SUBTERRANEAN TERMITE *RETICULITERMES* SPP. (ISOPTERA: RHINOTERMITIDAE) BAITING AND CONTROL IN HISTORICAL PUBLIC BUILDINGS IN ITALY

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Abstract - Many historical sites in Italy suffer severe damages to wood structures, works of art and ancient books due to well established subterranean termite populations (*Reticulitermes* sp., *R. lucifugus lucifugus*, *R. lucifugus corsicus*). In six field tests, termite colonies were treated with a baiting procedure based on the delivery of cellulose matrix impregnated with hexaflumuron, a slow acting chitin synthesis inhibitor. Six different large structures, in ancient towns, were chosen for their high historical value: a church, a museum, a monastery, a library, a cellar and a school. Treatments took place between 1995 and 1998, by means of baiting in underground and above ground stations. Different problems in contacting colonies, implementing networks of bait stations, finding effective concentration of hexaflumuron, managing reinfestation were overcome, and different decreasing trends were observed depending on the colonies features. In all sites total elimination of termite activity was reached in a period of between 3 and 12 months, delivering minimal quantities of hexaflumuron (0.3-3.4 g) to termites colonies.
Key words - Termite bait, hexaflumuron, colony elimination

INTRODUCTION

Termites cause serious damage to historical buildings, artistic wood structures and paper patrimony all over Italy. They have great economical importance and are a great threat for our cultural heritage. Subterranean termites, *Reticulitermes* spp., are the most destructive, they establish large colonies of up to one million individuals, requiring contact with the soil and continuos moisture supply. Historical towns in Italy undergo frequent termite infestations because of some peculiar feature of the buildings: unplastered brickwork, crumbling mortars, rising damp, structural wood in walls and ground; floors in direct contact with the ground; internal gardens with old wood, firewood, stumps and damp soil in shadow. Buildings are enclosed in large architectural complexes with no air circulation. Joined buildings aligned along the roads have walls and foundations in common, and can in no way be isolated: this enables termites to move from one building to another.

Cryptic habits of *Reticulitermes* make it difficult to recognize the infestation: only mud tubes, swarming or an accurate inspection can locate termite activity before serious damages and sensational destructions. Baiting of subterranean termites seemed to be one remedial control applicable to Italian historical sites. In fact conventional chemical approach is most often directed to soil under and around the building, to create a barrier with tens of kg of liquid termiticides, trough which the foraging worker termites cannot pass and survive. If creating an uninterrupted barrier of treated soil proves difficult in small, simple open sites, the effectiveness of these treatments is highly questionable in case of large complex and ancient sites, because of the described structural factors.

Aim of this research is to evaluate the effectiveness of termite control with a baiting process of cellulose matrix impregnated with an IGR chitin synthesis inhibitor, hexaflumuron: trofallaxis allows worker termites to pass bait to other nestmates, spreading toxicant within all the termite population; they have time for this since hexaflumuron doesn't affect termites until they begin to molt. This bait system was developed on north american termites in residential areas (Su and Scheffrahn, 1993; Su, 1994). Hexaflumuron as the active ingredient of baits was selected for its positive profile in previous laboratory tests (Robertson and Su, 1995) and for its effectiveness in field tests compared with metabolic inhibitors

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such as A-9248 or sulfuramid, as it is slow-acting, non deterrent, without adverse effects in sublethal dose levels, with dose-independent lethal time (Su and Scheffrahn, 1996).

We tested and adapted this baiting process to 3 different *Reticulitermes* species and varieties in 3 different towns in Italy, under different climate and structural conditions.

MATERIALS AND METHODS

Site selection

Three sites were selected in Bagnacavallo, a lowland town of about 10,000 inhabitants in northern Italy, with an extensive and well established infestation of a still unknown species of *Reticulitermes* (Bagnères and Clément, personal communication). The infestation was highly destructive and deeply rooted. This infestation, recently reported (Campadelli, 1987; Campadelli, 1988; Lozzia, 1990; Marini and Ferrari, 1993), has probably been active for 30-40 years. It's the largest reported infestation in Europe, extending over 15 hectares in the north-west part of the old town, with active termite populations in many public buildings and hundreds of houses (Ferrari et al, 1996).

We started with accurate characterization of the termite population in 2 different sites, adapting the Triple Mark Recapture technique (Su and Scheffrahn, 1986; Su and Scheffrahn, 1988; Su *et al.*, 1991). Two different populations were studied: the first in private residential area, was estimated as 640.000 ±33.000 insects on a minimum foraging territory of 675 m^2; the second population, in the monastery, was estimated to contain 1,085,000 ±92,000 insects, on a surface of 1500 m^2; maximum linear distance covered by a single worker was 45-50 meters in both sites (Marini and Ferrari, 1998). These results are consistent with that of the French subterranean termite *Reticulitermes santonensis* (Paulmier *et al.*, 1997) and the American eastern subterranean termite *Reticulitermes flavipes* (Su *et al.* 1993), taking into account interpretative cautions due to TMR method assumptions (Thorne *et al.*, 1996).

The monastery, (a large building complex with flower and vegetable gardens, church, bell tower, cloister, cellars, kitchens, laundry, etc.), was chosen for the bait process together with a large church and the local museum: all these places shared the characteristic of having a high historical and artistic value with impressive termite activity and damages in gardens, wood beams, altars, work of art, furniture, stairs and frames.

Two sites were selected in Rome, where severe termite infestations and damages were reported in the past years, all of them with no effective solutions available. *Reticulitermes lucifugus lucifugus* (Clément *et al.* 1982) is responsible for many spot infestations in the town and around it, being the major subterranean termite of economical importance in the Italian peninsula and Sicily. The first field test site in Rome was Campidoglio, a monumental building used as Rome Town Hall, where termites infested the Library with swarming and destruction of books and wood frames. The second was in the historical building of National Calcography on which lean the famous Fontana di Trevi, and where a termite colony, based in the damp underground cellars, swarmed every year in the exposition hall above. Both sites had a very limited soil access.

One site was selected in the town of Cagliari, Sardinia. In this large Mediterranean island, the termite variety of economical importance is *Reticulitermes lucifugus corsicus* with hundreds of attacks on ancient and modern buildings. We choose a highly infested part of a school as test site, with a long history of termite infestation and swarming. This site was the only previously treated with chemicals: 3 years before baiting, a permethrin solution was injected in attacked wood, without perceptible results.

Monitoring/baiting stations

Different prototypes of underground (UGS) and above ground stations (AGS) were tested, containing monitoring devices and cellulose bait matrix 0.1-0.2-0.5% (wt/wt) hexaflumuron; the highest concentration gave best results in our field tests, with no deterrence (Su, 1995). Underground station (Su *et al.*1995) contains wood monitoring devices or a perforated plastic bait tube containing 30 g of bait

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Table 1. Monitoring/Baiting network implemented in 6 historical buildings in Italy, and elimination of termite colonies by means of hexaflumuron baits.

Site	Termite sp.	Infested area (m^2)	Nº monitoring devices and station installed	Nº stations/ 100 m^2	% Connected station delivering bait	Months to elimination with 0.5% hxf baits (+Additional baiting)	HXF consummed (g)
MONASTERY	Reticulitermes sp.	4,000	134	3.0	31%	8 (+2)	3.4
CHURCH	Reticulitermes sp	2,500	76	3.3	43%	6 (+4)(+1)	3
MUSEUM	Reticulitermes sp	1,000	30	3.0	30%	6	0.4
LIBRARY	R. lucifugus lucifugus	1,000	56	5.6	25%	3	1.3
CALCOGRAPHY	R. lucifugus lucifugus	100	9	9	23%	12	0.3
SCHOOL	R. lucifugus corsicus	200	11	5.5	91%	4	1.21

matrix. A prototype of UGS Large can host a wood block as monitoring device and bait matrix in tubes or in boxes. These stations are placed under the soil when there is access to soil. Above ground stations are plastic boxes, developed to install an effective networks of bait in minimal soil access areas (Benson *et al.*, 1997). These stations are placed directly on infested wood or on termite mud tubes. All of them are provided with a lid and a pre-cut hole in their bottom. They are fixed to infested surfaces with screws and sealed with odorless silicon. Best dimensions were 15 x 9 x 5 cm containing 60 g of bait matrix (Ryder *et al.*, 1998).

From July 1998 the commercial prototypes of these 3 stations are available in Italy in the Sentri*tech termite baiting system (trademark of DowAgroSciences)with the names of Sentri Sol, Multi Sentri Sol, Box Esca. Other monitoring devices used in these field tests were wooden stakes (*Pinus* spp. and *Populus* spp.) in different sizes driven into free soil, and thin wooden probes diam. 0.5-0.8 cm (*Pinus* spp. and *Fagus* spp.) placed in holes drilled indoor and covered with discrete caps, in order to investigate termite presence and connect with termite colonies.

Investigations and installation of station network

To highlight active infested areas in each site and create well known foraging points, different investigation methods were used to install a network of stations adequate to each site.

Monitoring of all free soil around and inside buildings (gardens, roads, yards) was performed placing wood stakes and UGS every 2-5 meters. Since accessibility to free soil may be very limited in historical buildings, accurate visual investigation of all indoor wood, mud tubes on walls, cellars, neglected rooms and similar critical points was necessary.

An acoustic emission detector (AED) was employed. AED detect the specific sound frequency generated by termites using their mandibles to tear wood for consumption: it reveals significant activity of termite foragers in wood and where they are concentrated. On active points, UGS were directly installed with moistened bait matrix on drilled holes in infested wood. The stations were sealed to form a foraging chamber leading to termite galleries. Investigations with wooden probes were necessary where no exposed wood or mud tubes are discovered, and we had no close access to free soil. The final network of monitoring devices provides all information on termite activity and supports the baiting procedure and the post-baiting inspections.

Baiting procedure

Monthly inspections of the monitoring network were made in all sites. When wooden stakes and underground stations were found connected with termite colonies, UGS with bait tube was placed and renewed continuously to avoid a lack of food that could break the connection with the foraging ter-

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mites at the station. A self-recruitment procedure (Su, 1994) was adopted to increase bait consumption: termites recruited from survey stakes were forced to tunnel through bait in order to leave the tube and reach the soil, thus leaving specific semiochemicals cues in the matrix. In UGS Large, 6 bait tubes were placed, or 1-3 connected boxes fixed directly on infested wood blocks, from which temites moved to the baits. After three months from the elimination of all termite activity from the site, wood monitoring devices were replaced in the UGS.

In the AGS, directly placed on active foraging sites (Su *et al.*, 1997) we can have immediate or delayed bait consumption. It's necessary to regularly moist the boxes and to attach additional boxes on the original one before bait matrix is totally consumed, to ensure new food without disturbing the feeding activity.

In attacked wooden probes, covering caps were removed and a AGS fixed and sealed on the hole with the probe inside, from which termites moved into the foraging chamber. Termite presence and the amount of bait consumed in each UGS/AGS was visually recorded by monthly inspections. Baiting was terminated when termite activity ceased in all monitoring and baiting stations and in all detectable points of the building, confirmed by monthly post-baiting inspections.

RESULTS

Monastery

Termite swarming and extensive damages in the monastery complex S. Giovanni in Bagnacavallo, were reported from many years in every structure and in live trees of the gardens, caused by subterranean termite *Reticulitermes* sp. (ongoing classification). The population was estimated up to 1 million termites in the central area, but other populations were active in all neighboring buildings. In spring 1996, 134 monitoring and baiting devices (UGS, AGS, stakes, wooden probe) were installed in the 4000 m^2 area, (22 being AGS placed directly on infested or endangered wood). In summer 1996 42 bait stations were connected (31%) (AGS connected: 7) delivering cellulose matrix 0.5% hexaflumuron to termite population. From July 1996 termite activity decreased in all monitoring and baiting stations and in all investigated points of monastery, and ceased in September 1996 after 6 months baiting. From April 1997 reinfestation occurred in a restricted area bordering untreated private buildings, that in 1996 was infested but not connected with the TMR population. Termites followed old galleries and paths of 1996, and their activity was recorded before any wood damage in the building (investigated weekly) and owners alarm. After 2 months of additional baiting termite activity ceased, and no termite presence nor swarming has been recorded in this location during monthly surveys until December 1998, despite strong termite activity in neighboring buildings. It was concluded that monastery termite population was eliminated by consuming 3.4 g of hexaflumuron (Fig. 1).

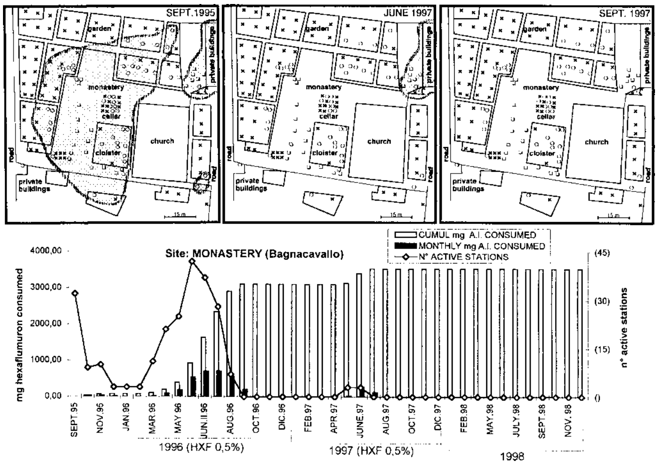

Figure 1. Monastery site in Bagnacavallo. Below: bait (hexaflumuron 0.5%) foraging activity of *Reticulitermes* sp. related to n° of monitoring/baiting stations attacked before,during and after a baiting program. Above: station network legend: circle =UGS; square=AGS; cross=stake or wooden probe. The central foraging territory was determined using a triple mark-recapture procedure, other termite territories using position of hit devices (shaded areas). Reinfestation area is reported in summer 1997.

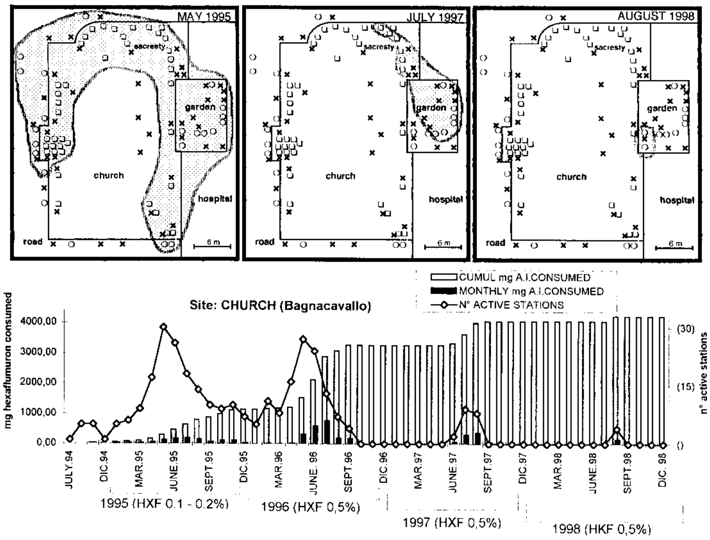

Figure 2. Church site in Bagnacavallo. Below: bait (hex.0.1-0.2-0.5%) foraging activity of *Reticu-litermes* sp., related to the n° of stations attacked before, during and after a baiting program. Above: station network legend: circle=UGS; square=AGS; cross =stake or wooden probe. Foraging territories (shaded areas) were determined by means of carefull investigations and record of positions of monitoring/baiting devices attacked, before baiting and during 1997 and 1998 reinfestation from unbaited Hospital area.

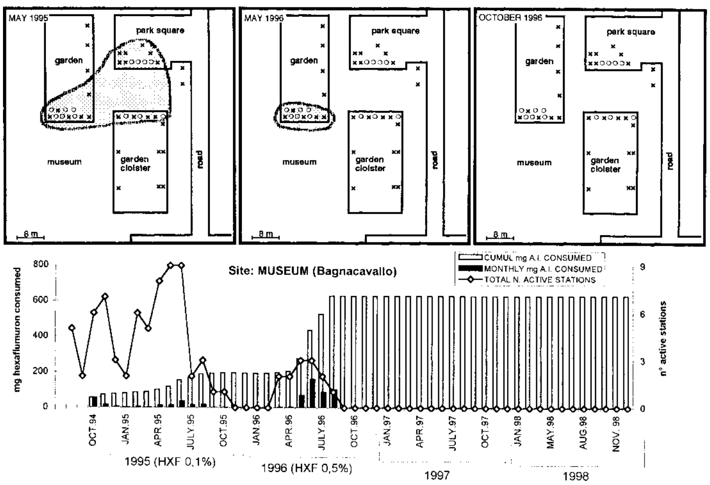

Figure 3. Museum site in Bagnacavallo. Below: bait (hex.0.1-0.2-0.5%) foraging activity of *Reticulitermes* sp., related to the n° of stations attacked before, during and after a baiting program. Above: station network legend: circle=UGS; square=AGS; cross =stake or wooden probe. Foraging territories (sha-ded areas) were determined by means of carefull investigations and record of positions of moni-toring/baiting devices attacked.

Church

The Church of S. Girolamo in Bagnacavallo suffered impressive destruction from termites in the past years. A monitoring-baiting net was established around and inside the church from 1995, and about 80 devices were used to monitor the 2000 m^2 (28 being AGS placed directly on infested wood: altars, tabernacles, choirs, benches, etc.). This site was the first baited area in Italy, from 1995: at this time, field trials where being conducted using 0.1 and 0.2% hexaflumuron in baits. In summer 1995, 33 stations were connected and 1.1 g hexaflumuron delivered, but with almost no effect: termite activity declined in autumn, but peaked again on spring 1996, with 28 bait stations (43%) connected (AGS connected were 19). In 1996 0.5% hexaflumuron baits were inserted in bait stations and in September 1996 after 8 months baiting no more termite activity was pointed out in stations nor in all the church wood.

In summers 1997 and 1998 reinfestation points appeared from the garden bordering the highly infested hospital (untreated building). It was possible to follow termite expansion step by step with the installed monitoring network and bait termites. Four months of additional baiting in 1997 and 1 month in 1998 were necessary to suppress all termite activity, before any wood damage in the church. At the end of 1998 a total of 3 g hexaflumuron in 0.5% matrix concentration was delivered to obtain elimination of termites inside and around the church (fig. 2).

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Museum

In the local Museum of Bagnacavallo infestations were found in doors, door frames and in sets of shelves. Only UGS and stakes were installed in gardens encircling the building: (a former monastery with gardens and cloister): 30 devices were installed on an area of about 1000 m^2. In summer 1995, 9 UGS were connected (30%) and 0.1% hexaflumuron prototype baits were delivered to termite population, but 0.2g of active ingredient at this concentration gave only winter decline of termite activity, and new peaks appeared in spring 1996. In 1996 we inserted 0.5% hexaflumuron baits in the 3 active stations, and in 6 months baiting 0.4 g were delivered, giving total elimination of termite activity in August 1996 (Fig. 3). No reinfestation occurred on 1997 - 1998 in this historical site, that is more isolated from neighborough infested buildings than the previous two.

Library

The Advocacy Department Library of Campidoglio, in Rome, and annexed rooms cover 1000 m^2 in two floors, with minimal soil access. For the monitoring phase all books were removed and infested books treated or destroyed. A network of 56 AGS and wooded probes was installed in march 1997 on infested woods, walls and floors behind and under infested books. In May 1997 14 indoor AGS (25%) were delivering baits 0.5% hexaflumuron. The termite colony was isolated (no termite activity

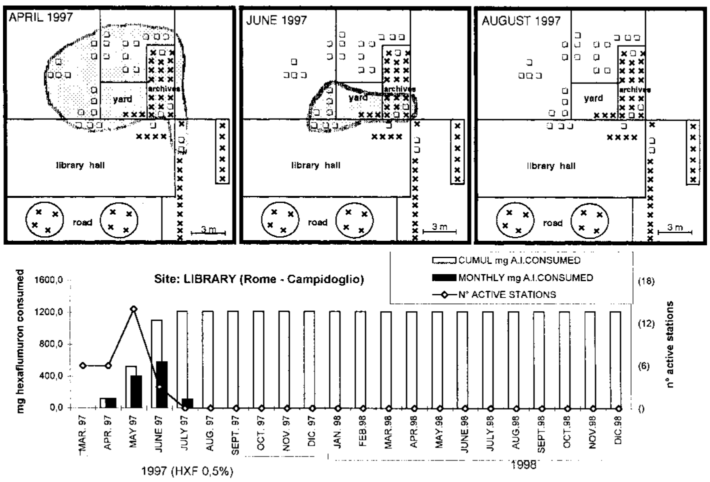

Figure 4. Library site in Rome Campidoglio. Below: bait (hex. 0.5%) foraging activity of *Reticulitermes lucifugus lucifugus*, related to the n° of AGS attacked during and after a bai-ting program. Above: station network legend: square=AGS; cross=stake or wooden probe. Foraging territories (shaded areas) were determined by means of carefull investigations and record of positions of monitoring/baiting devices attacked during and after baiting.

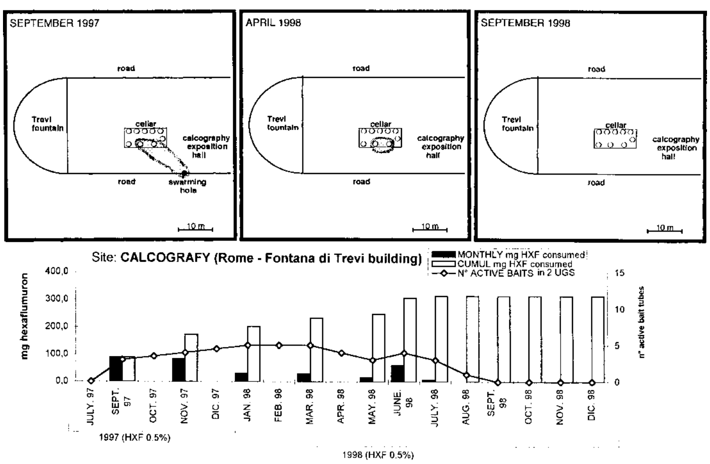

Figure 5. Calcography site in Rome Fontana di Trevi. Below: bait (hex. 0.5%) foraging activity of *Reticulitermes lucifugus lucifugus*, related to the n° of UGS attacked during and after a baiting program. Above: station network legend: cir-cle=UGS; cross=stake or wooden probe. Foraging territories (shaded areas) were determined by means of carefull investigations and record of positions of monitoring/baiting devices attacked during and after baiting.

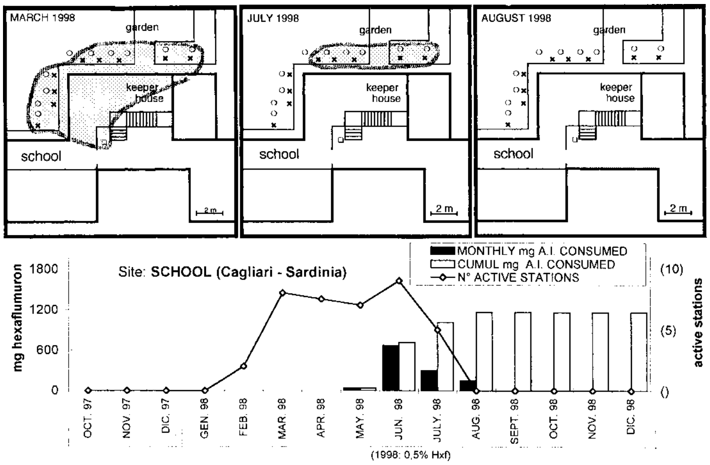

Figure 6. School site in Cagliari, Sardinia. Below: bait (hex. 0.5%) foraging activity of *Reticulitermes lucifugus corsicus*, related to the n° of stations attacked during and after a baiting program. Above: station network legend: circle=UGS; square=AGS; cross =stake or wooden probe. Foraging territories (shaded areas) were determined by means of carefull investigations and record of positions of monitoring/baiting devices attacked during and after baiting.

in all surrounding buildings and roads) and with no connections with the soil. Probably because of limited availability of water, moisture AGS baits were consumed readily, resulting in elimination of termite colony from all the area on July, after 3 full months of baiting, with total 1.3 g hexaflumuron delivered (Fig. 4). No swarming termites were reported on 1997-1998 for the first time after about ten years. At the end of 1998, after 18 months of post-baiting monitoring, all monitoring devices were removed, for esthetical requirements of the site.

Calcography

Accurate investigations were carried on summer 1997 in rooms, gardens and roads around the exposition hall of this large historical building in Rome, hosting National Calcography. Termite activity was detected only in one cellar (100 m^2) 4 m under road level, with very constant environmental conditions, where termites were foraging on strengthening pine beams. The access to free soil was minimal, and here a concentration of 9 UGS Large stations was installed: all around, on floors and walls, the cellar was covered extensively with thick concrete. In 2 stations (23%) termite started foraging from September 1997, and in the following 9 months little but continuos consumption was assessed in 5 bait tubes in side these 2 UGS Large. In summer 1998 foraging activity decreased in all bait tubes, and in September 1998 all termite activity ceased, after 12 months baiting. Total amount of hexaflumuron delivered was 0.3 g Fig. 5). No swarming termites were observed in 1998 in the Calligraphy exposition hall from swarming holes active in past years, nor in other points of the building.

School

In Sant'Aleniscedda School in Cagliari, Sardinia island, the apartment of the school keeper and some classrooms suffered from termite swarming and damages in door frames, over a total area of about 200 m^2 . A network of 11 devices was installed in October 1997 only outside in the garden, because no termite activity was detectable indoor after chemical injections in infested woods. Only 1 AGS was installed on a indoor swarming hole. In spring 1998 10 bait stations were connected (91%) and during summer delivered bait matrix 0.5% hexaflumuron to the termite colony. The AGS indoor was an active station, revealing the swarming point as a foraging area too. In August 1998, after 4 months baiting and 1.2 g of active ingredient consumed, termite activity was suppressed in all detectable points in the school area (Fig. 6).

DISCUSSION

In 6 historical buildings with minimal soil access, monitoring and baiting was effective in eliminating termite activity using minimal amount of toxicant (0.3-3.4 g).

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A durable stations network was established from the beginning after attentive inspections. Operating density was 3-4 monitoring-baiting devices/100 m^2 for large buildings, increased to 5-10/100 m^2 for smaller surfaces. Special placement of UGS were necessary in internal gardens, concrete floors, asphalt roads. AGS and wood probes were essential for buildings with no soil access and to begin baiting more rapidly. These networks, after baiting procedure, offer a continuos protection of properties from nearby termite populations, and can highlight invasions before new damages occur. They can be installed also as a preventive measure for long term monitoring of potential termite activity in sensitive areas of historical towns without signs of live infestations.

Results indicates that only the highest concentration of hexaflumuron (0.5%) gives stable effects in termite decrease. In 4 sites elimination of termite activity was achieved in one baiting sequence of 3-12 months; in particular Calcography site needed 12 months, and this slow effect may be related to the fact that only 2 stations were connected, so time for delivering the appropriate amount of toxicant to the whole colony was longer. Only follow-up monitoring can confirm colony elimination. In 2 sites (Monastery and Church) additional baiting was necessary to control reinfestation by nearby populations from surrounding buildings with high termite pressure. In these cases an extensive monitoring and baiting program in all infested areas, or large sectors, should be studied (Ferrari *et al.*, 1998), and carried on for many years.

This research demonstrates that Italian subterranean termites can be successfully baited in dense urban areas of high historical value and minimal open soil access. In these areas, each having very peculiar features, it becomes essential that every phase of termite control (investigation, monitoring, installation and management of bait stations network) is carried on by specialized professionals.

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