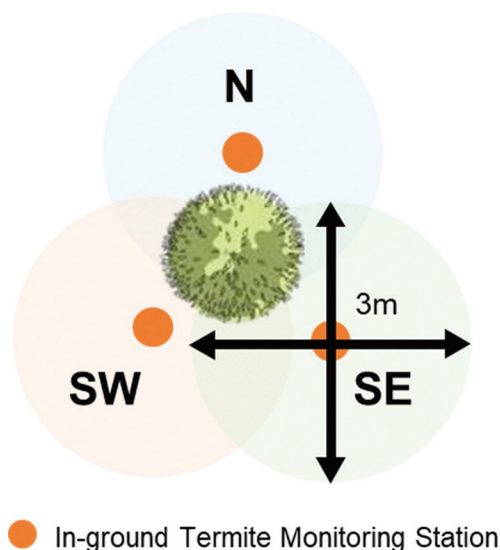


Figure 2. In-ground (IG) station placement for individual trees. Top-down diagram of IG stations (Left). Side-view photo of actual IG stations installed for one tree (Right).

rate by detected termites, collected lure wood from activated primary stations were washed, cleaned, and oven-dried for 48 hours according to protocol of Umar and Ab Majid (2020b). After 48 hours, lure woods were weighed and compared to their original packaging weight.

### Auxiliary Monitoring Station and Bait Consumption

An auxiliary monitoring station was installed next to the primary monitoring station when termites were detected actively feeding within a primary monitoring station. The purpose of the auxiliary station was to deliver CSI to detected subterranean termites and provide observational data on termite presence. To quickly activate the newly installed auxiliary station, foraging termites from the primary station were transferred together into the auxiliary station. After successful establishment of termite activity, 100 g of cellulose-powdered chlorfluazuron bait was then moistened with 250 mL of distilled water to substitute the lure wood within the activated auxiliary station. The bait was monitored weekly and replenished when more than 50% of the original CSI bait had been consumed. The total weight of CSI bait consumption was determined when termite eradication, defined as the disappearance of termites from both primary and auxiliary stations, had been achieved.

## Termite Species Identification

### Morphological Identification

Termite soldier specimens were used for species identification. With the aid of a dissecting microscope (Olympus SZ61; Olympus Corporation, Hachioji, Tokyo, Japan), the morphological characteristics of the head, mandibles, antennae, notum, size, and coloration of the termites were observed with reference to Tho (1992).

### Molecular Identification

Genomic DNA was extracted from the head of the termite soldier specimen to minimize contamination by gut endosymbionts. A Qiagen DNeasy® Blood & Tissue Kit (Qiagen N.V., Venlo, Netherlands) was used to extract DNA according to the manufacturer's instructions. COI, COII, and 16S genes were used for molecular identification. Successfully amplified products were sent to Axil Scientific Pte. Ltd. (Singapore) for bidirectional Sanger sequencing. The aligned sequences were compared with NCBI GenBank (NCBI, NIH, USA) using a BLAST search.

## RESULTS

### Activation of IG Stations and Detected Termite Species

Table 2 summarizes the termite species detected based on visual inspection and the actual termite species detected by IG stations as well as the associated

**Table 2. List of study sites with their corresponding associated tree species, identified termite species observed, and actual termite species detected by IG stations. IG (in-ground); GB (Gardens by the Bay); HP (Hort Park); SBG (Singapore Botanic Garden); BP (Bidadari Park); ECPSR (East Coast Park Service Road); ECP (East Coast Park); CBP (Changi Beach Park); CCR (Changi Coast Road).**

Type	Location	Site	Associated tree species	No. of trees assessed	Termite species detected based on visual signs and symptoms or past infestation	No. of activated IG stations	Activation time of IG station (week)	Termite species detected in IG station
Inland	GB	A	<i>P. sylvestris</i>	5	<i>C. gestroi</i>	2	3	<i>C. gestroi</i>
		B	<i>E. cyclocarpum</i>	7	<i>C. gestroi</i>	1	3	<i>C. gestroi</i>
		C	<i>S. aromaticum</i>	5	<i>C. gestroi</i>	1	10	<i>C. gestroi</i>
		D	<i>A. columnaris</i>	4	<i>C. gestroi</i>	4	1	<i>C. gestroi</i>
	HP	E	<i>C. pentandra</i>	1	<i>C. gestroi</i>	2	20	<i>C. gestroi</i>
	SBG	F	<i>A. cunninghamii</i>	8	<i>C. curvignathus</i> *	2	1 - 3	<i>C. curvignathus</i>
			<i>A. borneensis</i>	4	-	3	2 - 3	<i>S. medioobscurus</i>
		G	<i>A. cunninghamii</i>	17	-	6	5 - 13	<i>M. gilvus</i>
	BP	H	<i>Plumeria</i> spp.	1	<i>N. havilandi</i>	0	-	-
			<i>S. saman</i>	1	<i>N. havilandi</i>	0	-	-
			<i>B. arborescens</i>	1	<i>N. havilandi</i>	0	-	-
	ECPSR	I	<i>S. saman</i>	5	<i>M. carbonarius</i>	3	2	<i>M. carbonarius</i>
			<i>C. mitis</i>	10	<i>T. rostratus</i> <i>M. crassus</i>	0	-	-
Coastal	ECP	J	<i>C. equisetifolia</i>	9	<i>C. gestroi</i>	1	14	<i>C. gestroi</i>
		K	<i>C. odollam</i>	10	<i>N. havilandi</i>	1	2	<i>C. gestroi</i>
		L	<i>C. equisetifolia</i>	8	<i>C. gestroi</i> <i>M. crassus</i>	0	-	-
	CBP	M	<i>C. equisetifolia</i>	22	<i>C. gestroi</i>	0	-	-
		N	<i>C. equisetifolia</i>	10	<i>C. gestroi</i>	0	-	-
	CCR	O	<i>C. equisetifolia</i>	4	<i>M. crassus</i>	1	5	<i>M. crassus</i>
<i>X. chrysanthus</i>	13		<i>C. gestroi</i> <i>M. crassus</i>	0	-	-		

\**C. curvignathus* individuals were not visible from visual inspection but only obtained from felling one of the infested trees within the site.

activation time for all 145 trees in 15 sites (A through O) across all locations. For all sites in GB and HP, activation of IG stations by *C. gestroi* were achieved without apparent aboveground symptoms. Except for site D with trees displaying mud trails on trunks from active termite workers and soldiers found within the trails, the rest of the sites in these two locations did not have visible aboveground symptoms indicative of

termite infestations. Activation time ranged from 1 week (site D) to 24 weeks (site G).

In Singapore Botanic Garden, IG stations were activated by *C. curvignathus*, *S. medioobscurus*, *Macrotermes gilvus*, and *Macrotermes carbonarius*. It is important to note that the determination of *C. curvignathus* infestation in an *A. cunninghamii* tree at Site F was only obtained when one of the trees was

felled, and actual workers and soldiers were collected from inside the felled tree trunk. *Schedorhinotermes medioobscurus*, *M. gilvus*, and *M. carbonarius* activities were not observable aboveground, with no indication of mud trails, mounds, or actual workers and soldiers foraging on the ground. For stations at trees T1 and T2 (Figure 1A, Site F), *C. curvignathus* was the original species activating the stations. After *C. curvignathus* had been eliminated through CSI baiting, *S. medioobscurus* was found feeding on the lure wood in the same stations after 2 to 3 weeks. Furthermore, IG stations activated by *M. carbonarius* and *M. gilvus* showed sporadic patterns: different stations were activated at different times, and termite activities within activated stations were not continuously observed for more than one week. In general, activation time ranged from 1 to 3 weeks for *C. curvignathus*, 2 to 3 weeks for *S. medioobscurus*, 5 to 13 weeks for *M. gilvus*, and 24 weeks for *M. carbonarius*.

*Nasutitermes havilandi* was the predominant species found foraging in Site H of Bidadari Park and Site K of East Coast Park with extensive mud trails on tree trunks and branches, but none of the installed stations were activated by this termite species. Interestingly, at Site K, one of the IG stations was activated by *C. gestroi* from an unknown location. However, due to the intermittent flooding of this site, *C. gestroi* was observed to abandon the station after the flood subsided. The same station was re-activated by *C. gestroi* after one year but was abandoned again after another flood.

*Macrotermes carbonarius* formed big mounds at the base of *S. saman* trees at Site I and activated IG stations installed in this area within 3 weeks after installation. Meanwhile, *Termes rostratus* were the predominant species found in the *C. mitis* palm cluster but did not activate any of the installed IG stations. Similarly, *Microcerotermes crassus* were the species commonly observed in Sites I, L, and O but did not activate most of the installed IG stations except for one station in Site O. This station was installed right next to the *M. crassus* mound found on the ground. After the initial activation, the lure wood was retrieved for lab measurement and replaced with a new piece. The new lure wood piece was never activated again by the *M. crassus* for the rest of the study.

Although *C. gestroi* showed consistent activation of IG stations for most of the inland sites, *C. gestroi* activities could be observed from mud trails on trunks

of *C. equisetifolia* and *X. chrysanthus* but did not activate most of the IG stations in coastal sites (J through O), except for one station in Site K, which was described formerly, and another station in Site J. Site J activation only happened after 14 weeks from installation and approximately 1 to 2 weeks after 4 trees in this area were felled.

### Lure Wood Consumption Rate and Feeding Pattern

As seen from Figure 3, *M. carbonarius* and *M. crassus* had very low average weekly wood consumption rates with only 0.4 g/week and 0.5 g/week, respectively. *Macrotermes gilvus* consumed 9.3 g/week. *Coptotermes curvignathus*, *C. gestroi*, and *S. medioobscurus* consumed the most with 22.1 g/week, 19.7 g/week, and 16.8 g/week, respectively.

Figure 4 shows feeding patterns by *C. gestroi*, *C. curvignathus*, *M. carbonarius*, *M. gilvus*, *M. crassus*, and *S. medioobscurus* in lure wood. *Coptotermes gestroi* and *C. curvignathus* fed by creating clean and sharp carvings with extensive galleries that cut through lure wood piece. Meanwhile, *M. carbonarius* and *M. gilvus* displayed scraping patterns of feeding. These species did not create galleries that cut through lure wood pieces. As compared to *M. carbonarius*, *M. gilvus* appeared to scrape more aggressively and left rough texture on lure wood surfaces. *Microcerotermes crassus* also displayed scraping feeding patterns similar to *M. gilvus* and *M. carbonarius*, but to a smaller extent. *Schedorhinotermes medioobscurus* displayed a mixed feeding pattern that included a combination of carving and scraping.

### CSI Baiting and Colony Eradication

In this study, only activation by *C. gestroi*, *C. curvignathus*, and *S. medioobscurus* in sites A through F showed consistent weekly feeding of the lure wood. Therefore, the installation of auxiliary stations in conjunction with the primary stations was attempted for activated stations in these sites. As seen from Figure 5, the lure wood consumption rate from primary stations all decreased following CSI bait addition. Time elapsed from CSI bait addition to auxiliary stations to disappearance of termites, which indicated colony elimination, ranged from 3 to 7 weeks for *C. gestroi*, 6 weeks for *C. curvignathus*, and 16 weeks for *S. medioobscurus*. The total CSI bait consumption to achieve colony eradication ranged from 206.5 g

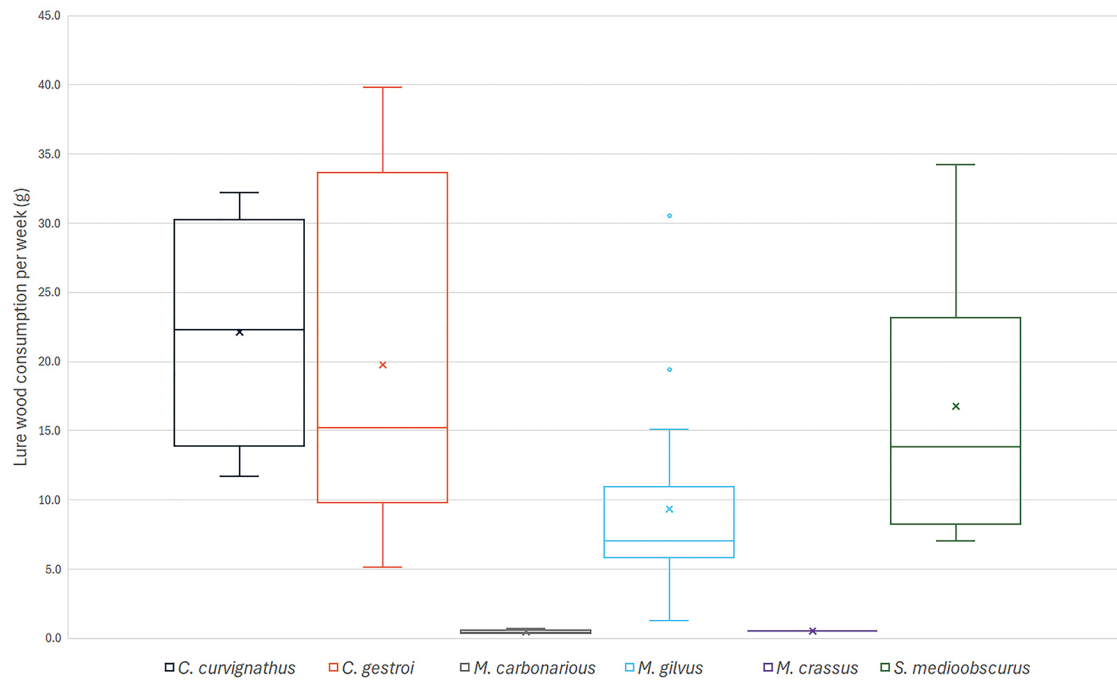


Figure 3. Box-plot of average weekly wood consumption rates by different termite species.

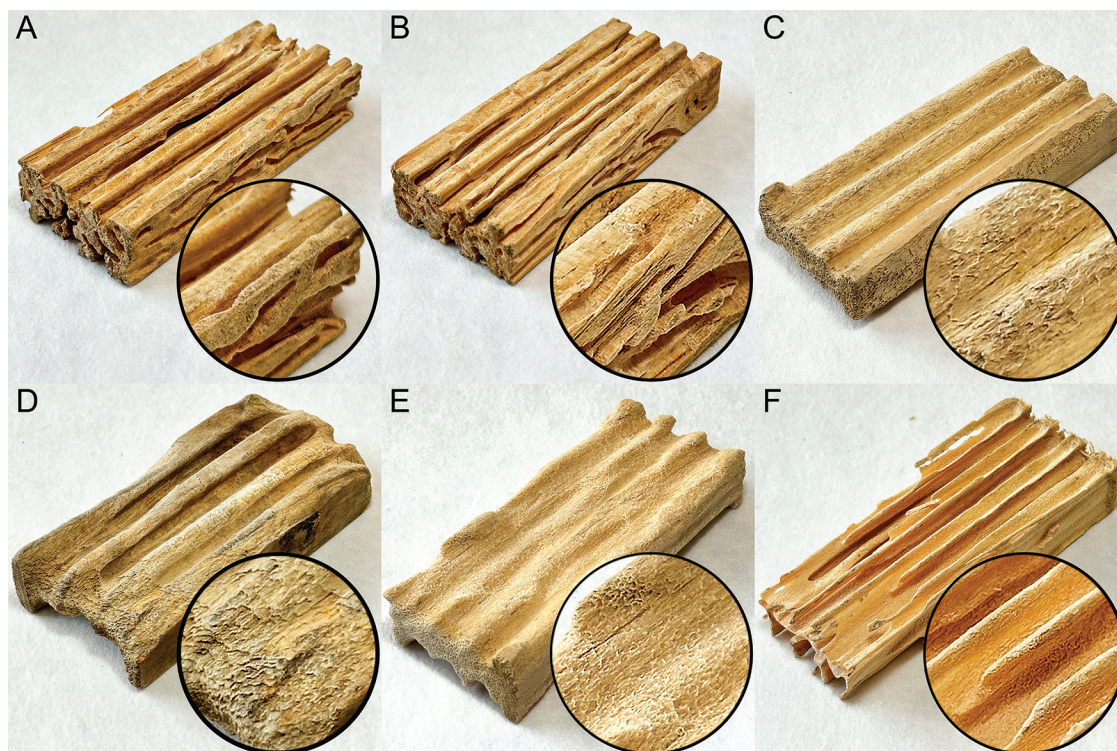
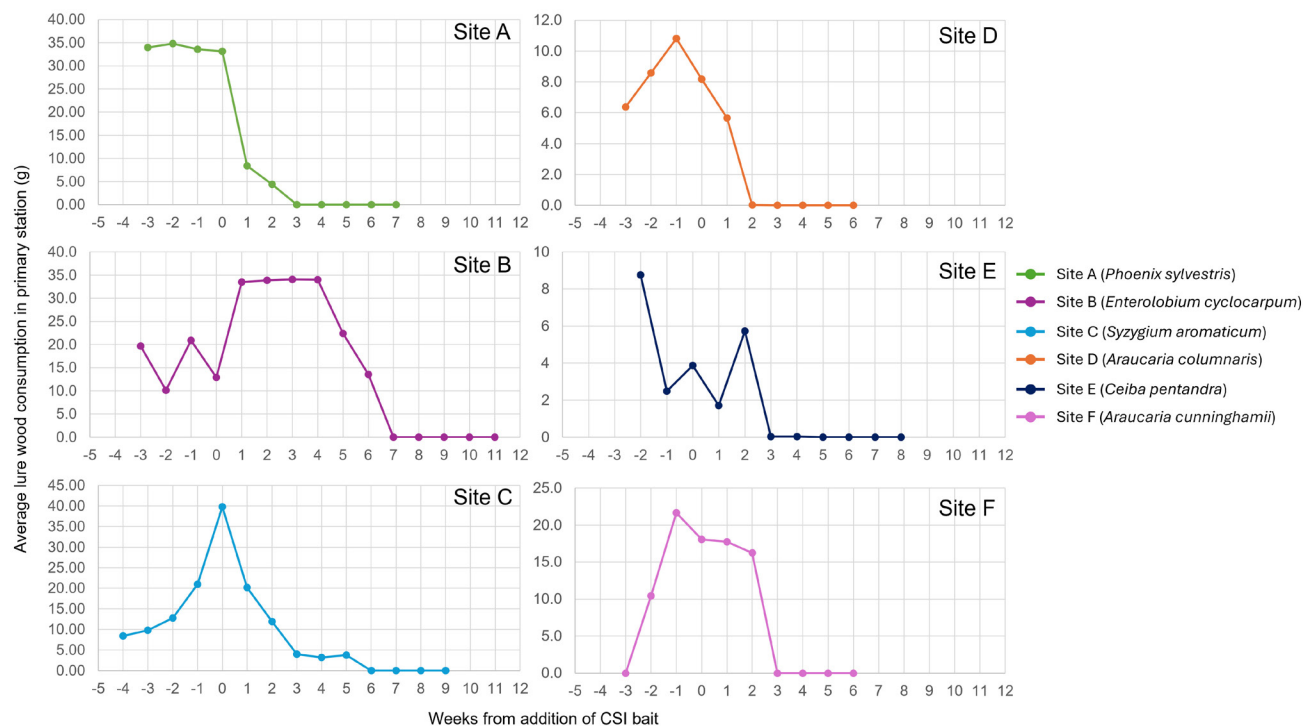


Figure 4. Feeding patterns of subterranean termites on lure wood pieces. (A) *C. curvignathus*. (B) *C. gestroi*. (C) *M. crassus*. (D) *M. carbonarius*. (E) *M. gilvus*. (F) *S. medioobscurus*.



**Figure 5.** Weekly lure wood consumption rates by termites in primary IG stations for different sites and plant hosts. Addition of CSI bait into auxiliary stations was marked as week zero.

to 408.5 g for *C. gestroi*, 240.6 g for *C. curvignathus*, and 324.9 g for *S. medioobscurus* (Table 3).

## DISCUSSION

### Monitoring Capacity of IG Stations for Subterranean Termite Detection

Based on the presented data, it was evident that IG stations were not a suitable tool for monitoring activities of subterranean termite species such as *N. havilandi*, *M. crassus*, and *T. rostratus*, with most of the installed stations remaining inactivated after one year. Meanwhile, the IG station was an effective monitoring tool for *C. curvignathus*, *C. gestroi*, *M. carbonarius*, *M. gilvus*, and *S. medioobscurus*, with installed IG stations activated by respective species in all inland sites. More importantly, for Sites F, G, and K, the presence of these subterranean termite species was not detected based on visual site inspection nor recorded in site inspection history.

However, the detection period showed great variation ranging from 1 week up to 24 weeks after installation. This observation aligns with that of field studies to delineate foraging territories and population sizes of *C. gestroi* that also found the inconsistency in activation of IG termite monitoring stations

(Su et al. 2023). In our study, the activation inconsistency could be attributed to various factors. Firstly, when comparing the combined activation rates for termite species shown to be detectable by IG stations, we could see the stark contrast between inland sites (37.5%) and coastal sites (3.9%). Considering the subterranean behaviors of the detected termites, sandy and saline soil type in coastal sites could have contributed to reduced foraging behaviors of termites underground, leading to the low activation rate of IG stations. Probably, the loose sand particles in coastal sites did not provide sufficient structural support for underground tunnels as compared to loamy soil as seen in inland sites. The low belowground activity of *Coptotermes* in coastal area has also been reported by Li et al. (2017), who found that termite infestation was generally lower in regions with higher salinity level. *Coptotermes* has weak salinity tolerance whereby dehydration symptoms will be quickly displayed after being subjected to saline water (Chiu et al. 2021). Nevertheless, *Coptotermes* still manages to inhabit trees in coastal areas due to their ability to obtain freshwater from the host trees. This reduces the need for underground movement in order to prevent desiccation (Chiu et al. 2021). Furthermore, at Site K,

**Table 3. Total amount of CSI bait consumed by termites until colony elimination and time to colony elimination. CSI (chitin synthesis inhibitor); GB (Gardens by the Bay); HP (Hort Park); SBG (Singapore Botanic Garden).**

Location	Site	Associated tree species	Associated termite species	Consumption rate of CSI bait (g)	Time for colony elimination for both stations (week)
GB	A	<i>P. sylvestris</i>	<i>C. gestroi</i>	206.5	3
	B	<i>E. cyclocarpum</i>	<i>C. gestroi</i>	408.5	7
	C	<i>S. aromaticum</i>	<i>C. gestroi</i>	266.4	6
	D	<i>A. columnaris</i>	<i>C. gestroi</i>	241.1	6
HP	E	<i>C. pentandra</i>	<i>C. gestroi</i>	380.5	5
SBG	F	<i>A. cunninghamii</i>	<i>C. curvignathus</i>	240.6	6
		<i>A. borneensis</i>	<i>S. medioobscurus</i>	324.9	16

frequent intermittent flooding caused termites to abandon IG stations shortly after activation, resulting in inconsistent detection. These sporadic activations may undermine the efficacy of CSI baiting by disrupting sustained bait consumption and reducing the quantity of toxicant transferred within the colony. Nonetheless, the successful detection of *Coptotermes* at Site K—despite its absence during visual assessment—underscores the value of IG stations in identifying infestations of this destructive species.

Lastly, we noticed that once successfully infesting a tree host, subterranean termite species such as *C. gestroi* and *C. curvignathus* had the tendency to forage within or near to the host trees. This behavior could be inferred from the fact that IG stations installed for trees in Sites C and E took 10 and 20 weeks, respectively, to be activated by *C. gestroi*, much higher than the median activation period of 3 weeks. Meanwhile, when trees infested with *C. gestroi* or *C. curvignathus* were felled, the removal of the primary food source repeatedly appeared to force the termites to actively expand their foraging range to find new food sources, leading to activation of nearby IG stations. Site D, with the highest activation rate (3 out of 4 trees) and fastest activation time (1 week after IG station installation) had 2 heavily infested *A. columnaris* removed before the study started. In Site J, all IG stations remained inactive for 13 weeks, but one of the stations became activated 1 week after a cluster of 4 heavily infested *C. equisetifolia* were felled. Similarly, activations of all stations at Site F happened 1 week after heavily infested trees were

felled, although the same set of stations remained inactive for 2 weeks prior to tree removal.

#### **Efficacy of Chlorfluazuron in CSI Bait as a Subterranean Termite Control**

Previous studies confirmed the elimination of termite colonies through CSI baiting via destructive excavation of termite mounds (Lenz et al. 1996; Lee et al. 2014) and underground nests (Yamauchi et al. 1997). In this study, we demonstrate the efficacy of CSI baiting through a 4-week baseline assessment of termite consumption rates (Figure 5). Initially, termites consistently consumed newly replenished wood blocks. However, following CSI baiting (designated as Week 0 in Figure 5), a sustained cessation of feeding was observed (3 to 7 weeks), strongly indicating colony elimination. Additionally, an increased soldier-to-worker ratio was observed toward the end of baiting, consistent with the known larvicidal mode of action of CSI. This effect directly reduces worker populations over time, further supporting colony collapse (Lee et al. 2014).

In terms of termite control, the reported data showed that CSI bait containing chlorfluazuron as the active ingredient was effective in eliminating *C. curvignathus* and *C. gestroi*, moderately effective against *S. medioobscurus*, and not effective in managing *M. carbonarius* and *M. gilvus*. According to Lee et al. (1999) and Sajap et al. (2000), *Coptotermes* has a higher feeding rate under the Malaysian tropical conditions. Tropical termite species tend to have smaller population sizes and smaller foraging

territories when compared to temperate species (Lee 2002). In Malaysia, a colony of *Coptotermes* requires a minimum of one month for suppression of the colony (Lee et al. 2007). In comparison with our results, the time taken to achieve complete termite colony elimination is similar, with the shortest time required for elimination being 6 weeks and the longest time required being 10 weeks. For *S. medioobscurus*, a minimum of 6 months was required for eliminating the entire *Schedorhinotermes* colony. This result aligns with those reported by Lee et al. (2007). Based on our observations of *Schedorhinotermes*, this species has shown feeding preference for wood over bait. This feeding behavior led to a slower horizontal transfer of active ingredients in the bait, resulting in a longer period required for colony elimination. Nonetheless, as discussed previously, *S. medioobscurus* has not been attributed as the primary cause of any tree failure in Singapore.

In this study, no baiting attempts were made for *M. carbonarius* and *M. gilvus*, as these species are not considered the target species for urban tree termite management. Furthermore, higher termites like *M. carbonarius* and *M. gilvus* exhibit distinct biological traits compared to lower termites, particularly the non-moulting nature of higher termite workers and their sporadic foraging behavior. These characteristics rendered low efficiency of CSI baiting (Lee et al. 2014; Chiu and Li 2024). Therefore, from a tree health management perspective, CSI baiting was an effective control method for controlling the two destructive species of subterranean termites in Singapore, which are *C. curvignathus* and *C. gestroi*.

### Comparative Field Study of Subterranean Termite Biology

There were 6 termite species found in this study to be foraging on the lure wood: *C. gestroi*, *C. curvignathus*, *M. carbonarius*, *M. gilvus*, *M. crassus*, and *S. medioobscurus*. Besides *C. gestroi* and *C. curvignathus*, which have been well studied due to their destructive feeding behaviors on structures and trees, the biology and feeding behaviors of *M. carbonarius*, *M. gilvus*, *M. crassus*, and *S. medioobscurus* have not been well documented. According to the literature, *M. carbonarius* and *M. gilvus* are mainly foraging species that feed on dead plant matters such as dead wood, leaf litter, and tree barks (Foo et al. 2014); *M. crassus* feed on decayed or weathered wood and dead

trees (Foo et al. 2014); and *S. medioobscurus* feeds on dead trees or tree stumps (Jasmi and Ahmad 2011; Foo et al. 2014). To our knowledge, there has been no published study that provided data giving comparative insight of potential damage of *C. gestroi*, *C. curvignathus*, *M. carbonarius*, *M. gilvus*, *M. crassus*, and *S. medioobscurus* in trees. Based on the reported weekly consumption rate of lure wood, *M. carbonarius* and *M. crassus* showed negligible lure wood consumption. For *M. carbonarius*, they have a preference for leaf litter over lure wood, which could be clearly indicated by the lesser amount of leaf litter around the termite mound. As for *M. crassus*, their diet is mainly on decayed tree bark and wood litter. This species showed no preference towards fresh wood in our study. Coupled with superficial scraping marks observed on lure wood, our data evidently showed these two species did not pose any risk to tree structural integrity.

Additionally, although belonging to the genus *Macrotermes*, *M. gilvus* displayed a much more aggressive feeding behavior on lure wood, with weekly consumption rates approximately 23 times higher than that of *M. carbonarius*. Despite the relatively higher consumption rate, *M. gilvus* is rather sensitive to its feeding resources. This species tends to abandon occupied stations easily due to slight disturbances which were likely a consequence of routine checks to the station. This finding aligns with the results reported by Iqbal et al. (2017). Furthermore, the feeding pattern of *M. gilvus* was mostly surface scraping with no tunneling, implying that this species would be limited to tree bark and exposed dead wood.

Interestingly, *S. medioobscurus* lure wood consumption was almost comparable to the notoriously destructive *C. gestroi* and *C. curvignathus*. More importantly, *S. medioobscurus* displayed a nearly similar feeding pattern on lure wood as compared to *C. gestroi* and *C. curvignathus*, as this species also created sharp tunnels through the wood as it fed, but to a much lesser extent. Such findings imply potential high damage on trees by *S. medioobscurus*. However, based on our field observations and tree inspection records, all cases of tree failure due to termite infestation in Singapore have been caused by *C. gestroi* or *C. curvignathus*. These results are similar to those described by Cheng et al. (2008), where *C. curvignathus* was the primary species that attacked both living and dead oil palms while *Schedorhinotermes*

was associated with plant residues. Therefore, despite the tunneling feeding behavior with a high consumption rate, *S. medioobscurus* appears to be a potent species that feeds on dead wood while being mostly nondestructive to living trees.

Besides providing a common criterion for comparison in terms of wood damage, we found that IG stations also provided insight into the subterranean termite interspecies dynamics within the site. For instance, data collected from the network of IG stations at Site G suggested that *M. gilvus* was the dominating species foraging the forest floor and *M. carbonarius* was the less dominant species. Meanwhile, data from the Site F stations revealed that *C. curvignathus* played a dominant and antagonistic role to *S. medioobscurus*. The latter species could only expand their foraging range and feeding behavior after *C. curvignathus* had been eliminated from the site.

Ultimately, effective termite management should begin with recognizing their ecological significance through the understanding of termite biology. Termites are not simply pests; many species serve as vital decomposers, contributing to global carbon cycling, nutrient redistribution, and soil health (Umar and Ab Majid 2020a; Ahmad et al. 2021). Concurrently, host susceptibility is another factor that should be considered, because different ornamental trees are known to have varying susceptibility to termite attack (Lee 2014). Generally, softwoods, such as pine, are among the more vulnerable to termites. In contrast, tropical species, such as teak, exhibit greater resistance towards attack by genus *Coptotermes* (Judd 2018). However, not all hardwoods are termite-resistant, as there are multiple factors that could affect the preference of termites, including secondary metabolites, wood density, wood composition, and nutritional value (Judd 2018).

The central challenge, then, is to move beyond broad elimination toward targeted, ecologically grounded strategies—prioritizing surveillance around susceptible tree hosts, focusing control efforts on the most destructive termite species, and preserving nondestructive decomposer species that play critical roles in sustaining urban ecosystem health.

## CONCLUSION

In this study, the IG-CSI system showed great effectiveness in monitoring several subterranean species and exerted significant control over the two most

destructive species, namely *C. curvignathus* and *C. gestroi*. The IG termite monitoring station is suitable for large-scale implementation complementary to visual inspection. The IG-CSI system can be easily scaled up to provide an additional layer of detection and control, which will help to reduce the risk of structural failure for susceptible tree species in urban landscapes. Compared to labor-intensive methods such as resistance drilling and sonic tomography, the IG-CSI system is more cost effective and could be integrated into tree assessment routines without major additional inspection workload. Given Singapore's high manpower costs, this system offers a more economical, viable solution for urban tree management in local context. Due to the nature of the chemical and targeted mode of treatment, the use of CSI as termite control is also much more environmentally friendly as compared to traditional chemical treatment with termiticides. Future work would entail optimizing the IG-CSI system to improve its detection efficiency for coastal environments and well-established termite colonies within infested trees.

## LITERATURE CITED

- Acda MN. 2014. Toxicity and transmission of thiamethoxam in the Asian subterranean termite *Coptotermes gestroi* (Isoptera: Rhinotermitidae). *Journal of Insect Science*. 14(1):222. <https://doi.org/10.1093/jisesa/ieu084>
- Ahmad F, Fouad H, Liang SY, Hu Y, Mo JC. 2021. Termites and Chinese agricultural system: Applications and advances in integrated termite management and chemical control. *Insect Science*. 28(1):2-20. <https://doi.org/10.1111/1744-7917.12726>
- Ahmed MAI, Eraky ESA, Mohamed MF, Soliman AAS. 2015. Potential toxicity assessment of novel selected pesticides against sand termite, *Psammodermes hypostoma* Desneux workers (Isoptera: Rhinotermitidae) under field conditions in Egypt. *Journal of Plant Protection Research*. 55(2):193-197. <https://doi.org/10.1515/jppr-2015-0026>
- Arakawa T, Furuta Y, Miyazawa M, Kato M. 2002. Flufenoxuron, an insect growth regulator, promotes peroral infection by nucleopolyhedrovirus (BmNPV) budded particles in the silkworm, *Bombyx mori* L. *Journal of Virological Methods*. 100(1-2):141-147. [https://doi.org/10.1016/S0166-0934\(01\)00414-1](https://doi.org/10.1016/S0166-0934(01)00414-1)
- Cheng S, Kirton LG, Gurmit S. 2008. Termite attack on oil palm grown on peat soil: Identification of pest species and factors contributing to the problem. *The Planter*. 84(991): 659-670. [https://info.frim.gov.my/infocenter\\_applications/eocompendium/FileCompendium/ec710.pdf](https://info.frim.gov.my/infocenter_applications/eocompendium/FileCompendium/ec710.pdf)
- Chiu CI, Li HF. 2024. Challenges in baiting to manage fungus-growing termite colonies. *Journal of Economic Entomology*. toae276. <https://doi.org/10.1093/jee/toae276>
- Chiu CI, Mullins AJ, Kuan KC, Lin MD, Su NY, Li HF. 2021. Termite salinity tolerance and potential for transoceanic

- dispersal through rafting. *Ecological Entomology*. 46(1):106-116. <https://doi.org/10.1111/een.12946>
- Chouvenec T, Foley JR IV. 2018. *Coptotermes gestroi* (Wasmann) (Blattodea [Isoptera]: Rhinotermitidae), a threat to the Southeastern Florida urban tree canopy. *Florida Entomologist*. 101(1):79-90. <https://doi.org/10.1653/024.101.0115>
- Cowie RH, Logan JWM, Wood TG. 1989. Termite (Isoptera) damage and control in tropical forestry with special reference to Africa and Indo-Malaysia: A review. *Bulletin of Entomological Research*. 79(2):173-184. <https://doi.org/10.1017/S0007485300018150>
- Dhang P. 2011. A preliminary study on elimination of colonies of the mound building termite *Macrotermes gilvus* (Hagen) using a chlorfluazuron termite bait in the Philippines. *Insects*. 2(4):486-490. <https://doi.org/10.3390/insects2040486>
- Foo FK, Ho JHH, How YF, Hu JJ, Koh PKH, Lee CY, Neoh KB. 2014. *Termites of Singapore: A scientific guide for pest management professionals*. Singapore: Singapore Pest Management Association. 176 p.
- Gautam BK, Henderson G. 2014. Comparative evaluation of three chitin synthesis inhibitor termite baits using multiple bioassay designs. *Sociobiology*. 61(1):82-87. <https://doi.org/10.13102/sociobiology.v61i1.82-87>
- Getty GM, Solek CW, Sbragia RJ, Haverty MI, Lewis VR. 2007. Large-scale suppression of a subterranean termite community using the Sentricon® Termite Colony Elimination System: A case study in Chatsworth, California, USA. *Sociobiology*. 50(3):1041-1050. [https://nature.berkeley.edu/upmc/documents/sentricon\\_suppression.pdf](https://nature.berkeley.edu/upmc/documents/sentricon_suppression.pdf)
- Greaves T. 1962. Studies of foraging galleries and the invasion of living trees by *Coptotermes acinaciformis* and *C. brunneus* (Isoptera). *Australian Journal of Zoology*. 10(4):630-651. <https://doi.org/10.1071/ZO9620630>
- Hu XP. 2011. Liquid termiticides: Their role in subterranean termite management. In: Dhang P, editor. *Urban pest management: An environmental perspective*. Wallingford (United Kingdom): CABI. p. 114-132. <https://doi.org/10.1079/9781845938031.0114>
- Iqbal N, Wijedasa LS, Evans TA. 2017. Bait station preferences in two *Macrotermes* species. *Journal of Pest Science*. 90:217-225. <https://doi.org/10.1007/s10340-016-0778-z>
- Jasmi AH, Ahmad AH. 2011. Termite incidence on an *Araucaria* plantation forest in Teluk Bahang, Penang. *Insects*. 2(4):469-474. <https://doi.org/10.3390/insects2040469>
- Judd TM. 2018. Cues used by subterranean termites during foraging and food assessment. In: Khan M, Ahmad W, editors. *Termites and sustainable management*. Vol. 1: Biology, social behaviour and economic importance. Sustainability in plant and crop protection. Cham (Switzerland): Springer. p. 159-180. [https://doi.org/10.1007/978-3-319-72110-1\\_8](https://doi.org/10.1007/978-3-319-72110-1_8)
- Karlinasari L, Lestari AT, Nababan MYS, Siregar IZ, Nandika D. 2018. Assessment of urban tree condition using sonic tomography technology. *IOP Conference Series: Earth and Environmental Science*. 203:012030. <https://doi.org/10.1088/1755-1315/203/1/012030>
- King EG Jr, Spink WT. 1969. Foraging galleries of the Formosan subterranean termite, *Coptotermes formosanus*, in Louisiana. *Annals of the Entomological Society of America*. 62(3):536-542. <https://doi.org/10.1093/aesa/62.3.536>
- Lai PY, Tamashiro M, Yates JR, Su NY, Fujii JK, Ebesu RH. 1983. Living plants in Hawaii attacked by *Coptotermes formosanus*. *Proceedings of the Hawaiian Entomological Society*. 24(2-3):283-286. <http://hdl.handle.net/10125/11161>
- Lee CC, Neoh KB, Lee CY. 2014. Colony size affects the efficacy of bait containing chlorfluazuron against the fungus-growing termite *Macrotermes gilvus* (Blattodea: Termitidae). *Journal of Economic Entomology*. 107(6):2154-2162. <https://doi.org/10.1603/ec14193>
- Lee CY. 2002. Subterranean termite pests and their control in the urban environment in Malaysia. *Sociobiology*. 40(1):3-10. <http://www.chowyang.com/uploads/2/4/3/5/24359966/040.pdf>
- Lee CY. 2014. Urban forest insect pests and their management in Malaysia. *Formosan Entomol.* 33:207-214. <http://www.chowyang.com/uploads/2/4/3/5/24359966/167.pdf>
- Lee CY, Neoh KB. 2023. Management of subterranean termites using liquid termiticides. In: Su NY, Lee CY, editors. *Biology and management of the Formosan subterranean termite and related species*. Wallingford (United Kingdom): CABI. p. 238-272. <https://doi.org/10.1079/9781800621596.0012>
- Lee CY, Vongkaluang C, Lenz M. 2007. Challenges to subterranean termite management of multi-genera faunas in Southeast Asia and Australia. *Sociobiology*. 50(1):213-221. <http://www.chowyang.com/uploads/2/4/3/5/24359966/089.pdf>
- Lee CY, Yap HH, Chong NL, Jaal Z, editors. 1999. *Urban pest control: A Malaysian perspective*. Pulau Pinang (Malaysia): Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia.
- Lenz M, Gleeson PV, Miller LR, Abbey HM. 1996. How predictive are laboratory experiments for assessing the effects of chitin synthesis inhibitors (CSI) on field colonies of termites? A comparison of laboratory and field data from Australian mound-building species of termite. In: *Proceedings of the International Research Group on Wood Preservation Meeting*. 1996 May 19–24; Guadeloupe, France. p. 1-11.
- Lestari AT, Wahyuningsih E, Syaputra M, Suparyana PK. 2021. Assessment of urban tree condition using VTA at Urban Green Space of Mataram University Rectorate. *IOP Conference Series: Earth and Environmental Science*. 918:012033. <https://doi.org/10.1088/1755-1315/918/1/012033>
- Li Y, Dong ZY, Pan DZ, Pan CH, Chen LH. 2017. Effects of termites on soil pH and its application for termite control in Zhejiang Province, China. *Sociobiology*. 64(3):317-326. <https://doi.org/10.13102/sociobiology.v64i3.1674>
- Linhares CSF, Gonçalves R, Martins LM, Knapić S. 2021. Structural stability of urban trees using visual and instrumental techniques: A review. *Forests*. 12(12):1752. <https://doi.org/10.3390/f12121752>
- Ngampongsai A, Permkam S, Sittichaya W, Saiboon S, Maharat K. 2020. Oral toxicity of chitin synthesis inhibitors (CSIs) and plant extracts to rubber termite, *Coptotermes curvignathus* Holmgren (Rhinotermitidae: Isoptera). *Bulgarian Journal of Agricultural Science*. 26(5):966-973.
- Osbrink WLA, Lax AR. 2002. Termite gallery characterization in living trees using digital resistograph technology. In: Jones SC, Zhai J, Robinson WH, editors. *Proceedings of 4th International Conference on Urban Pests*. The 4th International Conference on Urban Pests; 2002 July 7–10; Charleston, SC,

- USA. Blacksburg (VA, USA): Pocahontas Press, Inc. p. 251-258. <https://www.icup.org.uk/media/tczcbqx3/icup301.pdf>
- Osbrink WLA, Woodson WD, Lax AR. 1999. Populations of formosan subterranean termite, *Coptotermes formosanus* (Isoptera: Rhinotermitidae), established in living urban trees in New Orleans, Louisiana, U.S.A. In: Robinson WH, Rettich F, Rambo GW, editors. *Proceedings of the 3rd International Conference on Urban Pests*. The 3rd International Conference on Urban Pests; Prague, Czech Republic. Hronov (Czech Republic): Grafické Závody. p. 341-345. <https://www.icup.org.uk/media/fstnyly2/icup440.pdf>
- Parman V, Vargo EL. 2010. Colony-level effects of imidacloprid in subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*. 103(3):791-798. <https://doi.org/10.1603/ec09386>
- Randall M, Doody TC. 1934. Poison dusts. I. Treatments with poisonous dusts. In: Kofoid CA, editor. *Termites and termite control*. Berkeley (CA, USA): University of California Press. pp. 463-476.
- Ring DR, Henderson G, McCown CR. 2002. Evaluation of the Louisiana state program to treat trees infested with Formosan subterranean termites (Isoptera: Rhinotermitidae) in Louisiana. In: Jones SC, Zhai J, Robinson WH, editors. *Proceedings of 4th International Conference on Urban Pests*. The 4th International Conference on Urban Pests; 2002 July 7-10; Charleston, SC, USA. Blacksburg (VA, USA): Pocahontas Press, Inc. p. 259-266. <https://www.icup.org.uk/media/ldufa2na/icup227.pdf>
- Sajap AS, Amit S, Welker J. 2000. Evaluation of hexaflumuron for controlling the subterranean termite *Coptotermes curvignathus* (Isoptera: Rhinotermitidae) in Malaysia. *Journal of Economic Entomology*. 93(2):429-433. <https://doi.org/10.1603/0022-0493-93.2.429>
- Scheffrahn RH, Su NY. 2000. Asian subterranean termite, *Coptotermes gestroi* (=havilandi) (Wasmann) (Insecta: Isoptera: Rhinotermitidae). Gainesville (FL, USA): IFAS Extension, University of Florida. EENY128. 5 p. <https://doi.org/10.32473/edis-in285-2000>
- Shults P, Richardson S, Eyer PA, Chura M, Barreda H, Davis RW, Vargo EL. 2021. Area-wide elimination of subterranean termite colonies using a novaluron bait. *Insects*. 12(3):192. <https://doi.org/10.3390/insects12030192>
- Smith J, Su NY, Escobar RN. 2006. An areawide population management project for the invasive eastern subterranean termite (Isoptera: Rhinotermitidae) in a low-income community in Santiago, Chile. *American Entomologist*. 52(4):253-260. <https://doi.org/10.1093/ae/52.4.253>
- Su NY. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*. 87(2):389-397. <https://doi.org/10.1093/jee/87.2.389>
- Su NY. 2011. Technological needs for sustainable termite management. *Sociobiology*. 58(1):229-239.
- Su NY. 2019. Development of baits for population management of subterranean termites. *Annual Review of Entomology*. 64(1):115-130. <https://doi.org/10.1146/annurev-ento-011118-112429>
- Su NY, Monteagudo EJ. 2017. Hyperecdysonism in the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*. 110(4):1736-1739. <https://doi.org/10.1093/jee/tox178>
- Su NY, Mullins A, Chouvenec T. 2023. Elimination of structural and tree infestations of the Asian subterranean termite, *Coptotermes gestroi* (Wasmann) (Blattodea: Rhinotermitidae) with noviflumuron baits in above-ground stations. *Journal of Economic Entomology*. 116(3):909-915. <https://doi.org/10.1093/jee/toad077>
- Su NY, Scheffrahn RH. 1986. A method to access, trap, and monitor field populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the urban environment. *Sociobiology*. 12(2):299-304.
- Tho YP. 1992. *Termites of peninsular Malaysia*. In: Kirton LG, editor. Malayan Forest Records, No. 36. Jalan Jelutong (Malaysia): Forest Research Institute Malaysia. <https://ci.nii.ac.jp/ncid/BA25262011>
- Thorne BL, Breisch NL. 2001. Effects of sublethal exposure to imidacloprid on subsequent behavior of subterranean termite *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*. 94(2):492-498. <https://doi.org/10.1603/0022-0493-94.2.492>
- TreesSG. 2020. About the movement: The planting of one million trees. Singapore: National Parks Board. [Updated 2025 April 18]. <https://www.nparks.gov.sg/treesg/one-million-trees-movement/about-the-movement>
- Umar WASW, Ab Majid AH. 2020a. Efficacy of minimum application of chlorfluazuron baiting to control urban subterranean termite populations of *Coptotermes gestroi* (Wasmann) (Blattodea: Rhinotermitidae). *Insects*. 11(9):569. <https://doi.org/10.3390/insects11090569>
- Umar WASW, Ab Majid AH. 2020b. Sustainable termite management using innovative and selective termite baiting method. *IOP Conference Series: Earth and Environmental Science*. 549:012043. <https://doi.org/10.1088/1755-1315/549/1/012043>
- Yamauchi K, Ishikura H, Ogaku J, Maeda I, Aihara A, Uechi K. 1997. Field evaluation of the Centricron System—Confirmation of colony elimination. *Shiroari*. 110:2-6. <https://www.hakutaikyo.or.jp/library/3881>
- Yates JR, Grace JK. 2000. Effective use of above-ground hexaflumuron bait stations for Formosan subterranean termite control (Isoptera: Rhinotermitidae). *Sociobiology*. 35(3):333-356.
- Zimmermann D, Peters W. 1987. Fine structure and permeability of peritrophic membranes of *Calliphora erythrocephala* (Meigen) (Insecta: Diptera) after inhibition of chitin and protein synthesis. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry*. 86(2):353-360. [https://doi.org/10.1016/0305-0491\(87\)90305-1](https://doi.org/10.1016/0305-0491(87)90305-1)
- Zorzenon FJ, Campos AEC. 2015. Subterranean termites in urban forestry: tree preference and management. *Neotropical Entomology*. 44:180-185. <https://doi.org/10.1007/s13744-014-0269-y>

## ACKNOWLEDGEMENTS

The authors would like to express their deepest appreciation to the management teams of Garden by the Bay, Singapore Botanic Garden, National Orchid Garden, Bidadiri Park, East Coast

Park, StreetScapes SouthEast branch, Changi Beach Park, and HortPark for their support to make the study possible.

Jaren Wong Kak Leong (corresponding author)

National Parks Board of Singapore  
Plant Health Laboratory and Advisory  
Plant Science & Health Branch  
Horticulture & Community Division  
Singapore  
jaren\_wong@nparks.gov.sg

Derrick Nguyen Hoang Danh  
National Parks Board of Singapore  
Plant Health Laboratory and Advisory  
Plant Science & Health Branch  
Horticulture & Community Division  
Singapore

**Conflicts of Interest:** The authors reported no conflicts of interest.

**Résumé.** Contexte: Cette recherche a démontré le potentiel des stations de dépistage des termites dans le sol (DLS), couplées à l'appâtage par inhibiteur de synthèse de la chitine (ISC), comme démarche complémentaire à l'inspection visuelle pour la détection et le contrôle des termites dans les arbres à Singapour. Méthodes: En utilisant comme appât des morceaux de bois recueillis dans des stations DLS activées pour servir de base de comparaison, nous avons évalué le caractère destructeur des espèces de termites détectées et rapporté leurs schémas d'alimentation uniques. L'appâtage d'inhibiteurs de la synthèse de la chitine (ISC) avec du chlorfluazuron a été utilisé pour le contrôle des termites. Résultats: Un total de 6 espèces de termites a été dépisté: *Coptotermes gestroi* (Wasmann), *Coptotermes curvignathus* (Holmgren), *Schedorhinotermes medioobscurus* (Holmgren), *Macrotermes gilvus* (Hagen), *Macrotermes carbonarius* (Hagen), et *Microcerotermes crassus* (Snyder). Cependant, le potentiel de dépistage varie en fonction des conditions du site, dont des inondations intermittentes, une salinité élevée du sol et un comportement de quête de nourriture réduit après avoir niché à l'intérieur ou à proximité d'un arbre hôte. Ce comportement de diminution de recherche de nourriture pourrait en partie être affecté lorsque des arbres fortement infestés sont enlevés, forçant les termites à migrer et à chercher de nouvelles sources de nourriture, ce qui entraîne l'activation des stations DLS à proximité. En ce qui concerne la lutte contre les termites, l'appâtage ISC au chlorfluazuron a permis d'éliminer efficacement les colonies de termites de 3 espèces: *C. gestroi*, *C. curvignathus* et *S. medioobscurus*. La période d'élimination des colonies était respectivement de 3 à 6 semaines et de 24 semaines. Conclusion: Compte tenu de l'efficacité des stations DLS couplées à l'appât ISC dans le dépistage et le contrôle des espèces de termites souterraines, l'application à grande échelle de ce système dans un contexte d'arbres urbains est discutée.

**Zusammenfassung.** Hintergrund: Diese Studie zeigte das Potenzial von unterirdischen Termitenüberwachungsstationen (IG) in Verbindung mit Ködern mit Chitinsynthesehemmern

(CSI) als ergänzende Lösung zur visuellen Inspektion für die Erkennung und Bekämpfung von Baumtermitten in Singapur. Methoden: Anhand von Holzstücken, die aus aktivierten IG-Stationen gesammelt wurden und als Vergleichsgrundlage dienten, bewerteten wir die Zerstörungskraft der nachgewiesenen Termitenarten und berichteten über ihre einzigartigen Fressgewohnheiten. Zur Termitenbekämpfung wurden Köder mit dem Chitinsynthesehemmer (CSI) Chlorfluazuron eingesetzt. Ergebnisse: Insgesamt wurden 6 Termitenarten nachgewiesen: *Coptotermes gestroi* (Wasmann), *Coptotermes curvignathus* (Holmgren), *Schedorhinotermes medioobscurus* (Holmgren), *Macrotermes gilvus* (Hagen), *Macrotermes carbonarius* (Hagen) und *Microcerotermes crassus* (Snyder). Die Nachweisbarkeit variierte jedoch je nach Standortbedingungen wie zeitweiligen Überschwemmungen, hohem Salzgehalt des Bodens und vermindertem Futtersuchverhalten nach der Ansiedlung in oder in der Nähe eines Wirtsbaums. Dieses verminderte Futtersuchverhalten könnte zum Teil dadurch beeinflusst werden, dass stark befallene Bäume entfernt werden, wodurch die Termiten zur Wanderung und Suche nach neuen Nahrungsquellen gezwungen werden, was zur Aktivierung in der Nähe befindlicher IG-Stationen führt. In Bezug auf die Termitenbekämpfung konnte durch CSI-Köder mit Chlorfluazuron die Termitenkolonie von drei Arten wirksam beseitigt werden: *C. gestroi*, *C. curvignathus* und *S. medioobscurus*. Die Zeit bis zur Beseitigung der Kolonie lag zwischen 3 und 6 Wochen bzw. 24 Wochen. Fazit: Angesichts der Wirksamkeit von IG-Stationen in Verbindung mit CSI-Ködern bei der Erkennung und Bekämpfung von unterirdischen Termitenarten wird die großflächige Anwendung dieses Systems im städtischen Baumbestand diskutiert.

**Resumen.** Antecedentes: Este estudio demostró el potencial de las estaciones de monitoreo para termitas en el suelo (IG) en conjunto con cebo inhibidor de síntesis de quitina (CSI) como una solución complementaria a la inspección visual para la detección y control de termitas en árboles, en Singapur. Métodos: Utilizando trozos de madera de cebo recolectados de estaciones IG activadas como base de comparación, evaluamos la destructividad de las especies de termitas detectadas y reportamos sus patrones de alimentación únicos. Se utilizó cebo inhibidor de la síntesis de quitina (CSI) con clorfluazuron para el control de termitas. Resultados: Se detectaron un total de 6 especies de termitas: *Coptotermes gestroi* (Wasmann), *Coptotermes curvignathus* (Holmgren), *Schedorhinotermes medioobscurus* (Holmgren), *Macrotermes gilvus* (Hagen), *Macrotermes carbonarius* (Hagen) y *Microcerotermes crassus* (Snyder). Sin embargo, la capacidad de detección varió dependiendo de las condiciones del sitio, tales como eventos de inundaciones intermitentes, alta salinidad del suelo y comportamiento de forrajeo reducido después de anidar dentro o cerca de un árbol huésped. Este comportamiento de forrajeo reducido, en parte, podría verse afectado cuando se eliminan árboles muy infestados, lo que obliga a las termitas a migrar y buscar nuevas fuentes de alimento, lo que lleva a la activación de estaciones IG cercanas. En términos de control de termitas, el cebo CSI con clorfluazuron podría eliminar eficazmente las colonias de termitas para 3 especies: *C. gestroi*, *C. curvignathus* y *S. medioobscurus*. El tiempo de eliminación de colonias osciló entre 3 y 6 semanas y 24 semanas, respectivamente.

Conclusión: Considerando la efectividad de las estaciones IG acopladas con cebo CSI en la detección y control de especies de termitas subterráneas, se discute la aplicación a gran escala de este sistema en un contexto de arbolado urbano.