

ASSESSING POPULATION ESTIMATION TECHNIQUES FOR *ODONTOTERMES* TERMITES AT VARIOUS LOCATIONS IN MULTAN, PAKISTAN

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ABSTRACT

Termites are important soil dwelling insects known for their severe economic losses to agriculture, forestry, timber and construction sectors. Accurate estimation of termite colony population is critical for evaluating the efficacy of management strategies at a given site. Present study involved estimating the population of a fungus growing termite, *Odontotermes* spp. at three contrasting sites (urban, semi-urban, and agricultural areas) in District Multan, Pakistan. For this purpose, two contrasting techniques were applied: mark-recapture and constant removal methods (regression and maximum likelihood). The results indicated that mark-recapture yielded higher estimates at agriculture site (1851376) followed by urban (948153.45) and semi-urban site (737816.73). The constant removal technique yielded higher population estimates at semi-urban site (16932.36 by regression method and 10118.73 by maximum likelihood method) while the lowest estimates (9580.67-13670) were calculated at agriculture site by both constant removal methods. The findings will be helpful to explore population distribution pattern across different ecological zones and seasons, and study implications for termite management at different sites.

Keywords: Constant removal estimate; fungus-growing termites, *Odontotermes*; population estimation; mark recapture; various habitats.

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Published first online March 08, 2026

Published final May 05, 2026

INTRODUCTION

Termites are eusocial insects and ecologically significant soil-dwelling organisms, known for their caste-based polymorphism, cooperative brood care, and complex colony structure which may include hundreds to millions of individuals (Fei and Henderson, 2002). They are ecologically important as they help to recycle nutrients, decompose organic matter, and maintain soil structure, and are found in diverse habitats across all continents except Antarctica (Taylor, 2000). Exceptionally large population densities of termites have been recorded; for example, in savanna, the termite density with its living biomass is estimated about 70-110 kg/h (Govorushko, 2019). Most of the known termite species have a beneficial role in different ecosystems (Jouquet *et al.*, 2006); however, few are known due to their damaging nature to agricultural crops, forests, timber and lumber, causing economic losses (Verma *et al.*, 2009; Iqbal and Saeed, 2013). They are economically important, as they help in recycling and the breakdown of organic matter, dung removal, are used as food and feed source for human and animals, have medicinal uses, loosen the soil, improve soil fertility, and act as decomposers for waste cellulose products. But at the

same time, they are highly damaging polyphagous pests of forests, agricultural crops, plants, and structures. The harmful termite species in North America are 9, 16 in Australia, 26 in India and Pakistan, 24 in Tropical Africa, and 17 in Central America (Scheffrahn and Su, 2000). The distribution and abundance of soil organisms are dependent on multiple ecological factors like chemical and physical soil characteristics and local weather (Ettema and Wardle, 2002; Rossi and Allenby, 2003; Iqbal *et al.*, 2015). Moreover, life history characteristics such as size and growth of soil dwelling individuals, body size at maturity, life cycle duration and numbers of young ones, largely depends on the availability of soil resources (Bignell and Eggleton, 2000; Lenz *et al.*, 2009).

The colony size of termites is influenced by its surroundings, food supply, and location. Some colonies are small, while others may house hundreds of thousands of individuals. A mature colony of *Coptotermes formosanus* (Shiraki) may contain one to four million individuals (Su and Scheffrahn 1988). Termite colony of *Reticulitermes flavipes* Kollar, may have a colony size of about 200,000 termites and the colony may have a foraging range of about 100 m without any fix direction (Howard *et al.*, 1982). The common type of termite colony is a mound. Most of the species usually constructs

a distinctive mound, though mound sizes and shapes within a species can vary according to the geographical locations. All termites, other than grass eating species, make tunnels connecting their house structures to the food source and this connection of tunnels with soil is the indication of infestation by subterranean termites. A variety of tunnels constructed by termites are the reasons of humidity and darkness in the nest necessary to avoid desiccation and helping in foraging and protection from predators (Lewis, 1997).

Multiple techniques are used to estimate the termite populations, including direct counting (Darlington *et al.*, 1992; Iqbal *et al.*, 2015), mark-recapture method by Su and Scheffrahn (1988) and Evans (2004), and the constant removal technique (Evans, 2004; Iqbal *et al.*, 2015; Iqbal *et al.*, 2021). In the direct-count method, a primary termite nest is located, followed by excavation and counting of every individual present; however, the foraging workers are excluded (Evans *et al.*, 1999; Neoh and Lee, 2023). Mark-recapture is an alternative technique which is used in subterranean species, as their nests are much deeper for excavation. However, at the same time, it has limitations because dyes can be lost or transferred through cannibalism, marked individuals may not evenly mix with the unmarked individuals in the colony, and higher fluctuation in the colony estimates (Curtis and Waller, 1997). Many of the limitations the mark-recapture method has been reported by Thorne *et al.*, (1996) and Evans (2004). Another method, known as constant removal, was developed by entomologists and is used for insects including termites (Southwood and Henderson, 2000; Evans, 2004). Of all these methods, the mark-recapture technique is considered a suitable option for delineating termite colonies. The objective of the study was to estimate population of *Odontotermes* spp. in different habitat using constant removal and mark-recapture techniques. Here, we hypothesized that mark recapture technique produces higher estimates at agriculture sites due to its lower colony disturbance.

MATERIALS AND METHODS

Study sites: The study was carried out during April-October 2023 at three different sites including urban, semi-urban and agricultural areas/forest plantations. Three different locations were selected so as to represent diverse land use types and environmental conditions which may affect the termite activity. The sites differed in vegetation cover, soil disturbance frequency, and human interference, which play a crucial role in determining the termite colony establishment and population levels. The site selection was therefore, done to observe the *Odontotermes* population dynamics across this habitat and resource-based gradient. Five different locations were selected within each site, making a total of 15 sampling locations (Table 1). Every sampling point

was at least 50 m away from each other (Wood, 1991; Wen *et al.*, 2014).

In urban areas, for first three sampling sites, monitoring traps were installed on the borders of the residential lawns. For other two sampling sites, the monitoring traps were installed outside the houses, on the other side of the street, under the trees, including chinaberry tree (*Melia azedarach* L.) (Meliaceae), *Conocarpus* sp. (Combretaceae), and Indian beech tree (*Pongamia pinnata*) Adans. (Fabaceae). These trees were planted on a large residential lawn shared by multiple houses.

Five sites for semi-urban locations were selected which represented the transitional areas between the rural and the urban areas. The first four locations were inside a newly developed university campus of MNS University of Agriculture Multan Pakistan (Table 1). In these four sites traps were randomly placed on the unmanaged grass fields, with no agricultural interventions. The nearby tree species included gum arabic tree *Vachellia nilotica* (L.) (Fabaceae), black mulberry *Morus nigra* L. (Moraceae), Indian beech tree *Pongamia pinnata* (L.) (Fabaceae), *Conocarpus* sp. (Combretaceae), java plum *Syzygium cumini* (L.) Skeels. (Myrtaceae), and Indian jujube *Ziziphus mauritiana* Lam. (Rhamnaceae). The last site was selected in a newly developed plant nursery in a semi-urban area consisting of nurseries of garlic *Allium sativum* L. (Amaryllidaceae) and onion *Allium cepa* L. (Amaryllidaceae).

For agricultural and tree plantation locations, the traps were placed ~10 m away from the border of the agricultural fields. The crops cultivated in the fields included upland cotton *Gossypium hirsutum* (L.), common wheat *Triticum aestivum* L. (Poaceae), and maize *Zea mays* L. (Poaceae). Pesticide applications were made to manage insect pests in maize and cotton; however, no pesticide applications were done in wheat. While the forest plantations consisted of various types of trees including gum Arabic tree *Vachellia nilotica* (L.) (Fabaceae), Indian rosewood tree *Dalbergia sissoo* Roxb. (Fabaceae), sacred fig tree *Ficus religiosa* L. (Moraceae) and river red gum tree *Eucalyptus camaldulensis* Dehnh. (Myrtaceae).

Installation of monitoring stations: Underground monitoring stations were installed, each consisting of a cylindrical plastic container, having a volume of 7791.79 cm³. Holes were made on the sides and the bottom of the container by using hot iron rebar (6 mm width) held using slip joint pliers. Each of the wood bait stations had ten pieces of *Mangifera indica* L. (Anacardiaceae) wood as bait material, each measuring 22.86 cm × 7.62 cm × 2.54 cm.

The cylindrical plastic container was inserted by drilling a 30.48 cm deep hole underground. The plastic container was then covered with the thick polythene sheet

that was again covered with the soil by making the equal surface with the surrounding ground area. These stations were weekly monitored for termite activity. Numbers of termites from one piece of bait type were counted.

Population Estimation of *Odontotermes* spp.: Termite colonies of *Odontotermes* spp. were already delineated and named as colony 1 (C1), colony 2 (C2), colony 3 (C3) and so on. Termite activity in the monitoring stations of these colonies was monitored weekly. The population of *Odontotermes* spp. was estimated April-October 2023 by using two methods i.e., mark-release-recapture technique and constant removal technique (Evans, 2004; Iqbal *et al.*, 2015).

Estimation of population by mark-release-recapture technique: The method used was Captured, Marked, Released and Recaptured. Nile blue A and Neutral Red Fat stain dyes were used for marking. Termites were captured from a monitoring station with maximum termite population and marked by feeding the dyed filter papers with stains Nile Blue A (dye content = $\geq 75\%$, Macklin) and Neutral Red (dye content = 90%, Sigma Aldrich) @ 0.84g/200ml distilled water (Iqbal *et al.*, 2015). The total marked and healthy individuals were counted and placed in the respective monitoring station from where they were previously collected for marking. The termites from each colony were recaptured and numbers of unmarked and marked individuals were counted again. This recapture from alternate stations was repeated 3 times at weekly interval. Population of termites in a specific colony was calculated by using the methodology of Evans *et al.*, (1998) and Iqbal *et al.*, (2015). The mark-recapture population estimates were calculated using the Lincoln (1930) method:

$$PE_{MRi} = MU_i / (R_i + 1)$$

where PE_{MRi} is the mark-recapture population estimate of the i th sample, M = number of workers marked and released, U_i = number of unmarked workers in the i th sample and R_i = number of marked workers in the i th sample (i.e. the recaptured workers in that sample) (Southwood and Henderson, 2000; Evans, 2004; Iqbal *et al.*, 2015).

Estimation of population by constant removal technique: In each monitoring station ten pieces of wood were used. One monitoring station was sampled from each selected colony at each sampling date and all the collected termite workers were shifted to the laboratory where they were separated from soil by following the methodology of Gay *et al.*, (1955). The termite individuals from the monitoring stations of each colony were collected for four weeks (the station once sampled was not used in the next sampling). The population was estimated by regression method and also by following the methodology of Moran-Zippin maximum likelihood

method (Moran, 1951; Zippin, 1956; Zippin, 1958 and Southwood and Henderson, 2000).

In first method, plotting of the number of workers was done that were sampled on each occasion against the cumulative number of workers removed previously, and calculating sample size for $x = 0$. The second constant removal population estimate required the calculation of several parameters:

$$S = \sum^k (i - 1) y_i$$

where S is sum of the product of sample number i multiplied by the sample size y_i from $i = 0$ to the maximum of k samples,

$$R = q/p - kq^k / (1 - q^k)$$

where R is also the ratio S/T , where T = the total number of workers caught, p = probability of capture on any given occasion, and q = probability of not being captured on any given occasion, or $1-p$. Solving this equation for q by trial and error allowed the calculation of the population estimate thus:

$$PE_{CR} = T / (1 - q^k)$$

where PE_{CR} is the constant removal population estimate (Moran 1951; Zippin, 1956; Zippin, 1958; Southwood, 1978; Southwood and Henderson 2000). An estimate of the standard error of the population estimate was calculated also:

$$SE_{PE_{CR}} = (PE_{CR} (PE_{CR} - T) T / (T^2 - PE_{CR} - T) ((kp^k)2/q))^{0.5}$$

where $SE_{PE_{CR}}$ is the standard error of the constant removal population estimate, and PE_{CR} is the constant removal population estimate (Southwood, 1978; Southwood and Henderson, 2000). A ratio that measured the variation between the two estimates was calculated by dividing the constant removal population estimate calculated by regression with that calculated by the maximum likelihood method; this ratio was used as an indication of reliability, along with the regression slope and q (Evans, 2004).

RESULTS

Population estimation of *Odontotermes* spp. by constant removal and mark-release-recapture techniques

Population estimation of *Odontotermes* spp. in urban areas at Multan: In urban areas of Multan, all *Odontotermes* spp. colonies (C1-C11) yielded consistent and positive population estimates using both the regression method and maximum likelihood methods of constant removal techniques. Positive regression slopes and $q > 1$ showed the results were in line with the expectations of both methods (Figure 1a, 1b). The population estimates using the regression method ranged from 9,146 to 27,387 individuals, while estimates from the maximum likelihood methods ranged between 6,351 to 14,509 individuals (Table 2). In comparison, mark-

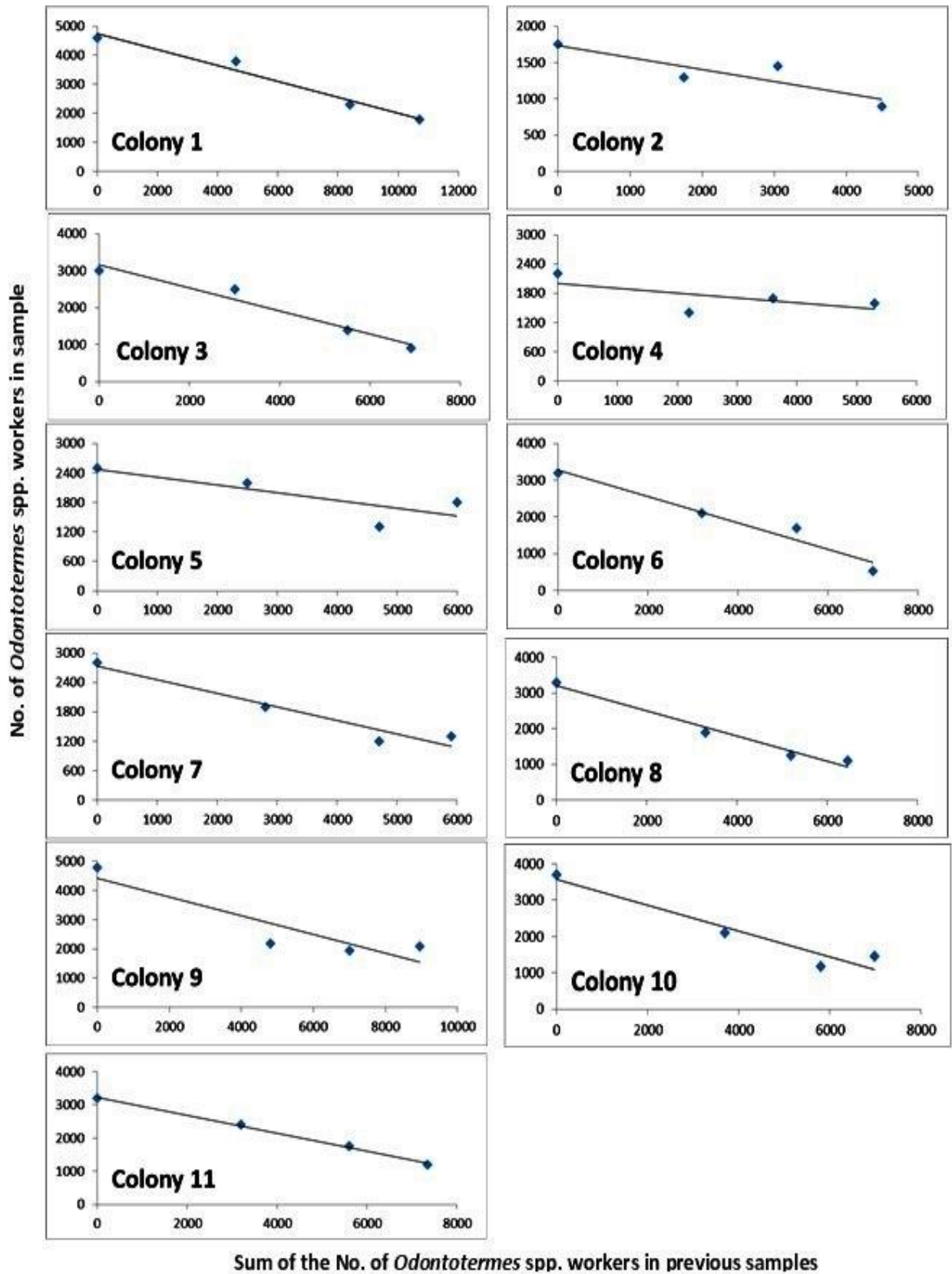


Figure 1: Regression plots for calculation of the constant removal population estimates of eleven colonies (C1-C11) of *Odontotermes* spp. in urban areas at Multan.

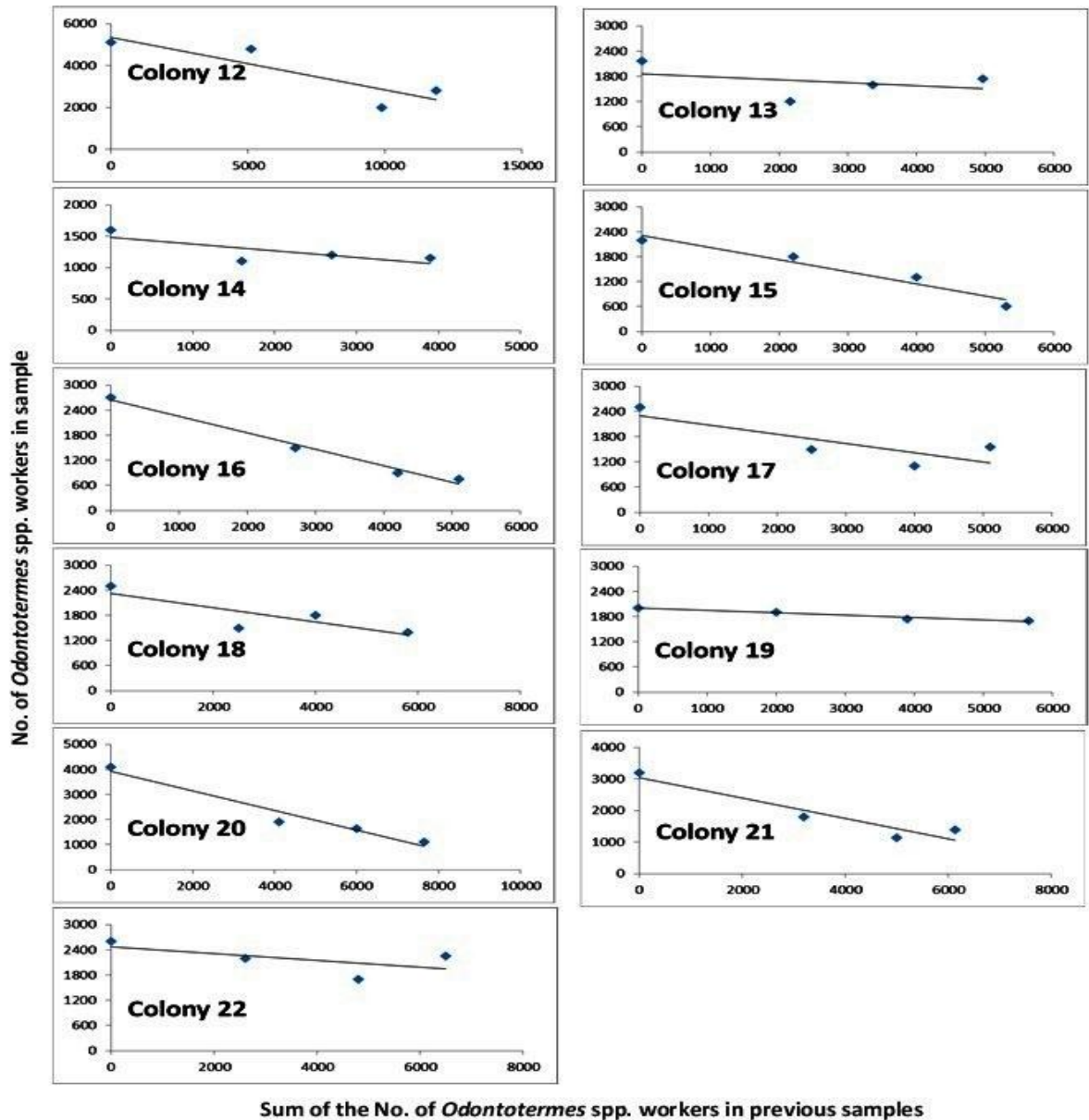


Figure 2: Regression plots for calculation of the constant removal population estimates of eleven colonies (C12-C22) of *Odontotermes* spp. in semi-urban areas at Multan.

release-recapture technique estimated higher population of these colonies, ranging from 447,550 to 1,723,908 (Table 2).

Population estimation of *Odontotermes* spp. in semi-urban areas at Multan: In semi-urban areas of Multan, *Odontotermes* spp. colonies, C12-C22, also had positive constant removal population estimates. The number of *Odontotermes* spp. workers (collected from each monitoring station) did not show significant difference among samples. The positive regression slopes of colonies and $q > 1$ showed that the results were in line with the expectations of methods (Figure 2a, 2b). The worker population ranged from 6707 to 35788 using

regression method, and from 6421 to 17562 based on the maximum likelihood method (Table 2). In comparison of the constant removal population estimation method, the mark-recapture technique calculated higher population estimates of C12-C22 colonies, ranging from 228,642 to 1,839,091 in semi-urban areas (Table 2).

Population estimation of *Odontotermes* spp. in agricultural areas at Multan: The number of *Odontotermes* spp. workers (collected per monitoring station) did not show significant difference in all three colonies (C23-C25) at agriculture areas of Multan. The positive regression slopes of colonies and $q > 1$ showed that the assumptions underlying constant removal method

were satisfied. (Figure 3). The population of workers across all three colonies at agricultural areas of Multan varied from 9,083 to 19,981 using regression method, and from 8,484 to 10,302 based on the maximum likelihood methods (Table 2). Comparison to the constant removal

method, population estimation of C23-C25 colonies using mark-recapture technique yielded higher termite worker population, ranging from 1,557,956 to 2,297,525 (Table 2).

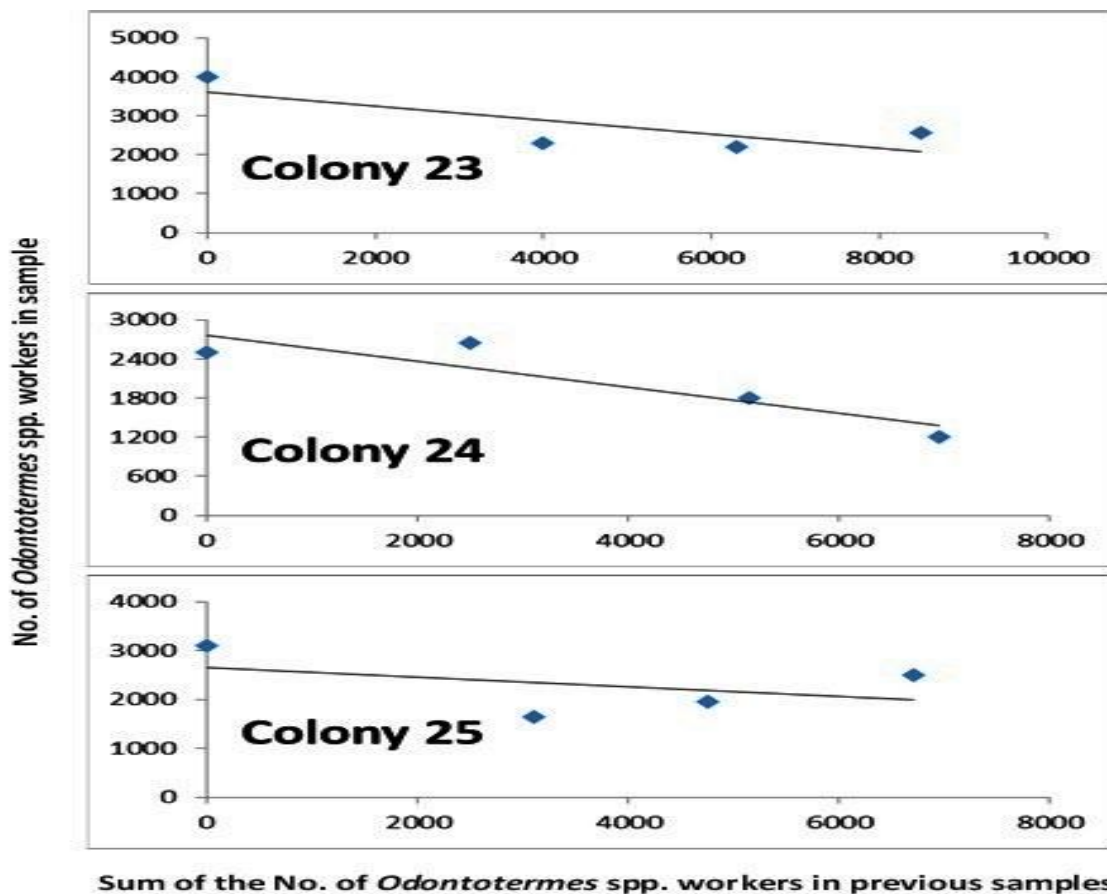


Figure 3: Regression plots for calculation of the constant removal population estimates of eleven colonies (C1-C11) of *Odontotermes* spp. in agriculture areas at Multan.

Table 1: Study sites at different locations in Multan, Pakistan

Location	Study sites	Study sites areas	Site coordinates
Urban	1	Nishtar Medical College & Hospital Multan (Residential area)	30.2011, -71.4416
	2	Nishtar Medical College & Hospital Multan (Residential area)	30.2015, -71.4418
	3	Nishtar Medical College & Hospital Multan (Residential area)	30.2019, -71.4409
	4	Mujahid Town, Old Shujabad Road Multan (Residential area)	30.1559, -71.4399
	5	Mujahid Town, Old Shujabad Road Multan (Residential area)	30.1535; -71.4361
Semi-urban	1	MNS University of Agriculture Multan, Pakistan	30.1576, -71.4493
	2	MNS University of Agriculture Multan, Pakistan	30.1458, -71.4477
	3	MNS University of Agriculture Multan, Pakistan	30.2451, -71.3042
	4	MNS University of Agriculture Multan, Pakistan	30.1467, -71.4482
	5	Near Head Muhammad Wala, Multan	30.2451, -71.3042
Agricultural Areas/Forest Plantation	1	MNS University of Agriculture Multan, Pakistan	30.1423, -71.4432
	2	MNS University of Agriculture Multan, Pakistan	30.1415-71.4472
	3	Bahauddin Zakariya University Multan, Pakistan	30.2574, -71.5146
	4	Bahauddin Zakariya University Multan, Pakistan	30.2580, -71.5106
	5	Bahauddin Zakariya University Multan, Pakistan	30.2580-71.5073

Table 2: Population estimates of *Odontoternes* spp. colonies of in urban areas, semi-urban and agriculture areas of Multan calculated by constant removal (regression and maximum likelihood methods) and mark-recapture techniques.

Site	Colony	Regression method		Maximum likelihood method			Ratio Regression/ Maximum likelihood	Mark-recapture population estimate
		Equation	Constant removal population estimate	q	Constant removal population estimate	SE		
Urban Area	1	y = 4746 - 0.273x	17345	0.610	14509	95.474	1.195	447550 ± 133826.994
	2	y = 1732 - 0.164x	10535	0.622	6351	68.372	1.659	751850 ± 216999.411
	3	y = 3153 - 0.312x	10087	0.578	8780	60.351	1.149	1723908 ± 233757.193
	4	y = 1994 - 0.097x	20510	0.657	8480	100.124	2.419	457972 ± 61429.492
	5	y = 2478 - 0.160x	15469	0.600	8961	70.284	1.726	1427706 ± 215046.023
	6	y = 3266 - 0.357x	9146	0.543	8247	46.815	1.109	1360628 ± 252927.764
	7	y = 2726 - 0.276x	9858	0.743	10356	209.703	0.952	1229367 ± 108425.74
	8	y = 2761 - 0.198x	13920	0.653	9961	105.565	1.397	476796 ± 110894.583
	9	y = 4431 - 0.321x	13774	0.618	12937	95.034	1.065	1004183 ± 79481.454
	10	y = 3570 - 0.355x	10055	0.586	9557	66.289	1.052	602972 ± 44140.028
	11	y = 2652 - 0.096x	27387	0.677	11647	134.999	2.352	946756 ± 296870.201
Semi-urban Area	Average		14371.45		9980.54			948153.45
	12	y = 5355 - 0.251x	21296	0.637	17562	125.700	1.213	746950 ± 121129.574
	13	y = 1864 - 0.071x	26192	0.747	9744	210.151	2.688	228642 ± 46557.653
	14	y = 1478 - 0.105x	14057	0.722	6934	145.330	2.027	260733 ± 81532.006
	15	y = 2312 - 0.291x	7938	0.588	6702	56.267	1.185	789109 ± 102182.091
	16	y = 2646 - 0.394x	6707	0.546	6421	42.098	1.045	730160 ± 204450.88
	17	y = 2303 - 0.220x	10425	0.672	8354	110.351	1.248	321759 ± 83210.280
	18	y = 2322 - 0.169x	13668	0.687	9264	129.349	1.476	805338 ± 212317.288
	19	y = 1998 - 0.055x	35788	0.743	13572	211.876	3.385	655238 ± 85219.279
	20	y = 3921 - 0.391x	10015	0.555	9656	54.656	1.037	1839091 ± 163335.159
	21	y = 3047 - 0.325x	9372	0.607	8713	72.544	1.076	988300 ± 281154.075
22	y = 2465 - 0.080x	30798	0.736	14384	216.766	2.487	750664 ± 21896.162	
	Average		16932.36364		10118.72727			737816.72
Agriculture Area	23	y = 3615 - 0.180x	19981	0.690	10302	164.254	1.397	2297525 ± 254040.733
	24	y = 3207 - 0.353x	9083	0.576	8484	58.569	1.071	1557956 ± 177843.097
	25	y = 3228 - 0.270x	11946	0.613	9956	80.662	1.200	1698647 ± 97249.103

q = probability of not being captured on any given occasion. SE = estimate of the standard error for the constant removal population estimates.

DISCUSSION

The current study examined the population sizes of *Odontotermes* spp. using two different methods: mark-recapture and constant removal (regression and maximum likelihood), across three different study sites in Multan, which were selected based land use type, i.e., urban, semi-urban, and agricultural site. The results showed that the mark-recapture technique yielded the highest population estimates at the agricultural site, followed by urban and semi-urban sites, while the constant removal method provided the highest estimates at the semi-urban site and the lowest at the agricultural site. These contrasting patterns show the ecological variation among the study sites as well as the potential of each method to estimate the termite activity and the colony structure.

Mark-recapture technique is widely used in ecological studies to estimate animal population sizes, where direct counts are not manageable (Jarrett *et al.*, 2022; Haney, 2023; Tourani, 2022). Subterranean termites have cryptic behavior and therefore the colony estimation is challenging (Lin *et al.*, 2025; Chouvinc *et al.*, 2022; Chouvinc, 2023). The technique has been used by many scientists around the world mainly for termite colony delineation (Haney, 2023) and population estimation (Su and Scheffrahn, 1988; DeMark *et al.*, 1995; Su *et al.*, 1991; Atkinson, 2000; Sajap *et al.*, 2000; Lee 2001; Lee *et al.*, 2006; Gazdick *et al.*, 2025). Huang *et al.*, (2006) estimated the population *O. formosanus* using mark-recapture technique at three sites in China. The population estimates (434,000-707,000) were lower compared to the estimates in the current study. This difference in population estimates might be due to the difference in the bait material, i.e., turnup straw boards. Recent studies provide evidence that the bait material type and size strongly influence the termite foraging preference and hence, the population recruitment towards the bait (Chiu and Li, 2025; Davoodi *et al.*, 2025).

In another study, AB Majid and Ahmad (2015) studied the population estimates (106,592-4,185,000) of Asian subterranean termite, *Coptotermes gestroi* (Wasmann) (Blattodea: Rhinotermitidae) at eight sites using pine wood billets as bait attractant. This study showed higher estimates at greenhouse site as compared to the sites with established building structures. These results were similar to our study as higher estimates were recorded at the agricultural site, compared to the urban and semi-urban sites. Similarly, a couple of studies (Ab Majid and Ahmad, 2011; Majid *et al.*, 2008) has demonstrated lower estimates of mound building termite *Globitermes sulphureus* (Haviland, 1898) (Blattodea: Termitidae) in wooden structures and of *C. gestroi* at single house unit house in Malaysia. Similar results were reported by Lee *et al.*, (2003), who gave population estimates of four colonies of *Ancistrotermes pakisticus* (Ahmad) (Blattodea: Termitidae) ranging from 1.07×10^5

to 5.59×10^5 . Ngee and Lee (2002) reported that the vegetation and presence of other termite species in a given area affect re-capture of termites and ultimately the colony population. They estimated the population of *G. sulphureus* ranging from 1.24×10^6 to 4.02×10^6 for two colonies. Gazdick *et al.*, 2025 also estimated the population of Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Blattodea: Rhinotermitidae) ranging between 531900 to 4193792 individuals. Studies have shown that the differences in spatial structure, colony age and environment also affect the recruitment of termites towards bait hence colony estimates (Davies *et al.*, 2021; Chiu and Li, 2025; Chouvinc, 2025).

The constant removal techniques estimate population size based on decreasing capture counts over successive collection events. This technique has not only been used for population estimate of termites (Evans, 2004), but also of other species including fish, reptiles and mammals (Rivera and McCrea, 2021). The current study represented the highest constant removal population estimates at the semi-urban site (16932.36 by regression; 10118.73 by maximum likelihood). The higher value might be due to complex habitat structure that supported higher termite recruitment over longer sampling periods, thus allowing better capture dynamics. Iqbal *et al.*, (2015) reported that the mean population of the fungus-growing termite, *Microtermes mycophagus* (Desneux) (Blattodea: Termitidae) ranged from 16,499 to 40,265 individuals per nest when estimated using the constant removal technique. The study also reported that population estimates obtained through this technique were relatively lower as compared to those reported by Ewart and French (1988) and Evans (2004). However, a reason of this difference could be the different termite species in these studies. Evans (2004) estimated the population of 15 colonies of milk termite, *Coptotermes lacteus* (Froggatt) (Blattodea: Rhinotermitidae) and found that colony sizes ranged from 451 to 172,000 individuals by using the regression method, and from 2,480 to 156,000 individuals by using the maximum likelihood method. In the current study, a total of 25 termite colonies were used to estimate population size, and it used both the regression and maximum likelihood methods, as done by Evans (2004).

For population estimation of termites, removal sampling has been validated against other methods; for instance, constant removal provided more reasonable forager population estimates for *C. lacteus* compared with mark-recapture technique, when sampling assumptions were satisfied in both cleared farmland and plantation habitats (Evans, 2004), which highlights the importance of habitat conditions on capture dynamics. Recent review shows that the termite sampling effectiveness and the abundance estimates may fluctuate with habitat complexity and disturbances, as termites are

functionally linked to soil structure, vegetation resources, and microhabitats (Davies *et al.*, 2021). Semi-urban environments differ from the agricultural sites as they contain a mixture of different landscape features, including ornamental plants, scattered wooden structures, and soil with less frequent disturbance levels (Kodym *et al.*, 2025). This heterogeneity creates stable conditions which allows the termite colonies to persist longer and maintain active foraging populations in the given area. On the other side, intensively managed agricultural lands have routine agricultural operations including tillage, chemical use, and crop rotation which disrupts the termite colonies and reduce their foraging efficiency (Ghode and Nema, 2025; Ghode, 2025). These differences in the habitat type provides the ecological support to the termite diversity. A study from urban ecosystem has documented the differences in the termite diversity and infestation levels on trees in less disturbed urban green belts (Afzal and Rasib, 2022). In agricultural ecosystem, the regular disturbance in soil might push termites to construct deeper colonies, which in turn may reduce the probability of termite capture over repeated removal events (Anyango *et al.*, 2020).

Beyond land use, the existing environmental conditions also play an important role in termite population estimation. The termite population is affected by soil moisture, organic matter, temperature, and arrangement/type of the plants in a given location (Anyango *et al.*, 2020; Istifanus *et al.*, 2023; Madonsela and Magagula, 2024). Agricultural landscapes has abundant organic matter and exposed soil surfaces, which facilitates the termite foraging and in turn could increase the probability of overestimation of termite population (Brichi *et al.*, 2023). On the other hand, urban and semi-urban sites, provides fragmented food resources which are scattered across different microhabitats, which reduces the probability of termite encounters, and in turn, lower population estimates. These differences due to the study sites explain the variations observed in the current study.

Conclusion: Termite population of depends upon the colony age and species however the *Odontotermes* spp. mark-recapture population estimates in the current study were comparatively higher in agriculture areas followed by urban and semi-urban areas. This study highlights that the mark-release-recapture technique consistently yields higher, and potentially more estimates of foraging termite populations as compared to the constant removal methods. These findings also show the importance of selecting population estimation protocols that minimize termite colony disturbance, which is crucial for the effective implementation of targeted baiting strategies in termite management programs.

Contribution of the Authors: Naeem Iqbal and Shafqat Saeed designed the study, Hafiza Tahira Gul performed

the experiment, Naeem Iqbal and Hafiza Tahira Gul analyzed the data, Naeem Iqbal, Shafqat Saeed and Ishtiaq A. Rajwana supervised the study, Hafiza Tahira Gul and Naeem Iqbal prepared the first draft of experiment, Shafqat Saeed and Ishtiaq A. Rajwana approved the final version of manuscript.

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