PERFORMANCE REPORT

SECTION 6

ENDANGERED SPECIES ACT

OKLAHOMA
DEPARTMENT OF
WILDLIFE CONSERVATION

FEDERAL AID PROJECT E-22-8

MANAGEMENT AND CAVE PROTECTION FOR THE OZARK BIG-EARED BAT AND GRAY BAT IN OKLAHOMA

OCTOBER 1, 2000 - SEPTEMBER 30, 2001

ANNUAL PERFORMANCE REPORT

STATE: Oklahoma PROJECT NUMBER: E-22-8

PROJECT PERIOD: 1 October 2000 – 30 September 2001

PROJECT TITLE:

Management and Cave Protection for the Ozark Big-eared Bat
(*Corynorhinus townsendii ingens*) and Gray Bat (*Myotis grisescens*) in Oklahoma

PROJECT OBJECTIVE:

To locate, determine ownership and develop and implement cave protection management plans for Ozark Big-eared and/or gray bat caves in Oklahoma.

INTRODUCTION:

About 18 of the 45 species of bats found in North America rely substantially on caves throughout the year and 13 use caves year-round (McCracken 1989). These caves are utilized as winter hibernacula, stop-over roost sites during migration, summer roost sites, or maternity sites where adult females give birth to their young. All North American bats listed as endangered or threatened by the U.S. Fish and Wildlife Service are cave dwelling species or subspecies (Harvey et al. 1999; McCracken 1989; Pierson, 1999). Two cave-dwelling species, the gray bat (*Myotis grisescens*) and Indiana Bat (*Myotis sodalis*), and one subspecies, the Ozark big-eared bat (*Corynorhinus townsendii ingens*), are of particular interest in Oklahoma. Each is federally listed as endangered by the U.S. Fish and Wildlife Service (1982, 1984, 1995). The gray bat and the Ozark big-eared bat are both obligate, year-round cave-dwelling bats. The Indiana bat hibernates in caves in winter and disperses during non-hibernating months to form roosts under bark and in tree cavities in hardwood forests (Humphrey et al. 1977; Kurta et al 1993; Laval and Laval 1980).

Persistent or casual human disturbance at maternity caves and hibernacula has been a major cause for the decline in population of most cave-dwelling bats (Am. Soc. of Mamm. 1992; Barbour and Davis,1969; Humphrey and Kunz 1976; Tuttle 1979). Disturbance at these caves may induce elevated mortality rates, poor recruitment, and actual colony abandonment. At hibernacula, premature arousal from bouts of torpor and hibernation ultimately consume stored energy reserves. Disturbance at maternity colonies adversely affects thermoregulatory requirements of non-volant developing young. Low reproductive rates, long generation times, and concentrations of populations in localized roosts are life-history characteristics indicative of North American cave-dwelling bats (McCracken 1989; Am. Soc. of Mamm. 1992; Thomas et al. 1990; Tuttle 1976; U.S. Fish and Wildlife Service. 1982). Such life histories and adverse effects of human disturbance present difficult challenges as wildlife managers and bat conservationists develop management objectives for protecting and recovering declining bat populations.

Contemporary efforts for bat conservation are concentrated on protecting caves and the various types of bat colonies that they harbor (Am. Soc. Mamm. 1992). These efforts usually are intended to eliminate disturbance resulting from human entry into caves. Protection is typically accomplished by construction of gates at cave entrances, fencing of cave entrances, placing warning signs at entrances, and maintaining a close and positive rapport with private landowners. Protection for cave-dwelling bat populations by placing gates in the entrances of caves can be an effective, immediate, and long-term method to deter human access to critical bat roosts (Humphrey 1978; Tuttle 1977; Tuttle and Stevenson 1977).

Populations of bats are presently protected with internal gate systems at 24 entrances to caves in eastern Oklahoma. Seven of those caves have been historically inhabited by colonies of gray bats. Thirteen entrances to caves inhabited by Ozark big-eared bats, big brown bats (*Eptesicus fuscus*), eastern pipistrelles (*Pipistrellus subflavus*), northern long-eared bats (*Myotis septentrionalis*), and a single hibernaculum of Indiana bats are protected similarly. Four caves that contain populations of Ozark cavefish (*Amblyopsis rosae*) and Ozark crayfish (*Cambarus* sp.) are also protected from human entry by internal gates.

Each of the 24 caves that have been gated in Oklahoma have unique physical characteristics regarding passage size, location of the nearest bat roost to the entrance, and number of entrances used by bats. Internal gates are placed in such a manner as to protect the nearest historical roost area to the cave entrance. Gate distances from cave entrances range from 3 to 17 m. Passage areas where gates are located range from 1.4 m^2 to 15 m^2. An often-used management approach in some areas of the gray bat's range involves gate construction that leaves the upper part of the passage open. Although this design may be perceived to be less obstructive to bat flights, it does not afford the same protection from human disturbance that a full passage gate does. In contrast, all internal gates in Oklahoma caves completely fill cave passages. Furthermore, two gray bat caves that are gated in Oklahoma have two entrances that are used during entrance and exit by bats. In those particular caves, both entrances are protected with complete gates, and estimates continue to indicate stable populations (Martin et al. 2000). Relatively small colony sizes (<30,000), relatively small gated passages conducive to lower volumes of airflow, and internal positioning of grill structures in "dark zones" of cave passages probably contribute to the apparent acceptance of full passage gates by resident bat populations in eastern Oklahoma. Acceptance is further substantiated by extant bat colonies that use caves in eastern Oklahoma with manipulated passages and entrances exhibiting stable populations (Martin et al. 2000; Puckette 2000)

Although placement of gates within "dark zones" of cave passages may be the most effective method to deter human access to critical bat roosts, their effects on resident bats and microclimate of cave interiors have not been measured completely (Humphrey 1978; Richter et al. 1993;Tuttle 1977; Tuttle and Stevenson 1977). Various designs of gate construction and resulting effects on bat flight have been tested (White and Seginak 1987). However, effects that gates have on the microclimate of cave interiors has not. It is suspected that cave gates alter airflow in cave passages. Altered airflow, in turn, may affect ambient temperature, humidity, and substrate temperature. Roost substrate temperatures influence body temperature and ultimately metabolic rates of hibernating bats (Humphrey 1978;McNab 1974;Richter et al 1993). Fetal and neonatal growth rates are affected directly by sub-optimal temperatures of pregnant females and juveniles. Poor thermoregulation in these bats may result in slow maturation, thus reducing survival and natality (Humphrey 1975;Studier and O'Farrell 1972). Also it is suspected that cave gates interrupt or impede the exit of large colonies of bats from roost caves. An increase in swarming activity before exiting or entering a cave that is gated may increase predation (Tuttle 1977, 1979; White and Seginak 1987).

The objectives of this project are the identification of caves that are considered critical habitat for Ozark big-eared bat and gray bat colonies in northeastern Oklahoma. Management/protection plans for one to three of these caves are developed and implemented during the project year as funding and time allow. These management/protection plans are coordinated with the appropriate landowners and may include posting a warning sign at the cave entrance, placing human restrictive structures at or within the cave such as fencing around cave entrance or constructing a gate/grill structure within the cave. Each cave is monitored to determine the effectiveness of the management plan, particularly gated caves, to determine the impact of the structure or other protection measures implemented at the site. As problems are identified with the cave protection plans, they will be corrected. In an attempt to address effects of cave gates on bat populations in northeastern Oklahoma, an additional component of this project is to collect data to compare internal ambient temperature, relative humidity, substrate temperature, and emergence times of bat flight between gated and non-gated caves.

PROCEDURES:

- **Proposed objectives listed below are designed to accomplish task B 1.6 and 1.7 of the 1993 Revised Ozark Big-eared Bat and Virginia Big-eared Bat Recovery Plan, and objectives 1, 1.2, 1.3.1, 3, and 3.2 of the 1982 Gray Bat recovery plan.**

  1. **The current landowner of each site will be identified, and after determined, proposed plans for the specific site will be discussed and permission to implement those plans will be sought.**
  2. **Determine the projected cost for the implementation of the recommended management plan.**
  3. **Obtain approval of the proposed maintenance plan from all pertinent agencies including the Oklahoma Department of Wildlife Conservation Wildlife Diversity Program, the U.S. Fish and Wildlife Service and individual landowners of each site.**
  4. **Upon approval of the maintenance plan for each site, the plan will then be implemented. Implementation of individual management plans will be determined on a priority basis. This priority will depend on the ability to effectively utilize available funds, in conjunction with the amount of human disturbance each site is receiving and the status of the population of Ozark big-eared bats or gray bats inhabiting the site.**
  5. **Each site where structures are placed for protection will be monitored twice annually after installation. One inspection will be conducted during the uninhabited season to inspect the structure or structures for possible vandalism. An additional monitoring visit will take place while the bats are utilizing the site. These surveys will be conducted as exit counts at maternity sites using infrared lighting and night vision scopes. This type of survey accurately determines the population of Big-eared bats using the site and if the newly constructed structures are inhibiting the flight of the bats into and out of the site.**
  6. **Reports of the progress of each management plan will be submitted to the Oklahoma Department of Wildlife Conservation Wildlife Diversity Program and the U.S. Fish and Wildlife Service. A final report will be submitted after the fifth project year. An annual performance report will be submitted at the end of each segment year.**

- **The following is a description of caves and procedures that were involved in the project during the 2000 - 2001 project year.**

PROCEDURE 1: CAVE OT-13

A summer population of about 14,000 gray bats have historically used cave OT-13 located in Ottawa County, Oklahoma (Martin et al. 2000). Lactating females and volant young were captured in a harp trap at the cave's entrance in July 1999 indicating use by a maternity colony of gray bats. Installation of an internal gate system to provide protection from human entry was initiated in spring 2000 and completed in spring 2001.

Warm-season climate variables (ambient temperature, substrate temperature, dew point, and relative humidity) were monitored within the cave's open passage for 6 consecutive weeks in September-October 1999 and January-March 2000 under open-passage conditions, and September-October 2000 and January-March 2001 after the internal gate system was installed. Climatic variables were measured using HOBO H8 continuous data loggers (Onset Computer Corporation, Bourne, MA). Three stations of data loggers were placed at specific distances (20 m, 40 m, 70 m) inside the cave entrance. One data logger at each station collected ambient temperature, relative humidity, and dew-point temperature. A second logger monitored substrate temperature using an external probe placed in a hole drilled 1 cm into the rock substrate. Loggers were attached together and suspended within 25 cm of the cave ceiling. If the cave ceiling could not be reached, loggers were suspended from a rock ledge about 1.5 m from the cave floor.

Difficulty in recording relative humidity occurred when logger sensors became saturated in the high-humidity cave environments. When that occurred, readings exceeded 100% and were considered inaccurate by the manufacturer. When recorded dew-point observations were lower than ambient temperatures, they were used to calculate relative humidity. A combination of actual relative humidity recordings and those that were obtained by using dew point and ambient temperatures resulted in a scattered representation of ambient cave humidity. Although useful for anecdotal inferences, they were not suitable for statistical comparisons.

To establish units for statistical analysis, observations for each of the 6 weeks were combined into a mean of 336 observations/week for ambient and substrate temperatures. An ANOVA compared long-term seasonal (warm season, cool season) ambient and substrate temperatures at specific distances (20 m, 40 m, 70 m) inside the cave passage. Additional observations were collected immediately before and after the internal gate system was installed in April 2000. Ambient and substrate temperatures were recorded every 30 minutes for 7 consecutive days before installing the gate system. Logger locations within the cave passage were located at 20 m and 40 m inside the cave entrance. Ambient conditions were not recorded during the period when actual construction took place. Post-gating observations were recorded every 30 minutes for 7 consecutive days after installation of the gate system was completed. To establish units for statistical analysis, recordings for each day were combined into a mean of 48 observations/day for ambient and substrate temperatures. An ANOVA compared short-term, pre-gating and post-gating ambient and substrate temperatures.

Results

No differences occurred in ambient temperatures at any distance (20 m: $F = 0.99$, $df = 1$, $P = 0.33$; 40 m: $F = 0.38$, df = 1, $P = 0.53$; 70 m: $F = 1.95$, $df = 1$, P = 0.16) between September-October 1999 in natural airflow conditions and September-October 2000 when the passage was gated with an internal gate system (Fig. 1). Within the same season, the substrate temperature mean was cooler after passage manipulation at a distance of 20 m ($F = 5.37$, $df = 1$, $P = 0.02$) but not at 40 m ($F = 0.00$, $df = 1$, $P = 0.99$) or 70 m ($F = 1.37$, $df = 1$, $P = 0.25$; Fig. 2). Ambient temperatures during winter between natural airflow conditions (January-March 2000) and gated airflow (January-March 2001) differed at all three locations (20 m: $F = 4.89$, $df = 1$, $P = 0.03$; 40 m: $F = 6.43$, $df = 1$, $P = 0.01$; 70 m: $F = 4.47$, $df = 1$, $P = 0.04$) in the cave passage (Fig. 1). Substrate temperatures differed at 20 m ($F = 4.86$, $df = 1$, $P = 0.03$) and 40 m ($F = 6.25$, $df = 1$, $P = 0.02$) but not at 70 m ($F = 3.16$, $df = 1$ $P = 0.08$; Fig. 2). Differences also occurred between ambient temperatures recorded 7 days before and 7 days after installation of an internal gate system at distances of 20 m ($F = 36.02$, $df = 1$, $P <.0001$) and 40 m ($F = 5.17$, $df = 1$, $P = 0.03$). Similarly, substrate temperatures differed at 20 m ($F = 20.04$, $df = 1$, $P = .0007$) and 40 m ($F = 20.40$, $df = 1$, $P = 0.0007$; Fig. 3).

PROCEDURE 2: CAVE AD-220

Past landowners of cave AD-220 located in Adair County, Oklahoma, had covered the < 2-m^2 entrance with a ¼" thick, solid iron door to discourage human entry into the cave. Only a 15-20 cm opening at the top of the door was available for entry by bats. Remarkably, the cave was annually used as a hibernaculum by a small population of 100-200 eastern pipistrelles. Old guano accumulations suggest that a small population of a colonial species, probably gray bats, historically used the cave as a roost site. It was suspected that presence of the solid iron door restricted access to roost sites by bats and that airflow into and out of the cave was obstructed resulting in a suboptimal ambient environment conducive to increased utilization. Cave biologists received permission from the current landowner to remove the iron door from the cave entrance in March 2000. An internal gate system covering <1.5 m^2 was constructed and installed 7 m within the cave passage in April 2001.

This progression of management efforts provided a unique opportunity to measure ambient climatic variables before and after various treatments were applied to a cave entrance. Climate variables (ambient temperature and substrate temperature) were monitored with the cave's airflow obstructed by the iron door for 6 consecutive weeks in September-October 1999. Additionally, data were collected for 6 consecutive weeks under obstructed conditions in March-April 2000. After the obstructive door was removed and natural airflow restored, seasonal observations were collected again for 6 consecutive weeks in September-October 2000 and March-April 2001.

To establish units for statistical analysis, recordings for each week were combined into a mean of 336 observations/week for ambient and substrate temperatures. An ANOVA was used to compare pre-gating and post-gating ambient and substrate temperatures at specific distances (15 m, 30 m, 70 m) inside the cave passage.

Subsequent observations were made immediately before and after the iron door was removed from the cave entrance in April 2000. Ambient and substrate temperatures were recorded every 30 minutes for 7 consecutive days before and after removal of the door. Data logger locations within the cave passage coincided with those used during long-term observations (15 m, 30 m, 70 m). Ambient conditions were not recorded during the day that actual removal of the obstruction took place. To establish units for statistical analysis, recordings for each day were combined into a mean of 48 observations/day for ambient and substrate temperatures. An ANOVA compared short-term observations of cave climate before and after removal of the obstructive door.

Internal ambient observations were again collected immediately before and after a 1.4-m^2 internal gate system was installed 7 m within the cave passage in April 2001. Cave climate was monitored and compared statistically as mentioned above. Airflow was also monitored using a sonic anemometer (Handar Instruments, Sunnyvale, California) placed 10 m inside the cave entrance. Airflow direction was monitored, and was moving into the cave from outside, thus flowing through the gate after its installation. An ANOVA compared pre-gating and post-gating airflow.

Results

No differences occurred in ambient temperatures at any distance (15 m: $F = 1.29$, $df = 1$, $P = 0.26$; 30 m: $F = 0.18$, $df = 1$, $P = 0.67$; 70 m: $F = 0.28$, $df = 1$, $P = 0.60$) between September-October 1999 when airflow was obstructed and September-October 2000 when the passage was unobstructed (Fig. 4). Within the same season, no differences occurred in substrate temperatures at 15 m ($F = 1.09$, $df = 1$, $P = 0.30$), 30 m ($F = 0.10$, $df = 1$, $P = 0.75$), or 70 m ($F = 0.18$, $df = 1$; $P = 0.67$; Fig. 5). Mean ambient temperatures during winter-early spring months between obstructed airflow (February-April 2000) and unobstructed airflow (February-April 2001) were cooler after removing the iron door and differed at 15 m ($F = 6.70$, $df = 1$, $P = 0.01$) and 30 m ($F = 5.32$, $df = 1$, $P = 0.03$), but not at 70 m ($F = 0.15$, $df = 1$, $P = 0.70$; Fig. 4). Similarly, substrate temperatures during those same comparisons were cooler after restoring natural airflow and differed at 15 m ($F = 18.07$, $df = 1$, $P < 0.0001$) and 30 m ($F = 7.19$, $df = 1$, $P = 0.01$), but not at 70 m ($F = 0.19$, $df = 1$, $P = 0.66$; Fig. 5).

Mean temperatures recorded 7 days before and 7 days after an iron door was removed from the cave entrance in April 2000 were warmer and differed at 15 m for ambient ($F = 22.87$, $df = 1$, $P <.0001$) and substrate ($F = 49.61$, $df = 1$, $P <.0001$; Fig. 6) temperatures. No differences existed in ambient temperatures at 30 m ($F = 0.62$, $df = 1$, $P = 0.43$) or 70 m ($F = 0.01$, $df = 1$, $P = 0.92$). Similarly, substrate temperatures did not differ at 30 m ($F = 3.21$, $df = 1$, $P = 0.08$) and 70 m ($F = 0.06$, $df = 1$, $P = 0.81$; Fig. 6).

Similar results occurred when comparing mean temperatures recorded 7 days before and 7 days after installation of an internal gate system in the cave passage in April 2001. Temperature means were warmer and differed at 15 m for ambient ($F = 28.60$, $df = 1$, $P <.0001$) and substrate ($F = 47.11$, $df = 1$, $P <.0001$; Fig. 7) temperatures. No differences existed in ambient temperatures at 30 m ($F = 1.12$, $df = 1$, $P = 0.30$) or 70 m ($F = 0.03$, $df = 1$, $P = .86$). Similarly, substrate temperatures did not differ at 30 m ($F = 3.35$, $df = 1$, $P = .08$) and 70 m ($F = 0.08$, $df = 1$, $P = 0.79$; Fig. 7).

Airflow did not differ when recorded 7 consecutive days during natural, unobstructed conditions and 7 consecutive days after an internal gate system was installed in the passage in April 2001 ($F = 0.01$, $df = 1$, $P = 0.94$; Fig. 8). Airflow direction was recorded at 30-minute intervals to ensure that it was flowing into the cave from outside, through the internal gate system.

Discussion

Long-term Seasonal Observations. During long-term, warm-season monitoring (September-October 1999, 2000) before and after passage/entrance manipulation, only a single significant difference occurred in ambient and substrate temperatures at cave OT-13 (T_s: 20 m), and no significant differences in either variable occurred at cave AD-220. These study caves have a tendency to breath "outwardly" during warmer seasons when internal air is cooler than outside air and outside air is warmer than the mean annual surface temperature (MAST). An internally placed gate located 12 m inside the entrance to cave OT-13 and an obstructive iron door covering the entrance to cave AD-220 thus had minimal effects on warm-season ambient and substrate temperatures.

Like most caves in eastern Oklahoma, the study caves tend to breath "inwardly" in winter months when external air is cooler than internal air temperatures and cooler than MAST temperatures. If airflow were impeded in any manner by manipulating an entrance, it would be magnified in these months when external airflow is carried into the cave's interior. Significant differences in ambient and substrate temperatures did occur at all but one substrate logger location (70 m) in cave OT-13 between winter 2000 (open passage) and winter 2001 (gated). Only one monitoring location considered deep in the passage of cave AD-220 (70 m) showed no significant differences in ambient and substrate temperatures between obstructed observations in winter 2000 and unobstructed observations in winter 2001.

Cool-season minimum and maximum ambient temperature means that differed at cave OT-13 ranged from 12.99 to 13.86°C before the cave was gated and from 11.99 to 13.46°C after gating. Ambient temperature means indicating significant differences at cave AD-220 during winter observations were 7.43-13.27°C when airflow was obstructed by an iron door and 5.80-13.16°C when open-passage conditions existed. Although statistically significant, these temperature ranges correspond closely with those observed at hibernating clusters of Ozark big-eared bats in Oklahoma (5.5-11.2°C; Clark et al. 1996) and Arkansas (<12°C; Harvey and Barclay 1990), and those indicated for gray bats (6-11°; U.S. Fish and Wildlife Service 1982). When an ANOVA compared ambient and substrate temperature ranges in caves OT-13 and AD-220, no significant differences occurred between open and manipulated passage conditions at any distance. Except on rare occasions, colonial gray bats are historically absent from all caves in eastern Oklahoma during hibernation. Therefore, any significant differences in climatic conditions with biological implications at roost sites caused by internal gate systems cannot be determined. However, observations of hibernating populations of Ozark big-eared bats in caves with internal gate systems indicate stable numbers (Puckette 2000). These data and observations suggest that although narrow temperature ranges before and after entrance manipulation may indicate statistical significance in winter, other cave microclimate characteristics may have greater biological implications for habitation by endemic cave fauna.

Short-term Pre- and Post-manipulation Observations. Typical seasonal warming can explain significant changes in mean ambient and substrate temperatures that occurred between observations collected 7 days before initiating construction of an internal gate system and observations collected 8 weeks later after its completion. However, actual differences between minimum and maximum daily means during the entire monitoring period were only 1.23°C (20 m) and 0.41°C (40 m) for ambient temperatures and 1.10°C (20 m) and 0.47°C (40 m) for substrate temperatures. Clark et al. (1996) reported ambient temperature ranges between 5.5-11.2°C at hibernating clusters of Ozark big-eared bats in Oklahoma caves. Minimum and maximum temperature ranges at cave OT-13 before and after installation of the internal gate system were much more narrow in ambient (12.96-14.19°C) and substrate (12.81-13.91°C) temperatures at 20 m. Similar narrow temperature ranges occurred in ambient (13.22-13.63°C) and substrate (13.34-13.91°C) temperatures at 40 m. Although these temperature changes represent statistical significance, their biological implications on endemic cave fauna may be minimal.

Internal ambient and substrate temperature means 7 days before and 7 days after manipulations at cave AD-220 were significant only at the monitoring station closest to the cave entrance (15 m). Airflow 10 m inside the cave entrance (3 m inside gate system), and ambient and substrate temperature ranges before and after installation of the internal gate system did not differ statistically. Differences in ambient and substrate temperatures at 15 m inside the cave entrance may be explained simply by variable climatic conditions that persist at this distance inside most cave passages. A lack of changes in mean daily airflow in this same region before and after gating is intriguing. Cave AD-220 has a single entrance that may have been more conducive to constant rates of airflow, as opposed to multiple entrances and distinct elevational changes creating greater variations in airflow. At this particular cave, manipulating the entrance and passage did not affect mean temperature variables at distances beyond 15 m, airflow within 3 m of the internally placed gate system, or temperature ranges inside the cave passage.

It is evident from these data that measurable impacts on warm-season microclimates of cave interiors by management treatments were minimal. These minimal impacts are substantiated by present bat colonies using caves in eastern Oklahoma that have manipulated passages and entrances that exhibit stable populations (Martin et al. 2000; Puckette 2000). Population estimates during maternity seasons in 2000 and 2001 at cave OT-13 after the gate system was installed were >12,000. These estimates were nearly identical to those collected prior to gating the passage (Grigsby et al. 1993).

An obvious gradient of effects of external climatic variables on internal climatic conditions exists in cave environments, being greater in the ecotonal environment near the entrance, and narrowing as passage length reaches 30-40 m and beyond. Passage size, entrance size, entrance orientation (vertical vs. horizontal), number of entrances, and passage to entrance elevational configurations determine rate of airflow into and out of a cave ecosystem. These factors are affected by large volumes of airflow movement in some caves, but lesser volumes in others. It is apparent from these data that caves with modified entrances and passages exhibiting what might be considered moderate to low volumes of airflow, indicate no changes when airflow moves outward in summer, and only slight changes in winter in ambient and substrate temperatures. It may be appropriate to assume therefore, that appropriately placed internal gate systems that allow ample airflow would have no effects on resident maternity colonies and other summer colonies of bats.

An absence of large colonies of hibernating bats in eastern Oklahoma preclude management recommendations pertaining to gating cave passages in winter. Humphrey (1978) and Richter et al. (1993) reported harmful effects of warm ambient and substrate temperatures at roosts of hibernating Indiana bats. Each instance resulted from anthropogenic modifications at cave entrances, specifically solid walls that impeded air exchange. Based on data from these experiments, it is recommended that current internal gates designs that are appropriately placed and allow persistent airflow within a cave passage be considered as a viable management option. This tactic is particularly important when casual or persistent human disturbance at critical bat roosts is of primary concern.

PROCEDURE 3: EVALUATION OF EXIT COLONY BEHAVIOR

Initiation of flight emergences at three gated and three open-passage caves was recorded at caves inhabited by colonies of gray bats in June and July 1999 and 2000. Flight emergence times were observed using an infrared light source and night-vision optics. This nonintrusive method produces minimal disturbance to exiting colonies while observing emergence initiation times, emergence duration, and even population estimates of relatively small colonies (U.S. Fish and Wildlife Service 1995). Swarming and circling by bats at a cave entrance as twilight approaches are typical and may allow bats to sample light conditions outside the cave (Twente 1955; Clark 1991). During this study, it was not unusual to observe 25-30 gray bats swarming (exiting and re-entering) in the entrance for 5-10 minutes before they actually began to exit the cave without re-entry. Exiting bats were counted continuously in 60-second increments. Emergence times were recorded when >30 gray bats exited a cave entrance without re-entry within a 60-second time period. That method was continued and a subsequent emergence time was recorded when >60 gray bats exited without re-entry within a 60-second interval.

Three exit observations were made at each of the six caves in 1999 and 2000 (*n* = 36). To remove effects of variations in light intensity attributable to changes in sunset times over a 5-week period, each recorded time was converted to minutes after official sunset. Official sunset times were derived from the nearest U.S. Naval Observation Station to each study cave. Range of distances between each cave and its nearest observation station was 8-15 km. Exit observations not conducted when there was a threat of rainfall. Extrinsic factors thought to effect emergence times such as cloud cover, extended twilight hours in summer months, and whether or not a colony was a maternity colony were not considered (Clark 1991; McAney and Fairley 1988). An ANOVA compared timing of flight exits of gray bats between gated and open passage caves.

Results

Mean exit times adjusted to minutes after official sunset did not differ between cave types when initiation of a colony exit was determined by >30 bats/60 seconds ($F = <0.01$, $df = 1,4$; $P = 0.979$; Fig. 9) or >60 bats/60 seconds ($F = 0.02$, $df = 1,4$; $P = 0.902$). Anecdotal observations did not reveal a relative increase in swarming at gated caves as is typical when colonies begin exiting from a cave, or dropping of any young at or near cave entrances.

Discussion

Many factors can delay a colony's exit or promote an early emergence from a cave entrance. Maternity colonies have been noted to emerge later, relative to sunset, during lactation (Clark 1991; Kunz 1974; McAney and Fairley 1988), and delayed emergence also may be a result of longer twilight hours in summer (McAney and Fairley 1988). In this study, all observations were made at maternity colonies of gray bats, except cave number 5 (Fig. 9) that contains a bachelor colony during the maternity season. It seems apparent, however, that emergence is most dependent on light intensity (Kunz 1974; Prakish 1962; Stebbings 1968).

The effect that an internal gate has on delaying departure from a cave has not been tested although White and Seginak (1987) tested effects of three gate designs on affinity of bat flight through a particular design. Speculation persists among cave biologists that placing gates in cave passages precipitates an increase in swarming by bats as they emerge from a cave, ultimately leading to an increased susceptibility to predation as bats try to fly through the gated passage (Clark et al. 1996; Tuttle 1977, 1999; White and Seginak 1987). Of the 36 exit observations, attempted predation (by an opossum, *Didelphis marsupialis*) was noted only once, and it resulted in the latest emergence noted during the entire study. The cave has an external grill over the entrance that is now left open year-round. An internal gate structure is presently located 12 m within the cave passage.

Cave biologists in Oklahoma have videotaped exit flights of gray bats through internally gated passages with no noticeable effect on bat flight (S. L. Hensley, personal communication), paralleling observations shown here. Many inferences are made in the literature on the inherent effects of gates on bat flight and increased susceptibility to predation. Distinctions must be made, however, between structures that are placed external to a cave entrance that are obsolete and known to affect bat flight (Ludlow and Gore 2000) and those that are currently placed within cave passages (Martin et al. 2000). It is speculated that relatively small colony sizes (<30,000) and small gated passages (1.4 – 15 m^2) used in this study contributed to dampening a perceived effect that internal positioning of grill structures have on bat flight and predation. This dampening must be considered when using internally designed gates to protect larger colonies of cave-dwelling gray bats and Indiana bats, requiring larger gated passages that are typical in other areas of these species' ranges.

Data and observations from these experiments show that stable populations of obligate cave-dwelling bats are found in caves protected with internally placed gate systems (Martin et al. 2000; Puckette 2000). Data indicate that these systems do not impede or delay exit flights of colonies of gray bats of 8,000-30,000 individuals. Evidence does not suggest that increased predation results from the presence of an internal gate system. It is recommended that current internal gate designs that are appropriately placed and allow persistent airflow within a cave passage be considered as a viable management option to eliminate casual or persistent human disturbance of vulnerable maternity and hibernating colonies of bats.

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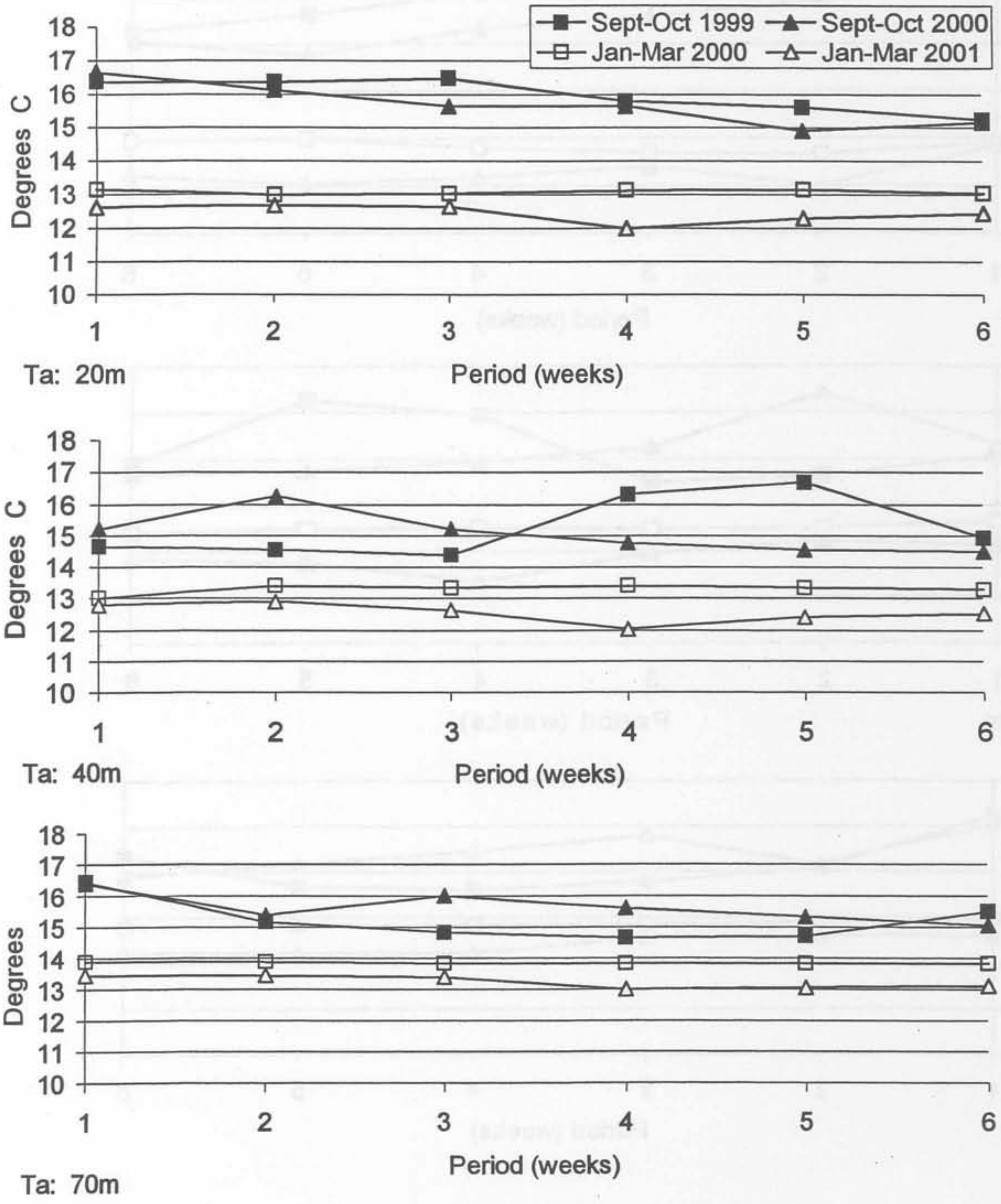


Figure 1. Ambient temperatures from cave OT-13 in Ottawa County, Oklahoma. Observations in summer 1999 and winter 2000 were during conditions of natural airflow into the cave. Subsequent observations in summer 2000 and winter 2001were after an internal gate system was installed 12 m inside the cave passage. Each data point represents a mean of 336 observations recorded every 30 minutes over a 7-day period (one week).

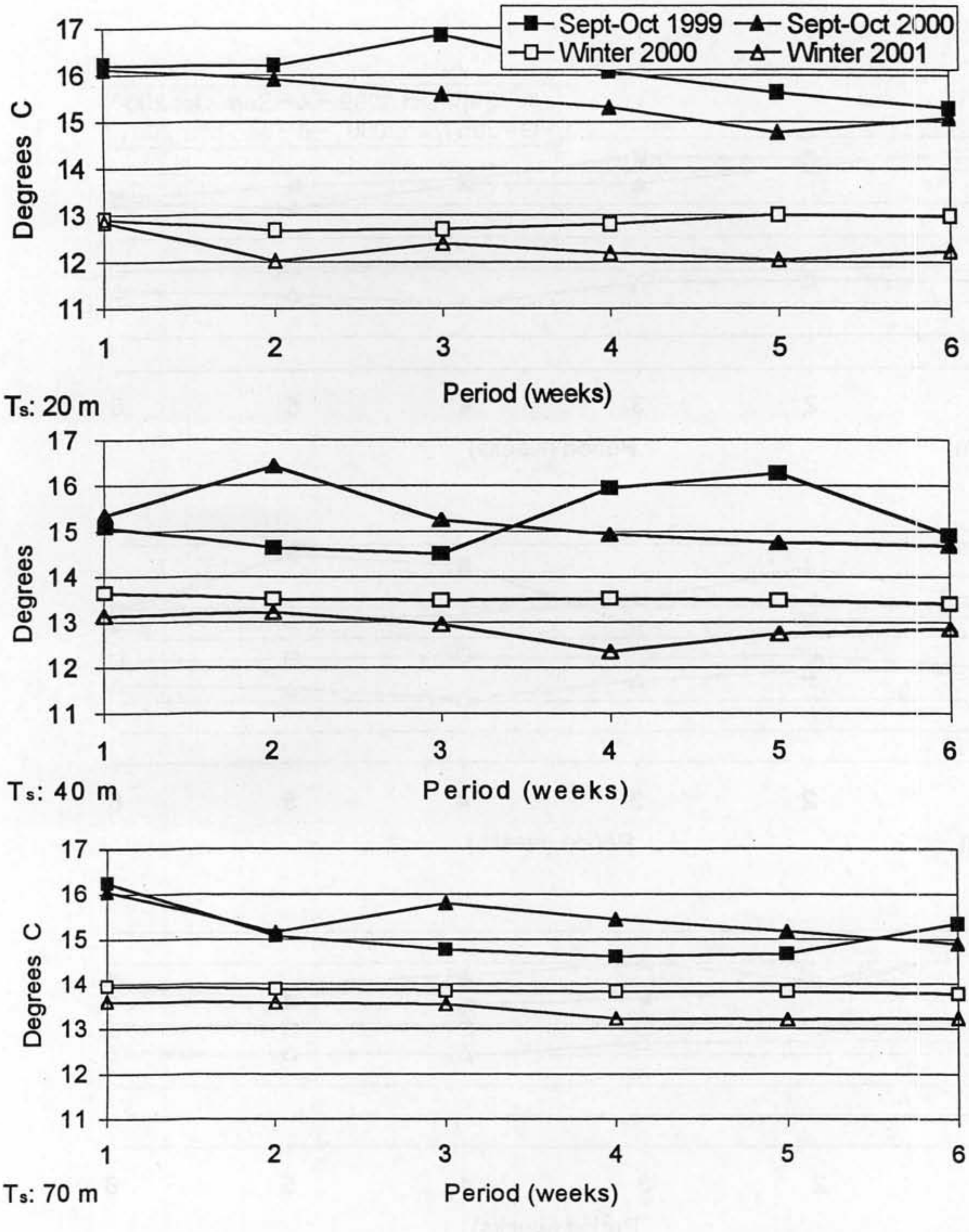
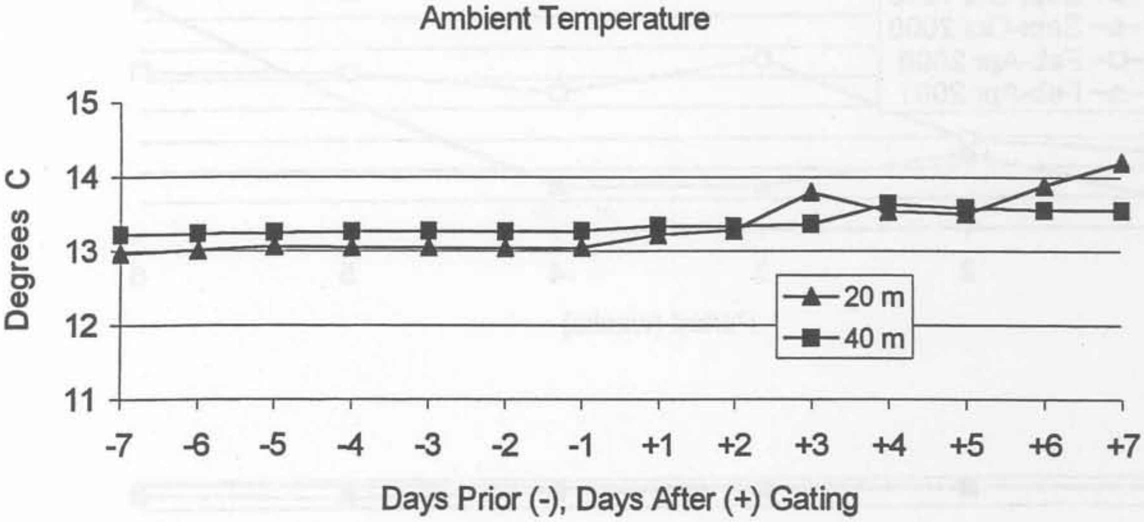


Figure 2. Substrate temperatures from cave OT-13 in Ottawa County, Oklahoma. Observations during summer 1999 and winter 2000 were during conditions of natural airflow into the cave. Subsequent observations in summer 2000 and winter 2001 were after an internal gate system was installed 12 m inside the cave passage. Each data point represents a mean of 336 observations recorded every 30 minutes over a 7-day period (one week).



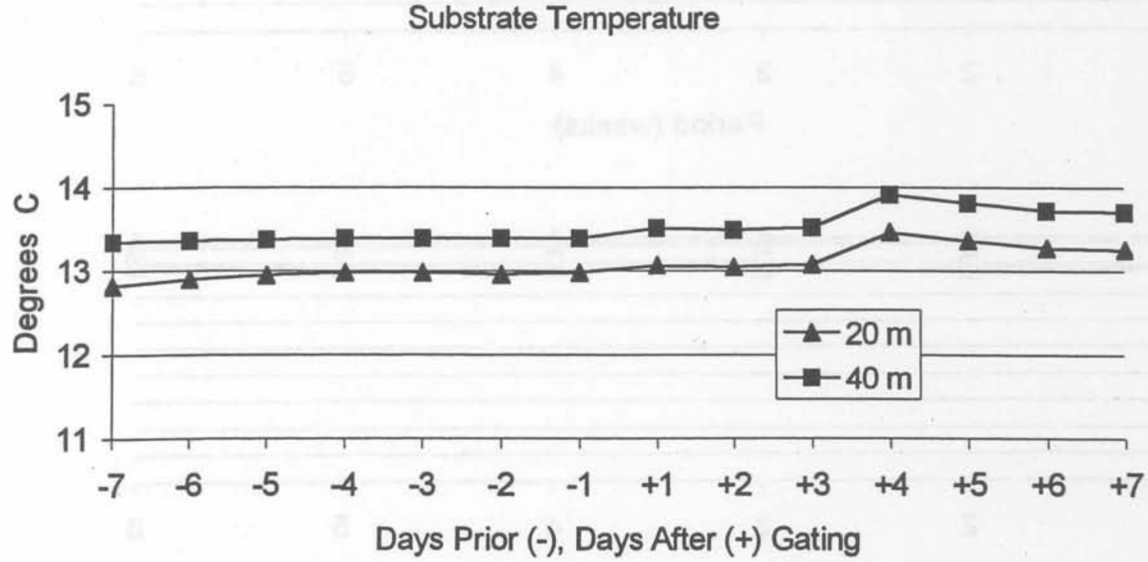
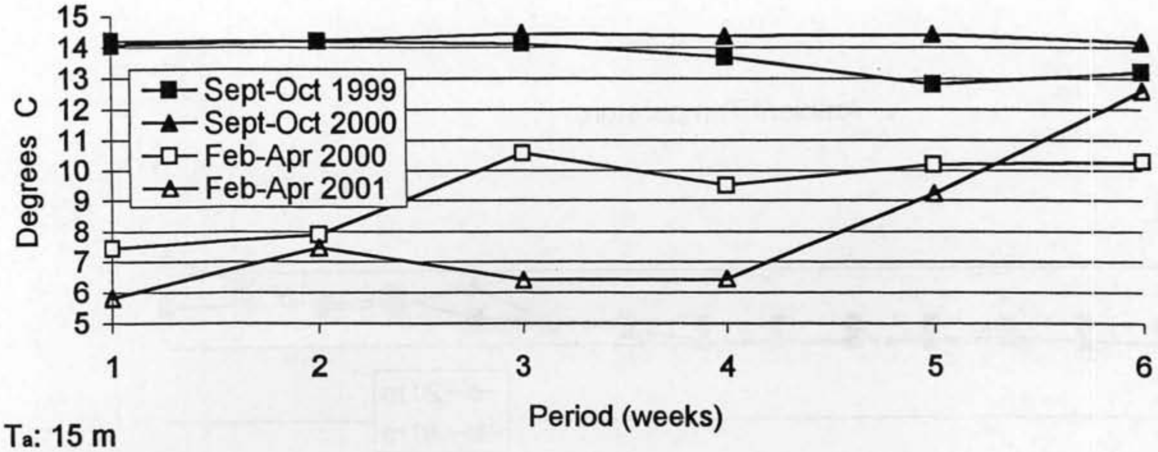
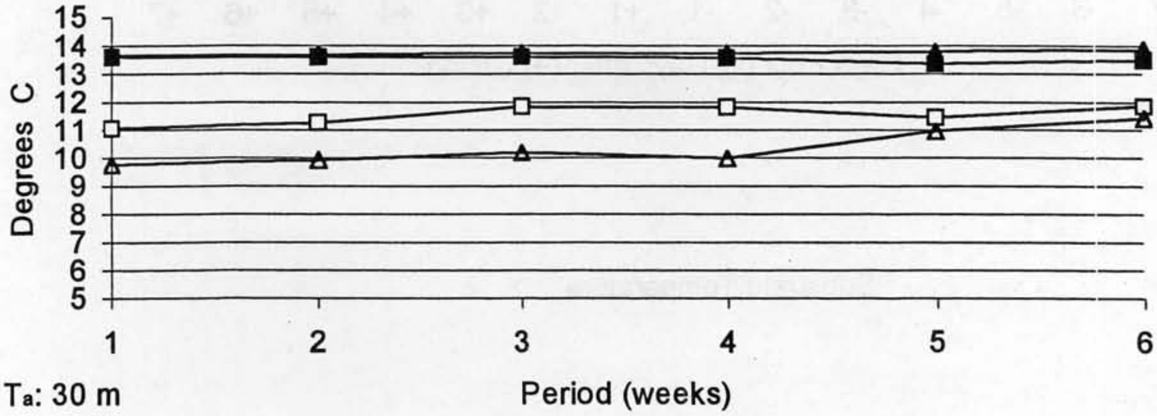


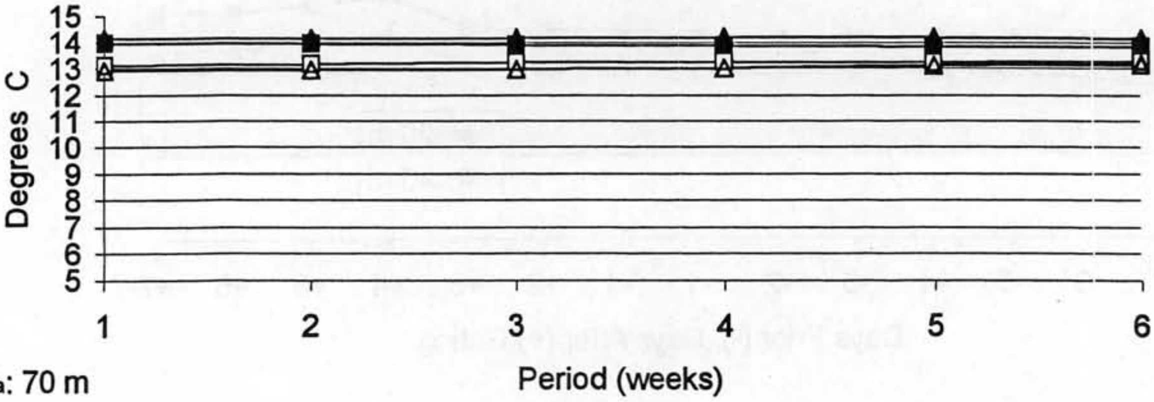
Figure 3. Ambient and substrate temperatures at cave OT-13 in Ottawa County, Oklahoma. Observations were made 7 days before and 7 days after an internal gating system was installed 12 m inside the cave entrance. Each data point represents a mean of 48 observations recorded every 30 minutes for a 24-hour period.



Ta: 15 m



Ta: 30 m



Ta: 70 m

Figure 4. Mean ambient temperatures from cave AD-220 in Adair County, Oklahoma, in September-October 1999 and February-April 2000 while natural airflow into the cave was obstructed by a solid iron door. Subsequent observations were made in September-October 2000 and February-April 2001 after the door was removed and natural airflow restored. Each data point represents a mean of 336 observations recorded every 30 minutes over a 7-day period (one week).

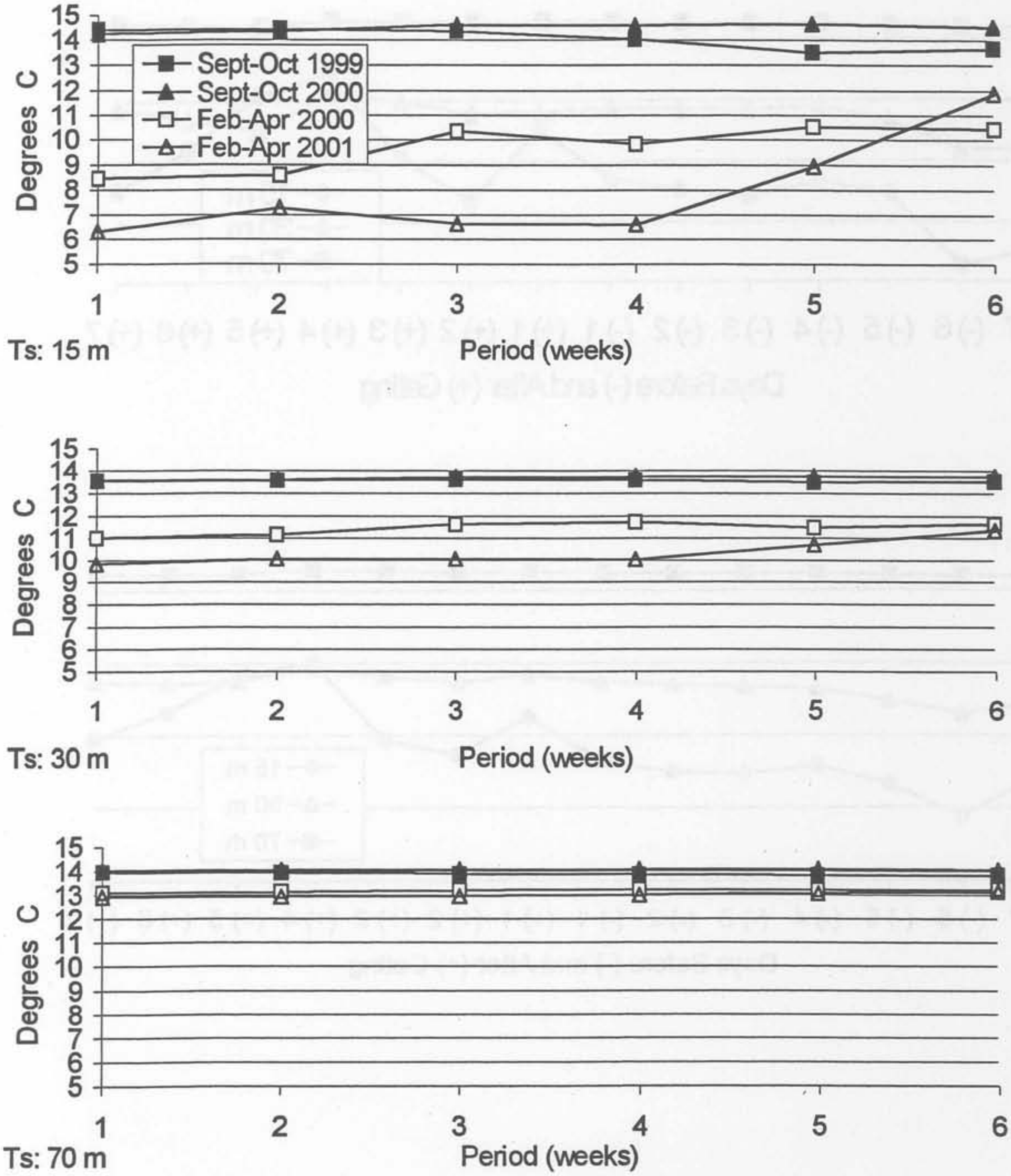


Figure 5. Mean substrate temperatures from cave OK-220 in Adair County, Oklahoma, in September-October 1999 and February-April 2000 while natural airflow into the cave was obstructed by a solid iron door. Subsequent observations were made in September-October 2000 and February-April 2001 after the door was removed and natural airflow restored. Each data point represents a mean of 336 observations recorded every 30 minutes over a 7-day period (one week).

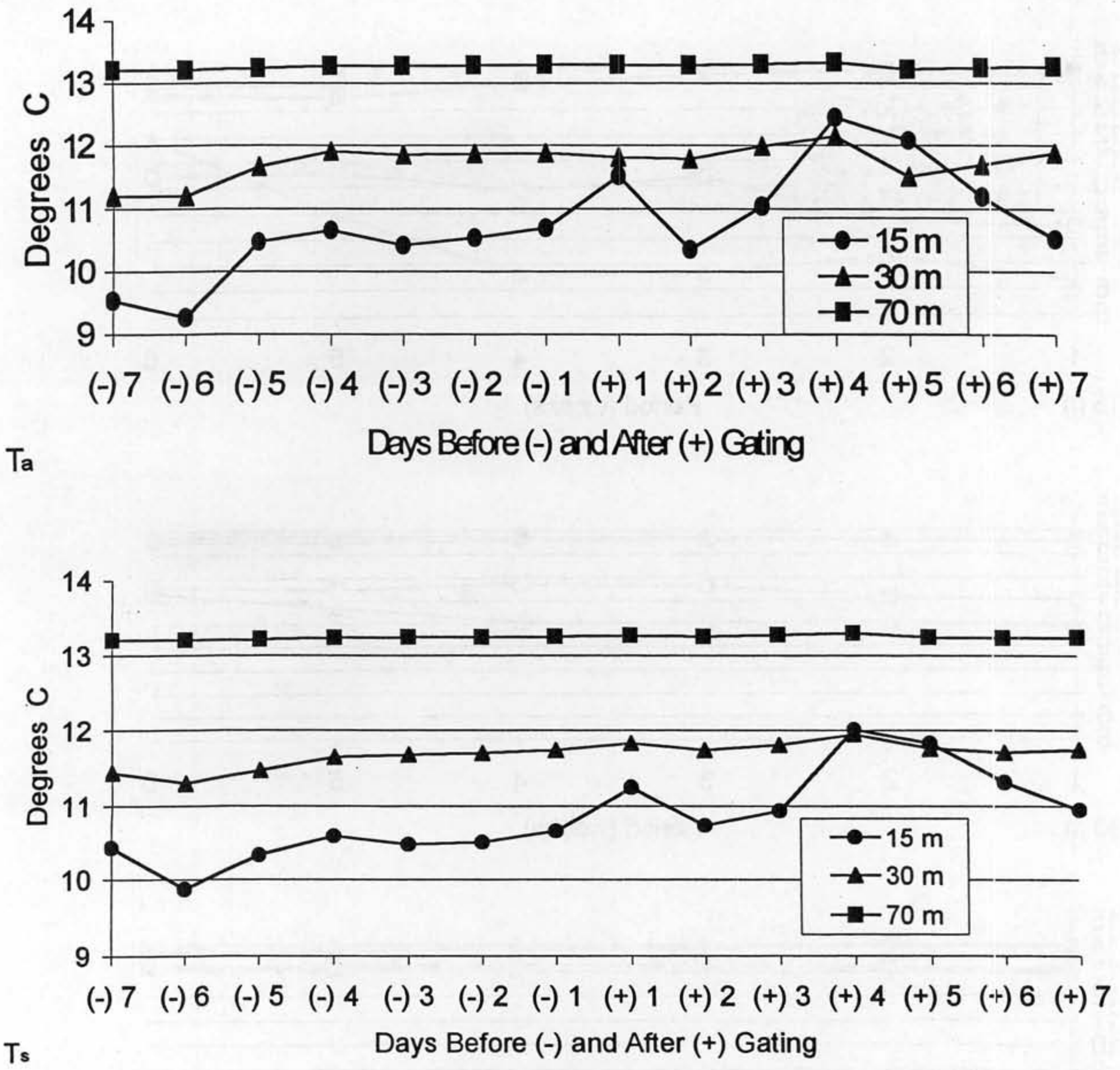
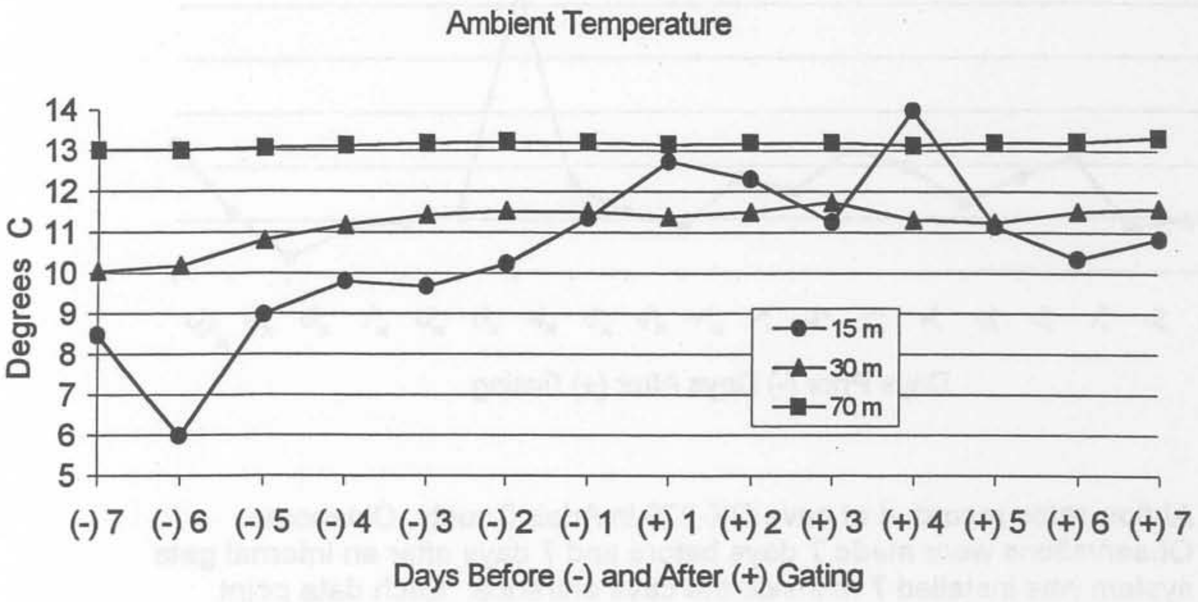


Figure 6. Ambient and substrate temperatures collected at cave OK-220 in Adair County, Oklahoma. Observations were made 7 days before and 7 days after an iron door covering the cave entrance was removed allowing natural airflow to resume. Each data point represents a mean of 48 observations recorded every 30 minutes for a 24-hour period.



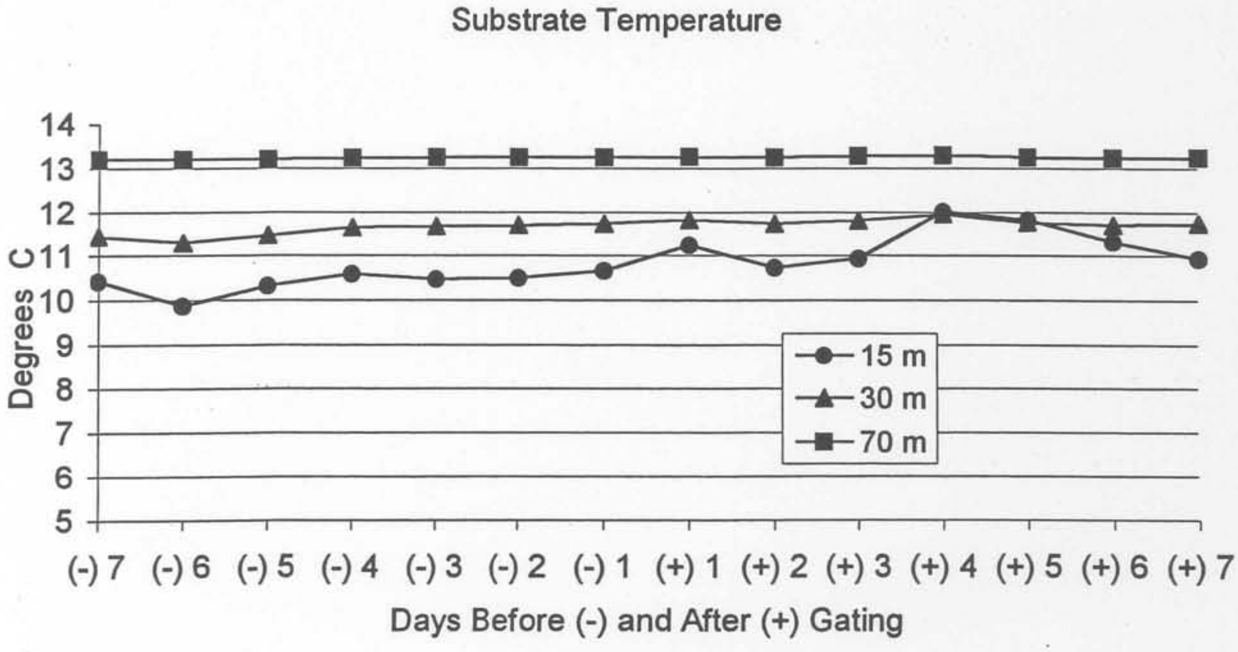


Figure 7. Ambient and substrate temperatures collected at cave OK-220 in Adair County, Oklahoma. Observations were made 7 days before and 7 days after an internal gate system was installed 7 m inside the cave entrance. Each data point represents a mean of 48 observations recorded every 30 minutes for a 24-hour period.

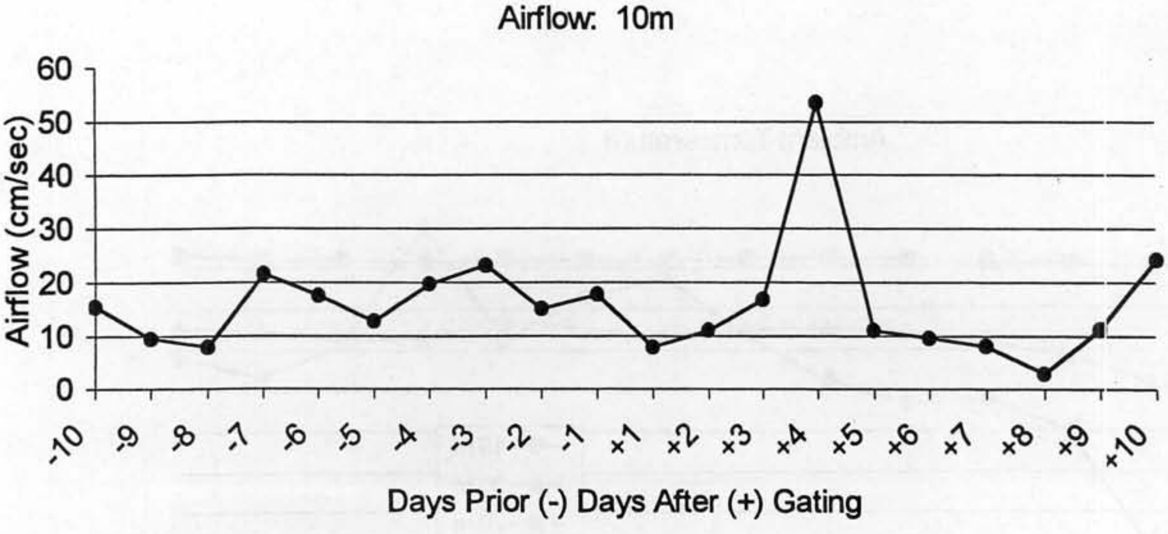


Figure 8. Airflow rates recorded at cave OK-220 in Adair County, Oklahoma. Observations were made 7 days before and 7 days after an internal gate system was installed 7 m inside the cave entrance. Each data point represents a mean of 48 observations recorded every 30 minutes for a 24-hour period.

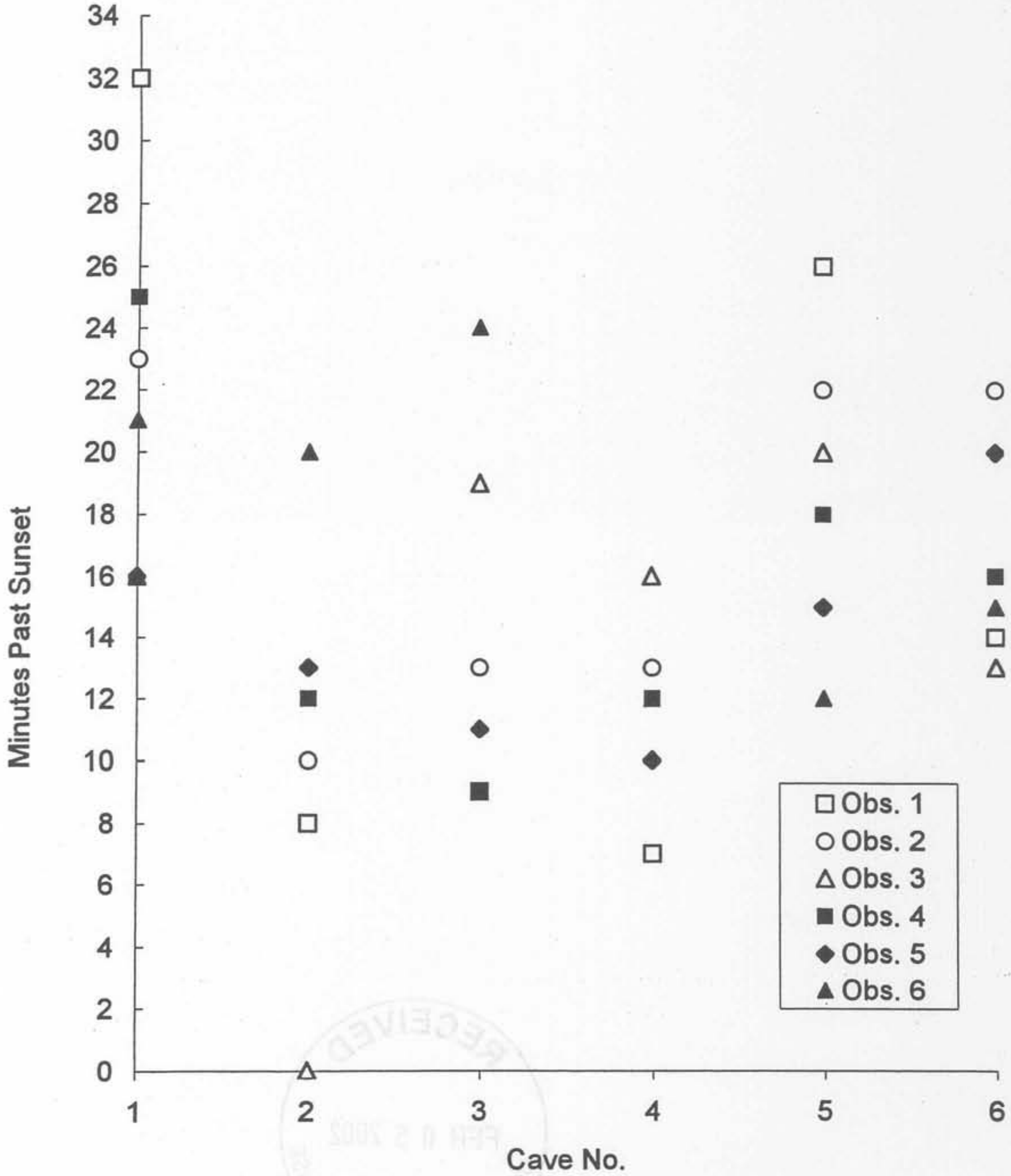


Figure 9. Timing of initiation of exit flights by colonies of gray bats at six caves in northeastern Oklahoma. Caves 1-3 contained internal gating systems for colony protection, and caves 4-6 had open passages. Data points represent time in minutes past sunset when 30 bats exited the cave in a 60-second period. Three observations were taken in summer 1999 and 2000 for each cave.