DISTRIBUTION AND STATUS OF BATS IN MINNESOTA

Final Report
Nongame Wildlife Program
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Bats occupy a unique place among vertebrates. Their ability to fly and echolocate separates them ecologically from other groups and has facilitated their successful colonization throughout the tropical and temperate portions of the world. Among mammals, bats are second only to rodents in abundance with 18 families and over 940 species. Reflected in their numbers is a vast diversity of life strategies, unparalleled by any other order of living mammal, that encompasses feeding and foraging habits, social and reproductive behaviors, roost and habitat selection, and morphological and physiological adaptations.

From a purely scientific and aesthetic point of view, bats offer an endless resource for inquiry and appreciation of their position in the natural world. From an economic and management standpoint, they are important controls on insect populations, they are exploited for their marketable, nitrogen-rich guano, and they have been implicated as vectors of disease. Bats are especially sensitive to habitat destruction and enviromental contaminants, and are particularly vulnerable to disturbance, either purposeful or inadvertant, by humans. In terms of their conservation, it is imperative that we more fully understand their natural history so that we may anticipate and minimize the detrimental impacts of human activities on this unique, yet rapidly declining, faunal group.

The past two decades have witnessed a rise in the number of studies on bats and there is a clear need for additional research. Locally, very little work has been directed toward bats. The inherent difficulties of locating and capturing secretive, volant, and widely-dispersed organisms almost certainly has limited the number and scope of research projects on bats in this area. Minnesota, characterized by insect-infested summers and cold, prolonged winters, presents a special challenge to those bats that exploit its resources. Typical of most temperate-region bats, all species in Minnesota feed on flying insects. The seasonal abundance of this food source potentially could sustain a large bat population within the state. However, the harsh winters and limited number of suitable refuge sites place severe constraints on bat population densities and survival rates. Several species are unable to over-winter in the state and are forced to make costly annual migrations. Those species that find suitable winter refuge tread a fine line between survival and starvation. The factors that exclude bats from Minnesota or limit their distribution and abundance need to be explored more fully, as do the behavioral and physiological responses of bats to such constraints. Through studies of Minnesota's bat fauna significant contributions can be made to both regional information and general knowledge of chiropteran biology.

The paucity of investigation on bats in Minnesota points to the unfortunate fact that we lack simple baseline information with which scientists and managers of nongame wildlife can assess the status of bat species in the state, detect any changes in distribution or abundance, and formulate management policy to ensure their continued representation in the state. The motivation behind the present study on the distribution and status of bats in Minnesota was this lack of information and the need to update and augment our existing knowledge on the state's bat fauna.

Minnesota bats. Minnesota currently includes seven species among its chiropteran fauna. All members of the family Vespertilionidae, they fall into two general categories, (1) cave bats and (2) tree bats, based on their habits. Cave bats commonly roost in caves, abandoned mines, and buildings, sometimes congregating in large numbers. In Minnesota, these include *Myotis lucifugus* (little brown bat), *M. keenii* (Keen's bat), *Eptesicus fuscus* (big brown bat), and *Pipistrellus subflavus* (eastern pipistrelle). All four species are known to hibernate in the state and to forage here in the summer. The tree bats typically roost singly or in small groups among the foliage of trees or on rock cliffs. Minnesota tree bats are *Lasiurus borealis* (red bat), *L. cinereus* (hoary bat), and *Lasionycteris noctivagans* (silver-haired bat). These bats apparently migrate into Minnesota during the warm months to forage and rear young, but vacate the state during the winter. There are two instances of possible over-wintering by *Lasiurus cinereus* and *Lasionycteris noctivagans* (Beer, 1954; 1956), but these seem to be exceptional cases.

The distributions of several other bat species approach the Minnesota border but, to date, have not been recorded in the state. However, the vagility of bats makes it reasonable to expect that a few individuals occassionally may wander into Minnesota. The most likely are *Myotis sodalis* (social bat), which is recorded in northeastern Iowa and southwestern Wisconsin and is federally classified as endangered, and *Nyctecius humeralis* (evening bat), which was previously listed as potentially or actually occurring in Minnesota (Ames, 1873; Herrick, 1892), but whose present-day distribution reaches only to central Iowa and southern Wisconsin. Other, less likely, entrants into the state may be *Myotis leibii* (small-footed myotis), *M. volans* (long-legged myotis), and *Plecotus townsendii* (Townsend's big-eared bat). Vigilance along the state's borders may ultimately result in records of these species, although resident or breeding populations in Minnesota are highly unlikely.

Historical perspective. Bats undoubtedly have been recognized as members of Minnesota's fauna since man has been present in this area. Nevertheless, comparatively little study has been directed toward understanding the natural history of the seven species of bats that occur within the state's boundaries.

The first published documentation of the bats found in Minnesota was by A. E. Ames in 1873. In that account, Mammalia of Minnesota, Ames listed only two species, Vespertilio lucifugus (=Myotis lucifugus) and Nycticeius crepuscularis (=Nycticeius humeralis). Presence of the latter species has never been documented again in the state and its original report probably resulted from misidentification. Johan C. Hvoslef, living in the vicinity of Lanesboro, Fillmore County, recorded E. fuscus and M. lucifugus in his 1882 field notes (Rysgaard, 1941). Eptesicus fuscus was officially added to the list of mammals in Minnesota in 1892, when C. L. Herrick included it with M. lucifugus as the entire chiropteran fauna of the state. Myotis keenii was first reported by C. E. Johnson in 1916, and A. R. Cahn (1921) considered it the most abundant bat in Itasca County in 1919. The first published investigation of wintering habits of Minnesota bats was by C. A. Evans (1934). In this description of bats hibernating in Minnesota, he reported 150 E. fuscus and a few M. lucifugus in one of the seven St. Peter caves in Nicollet County. Following repeated visits to these caves, P. subflavus, was later recorded as present in the state (Swanson and Evans, 1936).

The efforts of Charles A. Evans and Gustav Swanson in the early 1930's mark the first real scientific inquiry directed toward the bats of Minnesota. This was followed by a period of intense interest in Minnesota bats beginning in the early 1940's and extending into the mid-1950's. During this time, George N.

Rysgaard (1941*a*, *b*; 1942) examined all caves then known in Minnesota during the winter of 1940-1941 and found bats hibernating in 15 caves and mines over 10 counties in southeastern Minnesota. His work on the relative abundance, seasonal movement patterns, and roosting habits of the four species of cave bat made a significant contribution to the existing knowledge on bats hibernating in the state. Expanding on the banding work begun by Rysgaard, James R. Beer (1955), then professor in the Department of Entomology and Economic Zoology, University of Minnesota, and his students banded 3,871 *E. fuscus* in Minnesota and Wisconsin and monitored their survival and movements from 1940 to 1954. Beer and Richards (1956) looked at seasonal changes in the physiology of *E. fuscus* hibernating in St. Paul sandmines from 1949-1955.

There has been little work done with Minnesota's bat fauna since the burst of activity in the 1940's, with a few noteable exceptions. Acting upon a remark made by a 4th grader that there were bats in a sewer, Dr. Harry H. Goehring, then professor in the Department of Biology, St. Cloud State College, initiated a long-term banding program of all bats in a storm sewer in St. Cloud (Goehring, 1954; 1955; 1960; 1972). From 1951 to 1971, data were collected on the composition and survival of the bats utilizing this sewer as a hibernaculum. Bats in the sewer continue to be censused annually. Steece et. al (1982) examined the incidence of rabies among bats submitted to the Minnesota Department of Health between 1976 and 1980. David J. Tallman, with the assistance of members of the Minnesota Speleological

Survey, banded bats hibernating in a section of Mystery Cave, Fillmore County, from 1979-1984.

Bats have been collected as part of several faunal studies, Herrick (1885) in Big Stone County; Cahn (1921, 1937) in Itasca County, Quetico Provincial Park, Ontario, and Superior National Forest, northeastern Minnesota; Bailey (1929) in Sherburne County; Swanson (1943) in Itasca State Park; and Timm (1975) in Cook County. Accounts of the mammals of Minnesota have included incidental records and sightings of bats (Gunderson and Beer, 1953; Hazard, 1982; Heaney and Birney, 1974; Swanson, 1943).

Geographical background. Summer foraging bats have been reported to use a variety of man-made structures, hollow trees, log piles, vegetation, and rock cliffs for roost shelters. By contrast, suitable winter hibernacula are relatively few in Minnesota and are largely restricted to the southeastern portion of the state. Hibernacula serve for winter refuge and as centers of dispersal to summer grounds. They may also be used as summer day roosts by males and barren females. Therefore, the locations and number of these sites are important when considering the distribution and abundance of bats in the state.

A review of the geology of the state shows that few areas in Minnesota are likely natural sites for bat hibernacula. Caves are most commonly formed from sedimentary rock, excavated in sandstone and limestone through erosion by running water or ground water seepage, or by dissolution of limestone by the chemical reaction of groundwater with top soil and underlying rock (Ojakangas and Matsch, 1982). Most of the northern portion of the state is typified by glacial deposits overlying highly resistant igneous or metamorphic bedrock. The western region contains areas of sedimentary rock beneath thick glacial deposits and, with the exception of river valleys, the low topographic relief of this area provides little opportunity for cave formation. A few sites along the St. Croix and Kettle rivers in eastern Minnesota expose sandstone to the erosionary effects of the rivers, resulting in small caves.

Without doubt, the major area of cave formation in Minnesota is the southeastern quarter. This area was largely ice free during Pleistocene glaciation and is overlain by shallow glacial sediments. The hilly terrain typical of this area has resulted from dissection of soft sandstone bedrock by numerous stream systems (Ojakangas and Matsch, 1982). Additionally, the extensive limestone deposits are riddled with underground caverns and passages, verified by the fact that the overwhelming majority of caves listed by the Minnesota Speleological Survey are located in this region.

The cave formations of southeastern Minnesota offer ideal conditions for hibernating bats. In order for bats to overwinter successfully, these hibernacula must remain above $0^{\circ}C$, be resistant to large flucuations in the outside temperature, and maintain a relatively high humidity. Subterranean caverns are ideal as hibernacula because they maintain a constant year-round temperature near the mean annual temperature of the region (in Minnesota this is appoximately 8°C (47°F)). They are typically saturated environments due to the seepage of ground water and the presence of underground streams, and their passages are protected from above-ground weather changes.

Therefore, it comes as no surprise to find that the majority of state bat records are from the southeast. The caves and mines studied by Evans (1934), Swanson and Evans (1936), Rysgaard (1942), Beer (1955), and Beer and Richards (1956) were in this region, underlining the importance of karst topography in providing conditions essential to maintaining resident bat populations year-round.

Hibernacula do occur in regions of the state other than the southeast. These exceptions represent northern and western limits in overwintering sites for bats in Minnesota. The majority of known periferal hibernacula are man-made features, which include artifical storage caves in Hennepin, Ramsey, Scott, and Washington counties, storm sewers in Washington and Stearns counties and possibly other parts of the state, and vertical iron ore mines in St. Louis County. Important natural hibernacula include caves in Pine and Washington counties. These sites are discussed in more detail in the individual site descriptions (Appendix 3).

SUMMARY OF RESEARCH EFFORTS

The overall objective of the research was to gather population and distribution information on the seven species of bats found in Minnesota. This would involve monitoring the common species (*Myotis lucifugus* and *Eptesicus fuscus*), but concentrating on the five apparently less common species (*M. keenii*, *Pipistrellus subflavus*, *Lasionycteris noctivagans*, *Lasiurus borealis*, and *L. cinereus*). Specific questions we planned to examine were: 1) the sex and age structure of these species and whether there was a seasonal change to the sex ratio; 2) assessment of the current status of species reportedly rare in the state; and 3) the arrival and departure dates for migratory species and for resident species to local hibernacula.

The duration of the proposed study was 17 months, from spring, 1982, through fall, 1983. Our original schedule of activities was as follows.

Spring, 1982 - Collect early spring records of migratory species (netting and banding, shooting) from Anoka County and solicit information on bat concentrations from the general public by publicizing the existence of this study.

Summer, 1982 - Continue collecting from Anoka County, collection (netting and banding, shooting) by field crew surveying small mammal fauna in southern and western Minnesota, compilation of all available data from bats in the Bell Museum collection, development of radio transmitter for *Lasiurus cinereus*, preliminary work with ultrasound detection equipment to identify specific bat calls and record bat activity.

Fall, 1982 - Collect fall migratory records in Anoka County (netting and banding, shooting).

Winter, 1982-3 - Collect data on hibernating bats concentrating on the caves in southeastern Minnesota (identify, weigh, sex, band bats, measure temperature and humidity of hibernacula).

Spring, 1983 - Collect second year of spring data on migratory species in Anoka County.

Summer, 1983 - Collect data on maternity colonies and summer roost sites throughout the state, concentrating in southeastern Minnesota (netting and banding, shooting).

Fall, 1983 - Collect second year of fall data on migratory species in Anoka County.

Soon after the project began, we realized that the schedule as originally proposed could not be carried out. As pointed out in our original proposal, the paucity of studies on bat populations in Minnesota reflects the difficulty of working with these animals. Foraging habitat and water resources are rarely or never limiting. Thus, bats commonly are highly dispersed for much of the year, making them difficult to locate and capture. In particular, the tree bats (*Lasionycteris noctivagans*, *Lasiurus borealis*, and *L. cinereus*) proved extremely difficult to capture, requiring very different field techniques than were employed for the four cave bat species. An unanticipated amount of time and effort was necessary to locate important roost sites in the state and to develop equipment for handling and processing the bats. Further into the project, the discoveries of major hibernacula necessitated a rethinking of the objectives of this study. Discussing these developments with Lee Pfannmuller throughout the project, we modified the emphasis of our research and ultimately extended the study through March, 1985. A summary or our activities is given below.

Summer, 1982 - The field crew surveying small mammals in western and southern Minnesota began their field season netting for bats as well as trapping for small mammals. Six bats were caught over a pond in Winona County. They discontinued the netting further into the field season because of a lack of suitable water and/or flyways and because no additional bats were captured.

Fall, 1982 - Records of bats from the Bell Museum collection were compiled. When available, locality, date of capture, sex, age, standard measurements, and reproductive data were recorded for each specimen. Based upon the the cave listings of the Minnesota Speleological Survey and advice of Dr. E. Calvin Alexander, Department of Geology and Geophysics, University of Minnesota, certain areas of the state were identified as likely to have caves and/or mines suitable as winter hibernacula or summer roost sites. Particular caves and mines were marked for subsequent examination.

Winter, 1982-3 - An article, written by Birney, was published in the issue of the Minnesota Volunteer describing our study aims and encouraging people to contact us with information about bats. Field equipment for exploring caves was procured. The annual bat-banding trip of Tallman was conducted in Mystery Cave, Fillmore County. As an independent project, Tallman has been banding the bats in this cave and collecting information on species, sex, weight, and forearm length, each winter since 1979. Caves and mines in the Twin Cities area and those in Pine County were explored and field reconnaissance was conducted on caves and mines in the southeastern portion of the state. Sites in Pine and Washington counties were visited, as were two sand mines in Pierce County, Wisconsin. In an independent project, Nordquist examined the roosting positions of bats with respect to temperature stratification in Robinson's Ice Cave, Pine County.

Spring, 1983 - Based on the winter reconnaissance, several sites were designated as important hibernacula that merited additional attention. Collection of population information, including species, sex, weight, forearm length, cluster size, and roosting position, was initiated at these sites. Environmental parameters of the sites, such as temperature, humidity, air flow, and ceiling height, were noted. Banding of bats at these hibernacula was also begun, with particular emphasis on Maiden Rock Mine, Pierce County, Wisconsin. Several trips were made to Maiden Rock and the Red Wing sand mine to band bats during this period. Potential roost sites in Nicollet and Scott counties were examined. On a separate project, Nordquist investigated the influx of large numbers of bats to a Potlatch oxboard plant outside Cook, St. Louis County. During this time, the Iron Range area was explored for potential bat roost sites and individuals in the area were contacted concerning the presence of bats in the area. One site of particular importance, the Tower Soudan Mine in Soudan, St. Louis County, was first visited at this time.

Summer, 1983 - Tallman worked with a Boston University field crew in New Hampshire (under the direction of Dr. Thomas H. Kunz) that were working on bat populations in that area. Information was collected on equipment and techniques used in monitoring the bats. The major work conducted on Minnesota summer bat populations included the following: reconnaisance of caves and mines visited during spring field work, exploration of additional caves in southeastern Minnesota, follow-up on potential bat roosts from people responding to Birney's Minnesota Volunteer article, mist-netting and shooting bats over waterways, and location of maternity colonies in southeastern Minnesota. Bats were identified and banded, and standard measurements were taken. Work was continued on the Potlatch plant bats. During this work, a large concentration of bats was found in the Tower Soudan Mine and banding and data collection on these bats was initiated at this time.

Fall, 1983 - Southeastern cave reconnaissance continued and five permanent census sites in Maiden Rock Mine were established to assess population size, variation in densities within the mine, and seasonal change. Work on the Potlatch plant was continued. Additional permanent census sites were established in Maiden Rock Mine and a complete census of the Red Wing mines was conducted. Birney (1983) published a second Volunteer article discussing the importance of studying bats in Minnnesota.

Winter, 1983-4 - Winter censusing was made at Robinson's Ice Cave. The annual banding and censusing was conducted again at Mystery Cave by Tallman. We began efforts to secure certain caves and mines as important hibernacula to bats. Both the Minnesota and Wisconsin DNR and the Nature Conservancy were approached about protection of the hibernacula and owners of the abandoned sand mines were contacted.

Spring, 1984 - All important hibernating sites that had been located thus far were revisited during early spring. This included the sites in southeastern Minnesota surveyed during the summer, a new hibernaculum at the Brightsdale power plant, Fillmore County, the two Wisconsin sand mines, and the two caves north of the Twin Cities. In the smaller or less populated hibernacula, all accessible bats were identified and banded (or recapture on previously banded individuals recorded) and measurements were taken. For larger hibernacula, a sample of the total population was processed and banded, and estimates were made of the total population. For Maiden Rock Mine counts were made at the permanent census sites in early and late spring. For all sites, environmental conditions were noted. No visits were possible at the Tower Soudan Mine during this time because the hoist system was being overhauled. In anticipation of possible purchase of the Red Wing Mine by The Nature Conservancy, a complete map was made of the cave complex, including passages, shapes of entrances, and suggested management of the portions of the mine to prevent access by humans but maintain accessibility to bats. Conservancy personnel were shown the mine and its importance to the state's bats was discussed. Later, we met with the then-current lease holder of the Maiden Rock Mine, a representative of the Wisconsin chapter of the Audubon Society, and Merlin Tuttle of Bat Conservation International to discuss the preservation of this mine as a bat hibernaculum.

Summer, 1984 - Made summer census of Tower Soudan Mine and Spring Valley Caverns. Censused a large maternity colony in an old house scheduled to be demolished near Brightsdale power plant and monitured the bats present at the hibernating site.

Fall, 1984 - Made population counts at the permanent census sites in Maiden Rock Mine. Censused and banded bats at Robinson's Ice Cave.

Winter, 1984-5 - Censused hibernating bats in the major hibernacula. Banded bats were recorded and additional individuals banded and measured. Total counts or estimates of population size were made. Environmental parameters of the sites were recorded.

SUMMARY OF FINDINGS

Locations of Important Bat Sites

With few exceptions, important roost sites and areas of high bat densities were largely unknown prior to this study. The status of several hibernacula studied by earlier researchers, such as Rysgaard and Beer, had not been assessed since that time. A prerequisite to beginning work on the state's bats was to determine the best areas in which to concentrate our efforts. Having decided to direct the study primarily at the four species of cave bats for reasons discussed in the Summary of Research Effort section, we evaluated regions of the state according to the likelihood of suitable hibernacula. Summer maternity colonies and non-cave day roosts were also sought, and in practice proved to be most difficult to locate.

Site information was collected from a number of sources ranging from museum specimens to public complaints, and are discussed in more detail below. Although all are important sources of information, the variability in the kinds and quality of the data demand that they be used with some caution. It is impossible to claim that all bat populations and suitable roost sites have been identified across the state. Such a goal, while worthy of consideration in any long-range plan, would have been impractical within the confines of this study. However, we do believe that, based upon the existing information on Minnesota bats and our subsequent research efforts, our findings reflect general trends in the distribution of bats in Minnesota and that the major roost sites have been identified. Important sources of bat information are discussed below.

Museum specimens. The holdings of Minnesota bat specimens at the Bell Museum of Natural History, University of Minnesota, Minneapolis, includes over 820 specimens with records of occurrence for at least one species of bat in all but 17 of the 87 counties. The majority of specimens was obtained as incidental findings or during general mammal collecting trips. A significant contribution was made from bats collected for the rabies study (Steece et al., 1982). These, too, were primarily single captures sent to the Minnesota Department of Health for analysis. Other specimens were obtained during the earlier bat studies of Swanson, Rysgaard, and Beer. The distribution and number of records for bats taken in a given county correlate strongly with (1) areas of high human densities (for example, Hennepin and Ramsey counties), and (2) areas of intense research activity (for example, Clearwater and Itasca counties, near the Itasca Biological Station; Cook County where a county-wide mammal survey was conducted; and Ramsey, Nicollet, and Fillmore counties, where caves and mines with bats have been known for some time). Therefore, these data cannot provide reliable information concerning the relative abundances of bats throughout the state. They do, however, offer important records in the range of distribution of bat species in Minnesota, the general timing of arrival and departure for migratory species and initiation and cessation of hibernation for cave bats, reproductive information on timing of birth and size of litters, and indication of sex ratio, age composition, and seasonal changes among the bats in Minnesota.

Published reports. A number of regional studies and occassional sightings of bats in Minnesota have been published without the deposition of voucher specimens in museums. Some of these constitute the only published county records available; for example, Herrick's record of bats in Big Stone County (Herrick, 1885) and Cahn's account of *Myotis keenii* in Itasca County (Cahn, 1921). Evan B. Hazard's work on the mammals of Minnesota (Hazard, 1982) provides a thorough survey of holdings in a number of state collecting institutions and has included additional county records for bats in the state. In addition to distributional accounts, the ecological studies of such early investigators as Rysgaard and Beer provide invaluable information on species distribution, abundance, cluster size, roosting positions, and microhabitat preferences in several mines and caves. Not only have these studies indicated sites in which to focus our current research, they also have provided a basis for comparing any changes in population levels, sex ratios, or species composition since the initial studies were conducted. In some cases, these reports document major hibernacula that subsequently have been destroyed;

for example, the Seven Caves of St. Peter, studied by Rysgaard, Swanson, and Evans, and the St. Paul sandmines examined by Beer and Richards. The value of such publications is clear, despite a lingering degree of uncertainty resulting from the lack of specimens to confirm species identity and the inability to verify the accuracy of earlier counts and mearsurements.

<u>MSS cave list</u>. The assistance of E. Calvin Alexander, Department of Geology and Geophysics, University of Minnesota, and the Minnesota Speleological Survey (MSS) was crucial in locating caves and mines that might potentially have bats. They have compiled of a list of over 450 caves, mines, and sinks throughout the state, including information concerning location, elevation, length, and ownership for many sites and survey maps of the passages for several caves and mines. In addition, the members of MSS have had an interest in the bats utilizing caves and mines and have frequently made note of their presence or sign, alerting us to potentially important sites. Although MSS personnel freely admit that their cave list is far from exhaustive and is ever-expanding, being able to use this resource and to call upon their expertise have added immeasurably to the number of sites now known to house bats in the state.

<u>Public response</u>. A number of important locations, mostly summer roosts, were obtained from individuals who contacted us. Articles published in the Minnesota Volunteer (Birney, 1982; 1983;

Melander, 1985), university publications (Frothingay, 1985; Nordquist, 1985), and local newspapers (Anonymous, 1983; Dorn, 1984; Gardner, 1984), together with referrals from Wildlife Information at the Bell Museum and state agencies, helped alert the general public to the existence of this project. This, in turn, generated many inquiries and comments concerning problems of bats in homes or buildings, seasonal sightings, reports of dead or banded bats, and recollections of places where bats have been observed in the past. Some reports were exaggerated and high bat concentrations turned out to consist of only a few individuals or, in one case, a flock of swallows. However, many provided valuable information on the locations of maternity colonies and summer roost sites that were not previously known. State and federal wildlife managers and local law enforcement and park personnel were also important sources of information on bats within their areas of jurisdiction. They were often the people first contacted about bat problems or sightings and, thus, served as valuable reservoirs of local bat information.

Summary of Bat Locations

Drawing from the information gathered from the sources discussed above, the study investigated 110 sites, encompassing 17 counties in Minnesota and two locations in Wisconsin (Fig. 1). These sites are listed in Appendix 1, with the species and numbers of bats found and estimate of importance to bats. Not included

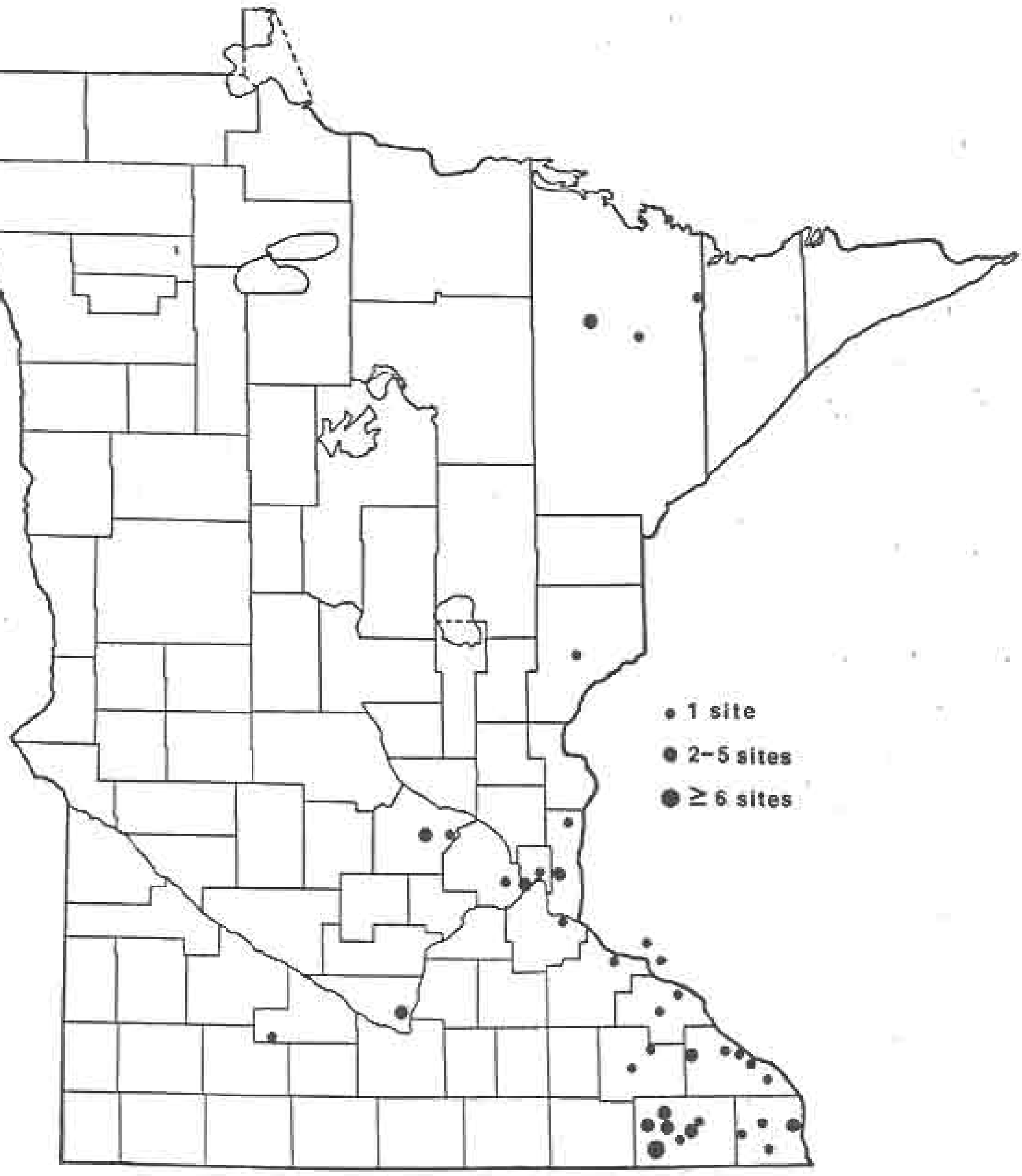

Fig. 1. Locations of sites where bats were found during this study.

are the numerous explorations into unnamed crevices and tunnels, the bat found periodically in buildings on the University of Minnesota campuses, or the chance observations of bats in flight. Of the 110 sites listed, 46 were found to have bats, 11 additional sites had bat droppings but no individuals were observed, 28 sites showed no indication of being used by bats, and 25 remain unknown, either because they were inaccessible due to owner objections, flooding, or difficult access or because they could not be found using the available locality information.

Among the unknown sites, several have the potential of being important to bats. These include Niagara Cave, a commercially operated cave and second largest in the state; Jordon Brewery Cave, in which Rysgaard (1941a, b; 1942) reported large numbers of bats; and Ford Sand Mine, beneath the Ford plant in St. Paul, which is 5,000 m in length. We hope to gain access to these sites during future explorations.

The locations where bats were found included a variety of natural and artifical sites. Nineteen sites were used by bats during the winter, 38 during the summer, and of these sites, 11 were utilized year-round. The summer records consisted of 31 actual roost sites and seven localities where bats were netted while foraging. At least seven maternity colonies of *Myotis lucifugus* and one of *Eptesicus fuscus* were found. All were located in building attics or inner walls. In fact, 20 summer sites were found in buildings of some kind, five were man-made tunnels or mines, and only six summer localities were natural caves. For the winter sites, nine locations were man-made mines or tunnels, two were buildings, and eight were natural caves.

Based upon the number of species, total number of bats, and the particular location, several sites where designated as major hibernacula. These include Brightsdale Tunnel, Spring Valley Caverns, and Mystery Cave in Fillmore County; Red Wing Mine in Goodhue County; Robinson's Ice Cave in Pine County; Tower Soudan Mine in St. Louis County; and Bay City Mine and Maiden Rock Mine, in Pierce County, Wisconsin. These sites have been the focus of most of our research effort and the data gathered from them comprise the bulk of our report on the state's cave bats. Each of these sites is described in detail in Appendix 3. A number of additional locations also provided valuable supplemental information. For example, Old Mystery Cave and Old Still Cave, which are within a few hundred feet of Mystery Cave, show interesting differences in species utilization; Bat River Cave, although largely inaccessible due to a river that flows from it, is used by bats year-round and has been reported to have large numbers of *Myotis* and *Pipistrellus* (Alexander, 1980); and Leslie Cave, a small cave with few bats, is the northernmost record for *Pipistrellus subflavus*.

Distribution and Abundance of Bats in Minnesota.

All bat species in Minnesota, with the exception of *Pipistrellus subflavus*, are considered to have a state-wide distribution (Hall, 1981; Hazard, 1982). Compilation of information from the sources discussed above and data collected during this study appear to substantiate this conclusion (Table 1). However, every species of bat occurring in the state, including the two most common species, Eptesicus fuscus and Myotis lucifugus, lack documentation in a number of counties (Figs. 2-8). These gaps in distributional records may not actually reflect an absence of bats from these areas. Sightings of bats may go unreported or records may exist among individuals, such as area park and wildlife managers or biology teachers, that are unknown to us. A lack of faunal surveys in certain regions of the state may also contribute to the paucity of records for particular counties. Indication that bats may be present but undocumented is suggested by two recent specimens, Lasiurus cinereus from Marshall County and Lasiurus borealis from Lake of the Woods County, obtained by regional nongame biologist, Katie Hirsch. These constitute new county records for these species. It is likely that additional efforts directed toward finding bats in counties with few or no current records will succeed in expanding the extent of distribution records for the state's bats.

An alternative interpretation of the distributional data is that the lack of records indicates regions of low bat densities. The majority of counties with no records of bats are clustered along the western border of the state in areas dominated by farmlands. This area may be less suitable to bats than other regions in the state. Several factors could be responsible if

Table 1. Documentation of bats occurring in Minnesota. (1--Current research findings; 2--Bell Museum specimens; 3--additional published reports. Species abbreviations: Mylu--*Myotis lucifugus*; Myke--*Myotis keenii*; Pisu--*Pipistrellus subflavus*; Epfu--*Eptesicus fuscus*; Lano--*Lasionycteris noctivagans*; Labo--*Lasiurus borealis*; Laci--*Lasiurus cinereus*; TS - total species recorded in county.)

County	Species							TS
	Mylu	Myke	Pisu	Epfu	Lano	Labo	Laci	
Aitkin	2					2		2
Anoka	2			2	2		3	4
Becker	2			2	3			3
Beltrami	2			2	3		3	4
Benton				2				1
Big Stone	3						3	2
Blue Earth	2			2	3			3
Brown				1,2		1		2
Carlton	2							1
Carver	2			2	3	2	3	5
Cass	2	3						2
Chippewa				2			2	2
Chisago				2				1
Clay	3					3		2
Clearwater	2			2	2	2	2	5
Cook	2	2			2	2	2	5
Cottonwood								0
Crow Wing	2			2				2
Dakota	2			2				2
Dodge	2							1
Douglas	2			2				2
Faribault				2				1
Fillmore	1,2	1,2	1	1,2		1		5
Freeborn	2			2				2
Goodhue	1,2	1,2	1,2	1,2				4
Grant	3					3		2
Hennepin	1,2	2	2	1,2	2	2	2	7
Houston	1,2		2	1,2	2	2		5
Hubbard	3			3	2	2	2	5
Isanti				2				1
Itasca	2	3		2		3		4
Jackson								0
Kanabec				2				1
Kandiyohi	2			2	3			3
Kittson								0
Koochiching	2						2	2
Lac Qui Parle								0
Lake	2							1
Lake of the Woods						1		1
Le Sueur				2				1
Lincoln						2		1
Lyon	3			3				2
Mahnomen	3							1
Marshall							1	1

Table 1. (continued)

County	Species: Mylu	Myke	Pisu	Epfu	Lano	Labo	Laci	TS
Martin	2			2				2
McLeod	2			2				2
Meeker	2			2			2	3
Mille Lacs	2			2		2		3
Morrison	2			2				2
Mower	2			2				2
Murray								0
Nicollet	1,2	2	1,2	2				4
Nobles				2				1
Norman							2	1
Olmstead	1,2			2				2
Ottertail	2			2				2
Pennington								0
Pine	1,2	1		1,2		2		4
Pipestone								0
Polk							2	1
Pope				2			3	2
Ramsey	2	2	2	1,2	2	2	2	7
Red Lake	2			2	3			3
Redwood				3				1
Renville				2		2		2
Rice	2			2		2		3
Rock								0
Roseau	2							1
St. Louis	1,2	1,2		2	3	1,3	2	6
Scott	2		3	2		2		4
Sherburne	2	3		2	2	3	3	6
Sibley				2				1
Stearns	3	2	3	2			3	5
Steele		2		2				2
Stevens							3	1
Swift								0
Todd	2			2				2
Traverse	2							1
Wabasha	1,2	3	2	3	1	3		6
Wadena	2				2			2
Waseca	2			2			2	3
Washington	1,2	1	1,2	1,2		2		5
Watonwan				2				2
Wilkin								0
Winona	1,2			1,2		1,2		3
Wright	1,2			1,2	2			3
Yellow Medicine						2		1
Total counties documented	55	15	10	56	18	26	21	

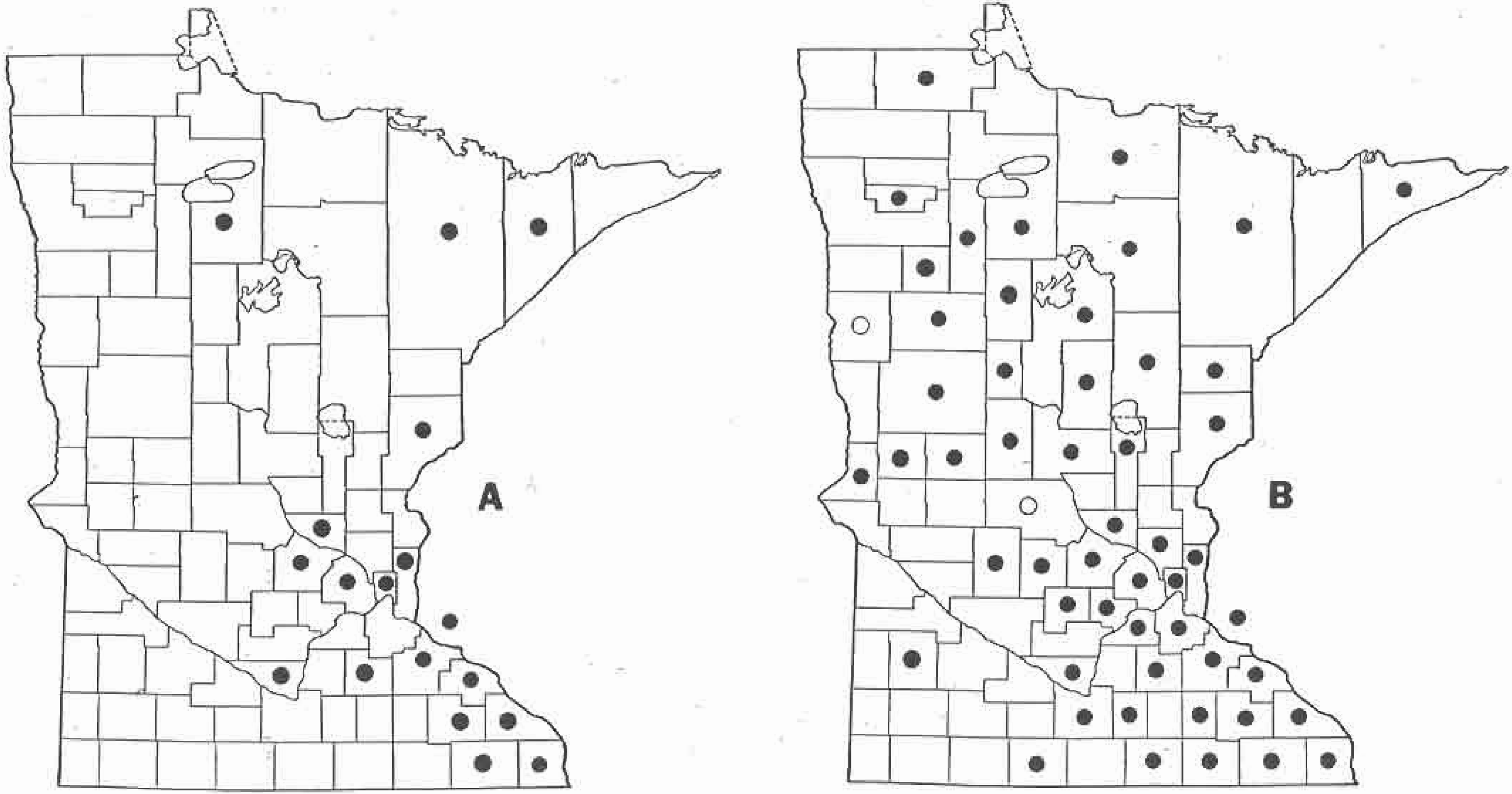

Fig. 2. (A) Winter and (B) summer distribution records for *Myotis lucifugus*.
(● - dated records of occurrence; ○ - reported in literature, dates unknown)

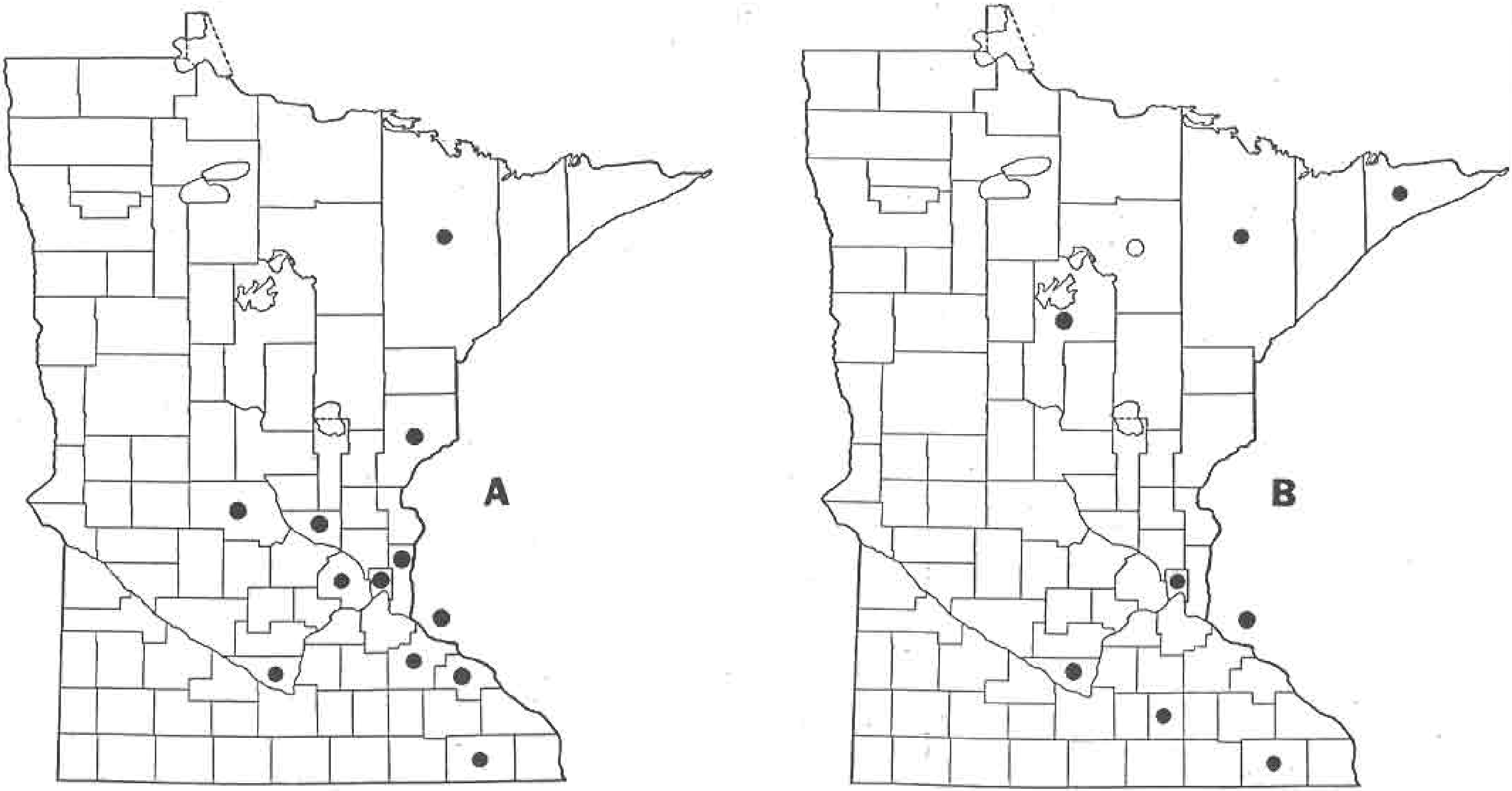

Fig. 3. (A) Winter and (B) summer distribution records for *Myotis keenii*.
(● - dated records of occurrence; ○ - reported in literature, dates unknown)

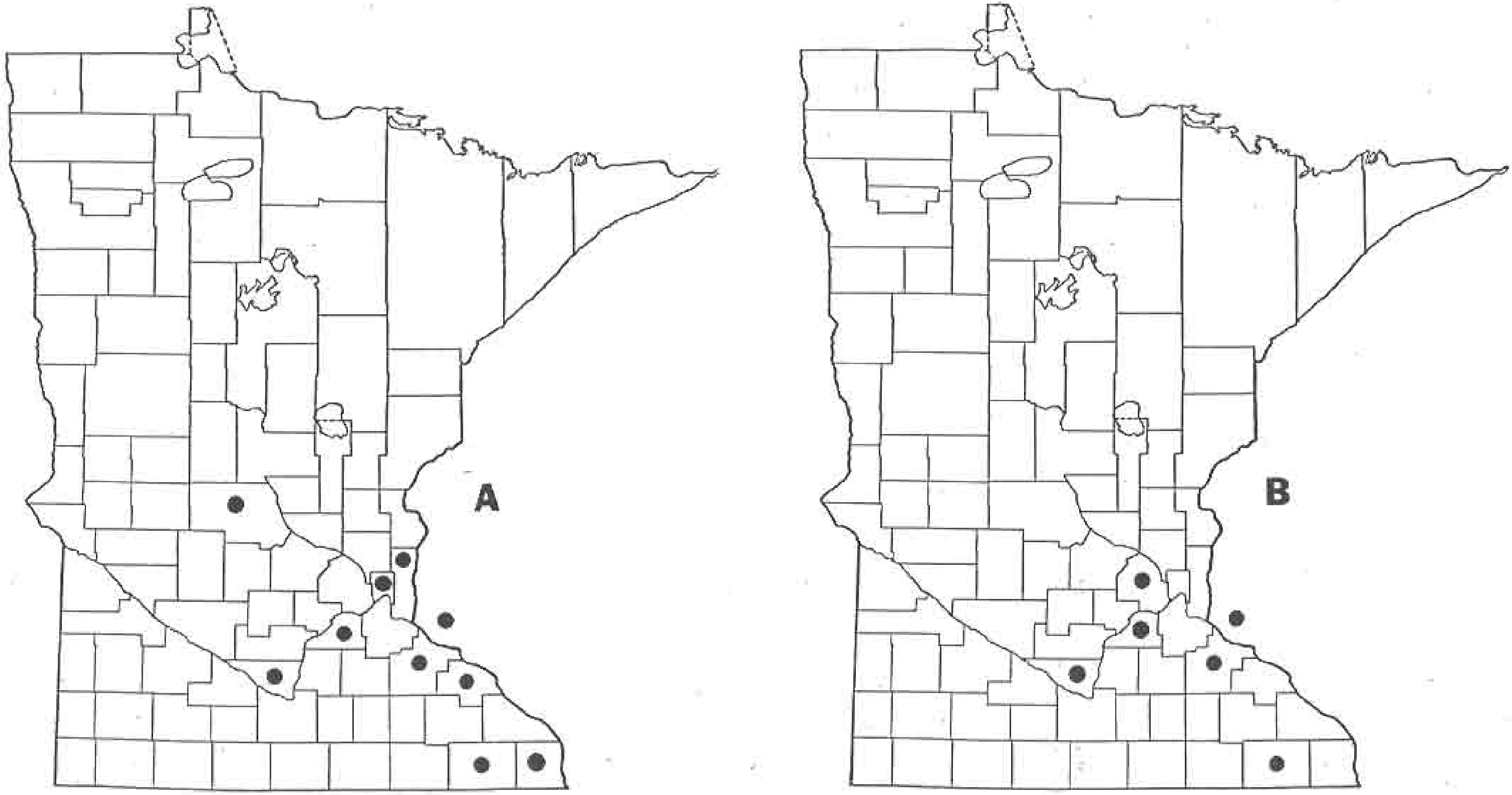

Fig. 4. (A) Winter and (B) summer distribution records for _Pipistellus subflavus_.

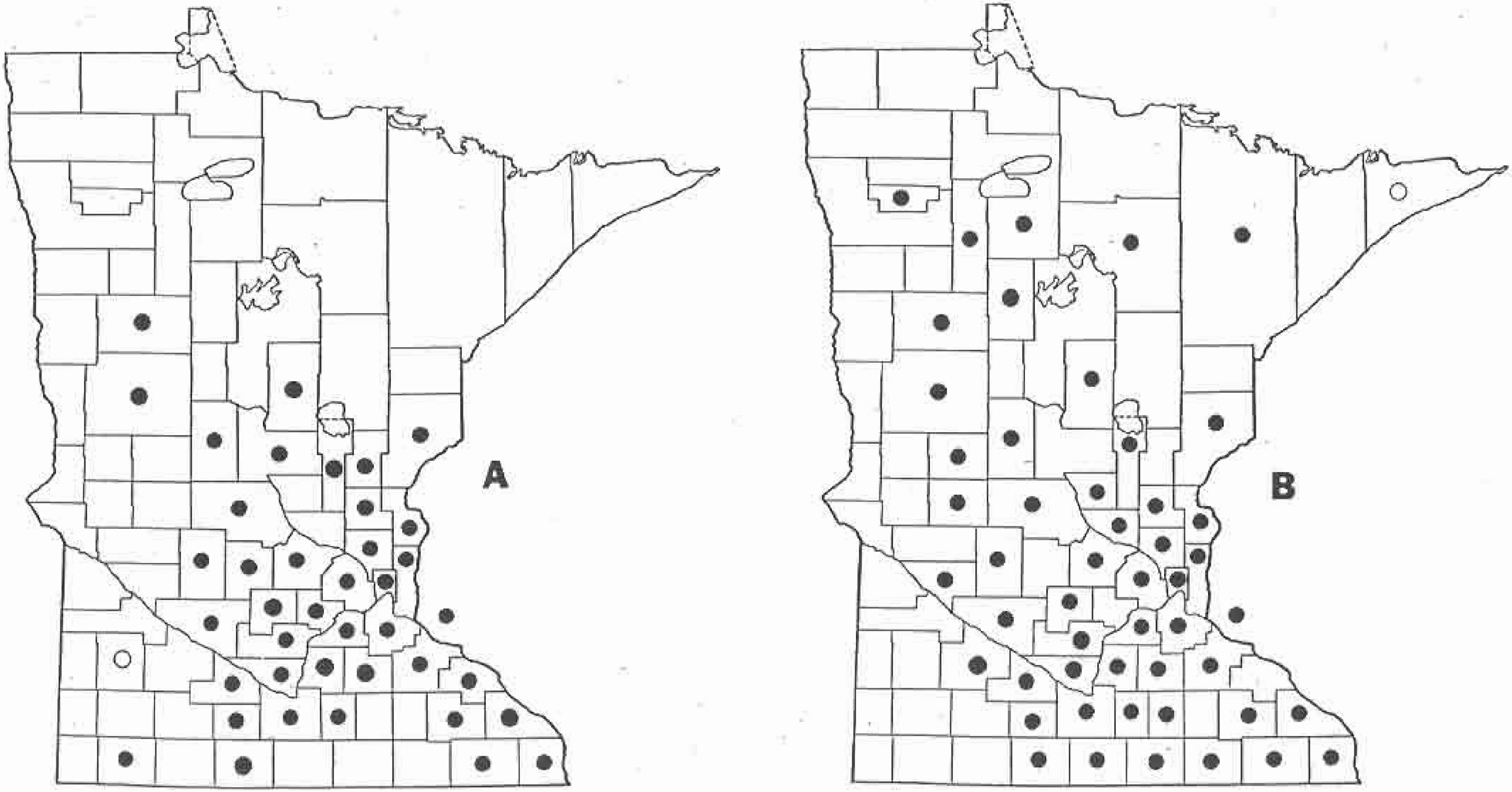

Fig. 5. (A) Winter and (B) summer distribution records for *Eptesicus fuscus*.
(● - dated records of occurrence; ○ - reported in literature, dates unknown)

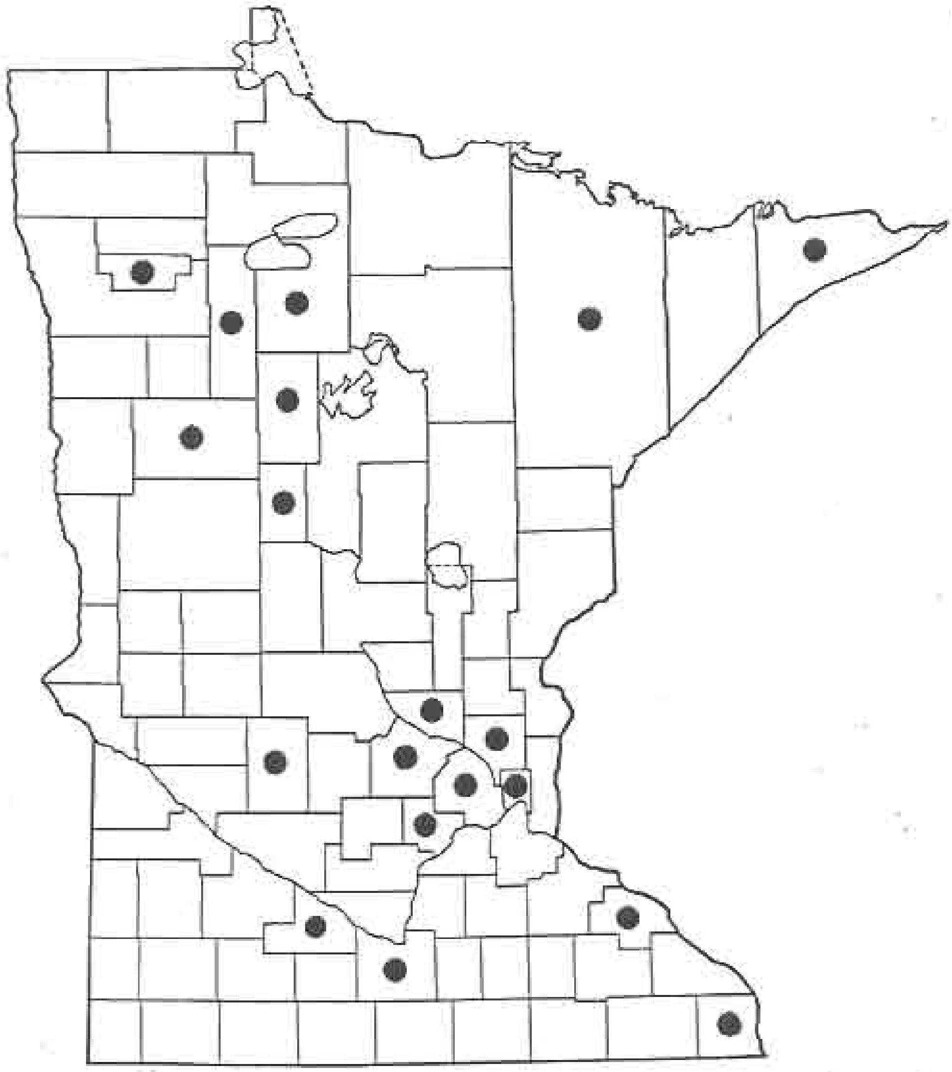

Fig. 6. Distribution records for Lasionycteris noctivagans.

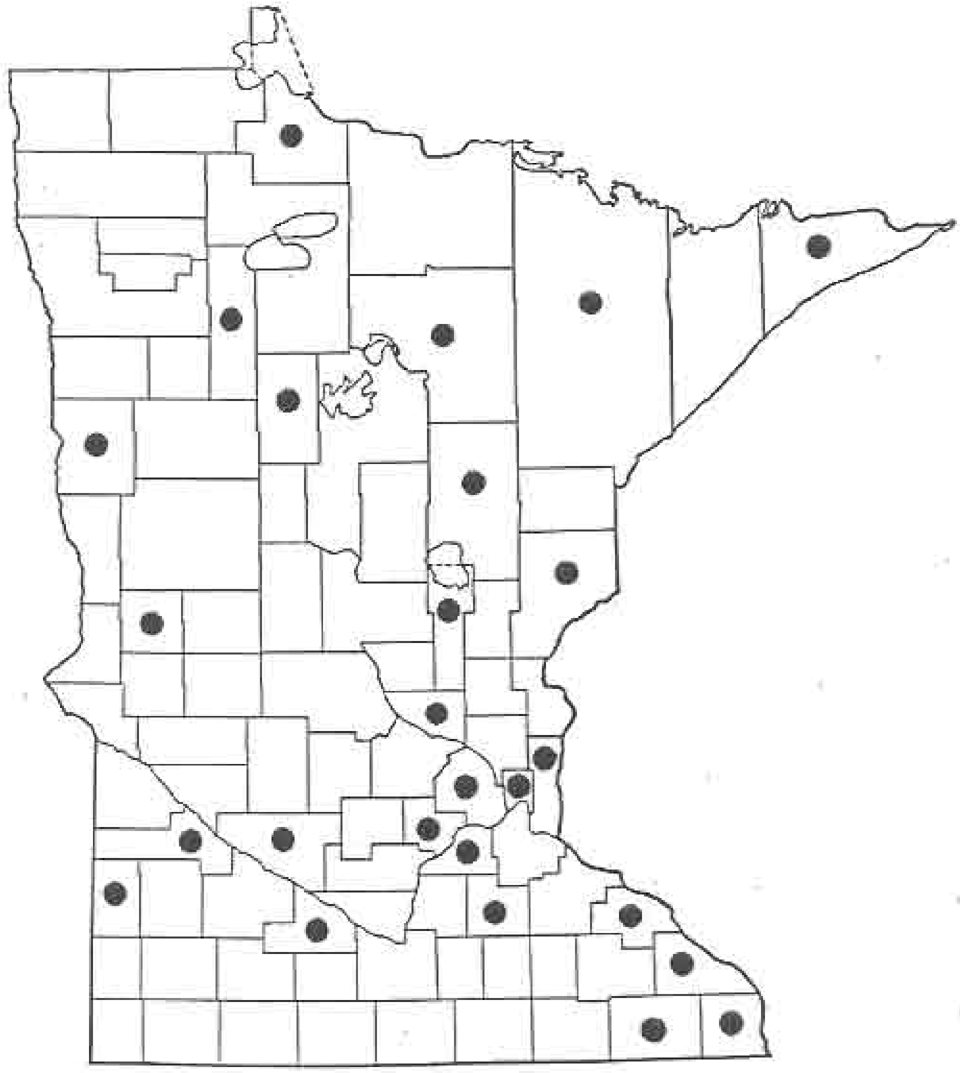

Fig. 7. Distribution records for Lasiurus borealis.

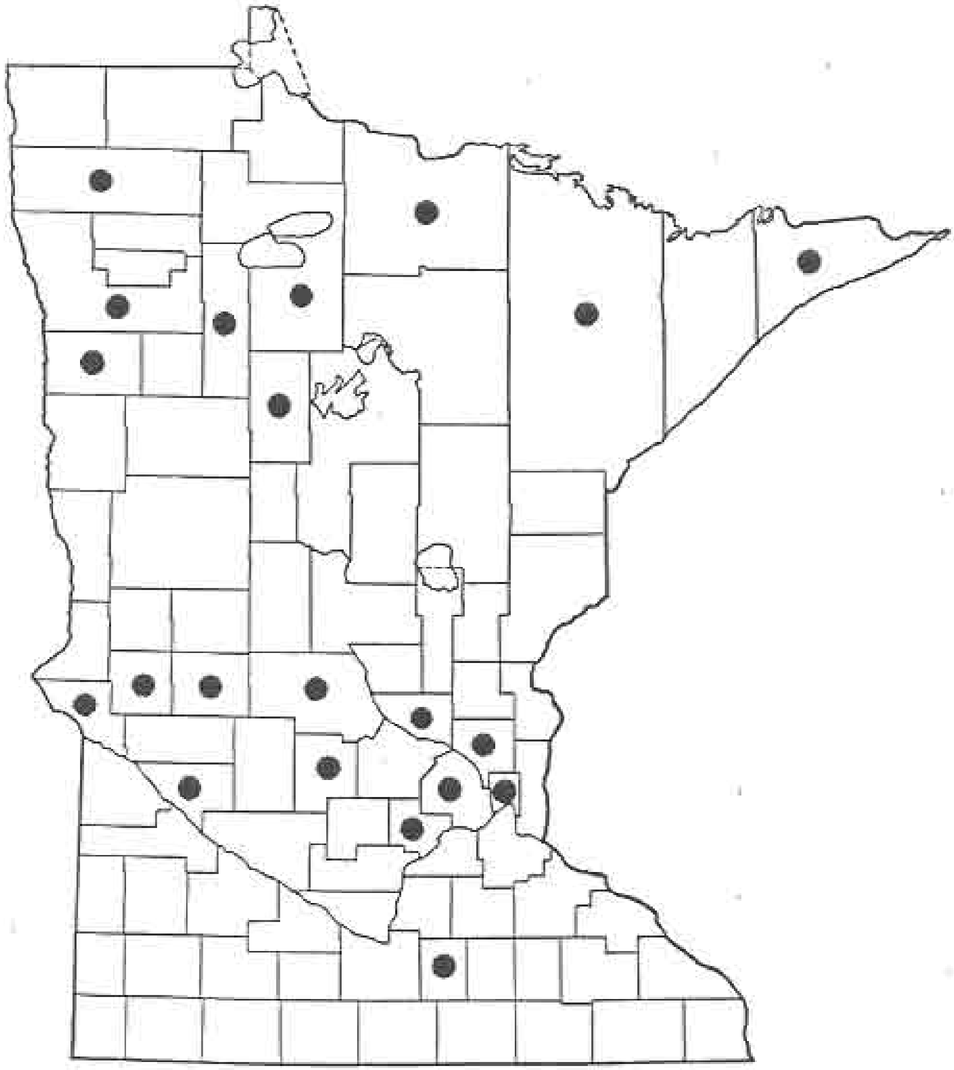

Fig. 8. Distribution records for *Lasiurus cinereus*.

lower density of bats in western Minnesota is actually the case. First, extensive agriculture limits the amount of forested habitat available as roost sites and feeding areas for those species that typically forage above the tree canopy or along the forest edge. Drainage of wetlands to increase tillable acreage has reduced the number of ponds and marshes that serve as larval development sites for flying insects on which bats feed. The reduction of food supply and suitable roost sites may reduce the number of bats exploiting this area or may restrict them to localized sites, such as river valleys or game refuges.

Secondly, our work has found that most major hibernacula are localized in the southeastern portion of the state (Fig. 1). Although bats have been known to migrate several hundred miles between winter and summer areas, studies on north-temperate cave bats show that during the summer the majority of bats can be found within 50 miles of their winter hibernaculum (Griffin, 1970). From eight band returns we received, the average distance traveled between winter banding site and summer recapture was 94 km (57 miles) and none of the bats was taken in a western county (Table 12, Fig. 14). Thus, although bats are fully capable of reaching the western portion of Minnesota, few may actually do so.

It must be stressed that these explanations for the distribution of bats in Minnesota are based upon an eclectic and incomplete data base. For most counties, the records of occurrence amount to a few specimens of one or two species and can provide no indication of local population densities. Only future research directed specifically at documenting the status of bat populations in particular areas can answer the many questions regarding how bats are distributed across the state.

Although the state's bat species often share common foraging areas and all feed on the insect resource base, aspects of their life histories are sufficiently different to merit separate discussions. A useful separation to make is that between the cave and tree bats, based upon migratory habits, winter residency in Minnesota, and aspects of roost site selection and social behavior. (A separate account of each species is given in Appendix 2.)

Cave Bats in Minnesota

Distribution and abundance. The four Minnesota cave bats, *Myotis lucifugus*, *Myotis keenii*, *Pipistrellus subflavus*, and *Eptesicus fuscus*, are year-round residents of the state. With the exception of *Pipistrellus*, they typically congregate in large numbers in caves and mines during the winter and the females collect in attics and barns during the summer to give birth to their young. They frequently return to the same roost sites year after year. Such gregarious behavior and site fidelity makes these bats relatively easy to study, compared to the solitary tree bats that occur seasonally in Minnesota and roost under bark or among tree foliage.

The comparatively greater abundance of cave bats relative to tree bats is supported by the existing specimen records. Those for cave bats are greatest both in numbers of individuals and in numbers of counties having documented records of occurrence (Table 1). However, even the two most widely distributed species, *Myotis lucifugus* and *Eptesicus fuscus*, are recorded in only 63% of Minnesota counties. *Myotis keenii* and *Pipistrellus subflavus* are poorly represented, with records from 22 and 12% of the counties, respectively.

Differences in individual species distributions and seasonal changes in these distributions are noted between the four cave bats. For the purposes of this study, winter extends from 1 November through 31 May and summer from 1 June to 30 October. Where it seemed useful to subdivide seasons further, 1 September - 31 October is considered fall and 1 April - 30 May spring. Although the initiation of winter and summer behavior may vary according to the weather conditions for a particular year, our observations have shown these time intervals to agree in most instances. The three species presumed to have state-wide distributions, *Myotis lucifugus*, *M. keenii*, and *Eptesicus fuscus*, all exhibit widely scattered summer records and highly localized winter records (Figs. 2, 3, 5). This suggests that although suitable summer sites may be found throughout the state, critical winter hibernacula are, for the most part, confined to southeastern Minnesota.

Eptesicus shows the least contraction of its range during winter. This may reflect its propensity to overwinter in buildings and other man-made structures, which is relatively less common in the two species of Myotis. A larger and more hardy bat, Eptesicus appears capable of withstanding, if not actually preferring, colder and less humid hibernating conditions. In contrast, Myotis lucifugus and M. keenii exhibit a significant shrinkage of their apparent ranges during winter (Figs. 2, 3). Those winter records that lie outside the southeastern quarter of the state represent either late May captures, such as Lake, Beltrami, Sherburne, and Wright counties for M. lucifugus and Sherburne and Stearns counties for M. keenii, or are hibernacula with suitable conditions to sustain bats through the winter (St. Louis, Pine, Washington, and Nicollet counties).

Pipistrellus subflavus differs from the other cave bats in a number of aspects. It is a solitary hibernator, usually found hanging singly and separated from other bats. It reaches the northwest limit of its distribution in Minnesota and thus most of the records for this species are restricted to the southeastern region. In this study, the most northern occurrence of Pipistrellus was in Leslie Cave, Washington County. Nearly every record of this species in Minnesota has been taken in or near a cave or mine, none has been captured in a building, and only one was taken while foraging.

Myotis lucifugus and Eptesicus fuscus are amply represented by specimens in the Bell Museum, attesting to their abundance in the state. From a total of 736 specimens of cave bats from Minnesota, *Eptesicus* and *M. lucifugus* comprise 55 and 40% of the records, respectively. *Pipistrellus subflavus* and *M. keenii* are poorly represented, making up only 3 and 2% of the records, respectively. Using these data to infer relative abundances of cave bats in the state, it would appear that *Eptesicus* is the most common, followed closely by *M. lucifugus*, while *Pipistrellus* and *M. keenii* are quite rare.

The literature on the relative abundance of these species in this area is quite variable. In Iowa, *Eptesicus* is the most abundant and widely distributed species, *M. lucifugus* is common but restricted in distribution, *M. keenii* may be as abundant as *M. lucifugus*, and *Pipistrellus* may be rare (Bowles, 1975). To the west of Minnesota, *Eptesicus* is locally common, *M. lucifugus* is common and widespread, *M. keenii* is largely unknown, and *Pipistrellus* is absent (Jones, et. al, 1983). No recent reports exist for Wisconsin, but an early study concluded that *Eptesicus* is not abundant, *M. lucifugus* is very common, *M. keenii* appears rather scarce, and *Pipistrellus* is the least common (Jackson, 1961).

Reports of abundance within Minnesota also offer differing assessments. Bailey (1929) found *M. lucifugus* the predominant bat in Sherburne County and did not mention *Eptesicus* or *Pipistrellus*. In northern Minnesota and adjacent Canada, Cahn (1921, 1937) reported *M. lucifugus* as the most abundant, *M. keenii* as locally abundant, and *Eptesicus* as distinctively uncommon (*Pipistrellus* does not occur in this area). Swanson (1943) recorded only two cave bats from Itasca State Park, M. lucifugus being very common and M. keenii being moderately common. Gunderson and Beer (1953) reported M. lucifugus as the most common summer bat but they had found no large winter concentrations. They concluded that Eptesicus was the most common winter bat but thought it much less abundant and more widely scattered during summer. M. keenii was thought to occur regularly in state caves and not to be as uncommon as collections indicate, and Pipistrellus was considered to be the least common cave bat in the state.

Our field data indicate that M. lucifugus is clearly the most abundant species in the state during both winter and summer. Of all the sites found to have bats, M. lucifugus occurred in the majority (Table 2). Eptesicus was found in less than half these sites, most being summer records in or near homes. During the winter M. lucifugus and Eptesicus were found hibernating in 91 and 64% of the sites, respectively (Table 3). Comparisons of the relative number of individuals found at the sites also showed a preponderance of M. lucifugus over Eptesicus. Table 4 gives estimates of mid-winter populations in the eight major hibernacula. These estimates were based upon total counts for the smaller hibernacula and sample counts for the larger ones. Except for Spring Valley Caverns, M. lucifugus comprised the major portion of the bat fauna in all hibernacula.

The early research on hibernating bats in the state consistently found Eptesicus to be the most abundant. Rysgaard,

Table 2.--Frequency of occurrence and seasonal use of 42 sites by cave bats.

Species	Winter only	Summer only	Year-round	Total sites Number	Total sites Percent
Myotis lucifugus	3	21	12	36	86
Myotis keenii	8	1	1	10	24
Pipistrellus subflavus	4	1	5	9	21
Eptesicus fuscus	11	6	0	17	41
Total sites	7	24	11	42	

Table 3.--Comparison of mid-winter abundance and frequency of occurrence of cave bats in regional hibernacula (species abbreviations as in Table 1; see text for explanation of data base).

Study and results	Species			
	Mylu	Myke	Pisu	Epfu
A. Rysgaard (1941b), Swanson and Evans (1936)				
% occurrence/all sites	12	29	53	82
% all bats/all sites	1	1	4	93
Mean % all bats/sites where occurs	30	5	35	93
Mean number individuals/ sites where occurs	9	2	7	92
B. Current study				
% occurrence/all sites	91	64	73	64
% all bats/all sites	98	1	<1	1
Mean % all bats/sites where occurs	65	7	28	27
Mean number individuals/ sites where occurs	21,561	180 (43)*	44	269

* Mean number without Tower Soudan estimates.

Table 4.--Mid-winter population estimates for major hibernacula (species abbreviations as in Table 1).

Site	Species				Total
	Mylu	Myke	Pisu	Epfu	
Maiden Rock Mine	200,000	100	150	500	200,750
Bay City Mine	10,000	50	100	500	10,650
Brightsdale Tunnel	300		50	75	425
Mystery Cave	1,000	50	20	5	1,075
Spring Valley Caverns	5	2	25		32
Red Wing Mine	300	5	10	300	615
Robinson's Ice Cave	1,000	50		500	1,550
Tower Soudan Mine	2,000	1,000			3,000

during the winter of 1940, explored all caves and mines known in Minnesota at the time. The numbers and species that he found, together with those from some of the same caves surveyed by Swanson and Evans (1936), are summarized in Table 3 and compared with winter estimates based on hibernacula found and surveyed during our study. Some striking differences in the frequency and relative abundance of M. lucifugus and Eptesicus are apparent between our findings and those of the previous studies. The earlier work found that Eptesicus occurred at most sites and made up the largest percentage of the bats hibernating at those sites. Myotis lucifugus was found at very few sites and in low numbers. Just the reverse is shown by our data. Although the numbers of M. lucifugus are inflated due to the large concentrations at Maiden Rock, Bay City, and Tower Soudan, the trend is still maintained by the other sites. Myotis lucifugus was consistently more numerous and occurred at more sites than Eptesicus.

An important question to consider is whether or not the population levels of Eptesicus have declined significantly in Minnesota since the 1940's. There is some circumstantial evidence to suggest that this may be the case. A number of Rysgaard's sites with high numbers of Eptesicus have been destroyed or are presently highly disturbed. The Seven Caves of St. Peter were cut away during construction of U.S. Highway 169, the Stillwater cave has been bricked up except for a small entryway, and the St. Paul sand caves are frequently used by area youth, who undoubtedly increase the mortality rate of bats utilizing these caves. Over

50 Eptesicus were found dead from B-B shot and stab wounds in one of the St. Paul caves in winter, 1981. A check of the same cave during winter of 1983 revealed no bats. Beer (1955), during his long-term work with Eptisicus in the St. Paul sand caves, reported a 60% drop in the population between 1949 and 1954. Goehring (1972) noted that a dramatic increase in the number of Eptesicus using the storm sewer correlated roughly in time with the demolition of 10-12 old houses in the St. Cloud area.

Rysgaard (1941) reported numbers of Eptesicus from two mines in Red Wing that correspond very closely with winter counts we have made in the Red Wing Mine. A photograph included in his thesis indicates that he was working at the same site. In this case, at least, it appears that the numbers of Eptesicus have not declined. However, recent cave-ins at the mine have made portions of the mine that previously contained Eptesicus unsuitable for hibernating bats.

Our data seem to indicate that Eptesicus is much less common than previously thought. Summer records amount to a few foraging captures, single individuals taken from houses, and only one documented maternity colony. In the winter, they appear to be restricted to a small number of hibernacula. More work is needed before the status of Eptesicus in Minnesota is fully understood. Efforts should be directed toward the discovery of additional winter hibernacula and more documentation of the species in summer.

Assessing the relative abundance of Myotis keenii has proven a difficult task for researchers. Although institutional records of this species are typically very low, it is believed by most researchers that they are more common than they appear (Bowles, 1975; Gunderson and Beer, 1953; Jackson 1961; Rysgaard, 1942). In most cases, this bat occurs sporadically and is found in low numbers. M. keenii closely resembles M. lucifugus, uses similar roost sites, and frequently roosts near or among clusters of M. lucifugus, thereby increasing the liklihood of being overlooked. There are, however, reports of this bat being locally abundant. Cahn (1921, 1936) found it very common in Itasca County, but rare in the Quetico Provincial Park, Ontario. Hitchcock (1949) found large numbers of M. keenii in an Ontario corundum mine, and Greeley and Beer (1949) reported that M. keenii outnumbered M. lucifugus three-to-one in a northern Wisconsin iron ore mine.

Our findings indicate that M. keenii can be expected to occur in any suitable hibernaculum within the state. The presence of M. keenii in 64% of all winter sites (Table 3) may be an under estimation due to its similar appearance to the far more numerous M. lucifugus. In most cases, M. keenii comprises a small proportion of the total bat fauna at a site (Tables 3, 4). Two notable exceptions are the Tower Soudan Mine and the seasonal influx of bats to the Potlatch oxboard plant in Cook. In both these cases, large numbers of M. keenii were encountered, comprising 30-35% of the bats at each site. Due to the proximity of the oxboard plant to the Tower Soudan Mine, it is quite possible that the Potlatch influx consisted of bats that usually hibernate at Tower Soudan (see a separate DNR report by Nordquist, 1983, for specific details). It is interesting to note that instances of high concentrations of M. keenii have all been in iron ore mines. Although it is suggestive that iron mines may be especially attractive to M. keenii, is it not known whether these mines offer particularly favorable conditions for hiberating M. keenii, or if other factors are involved. For example, the location of iron ore deposits may tend to be distributed in regions were populations of M. keenii are high. It is certainly an area deserving additional attention.

Little information was collected on the summer habits of M. keenii during this study (Table 2). A single summer individual was netted outside Bat River Cave, which in all liklihood supports a winter population of M. keenii as well. Male M. keenii utilize Tower Soudan mine during the summer, but no maternity colonies have been found to indicate how often females remain in the local area to have their young and how often and how far they may travel prior to parturition. One female banded at the Potlatch plant in autumn was recovered a year later 214 km southwest of the banding site. This was the greatest recapture distance recorded during this study and indicates that this species can travel widely. Much remains to be learned of the summer habits of this species.

Pipistrellus subflavus is the least numerous of the four cave bats and is found at the fewest sites (Table 2). All summer observations were males and non-pregnant females residing in sites that serve as winter hibernacula; no maternity colonies were located. Pipistrellus was found in 73% of the winter hibernacula, but only a few individuals were present at each site. The highest winter concentrations of Pipistrellus found during this study were at Brightsdale Tunnel and Spring Valley Caverns, where up to 24 have been counted. (The higher numbers for other sites listed in Table 4 are estimates calculated from sample counts and total extent of each hibernaculum).

Rysgaard (1942) reported 24 Pipistrellus in a sinkhole near Mazeppa. Our attempts to locate the sinkhole were unsuccessful and Dr. Rysgaard could not recall specific details of the location. The Marine cave in which he recorded four Pipistrellus is most likely Leslie Cave. During our winter visits to the cave, we have consistently found three Pipistrellus. Although not the same individuals, the numbers correspond well with Rysgaard's observation. The number of Pipistrellus counted at the Red Wing Mine during this study is actually higher than the numbers Rysgaard found. Although the data base for this species is small, our information suggests that this bat is nowhere common in its range in Minnesota but that its present numbers appear to be similar to those recorded more than 40 years ago.

Our data concerning summer movements and roost sites of Pipistrelllus are extremely sparse. As with M. keenii, maternity sites in the state are unknown. The natural history of Pipistrellus in Minnesota is an area deserving additional research.

Seasonal habitats of cave bats. The behavior and physiological requirements of cave bats change markedly between winter and summer. The conditions necessary for hibernation are quite different from those of a maternity colony. Therefore, it is not surprising that the habitats in which bats are found also vary with the season.

Winter hibernacula must maintain specific environmental conditions to sustain hibernating bats through the winter, but summer day roosts are not constrained by such narrow tolerance limits. Bats, particularly males, have been found roosting in a broad range of sites, such as under the bark or in hollows of trees, in rock crevices and wood piles, under shingles and siding, and behind shutters. Summer roost sites found during this study included caves, mines, and tunnels that are used as winter hibernacula, as well as houses and buildings that are utilized only during this season (Table 5). The summer sites examined can be divided into two distinct groups based upon their environmental conditions and use by the bats. The cooler caves, mines, and tunnels were occupied predominantly by males, whereas the hot attics, eaves, and barn rafters housed groups of pregnant females.

Unlike male bats, which can be found roosting at a wide variety of sites, pregnant females appear to select sites with

Table 5.--Summary of seasonal habitat types used by Minnesota cave bats (species abbreviations as in Table 1).

Season Habitat	Frequency of occurrence				
	Mylu	Myke	Pisu	Epfu	Total sites
Winter					
Sandstone caves	2	2	1	1	2
Limestone caves	6	1	4	3	6
Sand mines	3	2	3	2	3
Art'l caves, tunnels	2		1	3	4
Iron mines	1	1			1
Summer					
Sandstone caves	1			1	2
Limestone caves	6		1		6
Sand mines	2		2	1	3
Art'l caves, tunnels	1		1		4
Iron mines	1	1			1
Large buildings	2	1		2	3
House attics, eaves	10			1	10
House shutters, siding	3			1	4
Forested waterways	4				4

more specific environmental conditions for the birth and rearing of young. These maternity colony sites are typically hot, dark, and poorly ventilated, where the high temperatures may be crucial to the energetic economy of reproduction and may promote the rapid growth of young (Humphrey and Cope, 1976). All aggregations of bats found in house attics, eaves, and under siding were maternity colonies. These included 11 groups of M. lucifugus that ranged in size from a few up to approximately 500 individuals. A single maternity colony of approximately 10 Eptesicus was found behind the shutters of a home. No maternity sites have been found for M. keenii or Pipistrellus. The attic of a house that harbored a large maternity colony of M. lucifugus was 26°C (79°F) with 93% relative humidity. Although this was during the day, the bats were quite active, flying and moving rapidly along the underside of the aluminum roofing.

Bats found roosting in caves, mines, and tunnels during the summer were predominantly males, with a few, probably nonparous, females. In contrast to the active state of female bats in maternity colonies, bats roosting in these cooler environments were torpid. There are relatively few reports documenting caves and mines as important summer day roosts (Davis and Hitchcock, 1965; Krutzsch, 1961). Male bats are thought to roost singly or in small groups, finding shelter in a number of places away from the winter hibernaculum.

This study cannot specifically address the use of summer shelters other than hibernacula because only a few male bats were found outside these sites. Our summer efforts were directed toward monitoring seasonal changes at the hibernacula and investigating reports of concentrations of bats. Therefore, little time was spent searching for the more elusive sites where the majority of male bats reportedly roost. A lone male *M. lucifugus* was found in an attic. All other records of males outside hibernacula were associated with maternity colonies and may have been young of the year, although adult males are known to associate with maternity groups (Fenton and Barclay, 1980). The only other exception to these findings was the late summer influx of bats to the Potlatch plant in Cook. Here both males and females were found roosting together throughout the plant. This particular case appeared to be a unique event, most likely associated with migration between summer and winter grounds. Although an investigation of summer roost sites would add valuable information to our knowledge of the summer habits of cave bats, it would be a time-consuming and difficult project to undertake.

The number of bats using hibernacula as summer roosts is a small fraction of the total winter population, amounting to less than 2% in Red Wing Mine and Brightsdale Tunnel (Table 6). Other sites, for example Maiden Rock Mine, seem to maintain a sizeable population of *M. lucifugus*, which tend to cluster in large groups near the entrances. Both Humphrey and Cope (1976) and Davis and Hitchcock (1965) reported netting more bats flying through cave entrances than actually roost there during the day, suggesting that most may reside in the surrounding forests. However, netting

Table 6.--Average number of bats found during seasonal censuses in several hibernacula (abbreviations for species as in Table 1).

Site/Season	Species				Total
	Mylu	Myke	Pisu	Epfu	
Red Wing Mine					
Winter	38	2	3	204	247
Spring	50	1	3	19	73
Summer	3				3
Fall	7		4		11
Robinson's Ice Cave					
Winter	203			435	638
Spring	292	1		36	329
Fall	247			0	247
Spring Valley Caverns					
Winter	3	1	10		14
Fall	1		1		2
Brightsdale Tunnel					
Winter	388		19	21	428
Summer	1		6		7

outside Maiden Rock Mine indicated that the majority of bats were leaving the cave rather than entering from outside. The use of these cooler environments by males and barren females may be a means of conserving energy during the period when bats are accumulating fat stores for winter hibernation. Roosting in cool environments and the associated daily torpor may be a important strategy for bats in northern regions where they are faced with a short summer foraging period.

Winter roost sites are the most critical to survival of hibernating bats in this region. Because bats apparently do not feed in the winter, and all the energy to maintian them through winter is stored as fat, it is crucial that bats seek out winter roost sites that will place them under the least energetic stress. Physical conditions of winter roosts must minimize water loss and energy expenditure to the hibernating bats. Cool stable temperatures maintained above freezing and high humidity are important characteristics of hibernacula. These can be maintained in large, underground cavities with small entrances that dampen the effect of low or fluctuating outside temperatures, and cul-de-sac or labyrinth passages that protect bats from drafty corridors. Such characterisitics are present in the hibernacula examined in this study. Included among the winter roost sites that maintained a hibernating bat population throughout the winter were natural limestone and sandstone caves, man-made caves and tunnels, and sandstone and iron ore mines (Table 5). Not documented in this study, but recorded elsewhere are the use of storm sewers and buildings as hibernacula (Goehring, 1954, Rysgaard, 1942).

The hibernacula examined varied in their temperatures and relative humidities. Much of this variation was due to the amount of exposure and water seepage in the cave or mine. For example, Spring Valley Cavern is entirely subterranean. Its entrance is enclosed by a building. Intermittent streams, as well as substantial amounts of ground water seepage, maintain its high humidity levels. The environment in this cave is more stable, warmer, and humid than other hibernacula. In contrast, Red Wing Mine sits above the surrounding terrain with numerous entrances fully exposed to the outside. Dripping water is not evident. This mine is typified by colder and more flucuating temperatures, as well as lower humidities. Another factor influencing the range and stability in temperature and humidity of hibernacula is the size of the site. Large caves and mines, such as Mystery Cave, Maiden Rock Mine, and Tower Soudan Mine, are noted for their constant temperatures and humidities. Small hibernacula, such as Robinson's Ice Cave and Old Mystery Cave, exhibit greater extremes. Many of the small caves that we examined and found no bats or only sign may simply be too small and thus too variable in temperature and humidity to serve as suitable hibernacula. Although sufficient as summer day roosts, perhaps, they most likely drop below freezing during the winter.

Bats appear capable of overwintering under a number of different temperature and humidity regimes (Table 7, Fig. 9). However, there appears to be species-specific preferences for certain ranges of temperatures and humidities. This is evinced by the portions of hibernacula occupied by certain species, the roosting height or location, and the degree of clustering, as well as the type of hibernaculum used. A separate study conducted by Nordquist (1984) examined the location of hibernating bats with respect to temperature stratification in Robinson's Ice Cave. Bats appear to respond to shifts in the elevation of the 0°C isotherm by vertically adjusting the position of roost sites, selecting microhabitats with different degrees of exposure, and by altering the size of roosting clusters. The type and magnitude of response varied among the different species.

Eptesicus fuscus was found in a number of caves and mines, occurring in greatest numbers in the large sand mines and Robinson's Ice Cave (Table 4). Rysgaard (1942) felt *Eptesicus* showed no inclination to winter in natural caves. Our study shows this not to be the case. Natural caves often are more protected from cold outside air and tend to be wetter environments than sand mines. In the limestone caves where *Eptesicus* occurred, it was never found in large numbers, individuals hung singly, and the species typically roosted in the coldest and driest areas. In all hibernacula, *Eptesicus* characteristically was found near the entrance where temperatures are coldest and air movement often quite great. They were usually found roosting lower than other

Table 7.--Mean temperatures (T, ^{o}C) and relative humidities (RH, %) for winter roost sites (species abbreviations as in Table 1).

Site	Species											
	Mylu			Myke			Pisu			Epfu		
	T	RH	N	T	RH	N	T	RH	N	T	RH	N
Maiden Rock	8.2	93	3299	8	94	1	8.1	90	14	3.1	100	22
Bay City	6.9	92	2703	7	92	1	6.8	92	12	4.5	89	251
Brightsdale	7.9	100	109				7.4	100	28	3.8	100	36
Old Mystery	5.0		3							2.7		13
Spring Valley	7.5	94	2				7.8	94	12			
Red Wing	3.2	83	114	3.3		3	5.3	84	9	2.0	84	111
Leslie							9.0	94	6			
Robinson's	3.3		244	3.6		8				2.7		252
Overall mean	6.4	92		6.3	92		7.4	92		3.1	93	

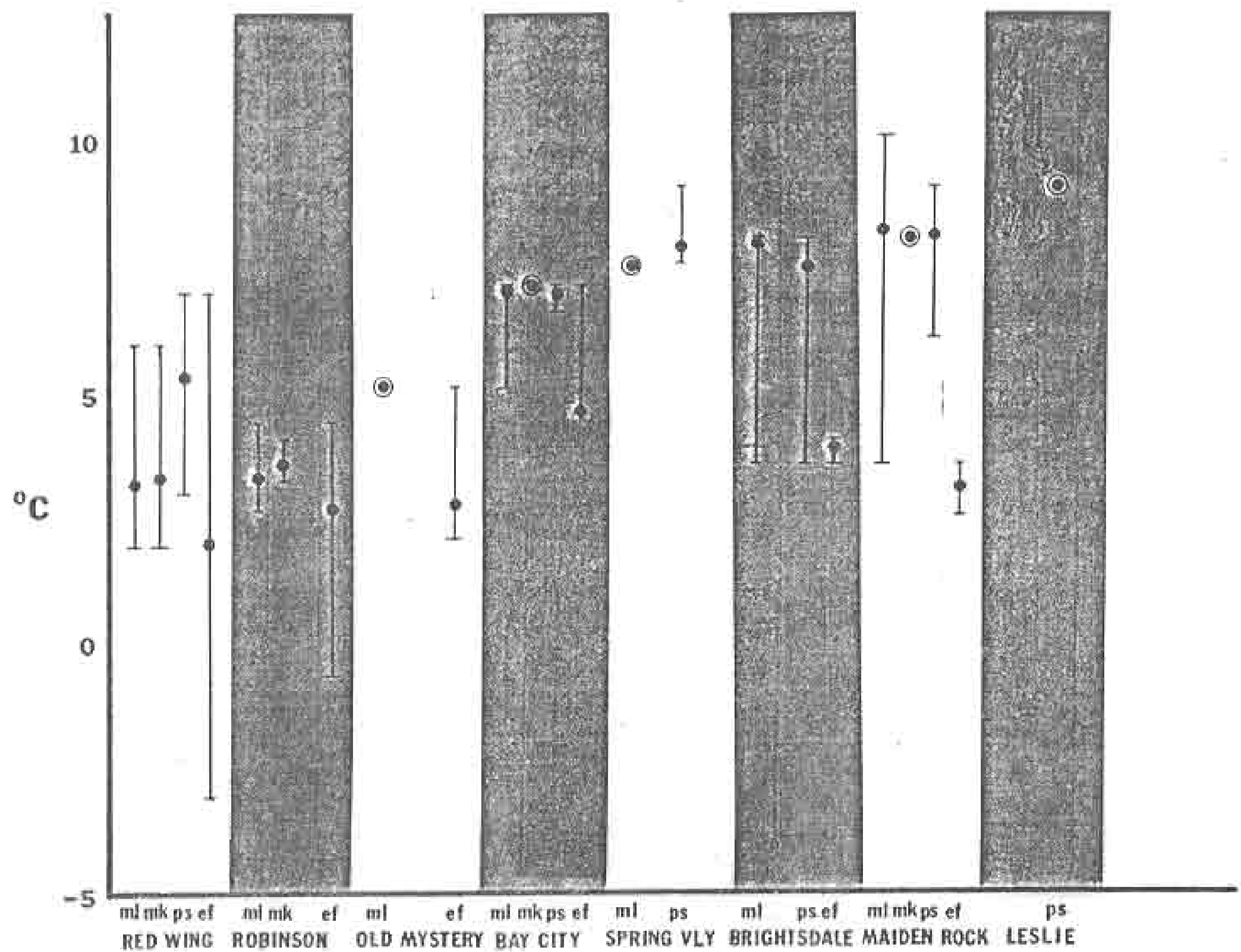

Fig. 9. Mean and range of winter hibernacula temperatures associated with roosting bats. (ml - *Myotis lucifugus*, mk - *Myotis keenii*, ps - *Pipistrellus subflavus*, ef - *Eptesicus fuscus*)

bats, commonly hanging along the wall and occurring in larger clusters (Tables 8, 9). These observations agree with those reported by Goehring (1954), Rysgaard (1942), and Evans (1934).

Beer and Richards (1956) found that Eptesicus hibernated under a wide range of temperatures and humidities (-0.8 - 14.4°C, $\overline{X}$ = 5.6°C; 38 - 100% R.H., $\overline{X}$ = 78.9%) suggesting that it shows relatively little habitat selectivity. Goehring (1954) and Rysgaard (1942) noted that humidites were lower near Eptesicus than by other bats. In our study, the humidity readings taken near Eptesicus indicate that they may occur over a range (84-100%) of relative humidities. Our data indicate that Eptesicus was present under the broadest range of temperatures, but that the majority of individuals were found within a relatively narrow set of roost site conditions.

In contrast to Eptesicus, Pipistrellus was found typically in the warmer hibernacula or the warmer portions thereof, where there is very little air movement. In most instances, they roost singly from the ceiling or high on the wall (Tables 8, 9). Goehring (1954) found Pipistrellus in the innermost section of the storm sewer where temperature and humidity were highest and air movement least. Rysgaard (1942) found this bat in areas of high humidity and where temperatures where never lower than 7.2°C. Our data also show that it selects sites of high temperature and humidity (Table 7, Fig. 9). Because these conditions were most frequently encountered in limestone caves rather than sand mines or other structures, it is not surprising to find that the majority of

Table 8.--Seasonal and species variation in roost position (C-ceiling; C/W-ceiling-wall boundary; W-wall; values given in percent of total bats) among bats found in major hibernacula (species abbreviations as in Table 1).

Site	Season	Mylu			Myke			Pisu			Epfu		
		C	C/W	W	C	C/W	W	C	C/W	W	C	C/W	W
Maiden Rock Mine													
	Spring	70	9	21				14	14	71	11	11	78
	Summer	21	57	21									
	Winter	0	0	100				0	0	100	0	0	100
Bay City Mine													
	Winter	79	21	0	100	0	0	14	0	86			
	Spring							25	50	25	50	0	50
Brightsdale Tunnel													
	Winter	95	5	0				74	21	6	50	6	44
	Summer	100	0	0				100	0	0			
Spring Valley Caverns													
	Winter	0	20	80	0	0	100	14	19	67			
	Fall	0	0	100				100	0	0			
Red Wing Mine													
	Winter	48	22	30	100	0	0	10	30	60	7	9	85
	Spring	60	10	30	100	0	0	67	0	33	0	0	100
	Summer	100	0	0									
	Fall	60	20	20				67	0	33			
Robinson's Ice Cave													
	Winter	33	67	0							0	0	100
	Spring	100	0	0	75	0	25				0	0	100
Tower Soudan Mine													
	Summer	36	36	21	63	17	20						
	Fall	16	42	43	36	28	36						

Table 9.--Seasonal variation in the mean ($\bar{X}$) and median (M) cluster size among bats found in the major hibernacula (N = number of clusters; species abbreviations as in Table 1).

Site	Season	Species											
		Mylu			Myke			Pisu			Epfu		
		$\bar{X}$	M	N	$\bar{X}$	M	N	$\bar{X}$	M	N	$\bar{X}$	M	N
Maiden Rock Mine													
	Winter	2.6	2	18				1	1	3	12.5	8.5	10
	Spring	1.5	1	416				1	1	7	4.2	1	9
	Summer	6.1	1	14									
	Fall	4.0	2	2				1	1	2	2	2	1
Bay City Mine													
	Winter	4.9	4.5	14	6	6	1	1	1	8			
	Spring							1	1	4	2	2	2
Brightsdale Tunnel													
	Winter	3.5	2	23				1	1	34	1.7	1	18
	Summer		1	1				1.2	1	5			
Spring Valley Caverns													
	Winter	1	1	5	1	1	1	1	1	21			
	Fall		1	1					1	1			
Red Wing Mine													
	Winter	2.9	1	27	2	2	1	1.1	1	11	3.0	1	99
	Spring	3.1	1	11	1	1	1	1	1	3	1.3	1	12
	Summer	1	1	3									
	Fall	1	1	13				1	1	8			
Robinson's Ice Cave													
	Winter	33.7	50	3							71.2	75	5
	Spring	11.0	7.5	4	11.3	7.5	4				7.2	2	5
	Fall	9.2	1	6									
Tower Soudan Mine													
	Summer	3.5	2	15	1.7	1	33						
	Fall	3.3	1	114	3.1	1	91						

Pipistrellus were found in natural caves (Table 5). An exception to this trend is Leslie Cave, a small sandstone cave that was the northernmost hibernaculum for *Pipistrellus* found during this study. However, only a small, isolated passage in the rear of the cave appears suitable. Here, a constant temperature of 9°C appears to be maintained despite large temperature flucuations in the main room of the cave.

Myotis lucifugus and *M. keenii* can be found roosting in the same area as *Pipistrellus* but tend to occur in higher numbers and in slightly cooler areas. Rysgaard (1942) associated the two species of *Myotis* with high temperatures and high relative humidities. Our data show that greater densities of *M. lucifugus* are found in more protected passages or near areas of water. Site selection by *M. keenii* is not demonstrably different from that by *M. lucifugus*, according to our data. However, neither species appears to be as restricted to warm, humid conditions as observed for *Pipistrellus*. *M. lucifugus* shows the widest range of occurrence within the hibernacula studied. *M. keenii* appears equally broad in hibernaculum selection, but is found in unusually high numbers in Tower Soudan Mine. Both species characteristically hang from the ceiling or high along the wall (Table 8). Group size of both is highly variable, ranging from single individuals to clusters of over 100. Rysgaard found *M. keenii* typically roosting singly and never associated with clusters of other species. Our data show that *M. keenii* commonly roosts with groups of *M. lucifugus*. The Tower Soudan data indicate that *M. lucifugus* tends to cluster in larger groups than *M. keenii*, which frequently hangs singly (Table 9).

Hibernacula are critically important to the survival of non-migratory, temperate-zone bats. In Minnesota, as much as seven or even eight months of each year are spent in the hibernaculum. Therefore the conditions of hibernacula and the behavior of bats to these conditions is of prime interest.

The period of winter hibernation varies among the four resident species (Fig. 10). *Eptesicus* vacates the hibernaculum well before the departure of any other species and returns later in the fall. Rysgaard (1942) reported a large influx of *Eptesicus* to hibernacula as late as 11 November, whereas other species had reached winter population levels prior to 24 October. Futhermore, changes in the number of *Eptesicus* throughout the winter indicated mid-winter movements between caves. Rysgaard found these bats leaving the hibernaculum by 11 April. Beer (1955) felt that stable wintering populations of *Eptesicus* are not reached until early December, when severe weather forces them to abandon less protected sites. Our data substantiate Rysgaard's observation that *Eptesicus* arrive at the hibernaculum later and depart earlier than the small bat species. Presumably, this bat forages later into the fall, perhaps feeding on insect species that remain active on warm nights after the first killing frost. We observed a few roosting *Eptesicus* as early as August, but peak numbers

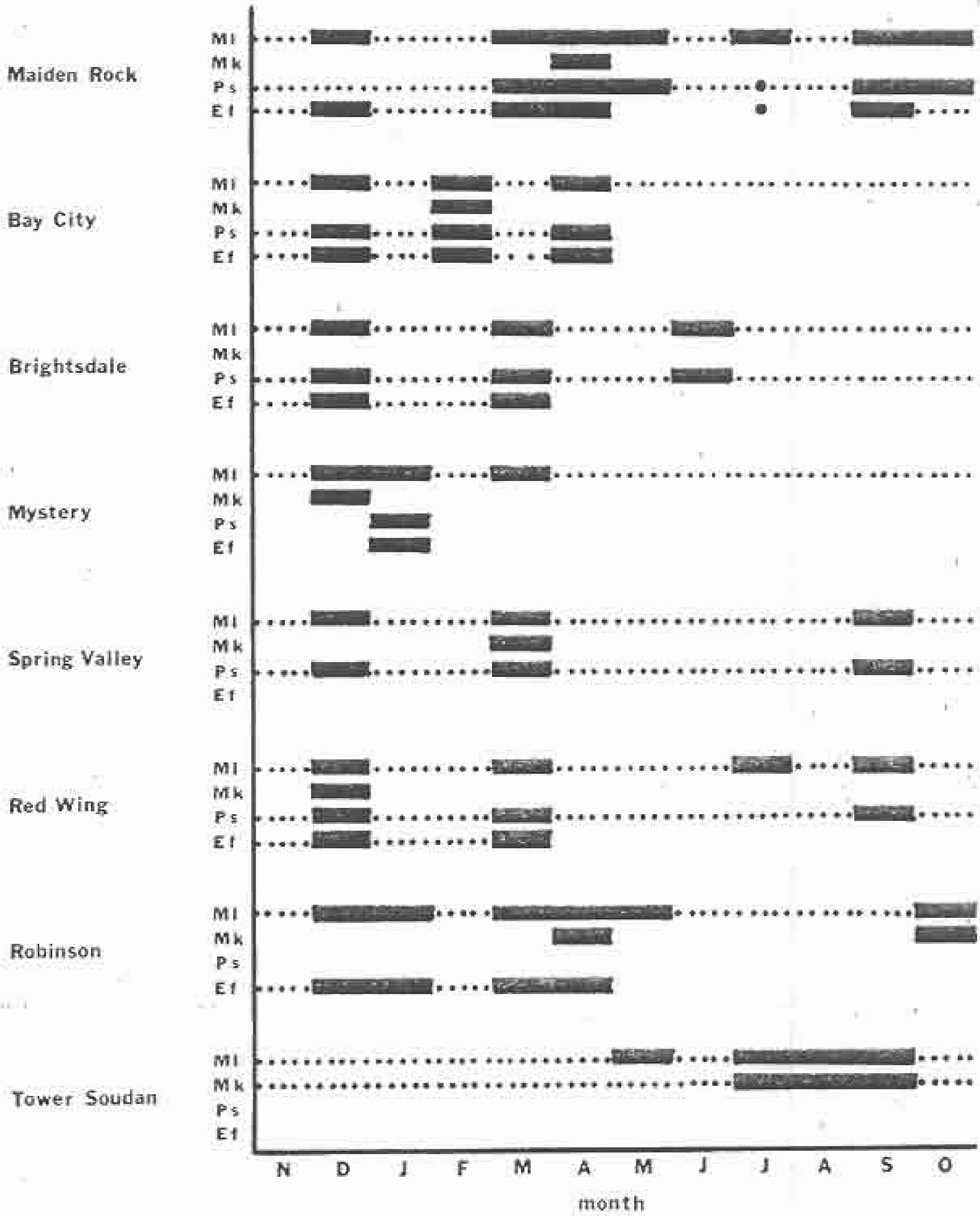

Fig. 10. Seasonal occurrence of cave bats at major roost sites. (Dotted lines indicate supposed, but undocumented, presence; species abbreviations as in Table 1.)

occurred after October. All Eptesicus had left the hibernacula by May (Fig. 10). We were not able to show any movement of individuals between caves during the winter.

Much of the information on seasonal use of the hibernaculum by Myotis lucifugus comes from studies in Maiden Rock Mine, where large numbers of bats were censused repeatedly. Our information on M. keenii and Pipistrellus is insufficient to detect significant trends. From these data, it appears that M. lucifugus does not leave the hibernaculum until early May, at which time the departure is quite sudden (Table 10, Fig. 11). Although the data do not clearly indicate the timing of return to the hibernaculum, it appears that many individuals are there by early October, but that the winter population is not fully established until late November or early December. Additional fall censusing will enable a closer estimate of arrival to be made. In New England, Davis and Hitchcock (1965) found that bats begin entering hibernacula in September and leave the site between April and May.

The seasonal density flucuations of M. lucifugus observed at Maiden Rock Mine are a composite estimate based on up to 12 census sites. When these sites are examined individually it is noted that the numbers of bats at each site vary markedly, up to a 50-fold difference among sites for a given census period (Table 10). The differences in bat counts between sites are greatest during the winter and least in the summer and fall (Fig. 11). One reason for the greater mid-winter variation in between-site counts is a

Table 10.--Seasonal changes in densities (individuals/m of passage) of _Myotis_ in Maiden Rock Mine.

Census location	Census date								
	1983		1984				1985		
	7 Sep	14 Sep	30 Mar	11 May	3 Oct	6 Dec	26 Apr	3 May	10 May
1		2.1	1.9	2.3	0.5	1.6	3.1	2.3	1.9
2		3.7	3.4	1.6	2.8	2.3	2.8	2.4	1.8
3	0.3	0.4	1.5	0.4	0.6	1.1	1.3	.9	0.8
4		0.2	1.3		0.3				
5	2.3	2.8	4.4	2.0	2.8		2.8	2.0	1.6
6		4.5	10.0	5.5	5.8	5.6	8.6	7.0	6.7
7	1.8	2.6	7.3	5.0	6.4	9.2	7.1	5.5	4.3
8		4.1		7.8	9.5	15.7	16.1	10.7	8.1
9			7.2	3.3	3.0	5.9	7.0	7.2	4.0
10				8.3	7.6	12.9	14.4	12.4	7.9
11		0.5	0.6	0.2	0.5	0.4	0.6	0.4	0.2
12	1.3	1.2	0.3	0.8	0.4	0.1	0.3	0.4	0.3
Mean density	1.4	2.2	3.8	3.4	3.4	5.5	5.8	4.7	3.4

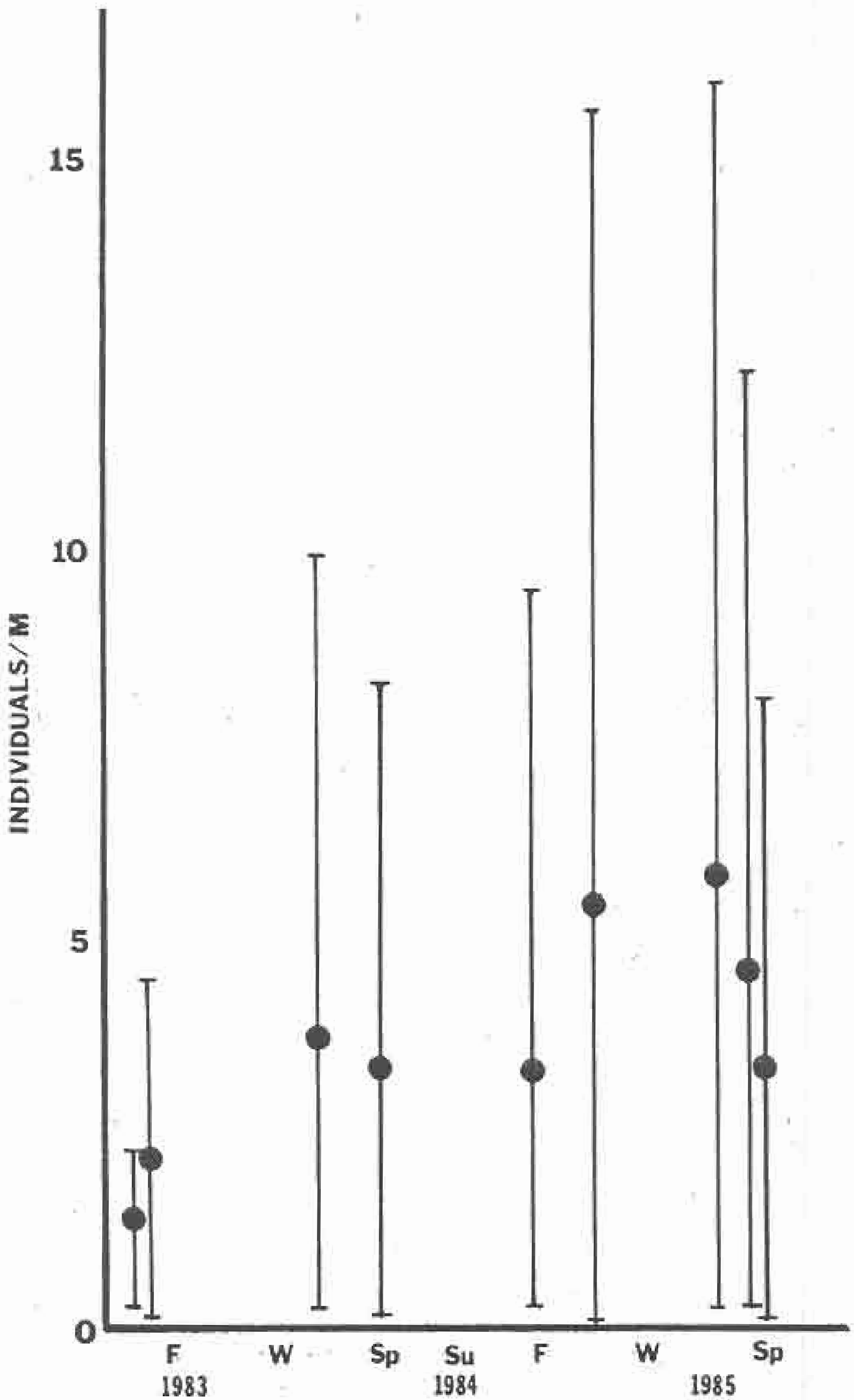

Fig. 11. Mean and range in seasonal densities of *Myotis lucifugus* at Maiden Rock Mine.

large congregation of bats in a few sites. These sites (locations 8, 10; Fig. 12), appear to receive the greatest influx of bats over the winter. This contrasts markedly with locations 3, 11, and 12, which show very little seasonal change in bat counts. Sites with consistently higher densities exhibited much greater seasonal flucuations than did lower density sites. High and low bat sites also differed in the season of peak density.

Among the majority of sites, including those with the highest overall density, peak numbers of bats were found in mid-winter. A few sites, such as locations 1, 2, 11, and 12, decreased in densities early winter as numbers were increasing elsewhere in the mine. These sites attained the highest densities in early spring. This suggests that bats were shifting roosting sites within the mine during the hibernation period. Other researchers have noted a change in roost sites in response to changing weather conditions (Beer, 1955; Davis and Hitchcock, 1965). Bats hibernating in Robinson's Ice Cave exhibited winter shifts within the cave that correlated strongly with flucuations in the cave temperature regime. It seems highly likely, therefore, that the differences in bat densities between sites at Maiden Rock Mine, and the changes in density throughout the hibernating period are in response to changing environmental conditions within the mine. However, except for areas close to the entrances, our measurements of temperature and humidity failed to demonstrate seasonal changes in conditions elsewhere in the mine. Additional examination, using more sensitive equipment, will be is necessary before

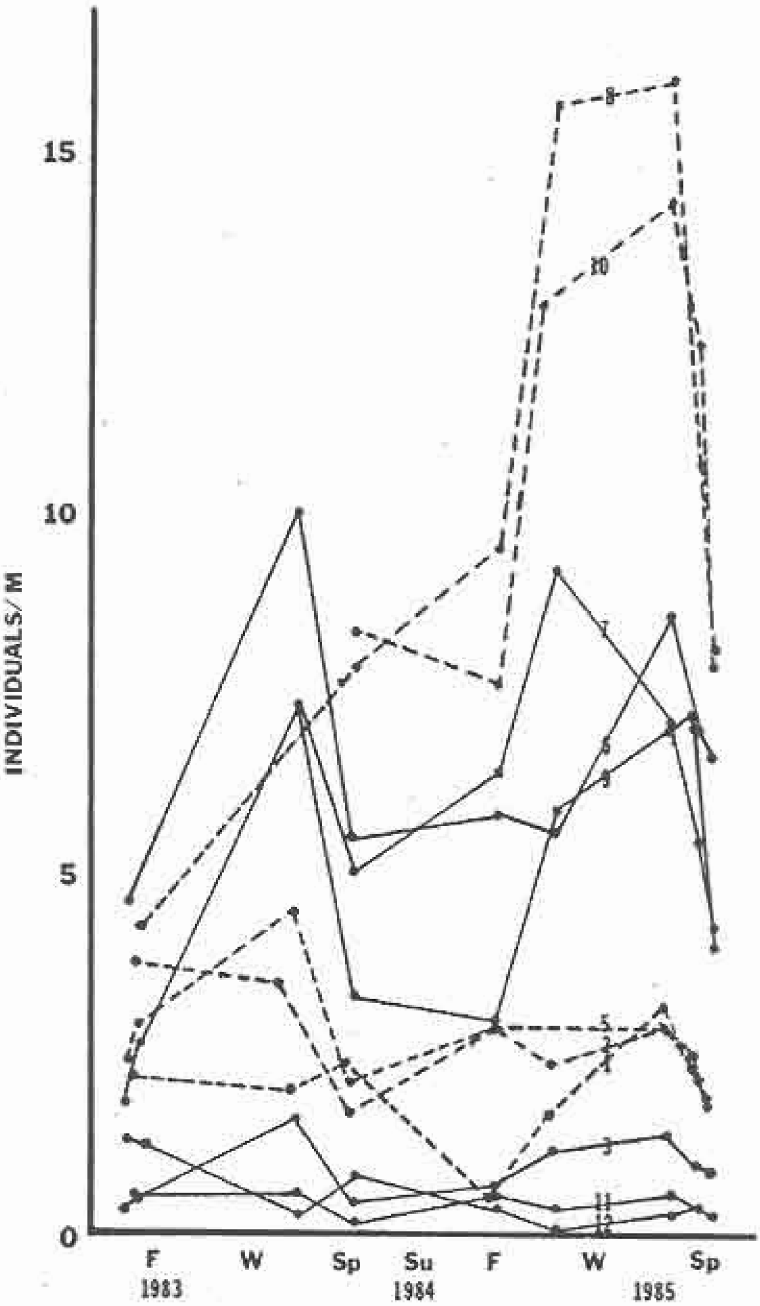

Fig. 12. Seasonal variation in densities of <u>Myotis lucifugus</u> for different areas of Maiden Rock Mine. (Numbers refer to specific census sites shown in Fig. 13.)

differences in environmental conditions among the sites can be adequately assessed.

The location of sites within the mine appears to have a strong influence on the densities of bats and the magnitude and timing of density flucuations (Fig. 13). Those sites nearest the entrances (locations 1, 2, 3, 11, 12) have the lowest densities of bats throughout the year. These sites also exhibit the greatest range of temperature flucuation in response to changes in the weather conditions outside the mine. Given that these sites do not differ from areas of higher densities with respect to the dimensions or composition of the passages, it appears that some aspect(s) of the environment of these sites make them less suitable to hibernating bats. Potentially adverse conditions might include extreme and/or variable temperatures, rapid air movement, and lower relative humidities.

The pattern of air flow through the mine may also affect the suitability of certain sites. For example, census locations 3, 5, and 6 are located in passages that make the most direct route between the two entrances and should, therefore, experience more air movement than periferal locations. Locations 3 and 5 exhibit much lower bat densities whereas location 6 has fairly high numbers. The sites with the highest numbers of bats, locations 8 and 10, are situated to the far west side of the mine in passages out of the direct path of airflow and some distance from either entrance. This strongly suggests that the degree of isolation from outside environmental conditions is an important criterion in

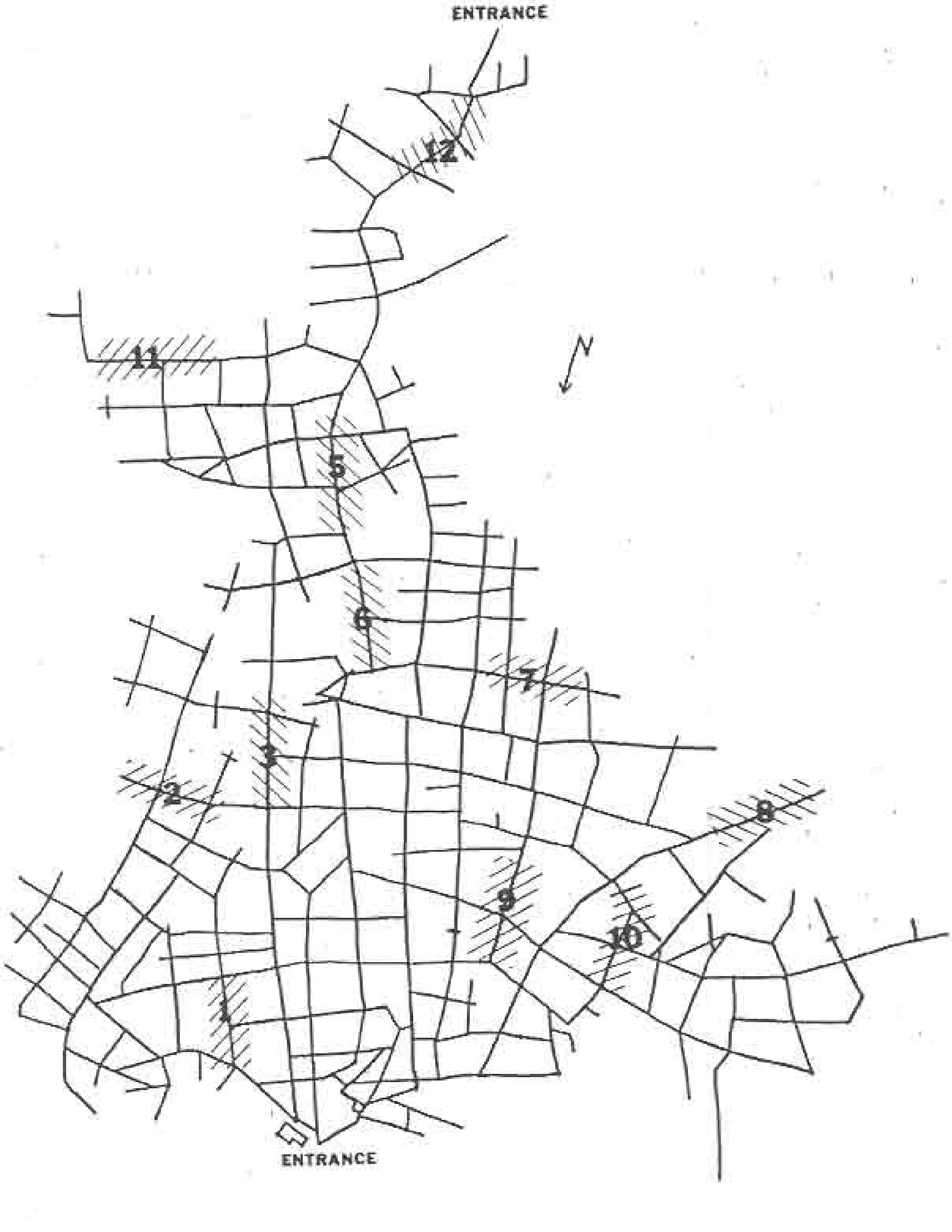

Fig. 13. Locations of census sites for <u>Myotis lucifugus</u> in Maiden Rock Mine.

Table 11.--Summary of banding efforts for major sites

Site	Location	No. bats banded
Bat River Cave	Fillmore Co., MN	50
Brightsdale Power Plant	Fillmore Co., MN	104
*Mystery Cave	Fillmore Co., MN	59
Spring Valley Caverns	Fillmore Co., MN	24
Redwing Mine	Goodhue Co., MN	151
Robinson's Ice Cave	Pine Co., MN	126
Potlatch Plant	St. Louis Co., MN	202
Tower Soudan Mine	St. Louis Co., MN	343
Maiden Rock Mine	Pierce Co., WI	345
Bay City Mine	Pierce Co., WI	72
Others	Various localities	261
Total		1,737

*D. Tallman banded an additional 835 individuals during his 5-year banding work.

Cave was made available to us (Gerboth, 1981; Tallman, 1979; 1982; 1983; 1984).

Eight banded bats were recovered away from the original banding sites (Table 12). Three Myotis lucifugus originally banded at Maiden Rock Mine, one M. keenii from the Potlatch Plant at Cook, two M. lucifugus from Mystery Cave, one Eptesicus from Robinson's Ice Cave, and another from a Lake Elmo home were reported to us. The maximum straight-line distance between banding site and recovery site was 214 km by the M. keenii. Two M. lucifugus banded with a different type of band than was used by this study were also returned to us. Based upon the band type and numbers, Tallman believes that they were the bats banded at Mystery Cave. With the exception of the banding at the St. Cloud Storm Sewer, we are aware of no other bat-banding projects in the state, and thus we have tentatively assigned these bats to Tallman's study.

All band recoveries were taken west of the site at which the bats were banded (Fig. 14). Although there would appear to be no apparent reason why bats would move west over another direction, other studies have shown that bats may travel from winter to summer roosts in predominantly one direction. In New England, M. lucifugus moves southeast from winter sites (Davis and Hitchcock, 1965). Myotis sodalis (social myotis) migrates north from Kentucky hibernacula and Tadarida brasiliensis (Mexican free-tailed bat) moves south from summer maternity sites to over-winter in Mexico (Griffin, 1970). The band recoveries from

Table 12.--Location and distance of banding returns from banding site.

Species	Sex	Banding site	Recapture site	Distance (km)
Myotis lucifugus	M	Maiden Rock, WI	Somerset, WI	69
Myotis lucifugus	F	Maiden Rock, WI	Faribault, MN	84
Myotis lucifugus	F	Maiden Rock, WI	Mankato, MN	142
Myotis lucifugus	F	Cherry Grove, MN	Alden, MN	106
Myotis lucifugus	M	Cherry Grove, MN	Wells, MN	119
Myotis keenii	F	Cook, MN	Two Inlets, MN	214
Eptesicus fuscus	M	Sandstone, MN	Sandstone, MN	0
Eptesicus fuscus	M	Lake Elmo, MN	St. Paul, MN	16
**Myotis lucifugus*	M	Cherry Grove, MN	Burnsville, MN	156
**Myotis lucifugus*	M	Cherry Grove, MN	Emmons, MN	98

* Bat probably banded by D. J. Tallman. See text for explanation.

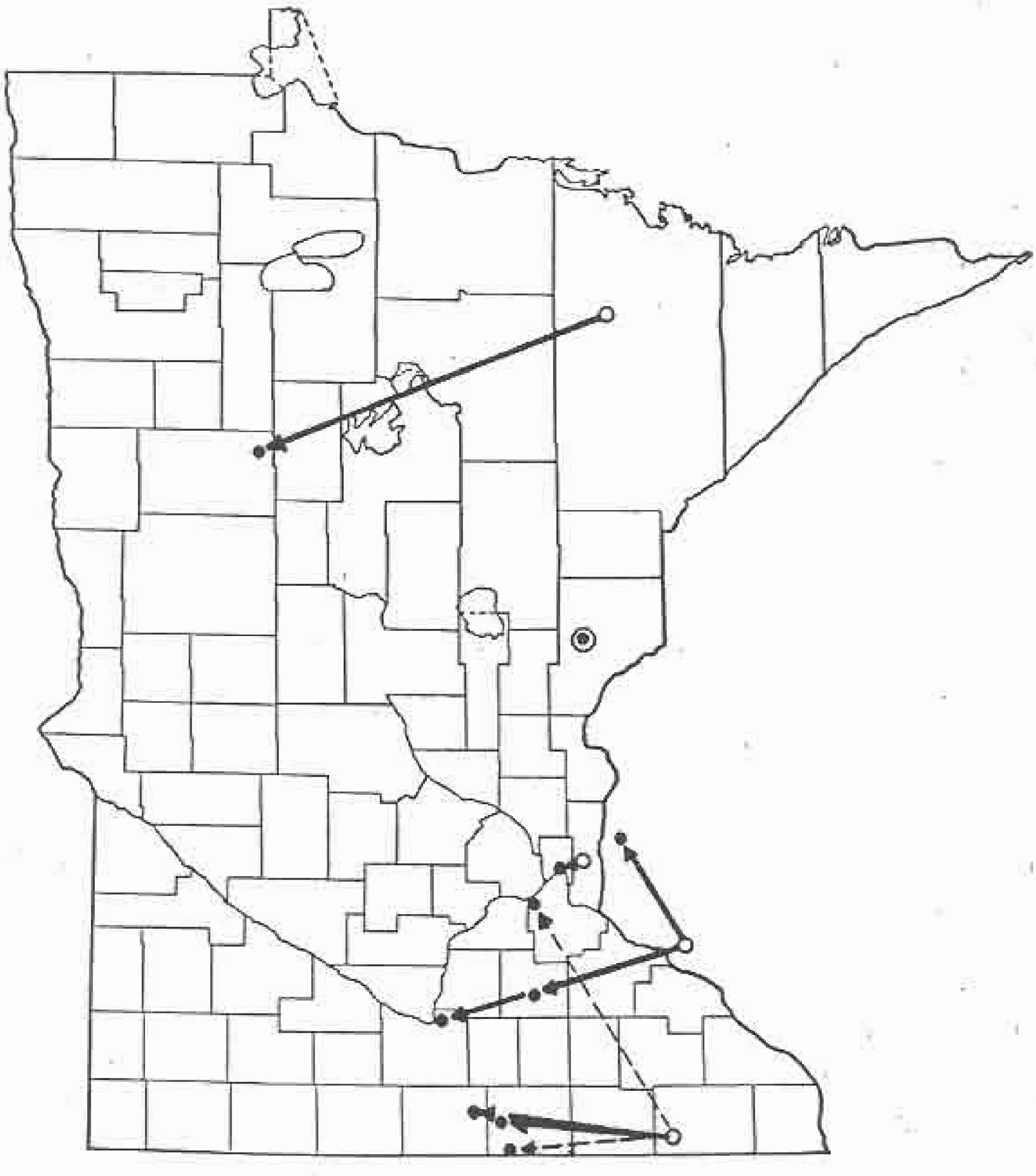

Fig. 14. Location and direction of banding returns from banding sites.

this study are too few to indicate any directional trends in the movement of bats between winter and summer sites. More recoveries are needed before the extent and direction of movemenmt among Minnesota bats can be understood. Hopefully, band recoveries will continue to accumulate over the years. However, additional efforts directed toward banding more bats and informing the public about the importance of reporting banded bats will greatly improve the chances of recovering banded bats.

Bats commonly use one or a few seasonal roost sites year after year. This site fidelity is variable depending upon the type of roost, the number of alternative sites in the area, the amount of disturbance to the site, and the proximity to food resources. Although there appears to be little loyality to temporary and abundant day roosts, strong attachment is shown for more permanent sites, including caves and man-made structures (Kunz, 1982a). This study has observed the recurrence of many banded individuals at the hibernaculum in which they were initially banded. We found no bat roosting in a hibernaculum other than the original banding site. Of the 74 recoveries of banded individuals, 44 (60%) were found in the same sections within the hibernaculum (Table 13). In several hibernacula, bats that were clustered together during the initial banding period were later recovered associated with the same individuals. In some hibernacula, for example Red Wing Mine and Robinson's Ice Cave, there are a limited number of roosting sites with appropriate environmental conditions for hibernating bats.

Table 13.--Summary of recaptures of banded bats (proximity to original banding site: 1 - same area within site, 2 - different area within site, 3 - area within site unknown).

Site	Species/Season banded	Season recaptured				Proximity		
		W	Sp	Su	F	1	2	3
Maiden Rock Mine								
	<u>Myotis lucifugus</u>							
	Spring	9		1	1	10		1
	<u>Eptesicus fuscus</u>							
	Spring	1			1	1		1
Bay City Mine								
	<u>Pipistrellus subflavus</u>							
	Spring	3				3		
Red Wing Mine								
	<u>Myotis lucifugus</u>							
	Winter	2				2		
	Spring	9				5	4	
	Fall	2					2	
	<u>Pipistrellus subflavus</u>							
	Fall	1						1
	<u>Eptesicus fuscus</u>							
	Winter	9				3	6	
	Spring	5				4		1
Robinson's Ice Cave								
	<u>Myotis lucifugus</u>							
	Winter				4	4		
	Spring	1			1	1		1
	<u>Myotis keenii</u>							
	Spring				1	1		
	<u>Eptesicus fuscus</u>							
	Spring		1				1	
Spring Valley Caverns								
	<u>Pipistrellus subflavus</u>							
	Winter		4				3	1
Brightsdale Tunnel								
	<u>Myotis lucifugus</u>							
	Winter	10				6	4	
	Summer	1					1	(Maternity)
	<u>Pipistrellus subflavus</u>							
	Winter	6		1		3	4	

Therefore, the probability of returning bats roosting in the same clusters is quite high. However, this association of individuals also was observed in Maiden Rock Mine, where many suitable roosting sites exist elsewhere in the mine. The evidence suggests that bats show a high degree of fidelity to winter sites and to specific areas within the hibernaculum. The repeated co-occurrence of individual bats may indicate that subpopulations, perhaps extended family groups, of bats maintain long-term associations. Reports of congregations of M. lucifugus have been interpreted to be more the result of localization of critical resources rather than underlying social structure, but it also is known that young accompany females to the winter roost sites (Fenton and Barclay, 1980). At this time, the data on banded individuals are not adequate to assess the relative degree of fidelity to subsites within the hibernaculum or the social attachments among individuals. However, our findings clearly point to some fascinating and potentially important aspects of the composition of hibernating bat populations.

The percentage of banded bats at a particular location can be used to estimate total population size or rate of population turnover. During this study, the number of banded individuals found among hibernating bats was always quite low, ranging from no banded individuals to under 10% of the bats censused. In sites such as Spring Valley Caverns, where every accessible bat was banded, we found no more than 29% of the bats were banded the following year. Tallman's banding of all bats along a specific set of passages at Mystery Cave found an average of 31% of the bats were banded during subsequent banding trips.

It is difficult to interpret the reduced counts of banded bats in the hibernating population because many factors can potentially influence the numbers observed. Some banded bats may not return to hibernacula where they have been disturbed or they may retreat to more secluded portions of the site. No banded bats have been recovered from Tower Soudan Mine, despite the fact that 343 have been banded there and another 202 have been banded nearby at the Potlatch plant. Differential mortality of banded bats also may reduce the number of banded individuals found in a hibernaculum.

All available data on the relative numbers of male and female bats were compiled from museum specimen records and censuses made during this study. There appears to be both species-specific and seasonal variation in sex ratio (Tables 14, 15). A degree of caution should be exercised when using the sex ratio data to interpret the composition of a local population. The differences in behavior and roost site selection between the two sexes, for example the segregation of females at maternity roosts during the summer, may affect their susceptibility to detection and capture. In addition, the sites in which cenuses are made can introduce a bias; for example, sampling caves and mines during the summer will produce overwhelmingly male counts, but such counts would not accurately describe the population structure of bats foraging in

Table 14.--Seasonal ratio of males to females calculated from preserved Minnesota bats specimens. (Number of individuals given in parentheses; M - all males). Species abbreviations as in Table 1.

	Species			
Season	Mylu	Myke	Pisu	Epfu
Winter	3.0 (8)	0.5 (3)	1.3 (21)	1.3 (120)
Spring	0.4 (25)	1.0 (2)	M (1)	2.4 (64)
Summer	0.9 (210)	0.7 (6)		1.3 (180)
Fall	0.9 (35)	1.0 (2)		2.0 (24)

Table 15.--Seasonal ratio of males to females among bats found in the major hibernacula (number of individuals given in parentheses; M - all males, F - all females). Species abbreviations as in Table 1.

Site	Season	Species Mylu	Myke	Pisu	Epfu
Maiden Rock Mine					
	Winter	1.6 (26)		0.5 (3)	0.8 (11)
	Spring	0.9 (211)		0.4 (7)	M (17)
	Summer	49.0 (118)		M (1)	15.7 (17)
	Fall	0.4 (7)		F (2)	F (2)
Bay City Mine					
	Winter	1.3 (61)	M (1)	1.0 (8)	M (2)
	Spring			M (4)	M (4)
Brightsdale Tunnel					
	Winter	2.6 (43)		1.2 (33)	1.4 (17)
	Summer	M (1)		2.0 (6)	
*Mystery Cave					
	Winter	7.6 (1062)	M (1)	F (1)	M (1)
Spring Valley Caverns					
	Winter	22.3 (3)	M (1)	0.2 (18)	
	Fall	M (1)		F (1)	
Red Wing Mine					
	Winter	1.4 (43)	3.4 (13)	1.4 (12)	0.9 (63)
	Spring	0.9 (32)	M (1)	2.0 (3)	1.5 (15)
	Summer	M (3)			
	Fall	3.4 (13)		0.6 (8)	
Robinson's Ice Cave					
	Winter	0.9 (19)			1.8 (11)
	Spring	1.0 (39)	2.5 (7)		3.2 (21)
	Fall	3.2 (33)			
Tower Soudan Mine					
	Summer	7.3 (43)	6.2 (42)		
	Fall	1.4 (294)	0.6 (139)		

* Data from 5-year study by D. Tallman.

the region. Best estimates of population sex ratios can be obtained from summer netting and winter counts within hibernacula. Winter censuses among the major hibernacula show male-to-female sex ratios ranging from 0.9:1 to 22.3:1 (Table 15). Censuses made during the spring and fall, when bats are in transition between summer and winter sites, may be expected to vary widely according to sampling time.

Summer to fall sex ratios of Myotis lucifugus and M. keenii collected from museum specimens show approximately equal numbers of males and females (Table 14). Assuming that the majority of these specimens were collected as single foraging individuals, they would indicate that the summer sex ratio is near 1:1. Because most of our summer samples were taken from hibernacula or maternity colonies, we cannot confirm or deny the validity of this ratio. In the hibernacula examined in this study, winter ratios of these species show a predominance of males. Hibernating populations of M. lucifugus made up mostly of males were reported in hibernacula near Thunder Bay, Ontario, (Allin, 1942) and Craigmont, Ontario (Hitchcock, 1949). Furthermore, Fenton and Barclay (1980) concluded that the majority of M. lucifugus in the northern portions of the distribution are males. If true, this raises interesting questions regarding the status and fate of females throughout the range of the species. We do know that females form maternity colonies as far north in Minnesota as Grand Marais, Cook County (Timm, 1975), but the summer sex ratio data available from northern Minnesota are inadequate to support or refute Fenton and Barclay's conclusion. Winter examination of the sex ratio of bats in Tower Soudan Mine may help determine if females shift their winter range further south than males.

All records of *Eptesicus* in Minnesota indicate that males outnumber females throughout the year. Beer (1955) suggested that the predominance of males results from differential mortality against females, but cautions that females may be more inclined to roost singly or in small groups in buildings and that winter sex ratios in caves do not give a true picture.

The winter sex ratios for *Pipistrellus* seem to depend to a large extent on the particular hibernacula, and there appears to be no strong trends toward males as is observed among the other species of cave bats (Table 14). Spring Valley Caverns departs markedly from other hibernacula in its dominance by *Pipistrellus*, 83% of which are female. Even though this population makes up the largest single winter sample for *Pipistrellus*, sample sizes are small. More records of this species are necessary before any trends in the sex ratio can be detected.

Tree Bats in Minnesota

Distribution and abundance. State distributional records for the three species of tree bat, *Lasionycteris noctivagans*, *Lasiurus borealis*, and *Lasiurus cinereus*, are patchy but not localized to any particular region, suggesting that these bats occur throughout most of the state (Figs. 6-8). Few additional data were collected on these species during our study. Five *Lasiurus borealis* and one *Lasionycteris noctivagans* were caught in Brown, Fillmore, Wabasha, and Winona counties (Appendix 1), and observations on *L. borealis* were made in Fillmore and St. Louis counties.

All three species are highly migratory and thought to vacate the state prior to winter. Although wintering sites are not well documented, circumstantial evidence suggests that they move southward at this time. The latest autumn records for the state are: *Lasionycteris noctivagans* - 5 October 1979, Houston County; *Lasiurus borealis* - 13 October 1977, Mille Lacs County; and *L. cinereus* - 3 September 1966, St. Louis County. Beer (1954) found the mummified remains of *L. cinereus* in a Ramsey County sand cave on 22 January 1950, where it apparently had tried to overwinter. Two years later, 23 January 1952, he found one *L. noctivagans* hibernating in a shallow cave in Washington County (Beer, 1956). These are the only records of tree bats hibernating in Minnesota. All three species have been recorded as roosting in caves and mines in southern states and hibernating in some parts of their ranges (Kunz, 1982*b*; Shump and Shump, 1982*a*,*b*). Although little is known about hibernation in L. noctivagans and L. cinereus, the physiological and behavioral responses of L. borealis to winter conditions suggest that they are adapted to hibernate for short intervals during cold weather. They apparently arouse frequently to forage rather than remaining torpid for prolonged periods, and thus are unable to survive long winters in caves (Barbour and Davis, 1969). If the other two species respond similarily, we can assume that Minnesota cannot sustain these tree bats over the winter.

The paucity of state records for tree bats makes it impossible to detect the onset of migration into or out of the state. The earliest spring records for tree bats in Minnesota are: L. noctivagans - 27 April 1945, Ramsey County; L. borealis - 20 April 1977, Hennepin County; and L. cinereus - 30 May 1956, Hennepin County. Some evidence suggests that fall migrations may be more precisely timed, whereas spring migrations appear to be spread out over several months (Kunz, 1982b; Shump and Shump, 1982a, b). This may be the case for bats moving into Minnesota (Fig. 15). Tree bats first appear in the state in April and May when night temperatures still drop below freezing and while the ground still may be covered with snow. However, a marked increase in adult captures occurs later in June.

Using the frequency of state-wide captures as rough correlates to population densitites, there appears to be seasonal differences in abundance for each species and variation among the species with respect to the timing and magnitude of density flucuations (Fig. 15). All three species show a general bell-shaped curve in individual captures throughout the season, with the greatest number of bats taken in mid-summer and fewer captured during early and late summer. Although of the increase undoubtedly is due to the recruitment of juveniles into the population, if adult and juvenile cohorts are viewed separately it appears that both exhibit a mid-summer maximum. The increase at the beginning of summer may be due to the gradual influx of bats from the south. Similarly, the decrease in number of captures in late summer may reflect movement out of state.

The variation among the three species suggests some potentially different strategies. Lasionycteris noctivagans appears early in the season and stays late in the fall, but shows less increase in the number of captures during the season. This suggests that this species is relatively rare in Minnesota, contrary to the conclusions of Bailey (1929) and Cahn (1937), both of whom considered this a numerous bat. An alternative explanation to its rarity in collections may be that its foraging and roosting habits make it less likely to come in contact with humans and thus that our sample is too small to detect any trends.

Lasiurus borealis is the best represented of the migratory bats by state records. It appears to be present in the state over the same period as L. noctivagans, but shows a notable increase in numbers during mid-summer, with the majority of captures occurring in August. Lasiurus cinereus exhibits a sharp increase in frequency of captures for June, but very few captures in August

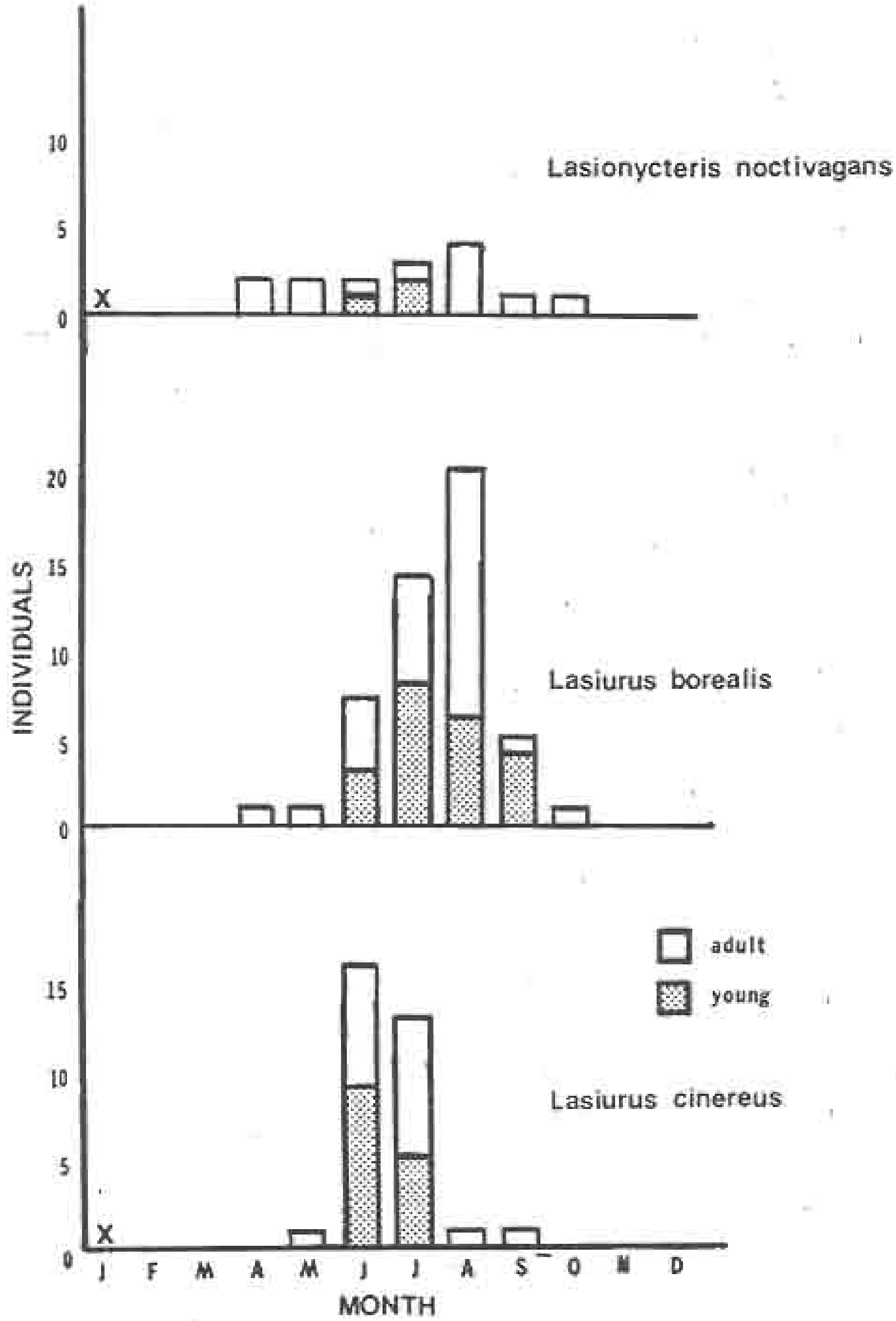

Fig. 15. Records of capture for Minnesota tree bats. (X - winter records; see text for explanation.)

when *L. borealis* is at its peak.

In northern latitudes, *L. cinereus* characteristically occurs in coniferous forests typical of northern Minnesota. The growing season in this region of the state is much shorter relative to southern Minnesota and killing frosts often occur until May and begin as early as August. Records for *L. cinereus* indicate that it has the most northerly distribution of tree bats (Fig. 8), and appears to have a much more compressed period of residency in the state. Juvenile recruitment is detected earlier in *L. cinereus* than in *L. borealis*. From the capture records it is tempting to speculate that there is considerably less tolerance in the timing of migration, parturition, and raising of young for *L. cinereus* than for *L. borealis*, which is found most commonly in the hardwood forests of southern Minnesota and has a longer period to forage and rear young before being forced to migrate.

Population structure. All three species of tree bats rear young in Minnesota, as evinced by the presence of pregnant and lactating females and juveniles among the state records (Table 16). The birth of young and the length of lactation does not appear highly synchronized (although lactating *L. cinereus* were found over a shorter interval than *L. borealis*) and there are no obvious regional trends in the timing. For example, pregnant or nursing females were found in northern counties at earlier dates than southern counties. This may reflect individual variation or the influence of year-to-year differences in winter severity on

Table 16.--Summary of reproductive data for Minnesota tree bats (number of records in parentheses).

Species	Pregnant females	Lactating females	Mean litter size	Volant juvenlies
Lasionycteris noctivagans	20 May-24 June (5)	9 July (1)	2.0 (6)	21 July (1)
Lasiurus borealis		3 July-11 August (3)	3.3 (3)	3 July (1)
Lasiurus cinereus		26 June-9 July (5)	1.8 (5)	6 July-30 July (4)

the initiation of gestation in the spring. Using the available data, it appears that the young are born in Minnesota from middle to late June. By July, females are nursing young and by the beginning of August most young are volant and foraging independently. This schedule agrees with records from adjacent states such as Iowa, Wisconsin, and Michigan (Kunz, 1982b; Shump and Shump, 1982a, b).

Adults collected early in the summer were predominantly female among all three species. Among adult bats, the percent of females collected from April to August were: Lasionycteris noctivagans - 86%; Lasiurus borealis - 82%; and Lasiurus cinereus - 75%. This strongly suggests that female tree bats are migrating to Minnesota to rear young. Such separation of the sexes is supported by the literature. Female L. noctivagans appear to migrate further north than males (Kunz, 1982b), male and female L. borealis seem to migrate at different times and have different summer ranges (Shump and Shump, 1982a), and the sexes of L. cinereus separate during warm months (Findley and Jones, 1964).

Notwithstanding that we have repeatedly pointed out the short-comings of data on Minnesota tree bats, some fascinating trends in seasonal abundances, population structure, and variation in reproduction among the three species are suggested. The natural histories of these species are the most poorly understood of the bats in Minnesota, they are unquestionablely the most difficult to study, and yet they hold promise for important discoveries in areas such as resource partitioning, optimal foraging, and reproductive strategies. They merit more research effort in Minnesota, both to augment our existing information and to contribute to a generally depauperate body of data on these species.

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