USFWS COMMENTARY SHEET
January 13, 1994

The USFWS has two major comments regarding the recommendations made in the following report. The first concerns the use of Logic and Amdro near caves harboring federally-listed endangered cave invertebrate species. Because the Environmental Protection Agency has not yet formally consulted (under section 7 of the Endangered Species Act) on the use of these chemicals near endangered species caves, the USFWS does not recommend their use in these areas at this time. Until this matter is resolved, fire ant control using chemical baits near endangered species caves should be evaluated by the USFWS on a case-by-case basis.

Currently, the USFWS recommends that only boiling water treatments be used on fire ant mounds within 10 meters (34 feet) of a cave opening or other significant karst feature that is near a cave with listed species. In the area between 10 meters and 90 meters, we recommend treatment with boiling water or small amounts of Logic and/or Amdro in such a manner that the bait cannot be picked up by non-target species. Chemical baits may be used according to the manufacturer's instructions outside of the 90 meter radius. Baits should be spread in the early morning in clear, dry weather to allow time for fire ants to gather most of the bait before sundown when cave crickets emerge from the cave to forage. All control methods should target red imported fire ant (*Solenopsis invicta*) mounds and avoid mounds of native ant species.

The second comment concerns the impacts of chemical control methods on the endangered invertebrates and associated fauna. While we understand the budgetary and time constraints of this project, we must emphasize that the following report does not alleviate our concerns regarding the impacts of Logic and Amdro on the cave fauna. Thus, we recommend continued monitoring of the cave fauna in areas where these chemicals are used to determine if any adverse effects occur. Use of Amdro or Logic within 10 meters of a cave opening and monitoring endangered species caves should be approved by the USFWS prior to implementation. A scientific permit under section 10(a)(1)(A) of the Act is required to conduct these activities.

Persons who have any questions or comments regarding this commentary sheet should contact the USFWS (Lisa O'Donnell or Ruth Stanford), Ecological Services, at 611 E. 6th Street, Room 407, Austin, Texas 78701 or at (512) 482-5436.

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FIRE ANTS AND ENDANGERED CAVE INVERTEBRATES: A CONTROL AND ECOLOGICAL STUDY

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Final Report Submitted to

Endangered Resources Branch
Resource Protection Division
Texas Parks and Wildlife Department
4200 Smith School Road
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FIRE ANTS AND ENDANGERED CAVE INVERTEBRATES: A CONTROL AND ECOLOGICAL STUDY

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"Additional food needed to support the large populations of S. invicta *may have two sources. First, polygyne fire ants may be diverting food from other scavengers in the food web. Second, they may be tapping into food resources previously unused by scavenging arthropods."*

— Porter and Savignano (1990)

SUMMARY

Red imported fire ants began invading Central Texas caves in 1988 and are now a serious threat to native cave faunas, including seven endangered arthropod species. This study aimed at controlling fire ants on eleven cave sites without affecting cave-dwelling species, such as cave crickets which leave the cave at night to forage. Most sites had thin soils. Observations were made on ant foraging in and near caves and cave crickets were observed to take chemical bait at a low rate. Three treatment methods were compared: Logic (fenoxycarb), Amdro (hydramethylnon), and hot water heated on a propane burner and poured on mounds. Treatment results also were compared to a control (check) plot and all were significantly better than no treatment after two months. Logic and Amdro were not significantly different from each other, but hot water was much more effective than the chemical baits. The hot water bucket method is too time-consuming to be used economically over large areas. Cost comparisons are presented and a hot water pressure washer is recommended for field trials because of its potentially high efficiency, efficacy, and specificity. If the pressure washer method tests favorably, it could be used in many areas to kill fire ants instantaneously and without significantly harming other species.

INTRODUCTION

Background

The red imported fire ant *Solenopsis invicta* Buren, originally from Brazil, invaded the United States in the 1930s through the port of Mobile, Alabama. The ant may have arrived in soil used as ship ballast. The species moved into Texas in 1956 and is currently expanding westward. Although limited to areas south of the -12° C (10° F) minimum temperature line, the red imported fire ant is expected to infest mesic areas across the southwestern U.S. and eventually invade the West Coast (Vinson and Sorensen, 1986). The species has already infested most areas of the southeastern U.S. The species, herein referred to as the "fire ant", is a major pest in the U.S. but also has a dramatic effect on the native soil fauna, ground-nesting vertebrates, and livestock wherever it invades (Porter and Savignano, 1990). Although the fire ant is known to control boll weevils, sugar cane borers, ticks, and other agricultural pests, it also has a detrimental effect on beneficial species that control those pests (Mark Trostle, Texas Department of Agriculter, pers. comm.). A very large number of studies has been devoted to the biology and control of the fire ant. For instance, a bibliography on the fire ant published by the U.S. Department of Agriculture currently includes about 1,450 references. Many treatment methods and pesticides have been developed and tested. This report details the results of a control and ecological study of the fire ant in cave areas near Austin, Texas, where seven endangered arthropod species and many other cave-adapted species occur. Three treatment methods were evaluated for efficacy and specificity regarding the fire ant in limestone karst areas with thin soils.

Endangered Cave Invertebrates

The endangered species of concern in this study include:

1. *Tartarocreagris texana* Muchmore, Tooth Cave pseudoscorpion, currently known from about four caves on the Jollyville Plateau in Travis County, Texas.

2. *Texella reddelli* Goodnight and Goodnight, Bee Creek Cave harvestman, currently known from about seven caves near the Colorado River in Travis County.

3. *Texella reyesi*, Bone Cave harvestman, which was formerly included in the definition of *T. reddelli*. This species occurs in about 69 caves from northern Travis to northern Williamson Counties.

4. *Neoleptoneta myopica* (Gertsch), Tooth Cave spider, which occurs in about four caves on the Jollyville Plateau in Travis County.

5. *Rhadine persephone* Barr, Tooth Cave ground beetle, which occurs in about 27 caves in northern Travis and southern Williamson Counties.

6. *Texamaurops reddelli* Barr and Steeves, Kretschmarr Cave mold beetle, which occurs in about four caves on the Jollyville Plateau in Travis County.

7. *Batrisodes texanus*, Coffin Cave mold beetle, which was included in the definition of *Texamaurops reddelli*. This species occurs in about five caves in Williamson County.

Threats to Endangered Cave Invertebrates

The fire ant is one of the more severe threats to the survival of cave-dwelling species in Central Texas. Except for limestone quarrying, probably no other threat in the area could cause as much rapid destruction of cave-dwelling species. The threat to endangered cave species is both direct and indirect, the latter through predation on food sources for the endangered species. Concerns about long-term threats to the cave fauna caused by land development and habitat destruction are important, but not as urgent as the need to control fire ants in and near caves.

In the late 1980s fire ants began colonizing karst areas in Central Texas, and cavers began reporting infestations in cave entrances (Elliott, 1992h). The Tooth Cave area was infested by 1988. In 1989 several cavers began reporting fire ants in caves near Austin and San Antonio. Elliott and Reddell (1989) found fire ants in Good Friday Cave and Cedar Elm Sink near Cedar Park in May 1989, but most caves investigated by them were unaffected. In 1990 there was a dramatic increase in the rate of infestations compared to the previous year. By August 1990, numerous caves were reported as having fire ant infestations. The weather was hot and dry in that month, up to 41° C (106° F). The ants probably were attracted to the nearly optimal conditions in the caves, which range from about 18-24° C (65-75° F) and about 95-100% relative humidity. Researchers noticed that the ants withdrew from the caves in the winter but returned in the spring. By 1991 at least 24 of the 64 (38%) known endangered-species caves in Travis and Williamson Counties had fire ants foraging inside from nearby mounds. By July 1993 46 of the 97 (47%) endangered-species caves were known to be affected (Tables 1 and 2). The true infestation rate is not known because no systematic surveys of the situation have been funded; however, these rates probably underestimate the true infestation rates, especially since some caves were only checked in the winter and some have not been checked for two or three years. Much of Central Texas is infested with polygyne (multiple-queen) colonies, which have much greater densities than the originally more typical, monogyne colonies. Infestations in Central Texas are much denser than in Brazil where the fire ant originated (Porter and Savignano, 1990).

The ants do not actually construct nests in caves except in some entrances where there is sufficient soil. Although there is relatively little food in the caves, fire ants have been observed preying on many species in caves. So far, fire ants have not been observed attacking the rarer troglobitic species, but that probably is only a consequence of rarity— it is highly unlikely for to observe fire ants taking a rare species during a one or two-hour visit to a cave, especially when one would only observe one of the endangered species for a few minutes under the best of conditions and one is being bitten by the ants. The writer has suffered up to 70 fire ant bites in studying one cave in Williamson County and has usually been bitten when passing through the entrance and twilight zones in fire-ant-infested caves.

Some caves with a very thin overburden, such as Bone Cave near Georgetown, have less natural insulation and may attain temperatures near 30° C (86° F) during extremely hot weather. Warmer caves such as Bone Cave may be more attractive to *S. invicta* since the temperature may be closer to the species' observed temperature preference of 28.3° C (Cokendolpher and Francke, 1985). Worker ants usually prefer very high humidities, especially if they are tending brood (Potts, Francke, and Cokendolpher, 1984). To date, no actual nests with brood have been observed in cave interiors, but several nests have occurred in sinkhole entrances where there was enough soil to construct a mound. The deep interiors of most Texas caves probably are too cool for raising brood, lack sufficient soil, or else new queens do not enter caves at all.

Fire ants have infested many caves along the Balcones Escarpment from Georgetown to San Antonio. Tables 1 and 2 summarize the 97 caves and one corehole currently known to contain the endangered species. There are at least 800 known caves and karst features (including sinks and springs) in the Balcones Canyonlands Conservation Plan area and adjacent areas, which include portions of Travis, Williamson, and Burnet Counties. Many of these caves do not contain endangered species but often contain other rare species.

Examples of caves with fire ant nests in the entrance are Cedar Elm Sink, Canyon Head Cave, and Temples of Thor Cave. The latter cave was a closed sinkhole that was dug open on May 9, 1991. On May 13 the endangered species *Texella reyesi* was found in the cave but fire ants were foraging in the cave from a mound located only one meter from the entrance. By May 21 ants were building a nest in the entrance and had to be killed with boiling water before the cave could be entered for study.

No ongoing fire ant control program exists for most of the known endangered-species caves. James Reddell and the writer have attempted to control fire ants at Tooth Cave for several years. Three cave preserves in Williamson County were set aside through an agreement among Melvin Simon and Associates, USFWS, and TPWD. Funds were budgeted, but have not yet been expended, to control fire ants on the three preserves: LakeLine Cave, Testudo Tube, and Temples of Thor Cave. LakeLine Cave Preserve has been treated twice in 1990 and 1991, but not since this study was done in 1991. Fire ants appeared again in LakeLine Cave in May 1993 (Elliott, 1993f). The Testudo Tube Preserve was relatively free of fire ants when the writer began a baseline ecological study of the cave in 1992, but fire ants are becoming more common on the preserve (none have entered the cave yet). The Temples of Thor Cave Preserve is infested with fire ants throughout and fire ants invade the cave each summer, despite a treatment during this study in 1991.

Study Objectives

The study objectives proposed to TPWD, and their general outcomes, included:

1. "To control fire ant infestations near approximately ten endangered species caves in such a way that the native cave fauna is not adversely affected. This objective will be achieved with as much economy and efficiency as possible, since the anticipated budget is somewhat limited." A necessary adjunct to this objective was the comparison of different treatment methods to evaluate which ones were safe and effective for future fire-ant-control programs on preserves. (Eleven areas were treated and another was used as a control plot. Efficacy was generally good, but reinfestations from immigrating new queens occurred within a few weeks. No damage to other fauna caused by treatments was observed.)
2. "To determine the species of ant occurring in and near the caves and the level of infestation." (All were *Solenopsis invicta*. Only one other species of ant was observed near, but not in, a cave.)
3. "To observe if ants are foraging or nesting in caves and what they are taking." (Foraging only was observed. A variety of prey was observed.)
4. "To observe the movements and feeding behavior of cave crickets (*Ceuthophilus* spp.) and daddy-long-legs harvestmen (*Leiobunum townsendii*), which exit the caves at night to forage." In addition, the contract required that "During the period between six weeks and three months following control treatment CONSULTANT shall: survey ant mounds within ½ hectare of cave opening; determine the extent to which fire ants have invaded the cave environment; and gather general observations on the presence of cave crickets and any endangered invertebrates." (This objective was basically achieved. The budgeted funds were not adequate to provide a population study of crickets, which would be necessary to assess the effects of insecticides and would take many man-hours and months to perform because the cricket populations are very dynamic. The writer has recently completed the field work for a year-long, baseline ecology study of three caves, including studies of crickets and harvestmen. Some of the results are reported herein.)

Table 1. Endangered Cave Invertebrates in Travis County, Texas. Compiled by William R. Elliott and James R. Reddell, July 12, 1993.
There are 33 endangered-species caves in Travis County. QUAD = USGS 7.5' topographic quadrangle, EAST/NORTH = UTM coordinates (m), EXPLEN/EXPDEP = explored length/depth of cave (ft), ELEV = entrance elevation (ft), TARTEX = _Tartarocreagris texana_ pseudoscorpion, TEXRED = _Texella reddelli_ harvestman, TEXREY = _Texella reyesi_ harvestman, NEOMYO = _Neoleptoneta myopica_ spider, RHAPER = _Rhadine persephone_ beetle, TMPRD = _Texamaurops reddelli_ beetle, BATTEX = _Batrisodes texanus_ beetle. X = present, P = tentative identification. FIREANTS = _Solenopsis invicta_ imported fire ant. Fire ant notes have been partially updated since March 1993; blank = unknown, 0 = no ants seen, 1 = ants in entrance only, 2 = moderate infestation, 3 = severe infestation, X = ants present but severity unknown, R = ants reported but not confirmed, T = treated October 1991. BCCP = Balcones Canyonlands Conservation Plan, LLMHCP = Lakeline Mall Habitat Conservation Plan, GISD = Georgetown Independent School District, RRISD = Round Rock Independent School District, TSNL = Texas System of Natural Laboratories.

	CAVE NAME	PRESERVE STATUS	QUAD	EAST	NORTH	EXPLEN	EXPDEP	ELEV	TARTEX	TEXRED	TEXREY	NEOMYO	RHAPER	TMPRED	BATTEX	FIREANTS
13	Amber Cave	Proposed, BCCP	Jollyville	609780	3365430	33	25	1041	X					X		1
28	Bandit Cave	Protected by owner	Austin W	617210	3349330	440	10	580		X						0
23	Beard Ranch Cave	(Ivanhoe)	Jollyville	613600	3362500	18	16	1000			X					
27	Bee Creek Cave	Proposed, BCCP	Austin W	'616430	3353310	125	20	600		X						
7	Bear Bottle Cave		Pflugerville W	623060	3367980	100	20	790			X					
1	Broken Arrow Cave		Leander NE	609360	3374720	50	25	1030					X			
29	Cave Y	(Parkstone PUD)	Austin W	613600	3348520	205	47	750		X						1
9	Cold Cave	Proposed, BCCP	Pflugerville W	623120	3366830	80	15	805			X					
25	Cotterell Cave	City of Austin	Austin W	618770	3360290	40	20	880			X					T3
10	Fossil Cave	City Austin, filled	Pflugerville W	621250	3365000	50	20	845			X					
5	Fossil Garden Cave	Proposed, BCCP	Pflugerville W	620580	3368900	95	17	880			X					3
16	Gallifer Cave	Protected, TSNL	Jollyville	609950	3364380	115	24	1055			X	P	P			T2
8	Hole-In-The-Road		Pflugerville W	622410	3367050	35	7	810			X					
	Jest John Cave	City of Austin	Jollyville	617480	3361740	217	24	880		P						
24	Jester Estates Cave		Jollyville	614900	3362600	30	15	950		X						0
15	Kretschmarr Cave	Protected, TSNL	Jollyville	610200	3364870	48	30	1040					X	X		2T
14	Kretschmarr Double Pit	Option on Land	Jollyville	609900	3365420	58	37	1045	P	P			P			0
	Lamm Cave	(Canyon Creek)	Jollyville	near Stovepipe									X			
	Little Bee Creek Cave	City of Austin	Austin W	616400	3351860	80	6	540		P						
11	McDonald Cave	Proposed to owners	Jollyville	609430	3367840	168	10	950			X					
3	McNeil Bat Cave	Proposed, BCCP	Pflugerville W	622220	3369140	150	25	860			X					
	Milliped Cave	(RRISD)	Pflugerville W	621670	3368900	100		880			X					
21	New Comanche Trail Cave	Proposed, BCCP	Jollyville	608850	3362960	60	13	1070			X	X				3C
6	No Rent Cave	Proposed, BCCP	Pflugerville W	621200	3368700	60	14	840			X					0
17	North Root Cave	Option on land	Jollyville	610220	3364345	40	15	1047					X			3T
2	Rolling Rock Cave	LLMHCP	Mansfield Dam	607900	3374100	50	25	1000					X			0
18	Root Cave	Option on land	Jollyville	610220	3364340	10	15	1047			X		X			3T
22	Spider Cave	Proposed, BCCP	Jollyville	612200	3362450	50	15	1030			P		P			0
12	Stovepipe Cave	Proposed, BCCP	Jollyville	611300	3366500	100	20	1000	P		P	P	X	X		0
20	Tardus Hole (Kretschmarr Fluted Sink)	(Developmt. prop.)	Jollyville	609910	3365380	42	21	1045					X			
19	Tooth Cave	Protected, TSNL	Jollyville	610180	3364200	166	18	1057	X		X	X	X	X		T1
4	Weldon Cave	Proposed, BCCP	Pflugerville W	621040	3369000	122	6	880			X					
26	West Rim Cave	(West Rim Dvlpmt.)	Austin W	618600?	3360290?						X					

Table 2. Endangered cave invertebrates in Williamson County, Texas. Compiled by William R. Elliott and James R. Reddell, July 12, 1993.
There are 64 endangered-species caves in Williamson County.

	CAVE NAME	PRESERVE STATUS	QUAD	EAST	NORTH	EXPLEN	EXPDEP	ELEV	TARTEX	TEXRED	TEXREY	NEOMYO	RHAPER	TMPRED	BATTEX	FIREANTS
	Abused Cave	GISD (Frost School)	Georgetown								X					
30	Beck Bat Cave	Protected, RRISD	Pflugerville W	622120	3373790	200	10	830			X					
31	Beck Blowing Well	Protected, RRISD	Pflugerville W	621680	3373600	26	12	845			X					
32	Beck Horse Cave	Protected, RRISD	Pflugerville W	621860	3374020	150	20	845			X					
	Beck Bridge Cave		Round Rock	622320	3375280			820			P					
33	Beck Pride Cave	Protected, RRISD	Pflugerville W	622023	3373990	500	30	835			X					
28	Beck Ranch Cave		Pflugerville W	621780	3374500	2200	30	830			X					R
	Beck Rattlesnake Cave		Pflugerville W								X					

Table 2. Williamson County, July 12, 1993, continued.

	CAVE NAME	PRESERVE STATUS	QUAD	EAST	NORTH	EXPLEN	EXPDEP	ELEV	TARTEX	TEXRED	TEXREY	NEONYO	RHAPER	TMPRED	BATTEX	FIREANTS
29	Beck Sewer Cave		Pflugerville W	622400	3374450	1000	30	820			X					2
34	Beck Tex-2 Cave	Protected, RRISD	Pflugerville W	621980	3373650	70	11	825			X					
36	Bluewater Cave #2	(Nelson Ranch)	Jollyville	611090	3373330	75	60	970					X			2
21	Bone Cave	(Esther Weir)	Round Rock	623100	3386260	74	26	880			X					3T
37	Boulevard Cave		Jollyville	611350	3373850	318	56	970					X			
	Broken Zipper Cave	(Cat Hollow)	Round Rock?								X					
23	Brown's Cave	Protected by owner	Round Rock	620820	3379340	117	42	875			X					
	Buttercup Creek Cave	(Lumberman's Assoc.)	Jollyville	610870	3373470			970					X			
26	Cat Hollow Cave #1		Round Rock	622780	3375350	450	25	810			X					2
27	Cat Hollow Cave #2		Round Rock	622530	3375200	600	25	810			X					3
38	Cedar Elm Sink	(Lumbermen's Assoc.)	Jollyville	611360	3374180	60	50	970					X			3?
1	Coffin Cave	(No recent study)	Cobbs Cavern	626400	3402900	800	60	780							X	
13	Coon Scat Cave	(Seminole Pipeline)	Round Rock	624400	3387200	262	37	850			X					3
25	Easter Cave	(Fern Bluff)	Round Rock	622980	3375900	12	7	800			P					2
22	Elm Cave		Round Rock	621500	3380000	40	10	850			P					
17	Fence-Line Sink	(Laubach family)	Round Rock	625150	3386660	150	15	810			P					2
9	Flat Rock Cave	(Wood Ranch Dvlpmt.)	Georgetown	622950	3389480	262	15	830			X					3
24	Flint Wash Cave		Round Rock	622850	3376420	100	20	810			X					1
	Formation Forest Cave	(Nelson, Mayfield R.)	Round Rock								X					2
39	Good Friday Cave		Jollyville	611280	3374200	50	25	980					X			3T
40	Harvestman Cave	(Lumbermen's Assoc.)	Jollyville	610850	3374130	25	15	990					X			3
41	Hideaway Cave		Jollyville	610830	3373900	300	35	970					X			R
19	Inner Space Cavern		Round Rock	625800	3386650	15000	80	790			X				X	0
47	LakeLine Cave	LLMHCP	Jollyville	614730	3371200	69	10	960			X		X			T1
	Lineament Cave	Robinson Ranch	Pflugerville W?								X					3
11	Lobo's Lair	(Jay Wolf)	Georgetown	622650	3389220	138	21	895			X					1
20	Man-With-A-Spear Cave	(Esther Weir)	Round Rock	622670	3386310	150	30	890			X					3T
35	Marigold Cave	Gated	Leander	611800	3374720	3000	89	950					X			2
48	McNeil Quarry Cave		Pflugerville W	623250	3370740	100	15	810			P					
	Mustard Cave	Robinson Ranch	Pflugerville W?								X					3
42	Nelson Ranch Cave	(Nelson Ranch)	Jollyville	610550	3373380	400	45	970					X			1
	O'Connor Cave	(Cat Hollow)	Round Rock?								X					
14	Off Campus Cave	Protected, GISD	Round Rock	624850	3387290	125	30	870			X				X	0
15	On Campus Cave	Protected, GISD	Round Rock	624600?	3387200?	100?	30?	830			X				P	1
	Ominous Entrance Cave	(Nelson, Mayfield R.)	Round Rock								X					2
4	Pussy Cat Cave		Georgetown	618300	3395640	108	14	925			X					0
45	Raccoon Cave		Round Rock	615040	3372400	50	21	960					X			x
6	Red Crevice	LLMHCP	Georgetown	623220	3394500	30	15	850			X				X	3
	Rock Fall Cave	(Robinson Ranch)	Pflugerville W?								X					1
16	Sierra Vista Cave	Proposed to owners	Georgetown	624880	3387280	60	30	870			X					1
2	Sore-ped Cave	Filled, Sept. 1991	Georgetown	627425	3398440	1000	30	735			X					0
	Stalagroot Cave	(Seminole Pipeline)	Leander NE	616920	3389550	100	20	945			X					
18	Steam Cave	(Laubach family)	Round Rock	625080	3386770	2000	30	820			X					
	Step-Down Cave		Round Rock	621100	3380350			875			X					1
	Stonewall Cave	(Fern Bluff)	Round Rock								X					
43	T.W.A.S. A Cave		Jollyville	610670	3374180	39	41	990					X			0
7	Temples of Thor Cave	LLMHCP	Georgetown	623300	3394350	637	61	840			X					3T
44	Testudo Tube	LLMHCP	Jollyville	609780	3373720	1200	25	1000					X			0
3	Texella Cave	Proposed to owner	Georgetown	626050	3397170	265	21	775			X					3
	Treehouse Sink	(Buttercup Creek)	Jollyville										X			
46	Underline Cave	To be filled, LLMHCP	Jollyville	614780	3371520	80	12	960			X					0
5	Unemployment Cave	Not studied yet	Georgetown	625000	3395000						P					1
	Vault Cave	(Beck Ranch)	Round Rock								X					
10	Waterfall Canyon Cave	(Wood Ranch Dvlpmt.)	Georgetown	623320	3389500	141	26	820			X					3
--	Well Trap #6	Filled- not a cave	Jollyville	614500	3371500	0	15	960					X			
8	Williams Cave No. 1	GISD (Frost School)	Georgetown	625440	3393650	356	9	760			P					3T
12	Wolf's Rattlesnake Cave		Georgetown	622560	3388980	40	10	890			X					0

MATERIALS AND METHODS

Tables 3-5 outline the general course of this project. The project was proposed to begin on about June 1 and end on September 1, 1991. I signed a contract with TPWD on June 25, 1991, which became effective on July 16, and preliminary field work began on July 26. Field work was delayed from August 14 until September 23 because USFWS required an amendment to my existing endangered-species permit to treat the cave areas. After the amendment was received I resumed field work, but I had to recensus a portion of the mounds at Tooth and Kretschmarr Caves. Many colonies had increased in size, so the resurvey was used to adjust the values of all mounds surveyed in July, either with a new observed value or a mean percent increase if the mound was not revisited in October. I also indexed new colonies that had been established at Tooth and Kretschmarr caves between August and October. Treatments ran from October 8-17 and follow-up surveys were generally about 8 weeks later, December 4-23. The delay in permitting pushed the follow-up surveys into a period when there were rapid declines in ant populations due to rain and cold weather. However, I was advised by Mark Trostle of TDA that TDA had found in a study that a fall treatment with Logic has longer-lasting effects on fire ants than a spring treatment, while two treatments per year were even more effective. This is documented in a letter with graphs by Homer Collins (attacment). Therefore, Mr. Trostle advised that the October treatments, especially with the prevailing dry weather, should be quite effective and worthwhile.

I selected caves for study by using a computerized ranking method that I wrote in dBASE. Of the 56 endangered-species caves then known in the Austin area, information on fire ants was available on 38. Caves were assigned a score of 0, 1, 2, or 3 based on the reported severity of the fire ant infestation. Each cave also received a composite rarity score based on the known rarity of all endangered species it contained. Rarity was 100 divided by the total number of known localities. A priority score was computed for each cave, which was the product of the composite rarity score times the fire ant score, and the results were ranked in descending order. The top 14 caves were initially selected for study, however Root and North Root caves are essentially one area, making a total of 13 areas. Upon the advice of the USFWS, the selection was adjusted to exclude New Comanche Trail Cave and Amber Cave in case the treatments were harmful to the cave communities. Instead, I used New Comanche Trail Cave as a control (no treatment) plot. Red Crevice was dropped because most mounds around it had already been killed with hot water or Amdro. I added Cotterell Cave to the selection because it is on an unmanaged preserve owned by the City of Austin and also contains several rare troglobitic species as well as the endangered *Texell reyesi*.

I evaluated fire ant activity in 9 caves by baiting with cheese squares for measured periods of time. An initial experiment with tuna-fish/grape-jelly bait, turkey wieners, and American cheese indicated that the cheese was faster, less messy, and easier to prepare in equal portions. I cut pre-packaged slices of American cheese into 16 squares about 2 cm square and weighing about 1.4 g each. I placed the cheese squares in clean, 35 mm film cans and transported them in a cooler to the field. I laid each cheese square on an inverted film can lid and noted the elapsed time with a watch. The bait exposure time varied from 24 min to 86 min (mean = 43 min) depending on the amount of time spent in the cave searching for fauna and observing fire ants. I usually placed baits at three locations in a cave: on the floor of the entrance, in the twilight zone (usually about 5 m from the entrance) and in the dark zone (10-15 m from the entrance). Upon returning to the bait station I resealed the can and the ants and bait with it and placed the can in a freezer box. I made notes on temperatures and on any ants seen near the bait. Upon returning home, I placed the container in a freezer. Later I emptied the dry, frozen ants onto paper and counted them. A total of 18 baits were scored from 9 caves in 3 time periods: July-August, September-October, and November-December. This method gave a crude measure of ant foraging activity in the vicinity of the bait but tended to underestimate ant activity in the dark zone as compared to the entrance. This was because most ants were found at the entrance where it was warmer, consequently the ants moved faster and they could recruit the closer ants more quickly. Nevertheless the method seemed adequate for getting an overall picture of ant activity rates through time and in different cave zones.

I hired Mr. James C. Cokendolpher from Lubbock, an experienced entomologist and fire ant researcher, to assist me in setting up the study and in censusing two of the plots using the Lofgren and Williams method. He also confirmed the species identification of the ants.

The Lofgren and Williams (1985) method is widely used to make field estimates of population sizes without using time-consuming mark-recapture or other statistical methods. However, the Lofgren and Williams method has

Table 3. Summary of Logic treatments of fire ants at 8 cave areas in Travis and Williamson Counties, Texas, 1991. The Lofgren and Williams indexing method (see Table 6) was used to estimate colony sizes before and after treatment and to derive an estimate of loss in aggregate population size for the mounds checked. "Reinfestation" refers to new colonies that became established after treatment. Although efficacy (population loss) can be high, new queens immigrating from the general vicinity can cause reinfestations, such as at Kretschmarr Cave. See Table 4 for hot water treatment results, which did not overlap Logic treatments.

CAVE (& man-hrs to treat)	Mounds Checked	Acres Treated	First Survey	Second Survey	Treated	Follow Up	Elapsed Days	Pop. Loss	Remarks
1. Tooth 1.08	36	2	8-7	10-6	10-8	12-4	57	88%	Dense woods. Previously treated with Logic 6-88, 9-90.
2. Kretschmarr 2.2	59	2	8-16	10-4	10-8	12-10	63	92%	Grassy. Dense populations. Bad reinfestation from vicinity.
3. LakeLine 1.23	17	2	9-3	10-9	10-9	12-10	62	75%	Mixed grass/cedar. Dense populations. Previously treated with Amdro 10-90.
4. Cotterell 0.97	7	2	9-18	—	10-10	12-16	67	67%	Thick cedar brakes. Reported reinfestation 5-92.
5. Gallifer 0.10	6	0.2	10-4	—	10-11	12-14	64	64%	Hardwoods/cedar, previously treated with Logic 9-90. New treatment encompassed mounds, fair results.
6. Root/North Root 0.03	1	spot	10-11	—	10-11	12-14	64	0%	Treated near 1 mound, poor results. Area badly infested by 12-14-91.
7. Good Friday 0.70	11	2	10-16	—	10-16	12-18	63	49%	Grass/cedar. Follow up on rainy day, ants were massed in mounds, probably gave biased high count.
8. Williams 0.67	9	1	10-17	—	10-17	12-23	67	90%	Grass, dense woods at edge of intermittent creek bottom.

Table 4. Summary of hot water treatments of fire ants at 9 cave areas in Travis and Williamson Counties, Texas, 1991. Mounds within 4 m of the cave entrance were treated with hot water only while mounds outside this radius were treated with bait only. Gallifer and Good Friday caves had no mounds within 4 m. The Kretschmarr plot contains Kretschmarr Cave and Kretschmarr Sink, each with 2 mounds treated.

CAVE (& man-hrs to treat)	Mounds Treated	Acres Treated	First Survey	Second Survey	Treated	Follow Up	Elapsed Days	Pop. Loss	Remarks
1. Tooth 0.75	5	0.01	8-7	10-6	10-8	12-4	57	99.8%	Dense woods. Previously treated with Logic 6-88, 9-90.
2. Kretschmarr 0.70	4	0.01	8-16	10-4	10-8	12-10	63	77.6%	Grassy. Dense pops.
3. LakeLine 1.11	6	0.01	9-3, 10-9	10-9	9-24 10-9	12-10	62	95.5%	Mixed grass/cedar. Dense populations. Previously treated with Amdro.
4. Cotterell 0.72	6	0.01	9-18	—	10-10	12-16	67	99.0%	Thick cedar. Reported reinfestation 5-92.
5. Root/North Root 0.33	3	0.01	10-11	—	10-11	12-14	64	100%	Area badly reinfested from vicinity by 12-14-91.
6. Williams 0.27	2	0.01	10-4	—	10-11	12-14	64	100%	Grass, dense woods in intermittent creek bottom.
7. Bone 0.23	1	0.01	10-14	—	10-15	12-23	69	99%-100%	Thin soil, mostly small mounds. Annihilated 1 mound near entrance.
8. Man-With-A-Spear 0.28	1	0.01	10-14	—	10-15	12-6	52	100%	Grass, open woods.
9. Temples of Thor 0.53	3	0.01	10-14	—	10-15	12-23	69	98.5%	Grass, open woods.

Table 5. Summary of Amdro treatments of fire ants at 3 cave areas in Williamson County, and the control plot at New Comanche Trail Cave, Travis County, 1991. Logic could not be used on the first three sites listed because of livestock being present. Hot water only was used on mounds within a 4 m radius of the entrance, while Amdro only was used outside of that radius. The control (no treatment) plot was surveyed to get some measure of fire ant population dynamics from October into December. Between December 14 and 24, 13 inches (33 cm) of rain fell, resulting in a considerable drop in ant populations. However, most of the treatment followups were finished before the heaviest rains.

AMDRO TREATMENTS—

CAVE (& man-hrs to treat)	Mounds Checked	Acres Treated	First Survey	Second Survey	Treated	Follow Up	Elapsed Days	Pop. Loss	Remarks
1. Bone 0.5	16	1	10-14	—	10-15	12-23	69	96%	Grassy, thin soil, small pops. 1 *Pogonomyrmex* nest present.
2. Man-With-A-Spear 0.6	14	1	10-14	—	10-15	12-6	52	79%	Grassy. Early follow up.
3. Temples of Thor 1.4	18	2	10-14	—	10-15	12-23	69	69%	Mixed grass & hardwoods. Dense populations.

CONTROL PLOT (NO TREATMENT)—

CAVE	Mounds Checked	Acres Treated	First Survey	Second Survey	Treated	Follow Up	Elapsed Days	Pop. Loss	Remarks
1. New Comanche Trail	10	0	10-6	12-14	—	12-24	69, 79	59% (85% by 12-24)	Cedar, grass, mild slope, ½ acre checked. Ants left cave between Oct. & Dec. Still reproductive in Dec. Some washout from 13" rains in Dec.

been statistically calibrated to yield the mean number of ants in each indexed mound. If desired, one can then estimate the aggregate population size of the mounds checked before and after treatment and extrapolate the population size for a larger area. New mounds that spring up after treatment are often from new queens that flew into the area. Therefore, to measure efficacy, one should examine the effects of treatment on those mounds that were actually treated. However, new mounds were observed, especially in the Tooth and Kretschmarr plots where nearly all mounds were flagged and accounted for. Most "reinfestations" noted in Tables 3-5 were deemed to be from immigration of new queens from the surrounding region, and not generally from treated mounds that may have divided or "recovered" (see Discussion).

The one-acre plots around Tooth Cave and Kretschmarr Cave were done first and were thoroughly surveyed for as many mounds as possible. We found about 95% of all mounds on these two plots. The two-acre plot at Cotterell Cave contained only 13 mounds, but 6 of them were near the entrance. Completely checking all mounds turned out to be quite time-consuming but worthwhile in providing some information on the preferred microhabitats of the ants and as a check on the more abbreviated indexing that I did at the other plots (usually without assistance). One does not have to index all mounds in each treatment plot; this would be extremely time-consuming and unnecessary. Also, as the study progressed it became apparent that indexing all mounds on all sites would take too much time and would limit the time needed to actually treat the ten plots and do follow-ups. I decided to try and control ants on as many of the plots as possible while collecting sufficient data to compare the three treatment methods. Therefore, I used aggregate results for the three treatment methods that were evaluated. It was very important to determine which method would be least harmful to cave crickets, which emerge from caves at night to feed. The amount of data collected was more than sufficient to make statistical comparisons of the three methods. Although the contract required surveys of ant mounds within ½ hectare of a cave opening I did not take this to mean that all mounds must be indexed by the Lofgren-Williams method. I examined each plot in detail and I estimated the number of mounds present. About 35% of the mounds were actually indexed, which is accepTable for this method. In the 11 plots, 235 mounds were indexed before and after treatment (146 for Logic, 48 for Amdro, 31 for hot water, and 10 for the "check" plot). A total of 15.3 acres were treated (11.2 for Logic, 4 for Amdro, and 0.1 for hot water), so about 15 mounds per acre were actually indexed, on the average. Densities were typically about 40 mounds per acre away from entrances, but often much higher near entrances. In all, about 630 mounds were treated with the three methods.

To index a mound, one takes a garden scoop and knocks the top off the mound, then taps on the ground with the scoop to alert the ants. The colony size is scored on a scale of 1 to 5 (see Table 6 below). A standardized population size for each index value can then be used for statistical analysis. Upon follow-up, dead mounds were noted as "0", but were given a numerical weight of "1" instead of 0 to avoid calculation problems. This is a slight modification of the Lofgren-Williams method. Notes were made on any signs of reproduction in the colony— if brood (larvae), alates (winged sexual ants), or queens were observed.

Table 6. Modified method of determining fire ant worker populations in the field, after Lofgren and Williams (1985).

Category	Age of colony (mo.)	Estimated no. of ants	Mean no. of ants weighting factor
0	dead	0?	1
1	1-2	< 100	100
2	3-5	100-1,000	550
3	6-12	1,000-10,000	5,500
4	13-24	10,000-50,000	30,000
5	24-36	50,000-150,000	100,000

Each mound that was indexed was marked with a wire survey flag with a unique number and carefully recorded. All indexed mounds were also surveyed with a Suunto compass (accurate to ½°) and paced off. This method was also used to survey the corners of each test plot. The survey data were useful in relocating some mounds later after intruders had taken some of the flags. Also, the positions of the mounds in relation to the outline of each cave could be plotted. Edges and corners of the plots were marked with surveyor's flagging or string if the vegetation was very thick. Survey data were plotted using the SMAPS survey program. Mr. Cokendolpher and I surveyed 32 mounds in a 1-acre area around Tooth Cave on August 7-8 and 49 mounds in the Kretschmarr Cave area to "calibrate" my eye to the method. Only one other obvious ant species was noted on the 12 plots— a large colony of *Pogonomyrmex* sp. (red harvester ants) was found on the one-acre plot at Bone Cave.

The writer and Dr. Dan Clair at the Texas Department of Agriculture (TDA) formulated a plan in which TDA provided the in-kind services of two fire ant specialists in the field. Mr. Mark Trostle and Mr. Andy Feild performed 6 of the 11 pesticide treatments and they lent a Cyclone spreader for the other treatments. Dr. Tom Bridges of the Ciba-Geigy Company reviewed the proposal and the company contributed 25 lb of Logic (fenoxycarb) fire ant bait at the writer's request. A number of individuals contributed field work to the study (see Acknowledgments). The U.S. Fish & Wildlife Service (USFWS) reviewed the proposal and made suggestions to improve the design.

Three treatment methods were used and compared. Different treatments were completely non-overlapping. The treatments were Logic (fenoxycarb) bait, Amdro (hydramethylnon), and hot water. Treatment schedules, acreages, and related information are presented in Tables 3-5. See Table 8 for details on number of mounds per type of treatment. The chemical baits were used according to U.S. Environmental Protection Agency (EPA) label restrictions. Hot water only was used on mounds within 4 m (13 ft) of a cave entrance. Hot water occasionally was used beyond this radius to obtain an adequate sample size for statistical analysis. The entrance was covered with a plastic tarp when baits were used to avoid accidental introduction of bait into the cave even though bait was never broadcast within the hot-water treatment area. Bait was broadcast with one or two Cyclone hand-cranked spreaders or with a gasoline-powered Solo blower at 1 lb per acre. The blower does not dispense bait as accurately as the spreader and was used only in areas of thick vegetation (Cotterell Cave) or when time was short. Bait was not applied before the dew was dry in the morning (usually after 10:00 am) or at air temperatures above 32° C (90° F) to ensure that the bait would not be degraded and that ants were foraging. Most applications were completed before mid-day.

The ants killed by hot water were all killed within a few seconds to a few minutes. Although some workers would have been foraging a few meters away and straggled back later, they would not have been able to reestablish the mound since they were sterile females and would die out. Probably no workers from bait-treated areas would have been killed by the hot water treatments, which were limited to the mound itself; this is because foreign workers are not welcome in other mounds. Therefore, even though the different treatments were in close proximity, there was no overlap of any consequence that would confound treatment results. This methodology was reviewed and approved by TDA.

TDA's fire ant control program is mostly based on the use of Logic at this time, which is favored because of its low ecological impact and low persistence in the environment. Logic, chemically a carbamate, acts as an artificial sex hormone that prevents reproduction. It shuts down egg production in existing queens and prevents ovary growth in young queens. Amdro (hydramethylnon) is a low impact bait which acts as a toxicant. It is a fluorinated compound. Both products deteriorate rapidly with sunlight and moisture and both have low toxicity to mammals. Both can affect non-target arthropod species. Logic is retained in the crops of worker ants for months and will continue to be fed to new queens, thus it can achieve a longer-lasting effect than Amdro, up to 5 or 6 months for spring treatments and up to 11 or 12 months for fall treatments (Mark Trostle, pers. comm.; Collins, 1991). Logic treatments from July through November are favored over spring treatments, but spring and fall treatments are even more effective. Many areas need to be treated twice a year.

It was beyond the budget resources of this study to assess the efficacy of the treatments for a long time. Followups had to be done 6 to 8 weeks after bait treatments, according to TDA practice. This put the followups into late autumn. No further followups could have been done until the spring of 1992, when the ants became active again. Based on discussions with several fire ant experts (Dan Clair, Ed Vargo, Mark Trostle, Tom Bridges, and James C. Cokendolpher), it appears that both Logic and Amdro would be generally accepTable for use around caves as long as cave crickets and other cave inhabitants did not feed directly upon the bait. Only Amdro could be legally used on ranchland during this study and for that reason treatments at Bone, Man-With-A-Spear, and Temples of Thor caves were made with Amdro. As of July 1993, Logic is now permitted on horse pastures if the horses are not to be consumed by humans (see attached label). Amdro is an older product that passed EPA registration requirements for agricultural use long ago, whereas such registration for Logic is still pending.

The treatment schedule should have allowed the ants to take the bait before dark, when crickets and daddy longlegs harvestmen (*Leiobunum townsendii*) exit the cave to forage. The fire ants are so voracious that most bait should have been picked up long before sundown. This treatment method had been used in the vicinity of Tooth and Gallifer caves in the fall of 1990 and was found to be effective. James Reddell (pers. comm.) reports that Gallifer had abundant crickets and *Texella* populations in March 1991 several months after the Logic treatment.

To assess the impact of Logic bait on cave crickets, I placed plastic discs (7.8 cm in diameter) on the ground at four widely spaced points during the treatments of Tooth and Kretschmarr caves. I observed that the bait tended to bounce off the hard plastic, but some grains stayed on the discs. It also appeared that neither ants nor crickets were very fond of walking on the plastic, although some did so. I periodically observed and photographed the grains to see if they disappeared before nightfall, if fire ants were taking the grains, and if cave crickets took any grains. This test was not entirely satisfactory but did provide some insights into foraging behavior (see Results). Further work on this problem could not be done because of a lack of time and funding, but the problem needs more study. Observations on cave fauna were also necessarily limited. However, my privately funded, long-term baseline ecology study since June 1992 has provided much more follow-up information on LakeLine Cave and Temples of Thor Cave. Monthly reports have been filed with USFWS and are partially summarized in Results below.

I purchased a Brinkmann propane cooker of 164,000-BTU capacity and a 25-lb propane tank to boil water in the field. Water was transported in two five-gal water jugs. Water was boiled in a 2.5-gal galvanized bucket with about a teaspoon of Palmolive liquid detergent. The detergent may help the water to penetrate the soil. With the burner at full heat the bucket would take 8 to 10 min to boil. The detergent tends to form a foamy layer on top that will boil over suddenly unless one stirs the bucket thoroughly. It is best to boil the water first, then add detergent while stirring. When the water boiled I would remove the bucket and pour the hot water in a slow, circular pattern on mounds, usually within 30 sec. About ½ to 1 gal was used on small mounds (up to index 3). A full bucket was often used on larger mounds. In some cases, 2 or 3 buckets had to be used on the largest mounds or those located over deep rock fissures or at the base of a tree where the nest may be quite deep. I watched to see if ants continued to come up out of the ground at such nests and would pour another bucket on the nest until activity stopped. One such nest over a deep fissure next to the entrance of Tooth Cave required 3 buckets of hot water to kill. Conceivably, some large or deep mounds might require up to 10 gal to kill. The water temperature was not measured but probably was almost boiling at the time it was poured.

I computerized my field notes in SMAPS (compass and pace surveys) and dBASE IV (mound data). I used SMAPS to produce maps of the treatment plots. I used the dBASE query language to interactively obtain counts, totals, and averages for each treatment method and cave and to adjust colony size data at Tooth and Kretschmarr caves. The entire data set is available on diskette.

Mound population sizes were calculated according to the Lofgren and Williams method, then aggregate population sizes were calculated based on the indexed mounds. I used chi-square tests (Sokal and Rohlf, 1969) to compare the mean mound population sizes for each treatment method versus the control plot (New Comanche Trail) and versus other treatments. Chi-square tests were also used to evaluate the effect on ant reproduction (presence or absence of queens, alates, or larvae).

Finally, I compared the relative costs in materials and man-hours for baiting versus hot water. In addition, I obtained information on hot water pressure washers available in Austin and projected the costs and efficiency for several scenarios involving treatments of cave preserves over several years.

RESULTS

Remarks on Study Plots

Complete descriptions and detailed maps of the following caves may be found in Elliott and Reddell (1989), Reddell and Elliott (1991), Reddell (1991), and Elliott (1991a-e, 1992b-g, 1993a-f). The locations of the 12 caves gare depicted in Fig. 1. Although all plots were surveyed with compass and pace, I present representative maps of six of the plots below (Figs. 2-7). Each map shows the outline of the cave and the ant mounds that were checked. Tables 3-5 give details per treatment and cave area on the number of mounds indexed, acres treated, survey dates, percent population loss of mean colony sizes, and general remarks. In general ant colonies were smaller but denser near cave entrances where the soil tended to be thinner (Table 8).

Travis County—

1. New Comanche Trail Cave (Fig. 2), located on the southern Jollyville Plateau, is only 18 m (60 ft) long and 4 m (13 ft) deep. The entrance is a sinkhole about 2 m (6 ft) in diameter and 2 m deep. The cave is formed in thin beds of limestone and appears to be marginal habitat for cave-adapted fauna. Nevertheless, the cave contains two endangered species and, seasonally, fire ants. On October 6, 1991, fire ants were attracted to cheese bait at the bottom of the entrance at 7.9 ants per minute but there were few ants in the twilight zone and no ants at the end of the cave. By December 14 no ants were in the cave. The site was used as a control (no treatment) plot and was visited three times. Ten mounds were indexed, all on a gentle slope in open areas near the entrance. Between December 14 and 24 about 33 cm (13 in.) of rain fell. There was a 61% loss in average mound size during this ten-day interval but some mounds were still reproductive on December 24. The large reduction in population size probably was the result of partial wash-out of the mounds coupled with a die-off from cold weather. However, the December 14 data are used as the follow-up because that was closer in time to almost all of the other follow-ups (see Tables 5, 7 and Fig. 9).

2. Tooth Cave (Fig. 4) is one of the most important caves in the area, containing five endangered species and a community of over 64 species (Elliott and Reddell, 1989). The cave has been visited by biospeleologists since 1963. Nearby Russell Cave, which was dug open during studies in 1988, is connected to Tooth Cave but the connection is not humanly passable. Tooth Cave has been gated and the entrance to Russell Cave closed with rocks since 1989. The entire plot is densely wooded with junipers and hardwoods. The cave is owned by the Texas System of Natural Laboratories, which also has Kretschmarr and temporary control over Root, North Root, and Amber caves.

The cave area was treated twice with Logic before this study. In June 1988 Chuck Sexton and Lou Jost flagged about 100 colonies in a 100 ft radius around the entrance (approximately one acre). Logic was placed in vials that ants but not crickets could enter. Chuck Sexton (pers. comm.) reports that this treatment seemed to have worked, but no report or map is available. On September 12, 1990, the area was treated again by TDA inspectors Mark Trostle and Andy Feild in cooperation with James Reddell, who represented Texas System of Natural Laboratories. TDA broadcast Logic with a blower over a 200 ft radius from the entrance, but most of the treatment was concentrated in the central clearing. No systematic survey of mounds was done. The Gallifer Cave area was treated on the same day.

The entrance to Tooth Cave is a gated sinkhole about 1.2 m (4 ft) long, 0.6 m (2 ft) wide, and 2.4 m (8 ft) deep. The entrance opens into the center of a single room 23 m (75 ft) long, 8 m (26 ft) wide, and about 1 m high. Tree roots and breakdown blocks along the northeast wall correlate to a small collapsed sinkhole on the surface. At the south end of the cave is the connection to Russell Cave. A total of 36 fire ant mounds were checked in a one-acre plot, but 2 acres were treated with Logic and about 150 m^2 (1600 ft^2), or 5 mounds, were treated with hot water (Tables 3 and 4). When first surveyed on August 7, 1991, many mounds were in the wooded areas but few were in the central clearing. By October 6 several new colonies were established in the clearing. Based on the recensus and assuming that 95% of the mounds were surveyed, the infestation on the plot before treatment was about 925,000 ants per acre. On October 8, 1991, the writer treated a two-acre area around the cave with a shaker can of Logic at about 1 lb per acre. Cave crickets were observed around the entrance area that night. Follow-up was on December 4. On May 24, 1992, I returned to the cave with James Reddell and Rolf Aalbu during the final writing of this report. New fire ant mounds were found in the clearing near the entrance and in the woods. Some of the old mounds were active again, despite an 88% population loss as of December 4, 1991. No ants were collected on cheese bait at three stations in the cave but some were seen at the entrance and on the east side of the room at a talus slope which connects to the surface. The temperature in the cave was 18.3-18.9° C and the relative

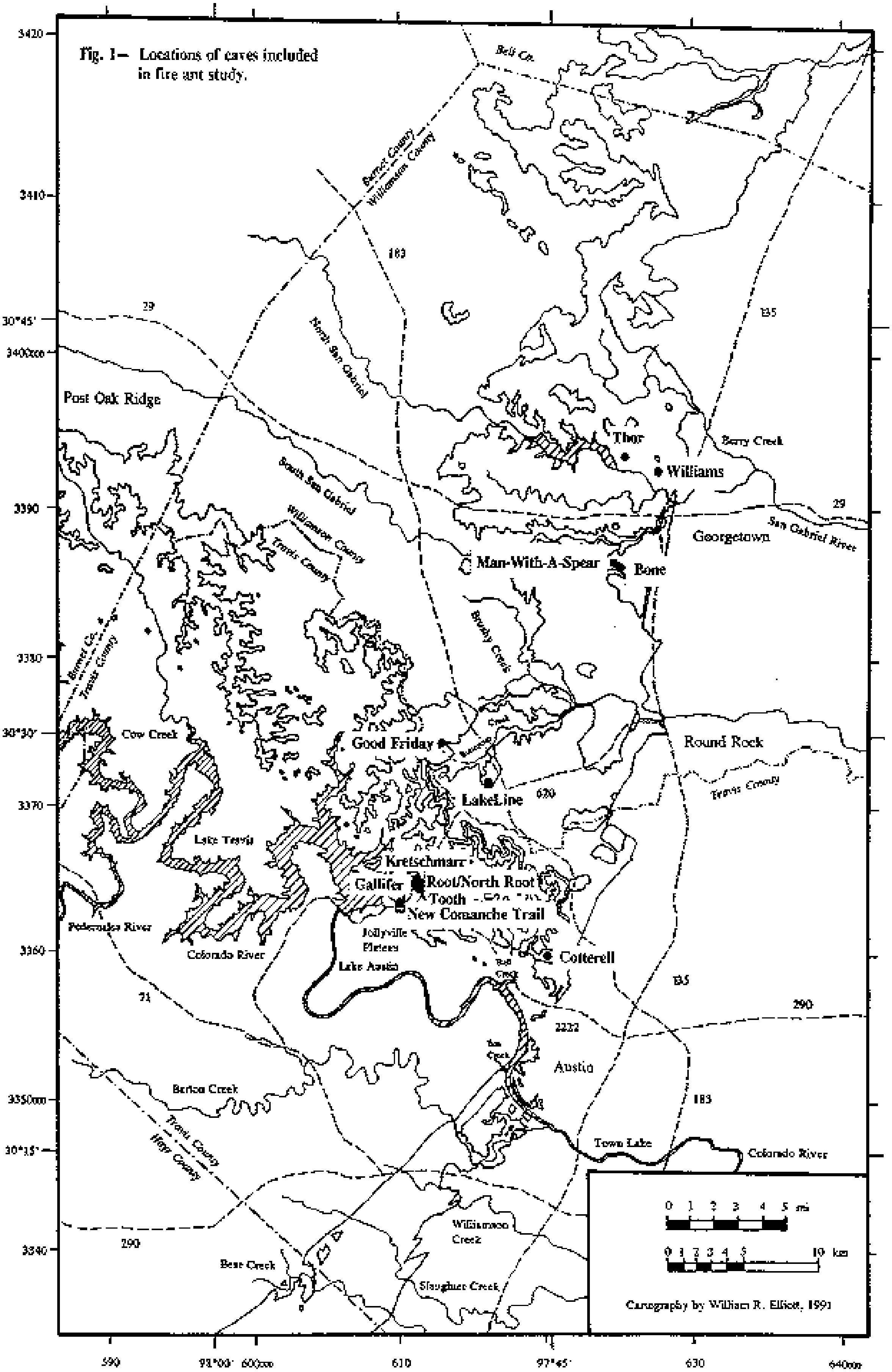
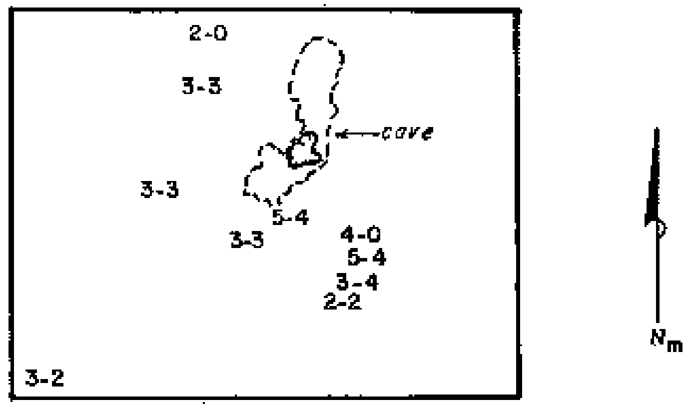


Fig. 1— Locations of caves included in fire ant study.

Fig. 2. New Comanche Trail Cave, the control (no treatment) plot for the study. The outline of the cave is shown. The entrance is the irregular circle with tic marks. The position of each fire ant mound that was indexed is shown as a two-number code: the first number is the Lofgren-Williams index when first checked in October, the second is the final check in December. Scale is 50 ft/in. (same as other cave maps).



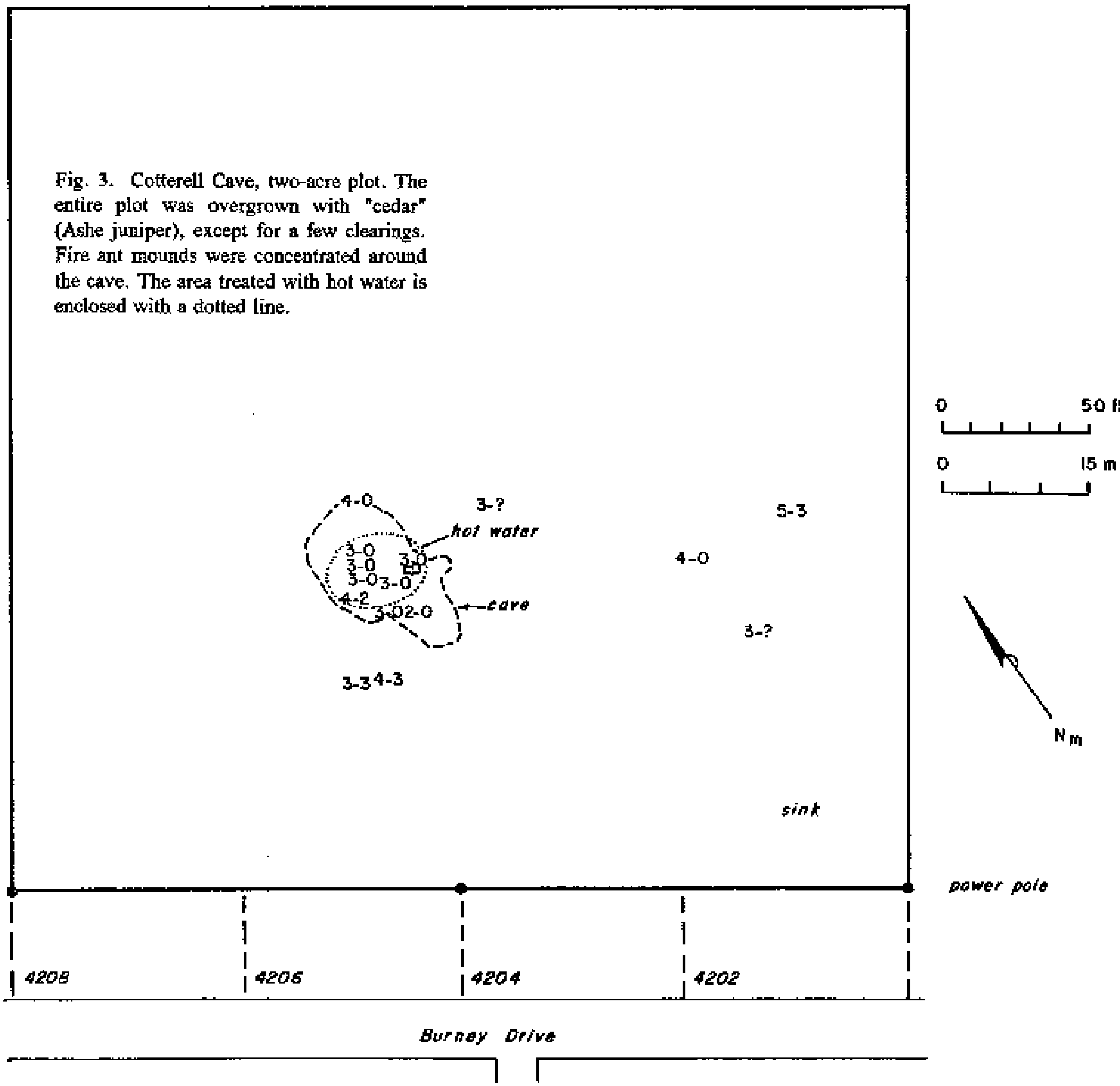


Fig. 3. Cotterell Cave, two-acre plot. The entire plot was overgrown with "cedar" (Ashe juniper), except for a few clearings. Fire ant mounds were concentrated around the cave. The area treated with hot water is enclosed with a dotted line.

humidity was about 99%. The soil in the cave was damp in most areas. In the entrance area we killed six new mounds and two old ones with 10 gal of hot water and about 1.5 lb of Logic was broadcast over one acre with a shaker can. James Reddell later reported that the treatments seemed to have been effective.

3. **Kretschmarr Cave** is in a one-acre preserve enclosed by a high, chain-link fence (Fig. 5, Tables 3, 4, 7). The entrance is a small sinkhole located near the center of the enclosure. The area also contains Kretschmarr Sink, located about 20 m (65 ft) east of Kretschmarr Cave. Although both are vertical shafts, Kretschmarr Cave contains cave-adapted fauna while the "Sink" seems to contain none. The gated entrance of Kretschmarr Cave is about 1 m (3 ft) in diameter and drops to a depth of 10 m (33 ft) and enlarges to 3 m (10 ft) long and 2 m (6 ft) wide. Vertical equipment is needed to enter the cave. At the 6.4 m (21 ft) level a tight crawlway leads to a second room where the cave's two endangered species are found. A total of 63 mounds were surveyed in the one-acre area, which was treated with Logic (59 mounds) along with an additional acre on the perimeter of the area. Four mounds near the two entrances were treated with hot water. The enclosure is heavily infested with fire ants, probably because it is mostly open and sunny while being located near developed areas. Based on the assumption that 95% of the mounds were surveyed, I estimate that Kretschmarr had 1.2 million ants in the enclosed acre before treatment, the worst infestation of all the plots surveyed. The area had not been treated before. Despite the heavy infestations, there were very few fire ants at the bottom of the cave when visited on July 26 and on December 10, 1991. The bottom of the cave is mostly dark zone. The Logic treatment was very effective in controlling the indexed mounds (a 92% loss in treated mounds) but significant reinfestation of new mounds occurred before the area was followed-up on December 10. Only 2 of the 59 previously indexed mounds (3%) had any signs of reproduction but 10 of the 21 "new" mounds (48%) were reproductive. Most new mounds probably were started by new queens flying in. The area had not previously been treated.

4. **Gallifer Cave** is located in a wooded area west of Tooth Cave. The area was treated with Logic on September 12, 1990, by TDA inspectors Mark Trostle and Andy Feild working with James Reddell. No mounds were surveyed. Reddell (pers. comm.) reports that cave crickets, *Texella reyesi*, and other fauna were abundant in the cave when he checked it in March, 1991. The gated sinkhole entrance is 2 m (6 ft) long, 1 m (3 ft) wide, and 1.5 m (5 ft) deep and opens into the southern end of a room approximately 15 m (50 ft) in diameter and nearly 1 m high. In the northwest corner the room drops into a 6 m (20 ft) long passage, which marks the cave's deepest point at 7.4 m (24.3 ft). The cave contains three endangered species. Fire ants were active only in the entrance on July 26, 1991, and had withdrawn by December 14 (Table 7). The area had been treated by James Reddell and TDA on September 12, 1990, with Logic and seemed to have had a low reinfestation rate.

5. **Root and North Root** caves are within 10 m of each other in a cedar (juniper) brake between Tooth and Kretschmarr caves. Both are very small sinkhole caves. Only three mounds were found near the cave entrances on October 11 and were treated with hot water. One nest was atypical— instead of a mound it was a diffuse network of tunnels just under a layer of juniper needle duff in the shade of a juniper tree (duff temperature 29.5° C). Another mound on the trail 100 m west of the caves was treated by sprinkling Logic in the immediate area around the mound, but this had poor results. The caves were not entered. Upon follow-up on December 14 the mounds treated with hot water were dead but there were four new mounds nearby and the general area was becoming badly infested.

6. **Cotterell Cave** (Fig. 3) is owned by the City of Austin. It is located in densely overgrown cedar brakes only about 30 m (100 ft) from houses on Burney Drive. Some of the homeowners dump yard rubbish over their back fences, which could harbor fire ants. The area was designated as a preserve in 1991 but only recently came under active preserve management by the City's Heritage and Conservation Program. The cave is visited by local youths who often leave trash. The entrance area was heavily infested with fire ant mounds on September 18, 1991. A survey of two acres centered on the cave revealed only six other mounds outside the entrance area although I could have missed some owing to the dense juniper. Most of the area has very thin, dry, juniper-duff soil. The ants may have preferentially established colonies near the entrance because of moisture in the cave or else new colonies generally cannot survive in the area. A large juniper root penetrates the ceiling of the cave, providing a perfect entry route for foraging workers. The cave entrance is a round sinkhole about 1 m (3 ft) in diameter, which drops 5.5 m (18 ft) into what is essentially one extended room about 18 m (60 ft) long and 6 m (20 ft) wide. Vertical caving equipment is required to enter the cave, which is hazardous to untrained persons.

A two-acre area was treated with Logic on October 10, 1991, but marking the boundaries and finding routes

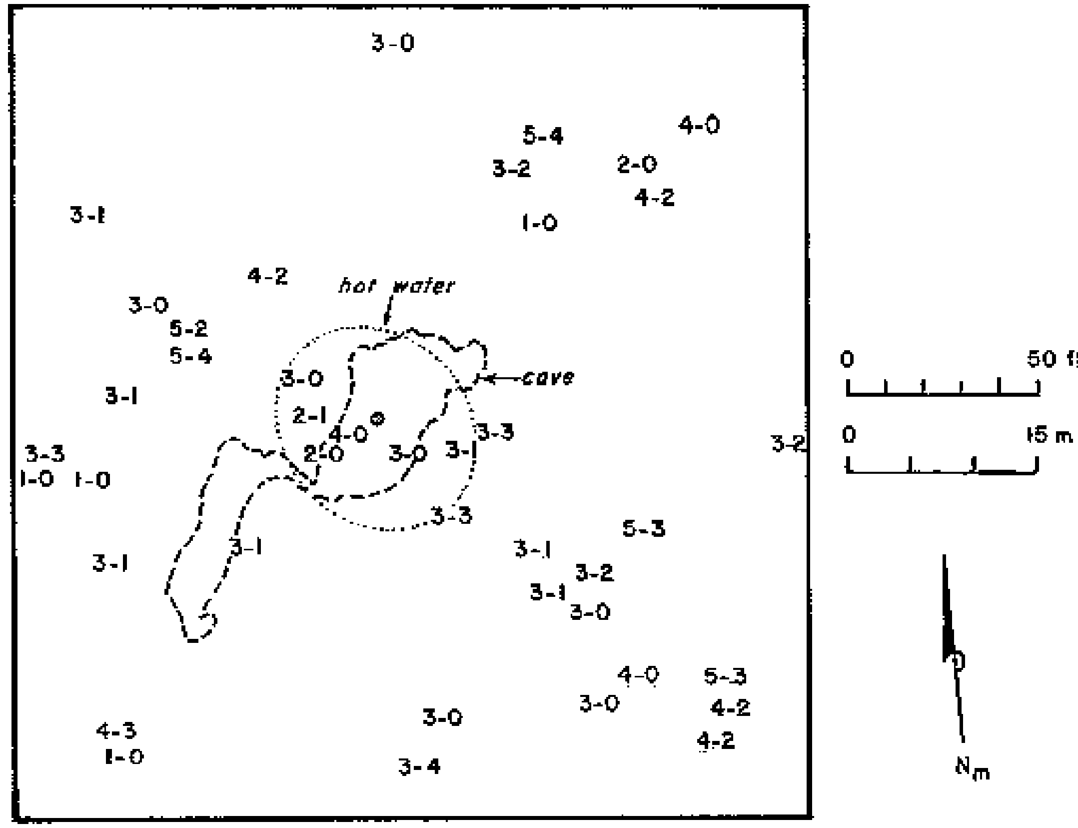


Fig. 4. Tooth Cave, one-acre plot. About 95% of the mounds in the plot were indexed, but two acres were treated with Logic. The plot was covered with hardwoods and cedar, but contained a few shady openings, such as the central area around the entrance. The plot contained about 925,000 ants per acre.

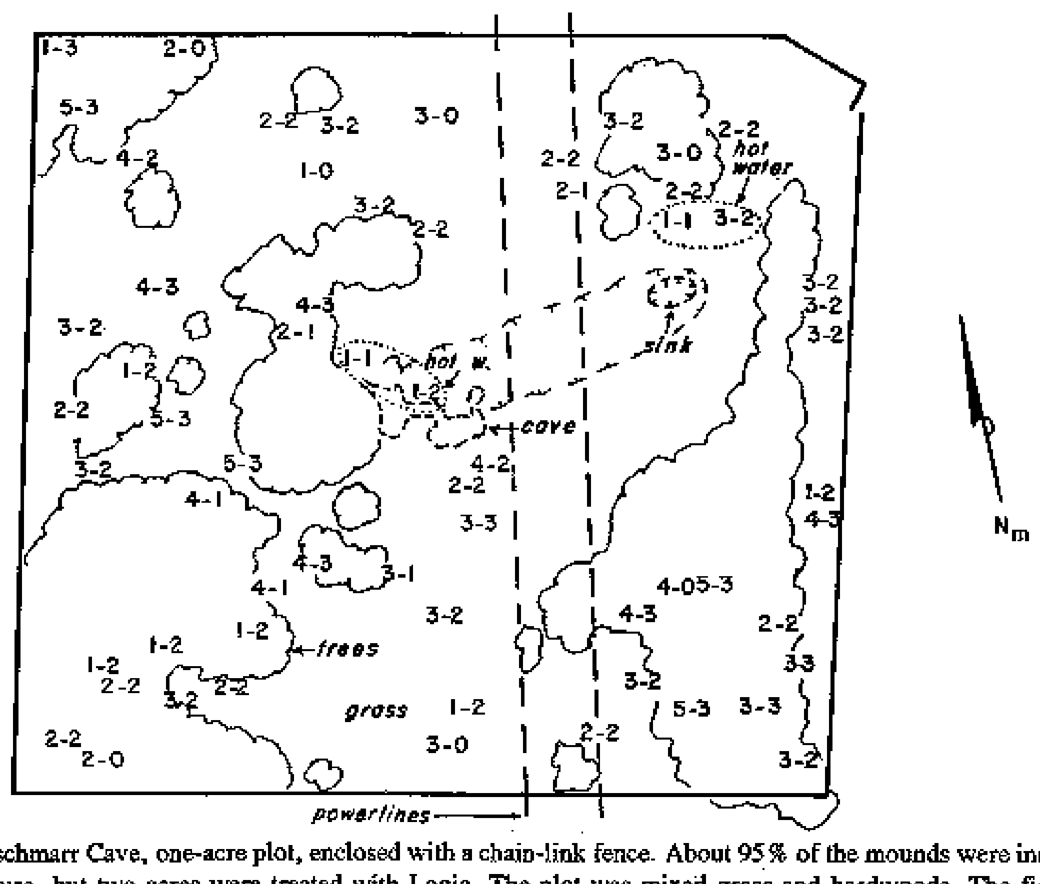


Fig. 5. Kretschmarr Cave, one-acre plot, enclosed with a chain-link fence. About 95% of the mounds were indexed in the enclosure, but two acres were treated with Logic. The plot was mixed grass and hardwoods. The fire ant mounds seemed to be denser on the edge of the shady areas. Trees are shown as irregular outlines. The plot contained about 1,200,000 ants per acre, the worst infestation seen in the study. Reinfestation was rapid after the treatment.

through the dense juniper took about two hours. Six mounds were killed with hot water near the entrance. A Solo blower and a Cyclone spreader were used to broadcast bait. Upon returning to the plot on December 16 I found that intruders had removed about 5 marker flags. Using the map I was able to relocate all but two of the mounds for follow-up. Although good control was achieved (67% with Logic, 99% with hot water), the entrance area was reinfested again by mid-May, 1992 (Mark Sanders, pers. comm.)

Preserve management of the area will be difficult unless it is fenced and some of the juniper removed. However, this may open up more habitat for ants. The cave contains one endangered species and a rich troglobitic fauna including two rare, undescribed *Cicurina* spiders. The cave is an important biological site and deserves good protection and management.

Williamson County—

7. LakeLine Cave (Fig. 6) is located on the LakeLine Mall property west of the intersection of RM 620 and U.S. Highway 183 in Cedar Park. It is owned by Melvin Simon & Associates, Inc. and has been set aside on a preserve of about 2.3 acres. The gated sinkhole entrance is about 1 m (3 ft) by 2.1 m (7 ft) and drops about 1.5 m to a crawlway leading into the Ledge Room. The cave is formed on two levels. One must crawl through an upper-level constriction to reach the rear of the cave, where one can drop down into a low, wide, bedding-plane room or continue into another such room on the upper level. The cave is about 21 m (70 ft) long and 3.2 m (10.5 ft) deep.

The LakeLine Cave area was treated previously with Amdro by Lee Stone on October 4 and about October 20, 1990. She used a "solicit and bait" method in which small chunks of wieners were set out on wire flags to attract ants. The flags were placed in a grid pattern of 10-ft squares. After a few minutes the ants were knocked off each wiener and a small amount of Amdro placed around the flag. Fire ants were seen entering the cave on the afternoon of October 4, 1990, and a treatment was done within a 50-ft radius of the entrance. She returned on about October 20 and treated the rest of the area within a 250-ft radius. No follow-up was done but this method has been used with good results in several City of Austin parks and natural areas (S. Lee Stone, pers. comm.).

The writer was engaged by the cave owner from May through December, 1991, to perform monthly ecological monitoring studies at the cave (Elliott, 1991a-e, 1992a). The studies resumed on a larger scale in June 1992, along with studies of Testudo Tube and Temples of Thor Cave as part of an Endangered Species Act "10(a) permit" to develop a mall on endangered-cave-species habitat. The studies encompass ecological studies of cave fauna, including surface studies of cave cricket and daddy-long-legs foraging behavior at night. The studies and land management will be administered under agreements by the company with the writer and the Texas Parks and Wildlife Department. Monthly reports (Elliott 1992b-g, 1993a-f) on these studies have shown that cave crickets have not declined after hot water, Logic, and Amdro treaments at LakeLine and Thor. Fire ants did not recur in LakeLine until April, 1993, while they have invaded Thor Cave each spring since treatment. Although no actual populations estimates of other cave-dwelling species could be done, counts of observable species in marked zones in each cave have shown no obvious decline in fauna either from treatments or fire ants. However, fire ants have been observed feeding on cave crickets and other species in both caves.

Studies at LakeLine Cave have shown marked seasonal and diurnal variation in temperature and humidity, as one would expect with a small, shallow cave. At night or during cold fronts cool air tends to sink into the entrance and flow along the floor toward the back of the cave. Cool air may tend to dry out the cave sometimes and probably influences the distribution of fauna within the cave. Warm, humid air tends to be trapped in the upper level at the back of the cave. Temperature changes in the rear, upper level lag behind surface temperatures by several weeks because of this trapping effect (Elliott, 1991e). Moisture enters the cave primarily along the central joint, resulting in a damp substrate along the centerline and drier conditions along the margins.

Fire ants were extremely active in the entrance on August 6, 1991, when 107 ants were attracted to cheese bait in 15 minutes (7.13 ants/min). After surveying 23 mounds on September 4, 1991, in a ½-acre area, I used the Lofgren-Williams method to calculate that the entire 2-acre treatment plot was infested with about 1,487,200 ants, or about 743,600 ants per acre. On September 24 ant activity was at 3.7 ants/min in the entrance. After hot water and Logic treatments of the area on September 24 and October 9, the entrance had 0.21 ants/min on October 30 and 0.02 ants/min on November 29. Few ants were seen in the cave interior after August, 1991. In 1992 no fire ants entered the cave but by May 1993 they were in the cave again. Crickets increased by spring 1993.

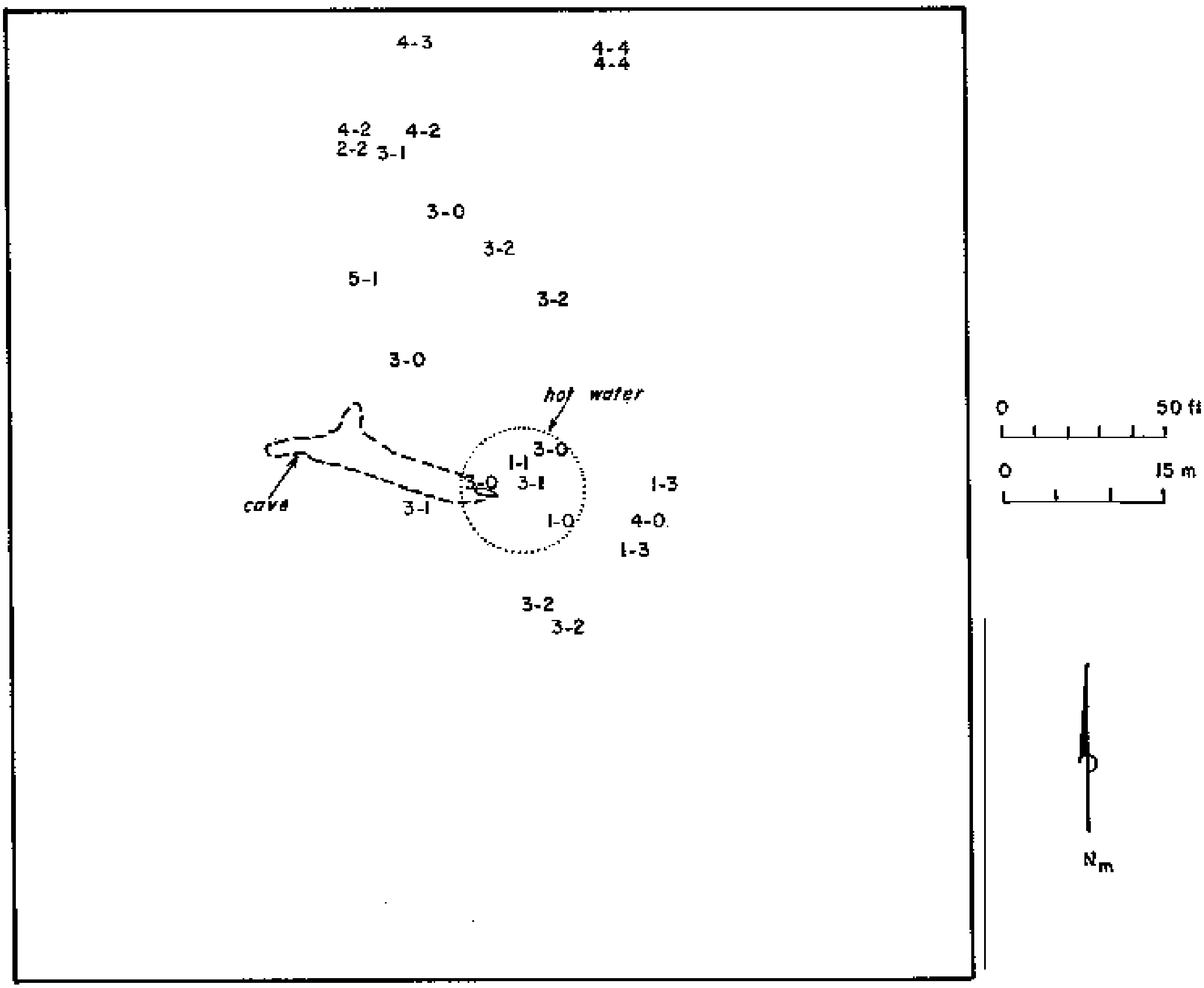


Fig. 6. LakeLine Cave, two-acre plot. Only ½-acre was checked for mounds, which was infested with about 750,000 ants per acre. The plot was mixed grass, cedar, and hardwoods. The cave is very shallow and the cave is heavily infested with fire ants at times. Ants have been seen entering the rear of the cave, probably from cracks in the rock, but most enter the entrance. This cave will be part of a long-term ecological study.

8. Good Friday Cave is located in the Buttercup Creek drainage west of Cedar Park in a grassy pasture with some junipers and is owned by Lumbermen's Association. The cave contains one endangered species. The pit entrance is about 3 m (10 ft) in diameter and 4.6 m (15 ft) deep. The sides of the pit are fractured and loose and coated with loose soil. The entrance narrows about 3 m down into two small slots. At the bottom a steep soil slope leads north into a crawlway. The crawl extends east-west and soon becomes tight at either end. A heavy fire ant infestation was observed by the writer and Marcelino Reyes on May 7 and June 19, 1989. The cave was not entered during the current study but a two-acre area was treated with Logic on October 16, 1991. Eleven mounds were checked but none were within 4 m of the entrance, so none were treated with hot water. The follow-up on December 18 was on a rainy day when the ants were concentrated in the mounds, resulting in an overestimate of the colony sizes and an apparent population loss of only 49% compared to the average loss of 87% with Logic treatments.

9. Bone Cave is located on the Weir Ranch southwest of Georgetown in an open pasture with thin soil and short grass. The entrance is a sinkhole in bare limestone about 1 m (3 ft) long, 0.5 m (1.5 ft) wide, and 3 m (10 ft) deep. The cave is an irregular, elongate room floored with breakdown about 26 m (85 ft) long, 3-5 m (10-15 ft) wide, and 5.8 m (19 ft) deep. The ceiling is only about 1 m thick. The cave was not checked on this study, but a heavy fire ant infestation had been observed in the cave on August 27, 1990, by the writer and Doug Allen. At that time ants were found even in the dark zone and the cave temperature was estimated at about 30° C (86° F) while the outdoor temperature was 41° C (106° F). The high temperature was due to the cave's thin roof. The 16 ant mounds surveyed on October 14, 1991, were smaller than in areas with thicker soil. The one-acre plot was treated with Amdro because cattle graze the area. One mound near the entrance was killed with hot water. One *Pogonomyrmex* nest existed in the area, but died out after the Amdro treatment. Follow-up was on December 23 and a 96% ant population loss was noted, the best achieved on any of the plots with chemical bait but still below the average loss obtained with hot water (99%).

10. Man-With-A-Spear Cave is located on the Weir Ranch near Georgetown in a grassy pasture with large shady areas. The cave entrance is in the southern end of a large, bowl-shaped doline, the northern half of which contains ant mounds. Ant mounds were located on thicker soil areas just south of the lip of the doline. The cave entrance had been heavily infested on October 7, 1990, when the cave was mapped by the writer and Allan Cobb. The cave was not baited with cheese before treatment in this study. However, ants were observed in the entrance on October 14, 1991, when we treated the area with Amdro (14 mounds) and hot water (one mound). A 79% ant population loss was observed by the follow-up date of December 6.

The cave is a solution chamber modified by massive breakdown. The total length is about 37 m (120 ft) and the depth is about 8 m (25 ft). The cave contains one endangered species, *Texella reyesi*.

11. Temples of Thor Cave (Fig. 7) is located north of Georgetown on the old Godwin Ranch, which has been set aside as an endangered-cave-species preserve under the LakeLine Mall Habitat Conservation Plan. The ranch is mixed grass and hardwoods— juniper was largely cut out about 15 years ago. The ranch still has cattle owned by the lessee. The entrance is in a fractured area at the base of a large tree, and was excavated on May 10, 1991, during a study for the City of Georgetown (Reddell and Elliott, 1991). The cave is about 70 m (228 ft) long and 19 m (61 ft) deep and contains one endangered species, *Texella reyesi*. The cave is excellent habitat for a variety of troglobitic species and is be part of a long-term ecological study by the writer. Soon after opening the cave fire ants infested the entrance from nearby mounds and some Amdro was put out around mounds in May. On August 30, 1991, I baited the cave with cheese and found 5.34 ants/min at the entrance and 0.16 ants/min in the Texella Room, which is barely in the dark zone. A short distance farther in there were only 0.06 ants/min. A two-acre area was surveyed by the writer and his father, Rawleigh S. Elliott, on October 14, 1991, and the area was treated with hot water (3 mounds) and Amdro (18 mounds) on October 15. A brief visit to the cave on November 6, 1991, by the writer and Lionel Friedberg found no fire ants and no *Texella* visible in the cave after the previous night had brought a cold front during which cold, dry air had sunk into the cave. Other fauna was at typical levels. The ants lost 69% of their population by December 23 when they were followed-up. No ants were found in the cave on December 23. In 1992 and 1993 fire ants reinvaded the cave each spring from a deeply entrenched colony at the base of a large cedar elm next to the entrance. No further treatments have been done since October 1991. The writer has counted cave crickets as they emerged in the evening each month since August 1992. I have seen no secular decline in the cricket populations since the treatment— only a normal seasonal cycle wherein the population peaks in the summer and largely remains in the cave in December and January (see Cave Cricket Observations below).

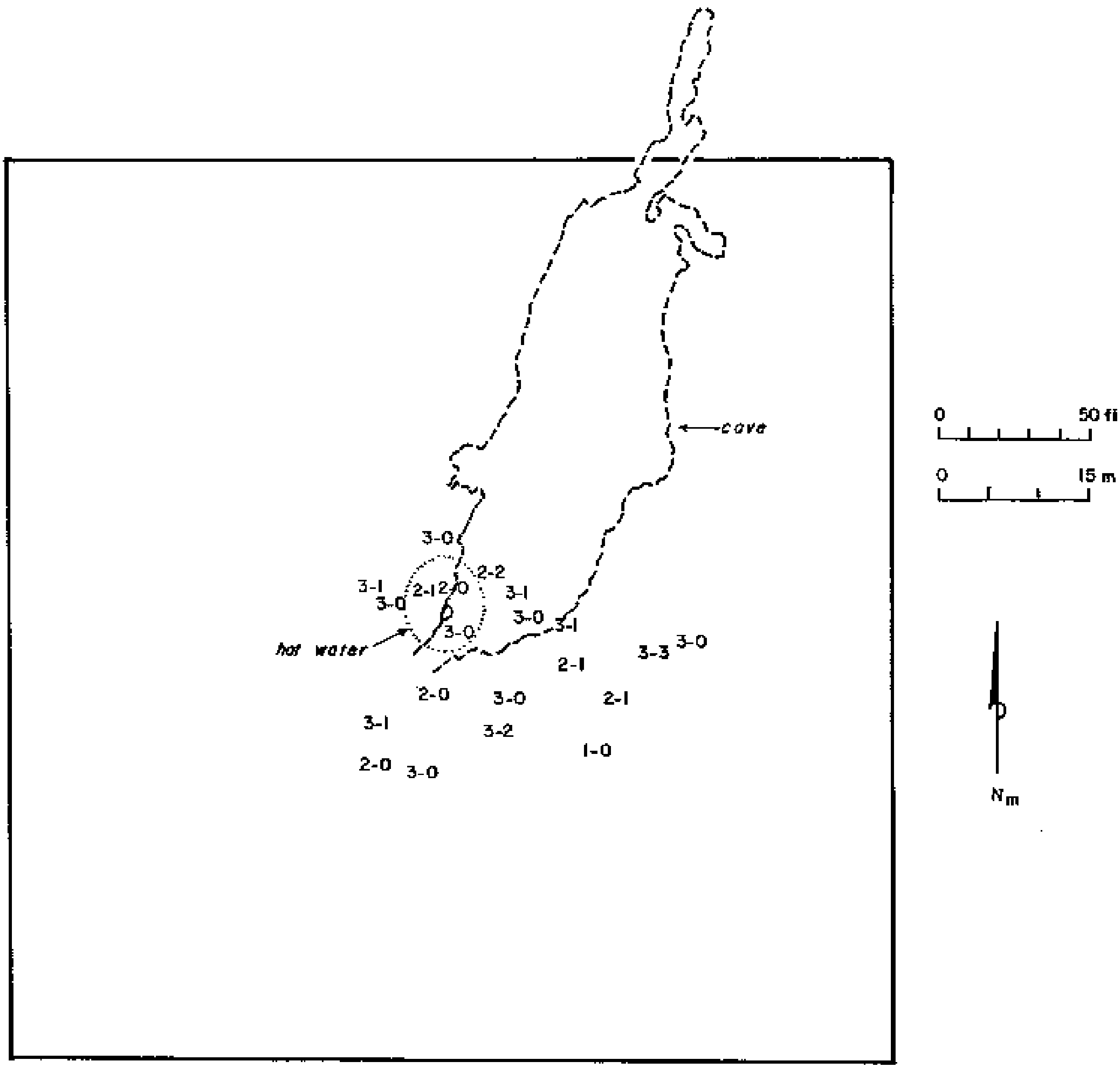


Fig. 7. Temples of Thor Cave, two-acre plot. Only a portion of the plot was checked for ant mounds. Ants began entering the cave within a few days of the entrance being dug open in May, 1991.

Although no population estimates of other species were possible because of the small observable numbers, all species that were initially found in the cave have been observed on most monthly visits. During these visits fauna is counted in zones marked in the cave. No obvious decline in observable numbers of *Texella reyesi* has occurred, but the numbers vary from 0 to 5 each trip. Fire ants often penetrate to the Zone 5 area about 30 m inside the cave where *Texella reyesi* is concentrated. The harvestmen rarely occur in drier areas closer to the entrance or in areas beyond Zone 5 where the humidity is high but less food and cover occurs. The areas beyond Zone 5, about half of the cave, are relatively abiotic flowstone or breakdown. Observations indicate that *Texella reyesi* has a very narrow preferred microhabitat. It would be an extremely rare event to witness a fire ant taking a *Texella* owing to the small observable numbers, but that does not rule out the possibility that the ants may prey on them, especially since *Texella* is slow-moving compared to other species. Even if such predation is infrequent it could cause a gradual decline in the small *Texella reyesi* population.

12. Williams Cave (Seven Room Cave) is located on the Jack Frost Elementary School property and is owned by the Georgetown Independent School District. The cave is about 109 m (356 ft) long and 2.7 m (8.8 ft) deep below the entrance. The cave is essentially a long passage subdivided into seven rooms by formations.

The one-acre plot varied from open grassland to dense woods in an intermittent creek. The cave had been sealed by the school district several years before but the fill had sunk sufficiently to give access in 1991 during a study for the City of Georgetown. The cave contains the endangered *Texell reyesi*. On August 1, 1991, cheese baits in the cave indicated ant activity at about 2.27 ants/min at the entrance. Fire ants were found at low levels nearly throughout the cave— about 0.06 ants/min in the Second Room (dark zone) were retrieved from cheese bait but none were retrieved in the Fifth Room, although some were seen in the Fourth Room nearby.

With the school district's permission I surveyed and treated a one-acre area around the cave with Logic and a Cyclone spreader (9 mounds indexed) and used hot water on 2 mounds on October 17, 1991. The follow-up on December 23 indicated a 90% loss of ant population in the indexed mounds.

Cave Cricket Observations

On October 8, 1991, I observed cave crickets and ants foraging for about two hours near Tooth and Kretschmarr caves. This was the first day of Logic treatments and there was a late start because the TDA personnel were unavoidably delayed. I treated the Tooth Cave area, finishing at 2:20 pm. Then the two TDA personnel and I treated the Kretschmarr Cave area, finishing at 4:30 pm. I placed two plastic discs on the ground at each plot to observe if the Logic grains would be picked up. I returned to the area at sunset (7:08 pm) and spent two hours observing at both plots. My observations suggested that most bait probably was picked up before sundown despite the late start. Crickets began exiting Tooth Cave at about 8:00 pm. Some bait remained on the test discs on the ground but this may have been because the discs were not inviting to most insects. Out of about 50 cave crickets closely observed at Tooth and Kretschmarr caves, one took a Logic grain from a disc. Twelve fire ants were observed taking bait from the four discs. One cave cricket was observed with a dead fire ant in its mandibles. Cave crickets were mostly seen on foliage, dead leaves, lichens on sticks, and grass, but they were not chewing although they used their palpi to probe the substrate. I was bitten by two cave crickets on my arms and observed several chewing on my camera strap on the ground. Possibly they were attracted by odor or salt. Ants were still foraging and taking bait from the discs when I left at 9:24 pm. The temperature dropped from 20.5° to 18.5° C (69° to 65° F) during this period.

No obvious effects on cave crickets or other cave species were observed after the treatments. Fauna was at typical levels in LakeLine Cave when visited on a different study on October 30, November 29, and December 31, 1991. Fauna was at typical levels in Temples of Thor Cave when visited on November 6 and December 23, in Tooth Cave on December 4, in Man-With-A-Spear Cave on December 6, in Kretschmarr Cave on December 10, and in Cotterell Cave on December 16. On May 24, 1992, there were abundant cave cricket adults and nymphs in Tooth Cave.

It was beyond the scope of this study to do exhaustive population estimates but the long-term ecological study of LakeLine Cave, Testudo Tube, and Temples of Thor since June 1992 has provided useful information. Counts of crickets emerging at night have shown that the observable cricket populations are influenced by temperature and season. At LakeLine in August 1992 (the first count) the emergence numbered 574 and increased to 824 by October, then decreased to 0 in December (however, there were still many crickets in the cave). In 1993 the cricket population is larger, with 2,600 emerging in June. At Temples of Thor Cave the emergence was 1,266 in August 1992, 6 in December, 1,611 in May, 1993, and 1,008 in June, 1993. As mentioned before, fire ants reinvaded LakeLine Cave in April, 1993, and Thor Cave in the springs of 1992 and 1993. The crickets have a basically annual reproductive cycle. Nymphs may be seen any time of year but are more abundant in the autumn. By May the ceiling-dwelling populations (*Ceuthophilus secretus* and *C.* n. sp.) are predominantly adults and sub-adults. The ratio of nymphs to adults during emergences ranges from 0.4 to 50 or more. Adults are more sensitive to light and low temperatures and will not emerge on cold nights even when nymphs emerge. The floor-dwelling crickets (*C. cunicularis*) are smaller, less abundant, rarely seen outside, and appear to be predominantly nymphs in the spring.

I have observed intense competition between cave crickets and fire ants for cheese bait that was set out at bait stations at different distances from the cave entrances. Cave crickets usually find the bait first and will feed on it until fire ants begin covering it. This succession occurs within a few minutes and is easily missed by observers. Adult cave crickets are strong and can usually hop away from attacking ants, but small nymphs are very vulnerable. Cave crickets are basically carnivorous. I have observed them feeding on dead insects and sometimes on fungi or ripe native persimmons. I have not seen them feeding on most plant materials or fruits, such as prickly pears. Fire ants are basically carnivorous but will consume almost anything juicy or odiferous. Cave crickets mostly feed within 5 or 10 m of the cave entrance, but large adults may travel 50 m or more.

Fire Ant Activity in Caves

There was insufficient time in this project to make many observations on food items taken by fire ants in the caves. Most ants carried no food and may have been foraging for moisture. I observed fire ants carrying chunks of white flesh, probably tissue from dead cave crickets, and small cricket nymphs. However, in other studies James Reddell and I have observed fire ants preying on the following species in many different caves in central Texas: earthworms, a *Vaejovis reddelli* scorpion, a *Tyrannochthonius* pseudoscorpion, troglobitic millipedes (*Speodesmus bicornourus* and *Cambala speobia*), hothouse millipedes (*Abacion texense*), collembolans, a troglobitic *Texoreddellia texensis* thysanuran, small and large cave crickets (dead or alive), various insect larvae, and a *Plethodon* salamander (Elliott 1991a-e, 1992b-g, 1993a-f; Reddell pers. comm.). Although most fire ant attacks occured on the cave floor, Reddell (pers. comm.) has observed fire ants attacking *Speodesmus* millipedes and crickets on cave ceilings.

In general fire ants were active mainly in the entrance zones of the nine caves that were baited with cheese (Table 7, Fig. 8). The number of ants in the entrance was usually directly dependent on the presence of ant mounds near the entrance, but inversely dependent on the depth of the entrance. Ants observed in deeper cave areas appeared to be sluggish compared to the typically rapid, foraging worker. Certain "ant guests", species that accompany the ants, were observed in LakeLine Cave: the small, grey millipede *Myrmecodesmus formicarius* and an unidentified species of bristletail. These species are indicative of the long-term presence of fire ants in the dark zone where the endangered species *Rhadine persephone* and *Texella reyesi* occur.

Since most cave entrances were shallow, ants were able to access most entrances without encountering low light and temperature. Kretschmarr and Cotterell caves had deep entrances with few ants at the bottom. However, in Cotterell ants were able to access the dark zone on a juniper root leading directly through the ceiling. Ant activity in the twilight and dark zones declined from a high in July-August to nearly zero by September-October and continued low until November-December. In contrast, fire ant populations on the surface and in the entrances continued to increase from July-August until about October, then declined by December. Mean cave temperatures generally declined about 0.5 to 1.0 °C from mid-summer to early autumn, which probably discouraged ants from traveling very far into caves. I observed a mean decrease in cave temperatures of about 4 C° between mid-summer and late autumn (from 22° to 18°). I interpret these data to mean that the ants can utilize the cooler, deeper parts of caves mainly in hot, dry weather but that entrance areas remain within the ants' temperature preferendum longer and also receive "spill-over" from populations increasing on the surface until cold fronts begin to arrive. Many fire ants survive the winter in central Texas in their mounds.

Some of the worst infestations deserve comment. In LakeLine Cave ants formed trails reaching to the end of the cave but the columns were thin in the dark zone. In the ongoing ecological study of LakeLine we observed ants entering the upper level at the far end of the cave on October 30, 1991, probably through cracks in the ceiling,

Table 7. Summary of fire ant activity in caves, measured as ants per minute attracted to cheese bait. Air temperatures in each zone are also given. See *Fig. 8.*

	Jul/Aug			Sept/Oct			Nov/Dec		
	Ent.	Twi.	Dark	Ent.	Twi.	Dark	Ent.	Twi.	Dark
Mean ants/min.	2.48	0.26	0.18	3.92	0.06	0.04	0.003	0.015	0.020
Range	0.03-7.13	0-1.50	0-0.91	0.11-7.92	0-0.11	1-0.07	0-0.02	0-0.06	0-0.10
Mean temp. °C	22.6	22.4	21.5	22.0	23.5	20.3	18.3	17.8	18.5
Temp. range °C	20.5-25.5	20.5-24.7	20.5-22.0	21.0-23.0	23.5	19.0-21.5	14.5-19.5	13.0-20.0	14.0-20.5
Sample size	7	7	7	3	3	2	8	8	8

although most entered through the entrance. LakeLine had up to 7.13 ants per minute at the entrance bait on September 24, 1991, the second worst infestation of the nine caves checked. Cotterell Cave had more ants in the dark zone (0.91 ants/minute) than at the entrance (0.38) on August 22, 1991. As mentioned above, a large juniper root penetrates the ceiling of the terminal room of Cotterell Cave, providing an "ant highway". Ants were observed attacking a large earthworm on the floor next to the root. New Comanche Trail Cave had the highest entrance infestation, 7.9 ants/minute on October 6, 1991. The entrance is broader than most and the temperature was 21.0° C there, but only 0.11 ants/min occurred in the twilight zone at 23.5° C and no ants occurred in the dark zone at 19.0°C. Temples of Thor Cave may not have been infested before the entrance was excavated in April 1991. By May ants had invaded the cave as far as the *Texella* habitat about 4 m (13 ft) inside. The entrance had 5.3 ants/minute on August 30, 1991, but none after treatments in October.

Treatment Results

Tables 3-6 and 8-11, and Fig. 9 show the results of the various treatments, per cave and per treatment. In general all treatment methods (Logic, Amdro, and hot water) were successful when compared to the control plot, which had a 58.6% population loss during the same period. The 10 mounds indexed at the control plot had a further loss during a cold period from December 14 to 24 when 13 inches of rain fell. I use the December 14 data for the control because it is closer in time to the followup surveys at the treatment plots. Table 8 shows the raw population losses of the different treatment methods and a "Corrected % Loss", which adjusts the loss to that predicted from the control plot with no treatment.

It is obvious that the hot water method was far more effective than the bait methods. Hot water alone killed 98.4% of the ants in 31 mounds (corrected for control population), while Logic (146 mounds tested) and Amdro (48 mounds tested) had corrected losses of 78.4% and 77.3% respectively. Chi-square tests showed all treatments to be significantly different from the loss measured on the control plot (Table 9). Hot water vs. control had the highest chi-square value. The only non-significant chi-square in the matrix of results was for Logic vs. Amdro; that is Logic and Amdro were about equally effective over the two-month interval of the test.

Tables 10 and 11 show the results of the treatments on reproductive capacity in the mounds, as measured by the presence of any brood, alates, or queens. Hot water was 100% effective in this test if only because it usually completely annihilated a colony. Therefore, it seems that queens were not escaping the hot water drenches. The key to this method, of course, is ensuring that the mound is thoroughly drenched. The only non-significant comparison was between Logic and Amdro, as before in the overall population loss tests. This is interesting in that Logic is a reproductive control. However, if a follow-up could have been done the next spring, Logic would have been expected to exert a longer lasting control (Mark Trostle, pers. comm.).

Table 8. Effects of treatments on mean fire ant colony sizes. The December 14, 1991, follow-up data at the control plot was used to correct the % loss at the treatment plots to that lost by treatment only. December 14 was closer in time to the follow-ups at the treatment plots than was December 24.

Treatment	No. Mounds	Before Treatment	After Treatment	% Loss	Corrected* % Loss
Logic	146	20,834	2,626	87.4	78.4
Amdro	48	9,860	1,312	86.7	77.3
Hot Water	31	9,689	91	99.1	98.4
Control, Dec. 14	10	25,860	10,711	58.6	—
(Control, Dec. 24	10	25,860	4,195	84.8	—)
Total	235	—	—	—	—

* Corrected to account for anticipated natural loss, projected from control plot.

Corrected loss = 100(1 - After/(Before X 0.586))

Table 9. Results of chi-square tests comparing treatment effects on mean fire ant colony sizes. All chi-square values were highly significant, except Logic vs. Amdro. Thus, all treatments had statistically significant results compared to the control plot but Logic and Amdro were not significantly different from each other. The larger chi-squares indicate greater statistical significance. Hot water was much more effective than other treatments.

	Logic	Amdro	Hot Water
Amdro	2.3 ns		
Hot Water	968.6***	975.9***	
Control, Dec. 14	903.5***	34.5***	1,304.2***

ns = not significant, $p > 0.05$
*** = $p < 0.001$

Table 10. Effects of treatments on reproduction in fire ant colonies. A mound was scored as reproductive if it contained any brood, alates, or queens. The December 14, 1991, follow-up data at the control plot was used to correct the % loss at the treatment plots to that lost due to treatment only. December 14 was closer in time to the follow-ups at the treatment plots.

Treatment	No. Mounds	Before Treatment	After Treatment	% Loss	Corrected* % Loss
Logic	146	73 (50%)	11 (8%)	85	70
Amdro	48	21 (44%)	3 (6%)	86	71
Hot Water	31	13 (42%)	0 (0%)	100	100
Control, Dec. 14	10	8 (80%)	4 (40%)	50	—

* Corrected to account for anticipated natural loss, projected from control plot.

Corrected loss = 1 - After/(Before X 0.50)

Table 11. Results of chi-square tests comparing treatment effects on reproduction within fire ant colonies. The tests were based upon percentages of all checked mounds that were reproductive. All comparisons were very to highly significant except Logic vs. Amdro. Hot water was more effective in reducing reproduction because it essentially annihilated most colonies.

	Logic	Amdro	Hot Water
Amdro	0.1 ns		
Hot Water	6.3**	5.4**	
Control, Dec. 14	7.6**	8.1**	18.6***

ns = not significant, $p > 0.05$
** = $p < 0.01$
*** = $p < 0.001$

Fire Ant Activity in Caves

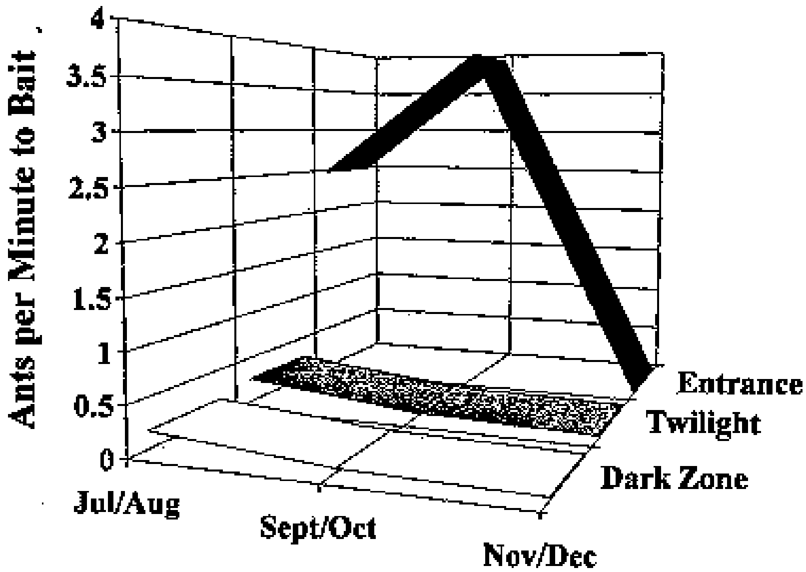


Fig. 8. Fire ant activity in caves, as measured in ants per minute captured on a cheese square at different locations in nine caves. Although the large decrease in ant activity by December resulted from treatments, the control plot (New Comanche Trail Cave) also lacked ants in December. Most ants were concentrated in entrances.

Fire Ant Treatments

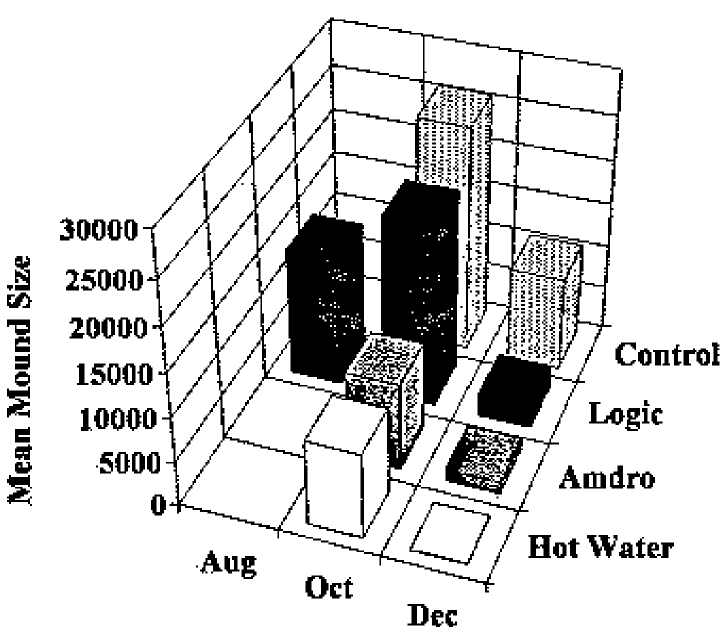


Fig. 9. Fire ant treatment effects in terms of mean mound size. Hot water had the best results. Mounds tended to be smaller near cave entrances where hot water was used. Logic and Amdro had essentially the same results.

DISCUSSION

The long-term effects of the fire ants on the community structures of the invaded caves are still uncertain. Considering Porter and Savignano's 1990 study there certainly is a large potential for severe ecological damage, both directly on the endangered species and indirectly on the entire food web both above and below ground. The problem is growing worse and we can probably expect most caves along the Balcones Escarpment to be affected by fire ants in the near future.

Had this study extended over six months, Logic might have shown better results than Amdro if it indeed be passed on from the crops of surviving workers. However, such an eventuality may be of little practical value because of the high reinfestation rates observed in some areas, which may swamp any such residual benefits. Most of the cave plots would need to be treated every six months.

Reinfestations mostly were caused, I believe, by immigration of new queens from the general region. This was especially true at Kretschmarr, which was more open to the sky than Tooth. Few reinfestations occured at Tooth, which is heavily wooded but near Kretschmarr. In some cases a new mound sprang up near a flagged mound and may have been built by workers from new queens in an existing polygyne colony. These polygyne colonies may be especially difficult to kill if young queens that have few workers happen to miss eating the bait. This is another possible reason why spring treatments with Logic are less effective than fall treatments— there may not be enough workers to bring bait to the new queens. An immediately devastating technique, such as hot water, may be more likely to kill young queens because it is not dependent on workers transporting bait back to the colony.

Observed cave fauna was at typical levels in caves checked after the treatments, but it was not within the scope of the study to do exhaustive population estimates. It must be admitted that cave crickets will take Logic bait occasionally, but fire ants probably will take almost all the bait if given ample time. Therefore, Logic or Amdro treatments should be done before noon if possible. Further tests should be done on this matter.

Until recently Logic was not registered by the EPA for use on agricultural lands, such as ranches where some of the caves occur. The current label allows Logic to be used, for instance, on horse pasture if the horses are not for consumption. If it is used on cattle pasture the cattle must be removed for a year. This study has shown that Amdro is about as effective as Logic in the short term. This study has shown no detrimental effects on cave fauna of an Amdro treatment near Temples of Thor Cave. A dilemma exists in that the USFWS does not currently allow Amdro to be used on endangered-species preserves. This restriction leaves no chemical baits that can be legally used near an endangered-species cave on a working ranch unless one could obtain an experimental permit for Logic from EPA. Further, a rancher also probably would have to obtain a USFWS permit to treat the areas around an endangered-species cave. Further complications are expected in that the Godwin Ranch at Georgetown is now a cave preserve under the LakeLine Mall Habitat Conservation Plan but the management plan has a lessee continuing to run horses and cattle on the ranch. Having a lessee working the property is advantageous for the extra fence maintenance and surveillance it provides. These problems need to be resolved.

Tschinkel and Howard (1980) reported that the hot water method was effective in a test on 14 mounds, but they did not compare it to chemical baits. Their test achieved about a 75% kill, but this is a crude estimate only. As seen in the present study, hot water treatments are very effective (98% kill) under the right conditions. It is important to ensure that the entire colony is drenched thoroughly and to observe if workers continue to come out of the mound a few minutes later. It is advantageous to treat a day or two after a rain when the ants are concentrated in the mounds and have built the mounds up making them conspicuous. During extended dry weather the method may be less efficient because mounds become more diffuse. Unlike the chemical baiting methods, it probably is best to treat the mounds when the ants are not foraging to obtain a maximum kill, such as on hot afternoons. These variables were not tested in this study. The hot water method was inefficient in time mainly because of waiting for the water to boil. The hot water bucket method is labor-intensive and in this study required carrying heavy equipment over rough ground for up to 10 minutes to reach a site. Logistically, killing more than a few mounds and thus having to fetch water would be an important limiting factor in some areas. Also, hot water drenches may not be applicable to fire ant infestations in deep soils where the deepest tunnels may be out of reach. The advantages of the hot water method are up to 20% better kill than chemical baits, instantaneous effects on a very limited area, and essentially no risk of significantly harming beneficial species since they are not in the mound. In real numbers a 20% better kill in this study translates to a residual ant population of about 16,667 on one acre instead of 183,000, or about 9% of the ants that would be left by chemical bait. These advantages are sufficient to continue to use hot water on fire ant mounds in cave entrance areas and to expand the area of treatment, especially since chemical baits still present a potential problem if the crickets feed on it.

The efficiency of the hot water method could be improved greatly with the use of a hot water "pressure washer". The writer obtained information on one commercial line of pressure washers, which can be rigged to deliver hot water or steam. Mr. Gus Carlson (pers. comm.) of Carlson Cleaning Equipment, Inc., Austin, supplied data on the Landa series of pressure washers. Mr. Carlson had sold one washer to a person who used it to exterminate fire ants commercially, but no data were available on his methods. The washer is equipped with a long, tubular spray attachment, which can be inserted deeply into a mound and triggered. Several models come with a gasoline water pump and a diesel burner. The units are mounted in a frame, which can be mounted on a tandem-axle trailer. Water tanks of 225 gal or greater capacity are available for a complete mobile rig. Landa Model PGHW5-3000 weighs 270 kg (595 lb), can produce 18.2 L/min (4.8 gal/min) of 93° C (200° F) water within two min of start-up. The estimated cost for this model with a 225 gal tank, tandem axle trailer, two hose reels, and sufficient hose to cover a half-acre is roughly $9,000. With such a device two personnel could work continuously for about half a day without having to fetch more water.

Table 12 presents comparisons of efficiency of the chemical bait, hot water bucket, and hot water pressure washer methods. About 40 mounds/acre were treated with Logic or Amdro in this study on a total of 15.2 acres for a total of about 600 mounds treated. The actual on-site man-hours (not counting surveying mounds or plot corners) was 9.48 hr, which resulted in a treatment rate of 63.3 mounds/man-hr. The hot water bucket method was much less efficient at about 6.3 mounds/man-hr but the efficiency probably could be doubled. One person could be kept very busy by using two propane heaters connected to the one propane tank, instead of one burner, and starting a new bucket about every five minutes. Based strictly on the rate at which the pressure washer can produce hot water, I estimate that two personnel could treat up to 60 to 120 mounds/man-hr in open areas. This does not account for the time that would have to be spent setting up, positioning hoses, fetching water, and maintaining the equipment, which could be major time constraints. To be realistic, the rate probably could never exceed the chemical bait method. Therefore, I have used a conservative estimate of 40 mounds/man-hr. The pressure washer could not be used at all in dense cedar brakes such as the Cotterell Cave area.

Table 13 is a cost comparison of using Logic (63.3 mounds/man-hr), an improved hot water bucket method (two burners and 12.6 mounds/man-hr), and the estimated pressure washer method (40 mounds/man-hr). Based on an assumed 200 acres, 40 mounds/acre, and twice-yearly treatments, Logic would be the most economical treatment method to cover large areas for one year only. Amdro is not considered here mainly because of USFWS restrictions on its use, but it would cost about the same as Logic. Hot water would still be used near cave entrances. The hot water methods would not be as economical to use over broad areas, even though they are more effective than chemical baiting. Over a five-year period, assuming no major repair costs, the pressure washer could be roughly economically competitive with the chemical bait method. The savings primarily would be in not having to purchase bait at about $8 per lb.

Treating 200 acres twice a year with a pressure washer probably would take two personnel about six to eight weeks of work each year if the 40 mounds/man-hr estimate is accurate. This means that the pressure washer could be used in other preserves for most of the year to treat fire ants or clean equipment, thus obtaining more good use than this simple cost analysis would hold. The pressure washer could also be useful in parks where instantaneous kill would be an advantage in ridding campgrounds and playgrounds of ants. Another option is to rent the equipment only for the time needed (see Recommendations).

Table 12. Comparison of efficiency of baiting and hot water methods. The first two methods could be done by one or two personnel. The hot water pressure washer would require two personnel and could be about as efficient as chemical baiting but would require field trials to determine its true efficiency. This comparison assumes about 40 fire ant mounds per acre.

Treatment	Total Acres Treated	Mounds Treated	Man-hrs	Gal/min	Mounds/man-hr
Logic/Amdro	15.2	≈600	9.48	—	63.3
Hot water bucket	0.22	31	4.93	0.25	6.3
Pressure washer	—	—	—	4.8	≈40?

Table 13. Cost comparisons for baiting, an improved hot water bucket method (using two burners), and a hot water pressure washer on a 200-acre, twice-yearly basis. Labor is figured at $10 per hr and Logic at $8/lb. Labor does not include travel time. Capital equipment includes the cost of a Landa PGHW5-3000 pressure washer, trailer, 225-gal water tank, and two hose reels. Costs for one year and five years are given. The hot water pressure washer method is figured at 40 mounds/hr and may be roughly comparable in cost to using chemical bait.

	Capital Equipment	Recurring Costs	Labor	Totals
One Year—				
Logic	200	3,200	2,530	5,930
Hot water bucket	300	200	12,700	13,200
Pressure washer	9,000	400	4,000	13,400
Five Years—				
Logic	200	16,000	12,650	28,850
Hot water bucket	300	1,000	63,500	64,800
Pressure washer	9,000	2,000	20,000	31,000

RECOMMENDATIONS

1. TPWD should sponsor a field trial of a Landa PGHW5-3000 pressure washer or comparable equipment, to test its efficiency in killing fire ant mounds on a cave preserve. Ant mounds should be indexed before and after treatment and the work should be carefully observed, timed, and noted. Mr. Gus Carlson has indicated that a one-day trial could be done at little or no rental cost. The equipment normally rents for $125 per day, $495 per week, or $1,495 per month.

2. Efficacy and specificity in killing fire ants should be a greater priority than strict economics in deciding which method to use. Depending on favorable results of the field trial, TPWD should purchase a pressure washer and put it to immediate use in cave preserves and other sensitive areas. Rental of the equipment may be a good alternative if the necessary options are available, such as two hose reels, tandem axle trailer, 225-gal or larger water tank, and at least 4.8 gal/min output. A 3/4-ton pickup is recommended to pull the rig. If the field trial is not encouraging TPWD should seek a low-cost source of Logic and purchase it twice a year to avoid storage and spoilage of bait. Cyclone "belly rubber" spreaders should also be purchased.

3. TPWD should sponsor a survey of fire ants in all known endangered species caves in Travis and Williamson counties. Currently there are about 97 such caves, most of which may be infested by now. Such a survey is urgently needed to prioritize cave areas for treatment.

4. Fire ants should be controlled at all infested endangered-species caves in Travis and Williamson counties, only using methods approved and promulgated by TPWD, USFWS, and TDA. Logic will have to be used in areas that are not accessible to a pressure washer. Treatments should be twice a year unless surveys indicate otherwise.

5. USFWS and TPWD should resolve the problems relating to a USFWS permit restriction on the use of Amdro which, when coupled with an EPA restriction on the use of Logic and management strategies that may be beneficial, causes a dilemma. The scientific reasons for USFWS's restrictions on Amdro need to be stated. At the same time a special EPA permit to use Logic on cave preserves that have cattle should be sought by TPWD and USFWS if necessary.

6. TPWD should sponsor seminars and cooperative extension work on fire ant control in parks and endangered-species preserves. A cooperative program between TPWD and TDA involving Logic exists and could be expanded (Morris and Steigman, 1991). All interested agencies should be asked to participate. The results should be applicable for future control of red imported fire ants in many areas where it would be desirable to avoid adverse impacts on the native fauna. Reliable methods are needed because it is anticipated that long-term control of fire ants will be a major management objective for the protection of endangered cave species and other fauna.

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