Colony Characteristics and Seasonal Activity of the Formosan Subterranean Termite (Isoptera: Rhinotermitidae) in Louis Armstrong Park, New Orleans, Louisiana[1]

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Abstract Beginning in 1998, multiple mark-recapture studies were conducted inside 12.75-ha Louis Armstrong Park in New Orleans, LA, to locate and characterize all detectable colonies of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), established within the park. This is the first attempt to characterize subterranean termite colonies on such a large scale within a defined area. As a result, 13 *C. formosanus* colonies were identified using characteristics such as mean worker weight (range, 2.96-4.54 mg), foraging territory size (range, 83-1634 m^2), and wood consumption rate (range, 0.6-5.2 g wood/monitoring station/day). In addition, six *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) colonies were identified throughout the park. A total of 251 of 785 (~32%) trees in the park were infested by *C. formosanus* colonies. Foraging territories of each colony remained relatively stable over a 4-yr period, with seasonal activity within monitoring stations increasing during the summer and decreasing during winter.

Key Words *Coptotermes formosanus*, *Reticulitermes flavipes*, mark-recapture

In the past few decades, mark-recapture procedures for characterizing subterranean termite colonies have been used extensively along with monitoring stations for *Reticulitermes flavipes* (Kollar) (Esenther 1980, Grace et al. 1989, Su et al. 1993), *R. hesperus* Banks (Haagsma and Rust 1995), *Heterotermes aureus* (Snyder) (Jones 1990), and the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae) (Lai 1977, Su and Scheffrahn 1988). Important colony characteristics that can be determined using this procedure include foraging territory area, mean worker weight, wood consumption rate, and a foraging population estimate. Probably the single most important result of establishing monitoring stations and releasing dyed termites is delineating the foraging territory of a given colony, especially when a subterranean termite colony is defined as a group of termites sharing interconnecting tunnels (Su 2001, Su and Scheffrahn 1998). Once this type of information has been established for a given colony, then evaluating the effectiveness of a chosen termiticide or baiting system can be determined. Upon treatment, the foraging territory and wood consumption rate for a colony should be affected in a

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manner that is noticeable in the monitoring stations and consistent with the treatment (Su 2003).

Beginning in May 1998, multiple mark-recapture studies were conducted in Louis Armstrong Park, New Orleans, to locate, identify, and characterize every *C. formosanus* colony before conducting further behavioral bioassays and treatments. Louis Armstrong Park is a fenced-in, 12.75-ha, city-owned urban park located to the northwest of the French Quarter in New Orleans. The four major structures in the park include the Morris FX Jeff Municipal Auditorium, the Mahalia Jackson Theater for the Performing Arts, a City of New Orleans Sewerage and Water Board pumping station, and the Perseverance Hall complex. The park has a long history of *C. formosanus* activity dating back to one documented introduction in 1973 of an infested stage that was placed inside the Theater (Scott and Scott 1996). The stage originated from Camp Leroy Johnson, which was one of several military bases credited for introducing *C. formosanus* from Asia to New Orleans after World War II (La Fage 1987).

The remainder of the park is comprised of three large parking lots, an artificial concrete lagoon, driveways and walkways, planters, and grass areas with planted trees (Fig. 1). The test site is completely bound by city streets. A preliminary, visual survey of the area revealed extensive *C. formosanus* activity in these trees. Other than Perseverance Hall, all other buildings are concrete and steel with a limited amount of wood infrastructure, suggesting trees and other nonstructural cellulose materials were the major food sources for these colonies within the park. The primary objectives of this study were to (1) determine how many trees were infested with *C. formosanus*, (2) determine how many *C. formosanus* colonies were present, (3) delineate each foraging territory, and (4) determine the foraging activity as expressed by the wood consumption rate of each colony.

Materials and Methods

Tree survey. In April and May 1998, every tree inside the park was thoroughly inspected for any evidence of live *C. formosanus* activity. Then, tree species and location were determined. All trees were visually inspected on a bimonthly schedule from 1998 to August 2001 for termite activity.

Mark-recapture studies. In April 1998, over 1500 pine (*Pinus* sp., 1.7 × 3.7 × 32.1 cm) stakes were driven into the soil approximately every meter in grass and shade areas, including planters, throughout the park to locate any subterranean termite activity. In addition, stake placement was concentrated along ground level roots of heavily-infested trees. These stakes were checked every month for the presence of termites. Active stakes were replaced with underground monitoring stations (UMS), as described by Su and Scheffrahn (1986). Each UMS consisted of a 3.78-L plastic bucket with a removable lid installed approximately 30 cm in the soil with 3 cm of the bottom cut out. Then, preweighed wooden blocks consisting of either 36 slats (~3.5 by ~13 cm by ~2 mm) or 18 slats (~8 by ~13 cm by ~3 mm) of spruce (*Picea* sp.), bound together, were placed inside each UMS, along with the termites collected from the stake. Every UMS was concealed in the soil to prevent any tampering within the public park. Each UMS was checked monthly after installation, and the block was replaced if a sufficient number of termites (>200 individuals) were present and/or at least half of the block was consumed. Field-collected blocks and termites were returned to the laboratory and processed within 24 h. Termites were carefully separated from the slats and debris and eventually workers, soldiers, and other castes were separated

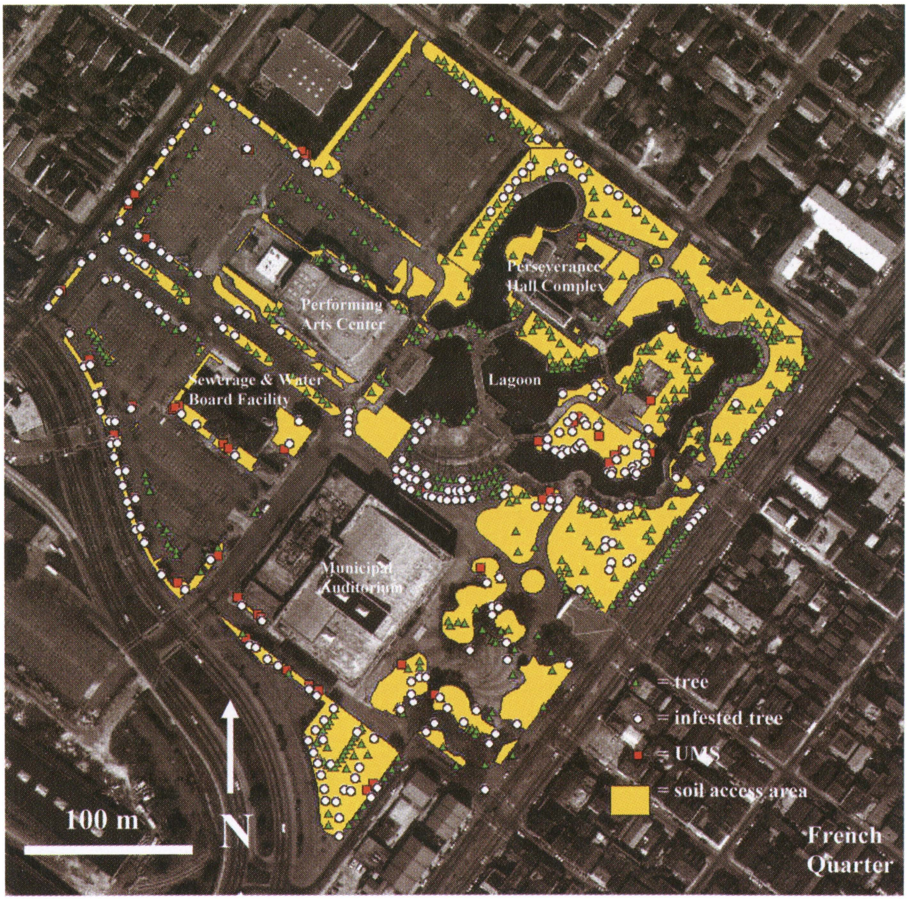

Fig. 1. Locations of major structures, lagoon, trees, *C. formosanus*-infested trees, UMSs, and soil access areas (3.2 ha total) in Louis Armstrong Park, in 2001.

from each other and maintained in temporary containers using the method described by Tamashiro et al. (1973). Subsamples (5 sets of 20 > third-instar workers, 1 set of 20 soldiers) were separated so that individual weights were calculated for each caste, and then the total number collected was calculated. Periodically, workers and soldiers were individually counted after taking subsample estimate weight measurements to confirm accuracy. Then, termites were placed in 100 × 15 mm Petri dishes containing filter paper (Whatman No. 1) dyed with either Nile Blue A (0.1% wt/wt), Neutral Red (0.5% wt/wt), or Sudan Red 7B (0.5% wt/wt) (Fisher Scientific, Pittsburgh, PA). Termites dyed with either Neutral Red or Sudan Red were visibly distinguishable from one another; however, Sudan Red was only used to characterize one colony (FST #11). Approximately 2 g of termites were placed in each Petri dish and remained for at least 6 d, or until the majority of workers had ingested a visibly sufficient amount of dye. They were then removed from the Petri dishes, weighed and counted again, and released back into the UMS from which they were originally collected. Then, marked termites were present in the field and the colony foraging territory was slowly defined after observing dyed termites in stakes, trees, and structures near the release site. Additional UMSs were installed when dyed termites were found in stakes near the original UMS release site. Wood blocks were collected again after three to four weeks (depending on termite activity) from all available UMSs from a particular area. The number of dyed termites recovered from each UMS was recorded and termites were weighed and counted, fed dyed filter paper again, and returned back into their respective UMSs. Only termites from UMSs containing previously-dyed termites were dyed and released to avoid errors in differentiating between two colonies possibly present in the same territory. In a few cases, mark-recapture studies were completed with one colony before beginning a study with a neighboring colony. Also, if two colonies were present in a defined area, then one colony was dyed with Nile Blue A and the other was dyed with either Neutral Red or Sudan Red 7B.

Foraging territory. The foraging territory of each *C. formosanus* colony was determined by connecting monitoring stations, stakes, and trees containing termites dyed with the same markers. Foraging territories were mapped on a geo-referenced, aerial orthophoto image (1 pixel ≈ 0.8 square foot) of Louis Armstrong Park using ArcView GIS version 3.1 software (Environmental Systems Research Institute, Inc., Redlands, CA).

Wood consumption rate. Blocks collected in the field were first separated from the termites, and loose debris was removed. The wood consumption rate (pixel loss/UMS/day) was calculated using the technique of Su and Messenger (2000) from 1998-2002. The wood consumption rate over time was estimated using video image analysis based on the amount of pixel loss (1000 pixels ≈ 0.9 g of wood) for each block.

Statistical analysis. Relationships between colony characteristics (mean worker and soldier weights for each colony, foraging territory, annual wood consumption rate) were examined using a linear regression model (SAS Institute 2000). Mean worker and soldier weights for every colony were analyzed using ANOVA (Student-Newman-Keuls Method) (SAS Institute 2000).

Results

A comprehensive, visual inspection survey of every tree in the park representing 24 tree species in 17 families revealed approximately 32% showed active *C. formosanus* infestations and/or damage (Table 1). Each tree had some form or another of termite activity, ranging from exterior mud tubes to previously fallen limbs, and the number of infested trees was widely distributed throughout the park (Fig. 1). Four of the most abundant and commonly infested tree species in the park included live oak (*Quercus virginiana* Mill.), baldcypress [*Taxodium distichum* (L.) Rich.], red maple (*Acer rubrum* L.), and sycamore (*Platanus occidentalis* L.) (Table 1). Only 6 tree species showed no evidence of termite infestation (Table 2).

Of the approximately 1500 survey stakes examined in May 1998, 100 stakes harbored *C. formosanus* activity. At the same time, 10 stakes were active with *R. flavipes*. UMSs were installed directly on 54 active stakes. Then, triple mark-recapture studies were performed on individual colonies between May 1998 and May 1999 revealing the presence of at least 13 individual *C. formosanus* colonies (Fig. 2) and six *R. flavipes* colonies. The foraging territories of *C. formosanus* colonies never

Table 1. Living trees attacked by *C. formosanus* in Louis Armstrong Park, from May 1998 to August 2001

Common name	Species	Family	Total number in park	Total number infested
American elm	*Ulmus americana* L.	Ulmaceae	4	4
Baldcypress	*Taxodium distichum* (L.) Rich.	Curpressaceae	137	44
Black cherry	*Prunus serotina* Ehrh.	Rosaceae	2	1
Canary Island date palm	*Phoenix canariensis* Chabaud	Arecaceae	18	4
Chinese parasoltree	*Firmiana simplex* (L.) Wight	Sterculiaceae	37	3
Chinese tallowtree	*Sapium sebiferum* (L.) Roxb.	Euphorbiaceae	8	1
Crabapple	*Malus angustifolia*	Rosaceae	3	3
Crapemyrtle	*Lagerstroemia indica* L.	Lythraceae	59	4
Green ash	*Fraxinus pennsylvanica Marshall*	Oleaceae	18	8
Hackberry	*Celtis laevigata* Willd.	Ulmaceae	1	1
Japanese magnolia	*Magnolia* x *soulangeana*	Magnoliaceae	12	3
Jerry palm	*Butia capitata* (Mart.) Becc.	Arecaceae	10	1
Live oak	*Quercus virginiana* Mill.	Fagaceae	115	50
White mulberry	*Morus alba* L.	Moraceae	1	1
Redbud	*Cercis canadensis* L.	Fabaceae	15	10
Red maple	*Acer rubum* L.	Aceraceae	36	34
River birch	*Betula nigra* (L.) Early Cully	Betulaceae	11	4
Southern magnolia	*Magnolia grandiflora* L.	Magnoliaceae	23	4
Southern red oak	*Quercus falcata* Michx.	Fagaceae	13	3

Table 1. Continued.

Common name	Species	Family	Total number in park	Total number infested
Sycamore	*Platanus occidentalis* L.	Platanaceae	132	49
Waxmyrtle	*Myrica cerifera* L.	Myricaceae	9	2
Water oak	*Quercus nigra* L.	Fagaceae	32	13
Weeping willow	*Salix babylonica* L.	Salicaceae	4	3
White oak	*Quercus alba* L.	Fagaceae	8	1
TOTALS	24 species	17 families	708	251

Table 2. Living trees showing no evidence of attack by *C. formosanus* in Louis Armstrong Park, from May 1998 to August 2001

Common name	Species	Family	Total number in park	Total number infested
Bradford pear	*Pyrus calleryana* Decne.	Rosaceae	13	0
Ginkgo	*Ginkgo biloba* L.	Ginkgoaceae	2	0
Jerusalemthorn	*Parkinsonia aculeata* L.	Fabaceae	3	0
Tulip poplar	*Liriodendron tulipifera* L.	Magnoliaceae	2	0
Southern Washingtonia	*Washintonia robusta* H. Wendland	Arecaceae	25	0
(small palms in planters)	N/A	N/A	8	0
Willow oak	*Quercus phellos* L.	Fagaceae	24	0
TOTALS	6 species	6 families	77	0

overlapped each other and were separated by zones of inactivity. Two *R. flavipes* colonies had foraging territories that overlapped *C. formosanus* territories (Fig. 3). On two occasions, an UMS located in foraging territories of both *C. formosanus* colony #1 and *C. formosanus* colony #2 were seasonally shared with each corresponding *R. flavipes* colony, with *R. flavipes* activity during colder months (Dec.-Feb.) and *C. formosanus* activity throughout the remainder of the year.

Foraging territories for each characterized *C. formosanus* colony were located along the perimeter and interior grass areas of the park situated among the planted trees, which were located predominantly along the perimeter (Figs. 1, 2). Dyed individuals were recovered from inside many trees within each territory confirming a connection with ground UMS activity. Activity from *C. formosanus* colony #5 and #6 was detected under the concrete parking lots approximately 2 m from the nearest UMS after seven 76.2 mm cored holes were drilled and fitted with pine stakes in early 2000.

Characteristics determined for each colony included mean worker weight, mean soldier weight, foraging territory area, and wood consumption rate (Table 3). Visual observations over time demonstrated that workers and soldiers within UMSs and throughout the foraging territory of each colony were very similar in size, but distinctly different ($f = 84.3$, $df = 207$, $P < 0.001$ for workers; $f = 91.8$, $df = 207$, $P < 0.001$ for soldiers) from neighboring colony individual sizes. As a result, worker and soldier weights showed a significant linear correlation ($f = 745.53$, $df = 207$, $P < 0.001$); whereby, colonies with large workers had large soldiers. There was also a significant linear correlation between worker weights and foraging territory size ($f = 27.47$, $df = 207$, $P < 0.001$) and worker weights and wood consumption rates ($f = 25.15$, $df = 661$, $P < 0.001$). Generally speaking, colonies with larger workers occupied larger territories, but smaller workers consumed more wood per station per day. Wood consumption rate values represent consumption rates throughout each year, which led to the

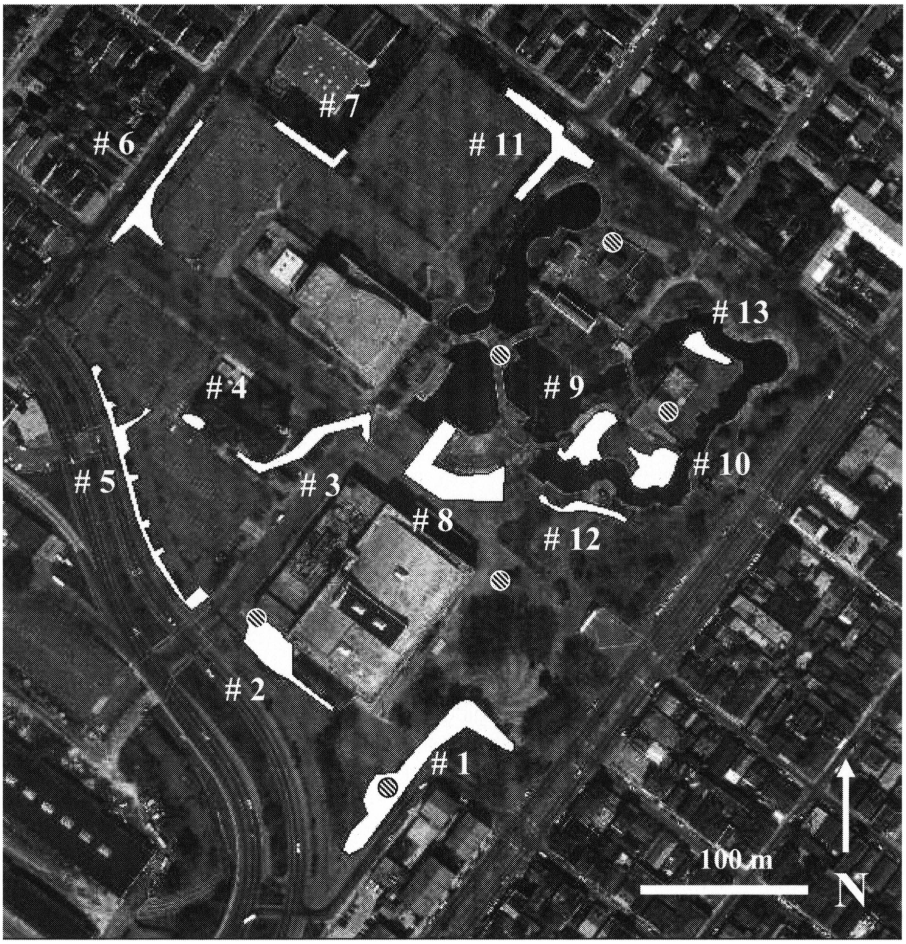

Fig. 2. Foraging territories of 13 characterized *C. formosanus* colonies in Louis Armstrong Park, in 2001. Small, patterned circles represent *R. flavipes* colonies.

higher variability in each comparison after correlation analysis. There was no significant correlation between foraging territory size and wood consumption rate (f = 0.89, df = 661, $P = 0.3454$).

Over time, the percentage of active UMSs ranged from 22-100% revealing distinct peaks and troughs in activity each year (Fig. 5). Wood consumption rate estimates varied from 0.6-5.1 g of wood consumed/UMS/day when pixel loss was converted to grams (Table 3). The standard deviation was very high for each colony because wood consumption was combined over time. The overall consumption rate revealed distinct peak and troughs in activity each year and from year to year. Combined wood consumption rate data for all *C. formosanus* colonies followed the general trends in combined percent of active UMSs (Fig. 3).

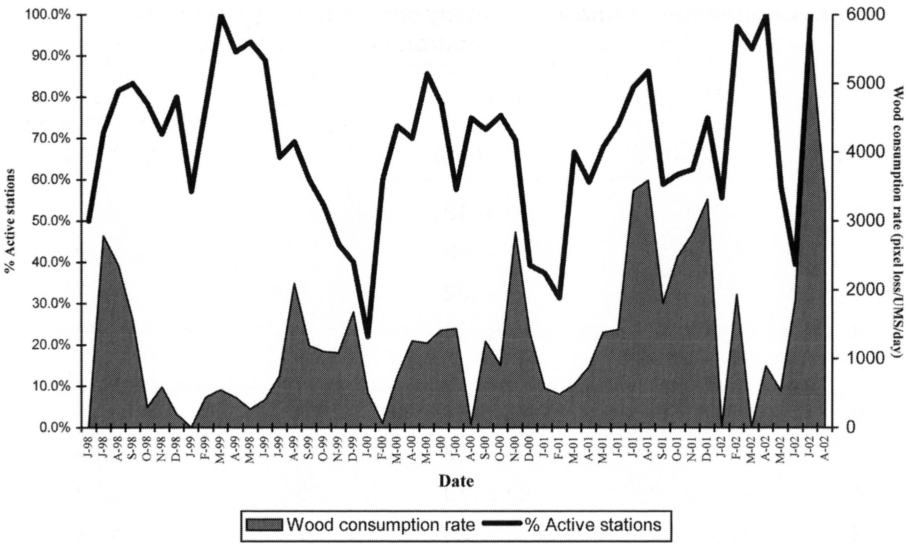

Fig. 3. Combined *C. formosanus* percent of UMS activity and wood consumption rate activity in Louis Armstrong Park, from June 1998 to August 2002.

Discussion

Every *C. formosanus* and *R. flavipes* colony in Louis Armstrong Park could be considered nonstructurally infesting colonies because only minor and incidental *C. formosanus* activity was found in each of the major structures throughout this 4-yr study. The majority of trees present in the foraging territories of each *C. formosanus* colony showed moderate to severe damage, and many trees collapsed during inclement weather because of the extensive feeding on the heartwood, which reduced structural integrity. Many of the same species have been previously listed as commonly attacked living trees by *C. formosanus* in urban settings (Spink 1967, Lai et al. 1983, La Fage 1987, Chambers et al. 1988). New findings from this study revealed *C. formosanus* will attack Japanese magnolias (*Magnolia* x *soulangeana*), Canary Island date palms (*Phoenix canariensis* Chabaud), and jelly palms [*Butia capitata* (Mart.) Becc.]. It is unclear why six species were not attacked; however, most of these trees were located on small grass islands/planters in the parking lots or were in areas of reduced termite pressure. At the same time, all of the willow oaks (*Quercus phellos* L.) and Bradford pears (*Pyrus calleryana* Decne.) were younger than the majority of trees in the park (less than ten years old).

The negative relationship between mean worker weight and wood consumption rate is supported by the findings of Su and La Fage (1984), whereby colonies with larger workers tend to consume less wood than colonies with small workers. Therefore, *C. formosanus* colonies in the park with larger workers and lower wood consumption rates may be older colonies in decline. This result appears to be supported by the findings of Grace et al. (1995). Also, the positive relationship between worker

Table 3. ***Coptotermes formasanus*** **colony characteristics after multiple markre-capture studies in Louis Armstrong Park, from 1998 to 2001**

Colony	Mean worker weight (mg)	Mean soldier weight (mg)	Foraging territory area (m^2)	Annual wood Consumption rate (g/UMS/day)
1	3.76 ± .18	3.63 ± .13	1,634	2.30
2	3.93 ± .25	3.64 ± .22	738	1.49
3	4.25 ± .30	4.22 ± .32	591	1.31
4	2.96 ± .31	2.95 ± .35	83	4.65
5	4.40 ± .20	4.36 ± .22	818	2.65
6	4.28 ± .25	4.11 ± .18	600	0.61
7	3.71 ± .16	3.42 ± .16	253	2.84
8	3.83 ± .19	3.83 ± .13	1,186	3.70
9	4.54 ± .22	4.17 ± .20	506	1.44
10	3.17 ± .17	3.05 ± .09	505	3.42
11	3.59 ± .21	3.18 ± .21	724	2.73
12	3.35 ± .13	3.16 ± .11	248	5.17
13	3.93 ± .21	3.59 ± .05	227	2.20

size and foraging territory from *C. formosanus* colonies in Armstrong Park suggests older colonies tend to have large and well-established foraging territories.

Foraging territories were also similar in total area (from 83-1634 m^2) to *C. formosanus* colonies from previous reports (King and Spink 1969, Su and Scheffrahn 1988). Future studies will involve the use of DNA fingerprinting analysis for each colony to validate the use of mark-recapture studies in determining the foraging territory of a unique colony. In recent years, DNA fingerprinting has been used to delineate the foraging territories of *C. formosanus* in Hawaii (Husseneder and Grace 2001).

Activity within each territory was affected by colder temperatures, as evident in the wood consumption data and UMS activity during winter months. Other studies have confirmed this seasonality in *C. formosanus* populations in Louisiana (Waller and La Fage 1987, Delaplane et al. 1991). The amount of rainfall over time may have reduced activity in many UMSs throughout the park. Near-drought conditions were experienced in New Orleans during the year 2000, which likely leads to an overall reduction in wood consumption and UMS activity in July and August 2000 (Fig. 3).

Personal field and laboratory observations of interspecific encounters between workers and soldiers of *C. formosanus* and *R. flavipes* always resulted in either immediate aggression or retreat. In this study, *R. flavipes* colonies present in *C. formosanus* territories were only found in UMSs after months of C. formosanus inactivity during colder periods of the year. As temperatures rose, and *C. formosanus* activity returned to the vicinity of the *R. flavipes* activity, the *R. flavipes* colony would abandon the UMS within weeks of it becoming active with the *C. formosanus* colony. Interspecific exclusion of *R. flavipes* by *C. formosanus* in urban locations has also been documented in southeastern Florida (Su and Scheffrahn 1988).

It was uncertain whether *C. formosanus* colonies in Louis Armstrong Park would exhibit any type of intercolony aggression. On one occasion during summer 1999, a dead, blue-dyed worker from *C. formosanus* colony #4 was recovered in a UMS occupied by nearby *C. formosanus* colony #5. This observation has lead to further investigations into possible aggressive interactions among *C. formosanus* colonies in the park, especially among neighboring colonies. Aggressive behavior between neighboring colonies may help explain why foraging territories were distinct in the park and why there were areas of inactivity between territories. In addition, future studies involving the elimination of selected *C. formosanus* colonies in the park may determine if neighboring colonies are capable of reinvading previously occupied foraging territories.

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