COO-1332-99

FALL AND WINTER MOVEMENTS AND ACTIVITY OF MUSKRATS IN EAST-CENTRAL MINNESOTA

A THESIS
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BY
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DISCLAIMER

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INTRODUCTION

The muskrat (*Ondatra zibethica*) has received wide attention from many and varied groups of people. Economic considerations primarily account for this interest, positively as a fur bearer and negatively as a burrower into man-made earthen structures. Thus, while muskrats have long been a prime source of income for inhabitants of remote areas and for people facing economic depression, in some areas attempts are being made to eradicate muskrats due to the damage they cause to dams and canals (Storer 1937).

In addition, certain biological attributes of the muskrat have stimulated a large amount of research. These include dispersal and mass movements, possible cyclic fluctuations of population size, influence on habitat, susceptibility to epizootics, unusual sex ratios, and its wide occurrence in the northern hemisphere.

The muskrat's ability to affect its habitat under high population densities has been described by Lynch, O'Neil and Lay (1947) and O'Neil (1949) for the Louisiana muskrat (*O. z. rivalcius*) which inhabits the Gulf Coast and by Harris (1952) and Dozier, Markely and Llewellyn (1948) for *O. z. macrodon* in Maryland. As length of breeding season decreases and environment becomes more limiting in northern latitudes, habitat destruction becomes less frequent. Errington (1963) reports that damage from overuse by muskrats was never as severe in northern marshes as in marshes in Louisiana.

Historically muskrat research has answered many questions, especially those concerned with management of habitat. However, many aspects of their life history are not well understood. These include daily and seasonal movements, the relationship of population fluctuations to cycles, activity patterns, territoriality, and predation.

Movements of muskrats are mentioned in many publications concerning the animal. Errington (1963) differentiates between spring, autumnal, and emergency movements. His research indicates that emergency movements can occur at any time of the year and are generally related to deteriorating habitat conditions such as drought, freeze out, and/or depletion of food. Beer and Meyer (1951) relate spring and autumnal movements to changes in physiology.

The muskrat has contributed to the controversy surrounding cyclic phenomenon in animal populations in the northern hemisphere. Errington (1954, 1957, and especially Chapter 17, 1963) discusses this in detail. He stresses the need to look at characteristics of the population other than fluctuations in number. Ability of the muskrat to quickly repopulate (and sometimes overpopulate) suitable habitat and lack of stability of this habitat often result in large fluctuations in density. Mathiak (1966), studying muskrats on Horicon Marsh in Wisconsin, found that large populations could develop rapidly and were then subject to extensive losses from disease, winter weather, and emigration. The resulting population fluctuations, when observed over a long time period, invite cyclic interpretations.

Few data are available on daily activity periods, especially during the winter in the northern part of the range. Previous workers have indicated that, in general, muskrats are nocturnal. However, O'Neil (1949) commented that they are active between 4 p.m. and 6 a.m., 80 percent active at night, and are more diurnal under high populations. Errington (1963) agreed with these comments and also mentioned that meteorological conditions determined activity patterns to some extent.

Similarly, little information has been obtained on daily movements, territoriality, and home ranges of muskrats. This paucity of data is attributed to lack of suitable field techniques. Recaptures of marked animals are often low due to heavy mortality and sightings of marked animals are difficult to obtain at night or when the animals are in water. The development of telemetry as a technique for studying wild animals living under natural conditions provided an opportunity to collect information on both of the above aspects of muskrat behavior.

This paper reports on movements and activity of muskrats from July 30, 1969 to May 1, 1970 on the Cedar Creek Natural History Area (CCNHA) in east-central Minnesota. Data were collected from animals using creek and marsh habitats and were analyzed with reference to seasonal changes and to certain environmental factors. It is hoped that the findings presented will be of value in understanding the mode of survival of muskrats in a northern climate.

HABITAT DESCRIPTION

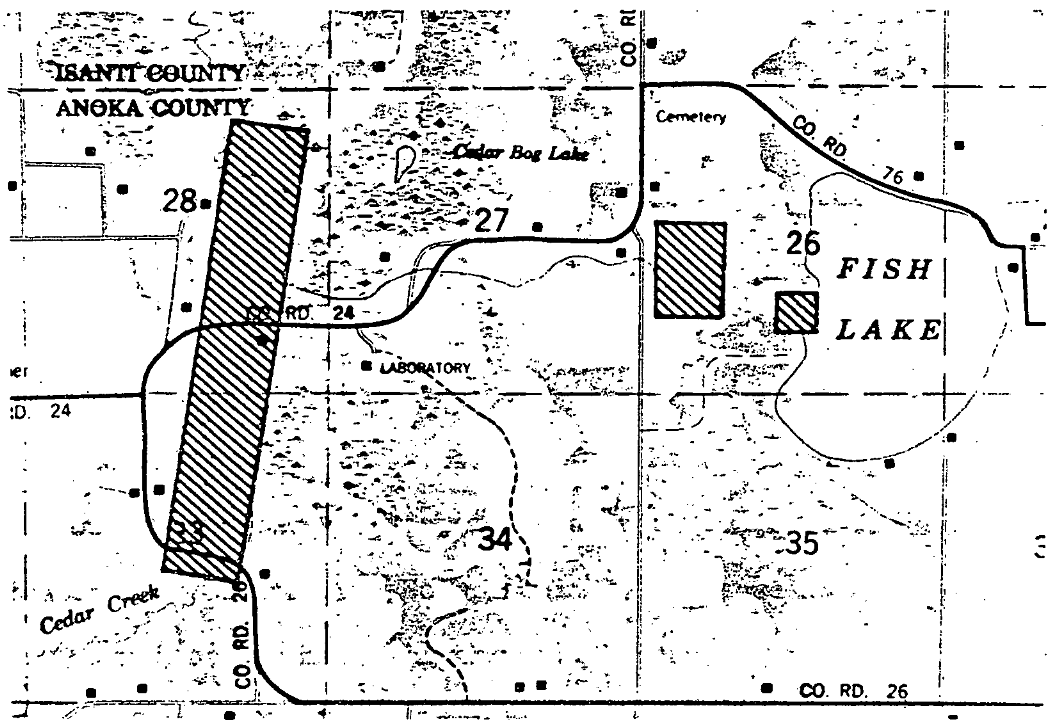
The CCNHA covers an area of about 5800 acres and contains a diverse mixture of habitats (Bray *et al.* 1959, Pierce 1954). This study was conducted on three relatively small areas within the CCNHA (Fig. 1).

Cedar Creek is a small, meandering stream flowing through the CCNHA. The section of the creek where this study was conducted is mostly mud-bottomed and slow moving. Depths range from one to three feet in straight sections to four to seven feet in bends. Habitat in the creek valley is characterized by large sedge (*Carex spp.*) meadows with alder (*Alnus rugosa*) coming in near the upland. Small spring-fed streams enter the creek at numerous locations. Floating sedge mats with small openings are often found at these entry points.

In many areas banks are from six inches to one foot higher than sedge meadows adjacent to the creek and are grass covered. These banks are often honeycombed with old muskrat burrows. At normal water levels the banks rise vertically from the water surface and are undercut at places. Mud or sand bars are not common. This type of habitat extends to the southern boundary of the study area where the creek abruptly becomes shallow and less sluggish and where sedge meadows end.

The Peterson Marsh study area is a 120 acre shallow cattail (*Typha latifolia*) marsh about 1.2 miles east of the creek. Although water levels fluctuated with rainfall, open water was

Figure 1. A portion of the Cedar Creek Natural History Area located in northern Anoka County, Minnesota. The three study areas are shown by crosshatching.


ISANTI COUNTY
ANOKA COUNTY
Cedar Bog Lake
Cemetery
CO. RD. 76
28
27
26
FISH
LAKE
CO. RD. 24
LABORATORY
34
35
Cedar Creek
CO. RD. 26
CO. RD. 26

confined to several shallow ditches and small muskrat "eat-outs". Dense cattail stands were interspersed with horsetail (Equisetum spp.), sedges, and water lilies (Nuphar variegatum).

A shallow ditch connects the Peterson Marsh with Fish Lake, located .2 mile to the east. Water flows into the marsh from Fish Lake only during high water. The study area on the western side of Fish Lake contained a 400 foot long pool enclosed by cattails. Bulrushes (Scirpus spp.) were common in this area.

Major water level changes occurred shortly after the beginning of the study. In late August levels were dropping so that muskrat burrow entrances, previously under water, were being exposed. By September 1 the water in the Peterson Marsh had dropped about one foot so that the water surface was near the rhizome level of large areas of cattails. No appreciable increase in water level in the marsh occurred during the fall because of rain, although the creek level fluctuated somewhat.

By the time permanent snow arrived on November 18 the marsh had frozen one to two inches. A total of 34 inches of snow fell in December. The ice cover remained thin until early January when cold temperatures, wind action, and granulation thinned and compacted snow, causing the marsh and lake to freeze deeper. Snow cover averaged about 18-20 inches by the first part of January; however, snow had drifted into the cattails to a level of three to four feet, especially on the western shore of Fish Lake. A warm period which resulted in water accumulation on top of the ice occurred about March 1. Thawing of lake ice began about April 1 and April 8 was the last day that it was possible for a person to walk on the ice.

Snow cover and wind action along Cedar Creek resulted in erect stands of grasses and sedges being filled in with snow, sometimes leaving air pockets along banks. The creek remained mostly ice-free until late December and periodically opened up during warm periods throughout the winter. Spring melt caused the water level to rise to the top of the creek banks about April 5.

METHODS

TRAPPING

Muskrats were live-trapped with both single and double door live traps. On the creek study area traps were placed on mud bars, in muskrat paths in the grass on the creek bank, and in holes in the banks. In some cases successful trap sets were made by digging a hole in the bank at water level with a trenching tool and fitting a single door trap into it. Often muskrat sign was found on floating sedge mat projecting into the creek. Traps placed here were more successful if covered with grass, aquatic vegetation, and mud so that only the doors were exposed.

Trapping was unsuccessful on the creek after the onset of snow and ice conditions in late November. After this date muskrat sign was not found regularly in any area. Apparently, most activity was being conducted in open water areas or under snow and ice.

On the Peterson Marsh study area traps were placed on feeding platforms and on lodges. The most successful sites were on lodges with the traps covered with lodge material. After freeze-up traps were placed inside lodges by cutting a hole in the lodge above the ice surface. Single-door traps were placed in the hole with the door to the interior of the lodge. Material from the lodge was used to cover the exposed part of the trap and snow was shoveled over the lodge. During periods of extreme cold the traps were lined with canvas. At all times the trap hole was covered with as much material as was possible to prevent the inside of the lodge from freezing.

Vegetation and mud often impeded action of the doors on traps. This problem was solved by making the door action more forceful by attaching a spring from the middle of the door to the roof of the trap.

Traps were baited with rutabagas, apples, potatoes, carrots, or commercial lures. Commercial lures made by Hawbaker and Sons, Ft. Loudon, Pennsylvania, were successful.

HANDLING

Captured muskrats were taken to the laboratory, placed in a chamber and anesthesized with ether (Balser and Kinsey 1962). It was necessary to hold animals in the ether box at least 12-13 minutes since they would hold their breath this long. If the box were opened earlier they would obtain fresh air and hold their breath again. Some experience was necessary to know when the animal became unconscious. The best procedure was to closely observe the animal through the plexiglass window in the box and to remove it after breathing resumed.

While anesthesized, muskrats were weighed, sexed, measured, ear-tagged, and fitted with a collar radio transmitter. Ear tags used were 1/4 inch, #1 size manufactured by the National Band and Tag Company. Sex determination was made by following the pelvic examination technique described by Mosby (1963). Animals were classified as young or adult by weight and measurements as described by Erickson (1963).

TRANSMITTERS

Transmitters were of the collar type with a loop antenna described by Cochran and Lord (1963) and Mech *et al*. (1965). Mallory batteries with an expected life of 60-90 days were used. Waterproofing was accomplished by dipping the transmitter and antenna in Perm, an acrylic plastic. After hardening, the plastic was ground down as thin as possible to minimize weight. Total package weight of collars successfully carried by muskrats was from .60 ounces (17 grams) to 1.13 ounces (32 grams), equivalent to 2.1 percent to 4.7 percent of the animal's weight. Weight of the transmitter was within the limits suggested by Brander and Cochran (1969). No adverse effects of the transmitter were noted except for some scratching immediately after release.

DATA GATHERING

Location and activity data on some of the muskrats were recorded automatically on the Cedar Creek telemetry system (Cochran *et al*. 1965). Locations were determined from the microfilm record at 10 minute intervals. Onset and cessation of activity periods were recorded to the nearest minute; the minimum length of a period recorded being about two to three minutes.

Field checks were made with portable directional receivers of animals in areas where system errors were large (Heezen and Tester 1965) or which were beyond the range of the automatic telemetry system. Muskrats on Fish Lake and the Peterson Marsh were also located while checking traps to determine lodge use.

Data on weather were obtained from the Cedar Creek weather station which records temperatures on an hourly basis, barometric pressure continuously, and light on a Langley/day basis.

RESULTS

Analysis of activity and movement data was concentrated on those muskrats monitored in high accuracy areas of the telemetry system. Some methods of presentation required that the data record be nearly unbroken. Data on other animals with discontinuities in their telemetry records were examined as closely as possible to determine similarities and differences. Information on all radio-tagged muskrats is given in Table 1. Observations concerning dispersal, homing, mortality and habitat were to some extent incidental but do contribute to a better understanding of the ecology of muskrats in fall and winter on CCNHA.

ACTIVITY PATTERNS

Data on activity patterns of 16 animals were recorded on the automatic telemetry system for periods ranging from 7 to 62 days (Table 1). Nearly complete records giving onset and cessation of daily activity periods are presented for four of these animals (Figs. 2 through 4).

Occasionally, in the activity record, onset or cessation occurred while no signal was being recorded. These times were estimated by using the midpoint of the unknown period. Estimations were made for about two percent of the total of onset and cessation times. Onset or cessation of activity was usually abrupt. Sometimes activity of a few minutes duration occurred between major activity periods. However, since no change in

Table 1. Radio-tagged muskrats on the Cedar Creek Natural History Area, east-central Minnesota from July 29, 1969 to April 25, 1970.

Animal Number	Sex	Age	Period Monitored	Number of Days	Location	Used for Activity Analysis	Comments
1969							
1901	M	Ad	July 29-Sept 8	41	Cedar Creek	X	Transmitter quit, no recapture
1902	M	Ad	July 31-Sept 3	34	Cedar Creek	X	Transmitter quit, no recapture
1903	F	Yg	Aug 7-Sept 1	24	Cedar Creek	X	Transmitter quit, no recapture Dispersed
1904	F	Ad	Aug 27-Sept 2	6	Cedar Creek		Possible handling death, no recovery of animal
1905	F	Ad	Sept 9-Nov 9	62	Cedar Creek	X	Transmitter quit, no recapture
1906	F	Yg	Sept 15-16	1	Cedar Creek		Death after release, possible predator, no recovery of animal
1907	M	Ad	Sept 18-Oct 23	34	Cedar Creek	X	Homed twice after displacement, dog kill during dispersal
1908	F	Ad	Sept 22	1	Cedar Creek		Probable handling death
1909	M	Ad	Sept 22-Oct 9	17	Cedar Creek	X	Displaced, homing, fox kill
1910	M	Yg	Sept 22	1	Dispersing		Death, probably from handling

Table 1. Continued.

Animal Number	Sex	Age	Period Monitored	Number of Days	Location	Used for Activity Analysis	Comments
1911	F	Ad	Sept 23-25	2	Cedar Creek		Death, possible predator, no recovery, dispersal
1912	F	Ad	Sept 27-Nov 6	40	Peterson Marsh	X	Transmitter quit, no recapture
1913	F	Ad	Oct 31-Nov 30	30	Peterson Marsh	X	Mink kill
1914	F	Ad	Oct 31-Nov 15	15	Peterson Marsh	X	Mink kill
1915	M	Ad	Oct 31-Nov 26	27	Peterson Marsh	X	Transmitter quit, no recapture
1916	F	Ad	Nov 1-21	20	Cedar Creek	X	Transmitter quit, no recapture
1917	F	Juv	Nov 2-9	7	Cedar Creek	X	Transmitter quit, no recapture
1918	M	Ad	Nov 4-25	21	Peterson Marsh	X	Mink kill
1919	M	Juv	Nov 3-15	12	Peterson Marsh		Transmitter quit, no recapture
1920	F	Juv	Nov 17-18	1	Dispersing		Death after release, unknown cause

Table 1. Continued.

Animal Number	Sex	Age	Period Monitored	Number of Days	Location	Used for Activity Analysis	Comments
1970							
1921	M	Juv	Jan 12–18	7	Peterson Marsh	X	Death, unknown cause
1922	F	Juv	Jan 15–Feb 4	20	Peterson Marsh	X	Fox kill
1923	F	Juv	Jan 15–24	9	Peterson Marsh	X	Probable mink kill
1924	M	Juv	Feb 1–3	2	Fish Lake		Death, probable handling
1925	M	Ad	Feb 6–Mar 1	25	Fish Lake		Death, unknown cause
1926	F	Ad	Feb 20–Mar 18	26	Fish Lake		Transmitter quit, no recapture
1927	M	Ad	Mar 21–25	4	Fish Lake		Transmitter quit, no recapture
1928	F	Ad	Mar 27–Apr 8	12	Fish Lake		Road kill during dispersal
1929	M	Ad	Mar 27–Apr 25	29	Fish Lake		Transmitter quit, no recapture
1930	M	Ad	Mar 30–Apr 3	4	Dispersing		Mink kill after dispersal
1931	F	Ad	Apr 9–14	5	Dispersing		Transmitter quit, no recapture

Figure 2. Daily activity pattern of muskrat 1902, July 31 to September 2, 1969. Horizontal lines show major periods of activity.

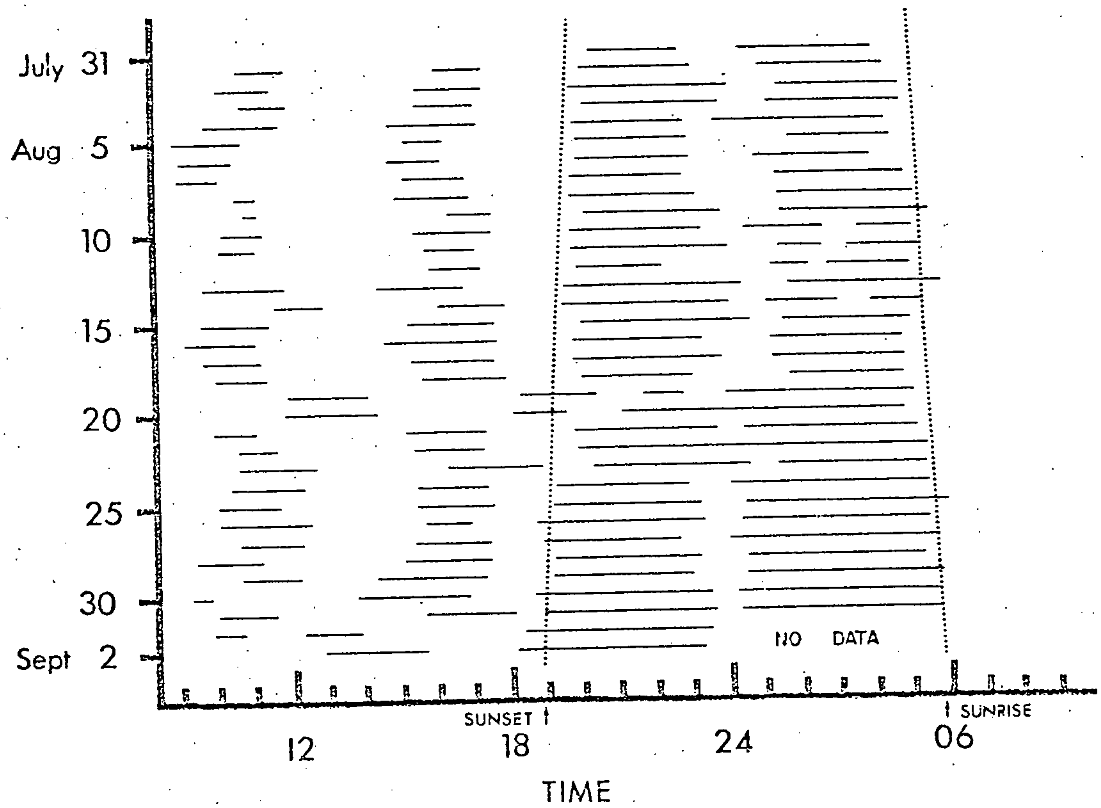

July 31
Aug 5
10
15
20
25
30
Sept 2
NO DATA
SUNSET
SUNRISE
12
18
24
06
TIME

Figure 3. Daily activity pattern of muskrat 1905, September 10 to November 9, 1969. Horizontal lines show major periods of activity.

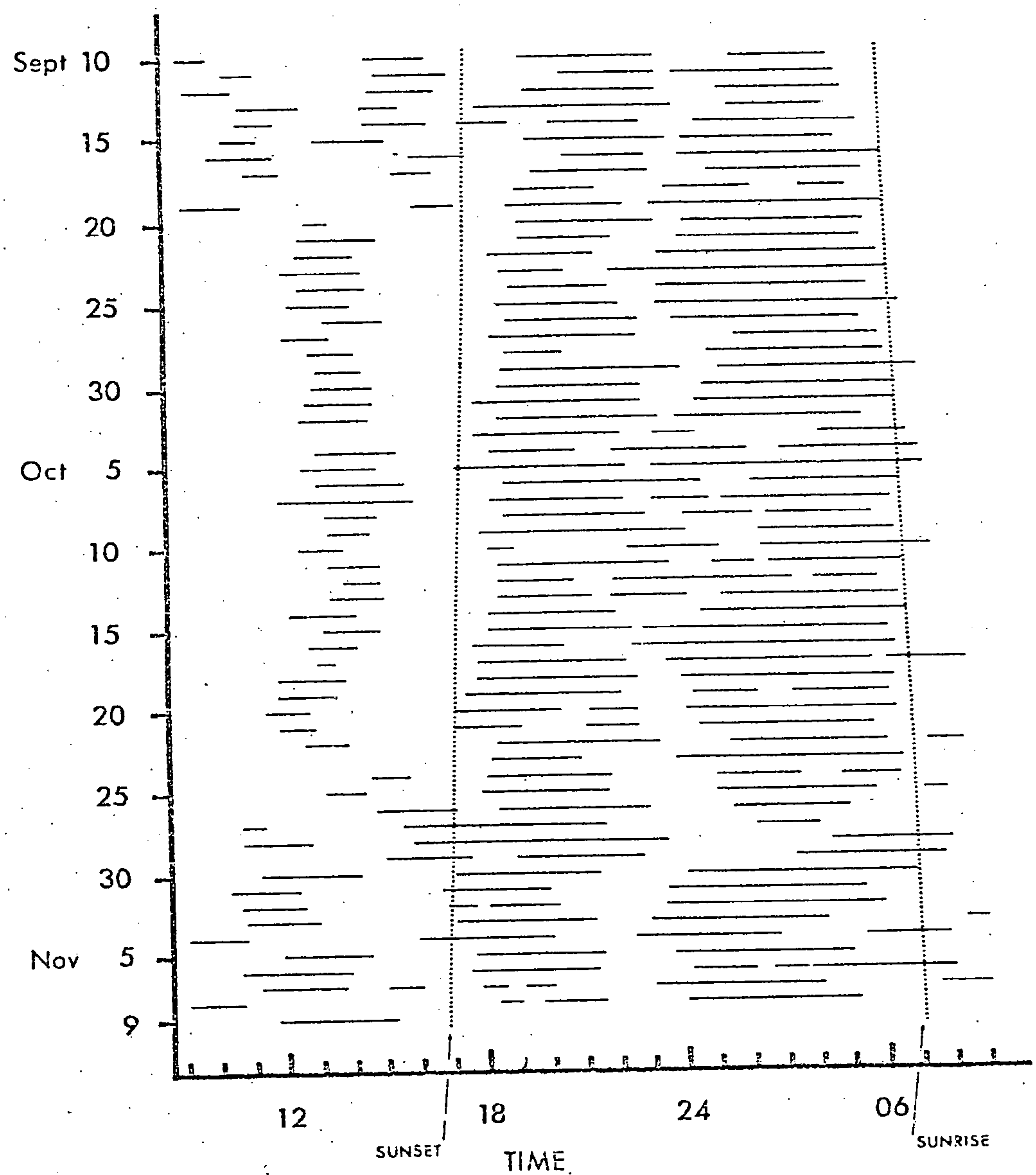
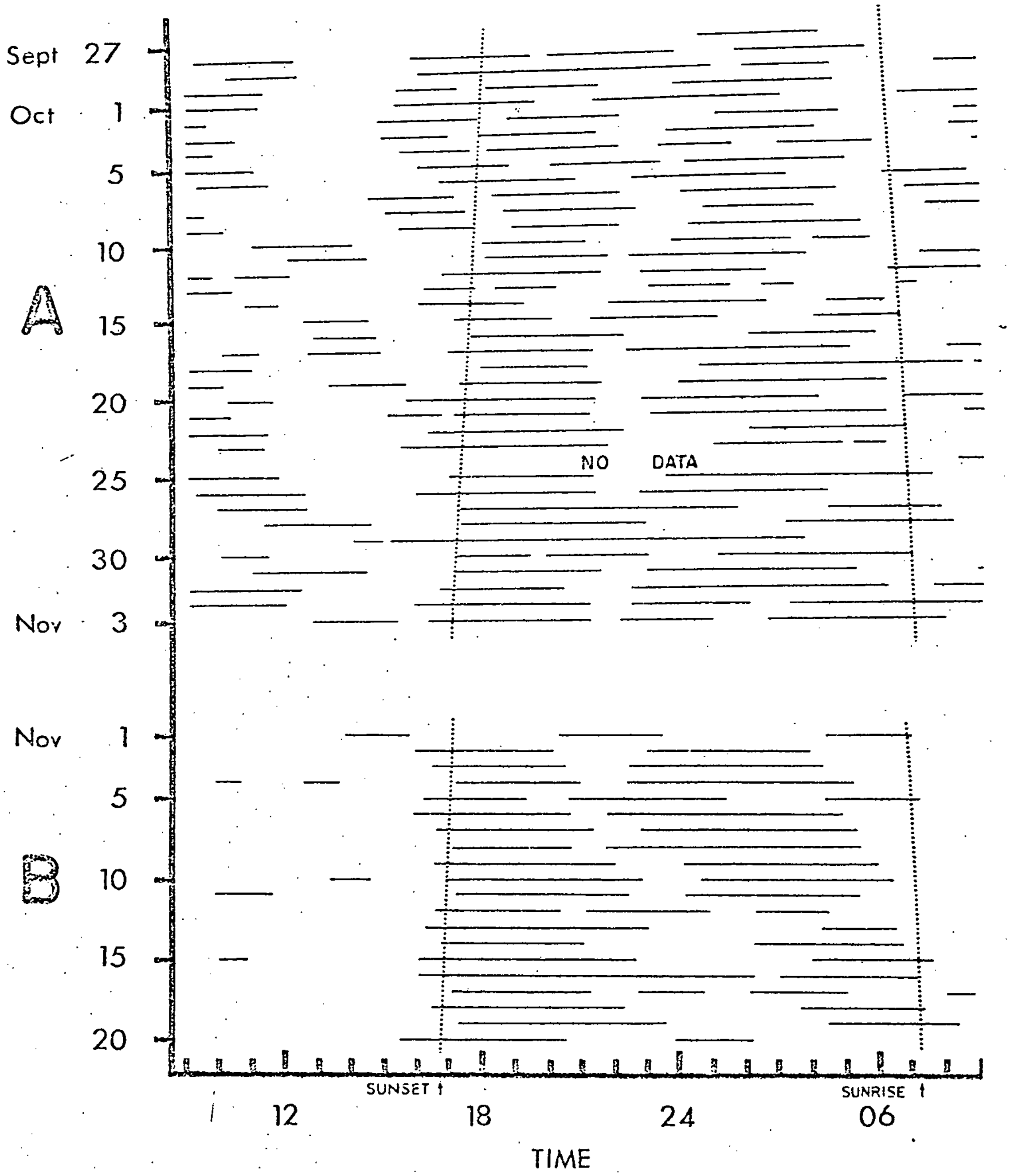

Sept 10
15
20
25
30
Oct 5
10
15
20
25
30
Nov 5
9
12
18
24
06
SUNSET
SUNRISE
TIME

Figure 4. A. Daily activity pattern of muskrat 1912, September 27 - November 3, 1969.
B. Daily activity pattern of muskrat 1916, November 1-20, 1969.
Horizontal lines show major periods of activity.



Sept 27
Oct 1
5
10
15
20
25
30
Nov 3
A
NO DATA
Nov 1
5
10
15
20
B
SUNSET
SUNRISE
12
18
24
06
TIME

location occurred during these times this activity is not included in Figures 2 through 4 and 8 through 11.

Several features of muskrat activity may be seen in Figures 2 through 4. The number of activity periods per day was usually two, three, or four, and occasionally five. Most activity occurred at night and in most cases began and ended about sunset and sunrise. There was in almost all cases at least one time of inactivity during the night. Temporal shifts of periods occurred. Data for muskrat 1905 (Fig. 3) show this beginning on September 20 and again about October 26 with daylight periods. Another shift began for 1912 (Fig. 4A) on October 10. The daylight pattern after this day became less regular and was somewhat similar to that of 1905 after October 26.

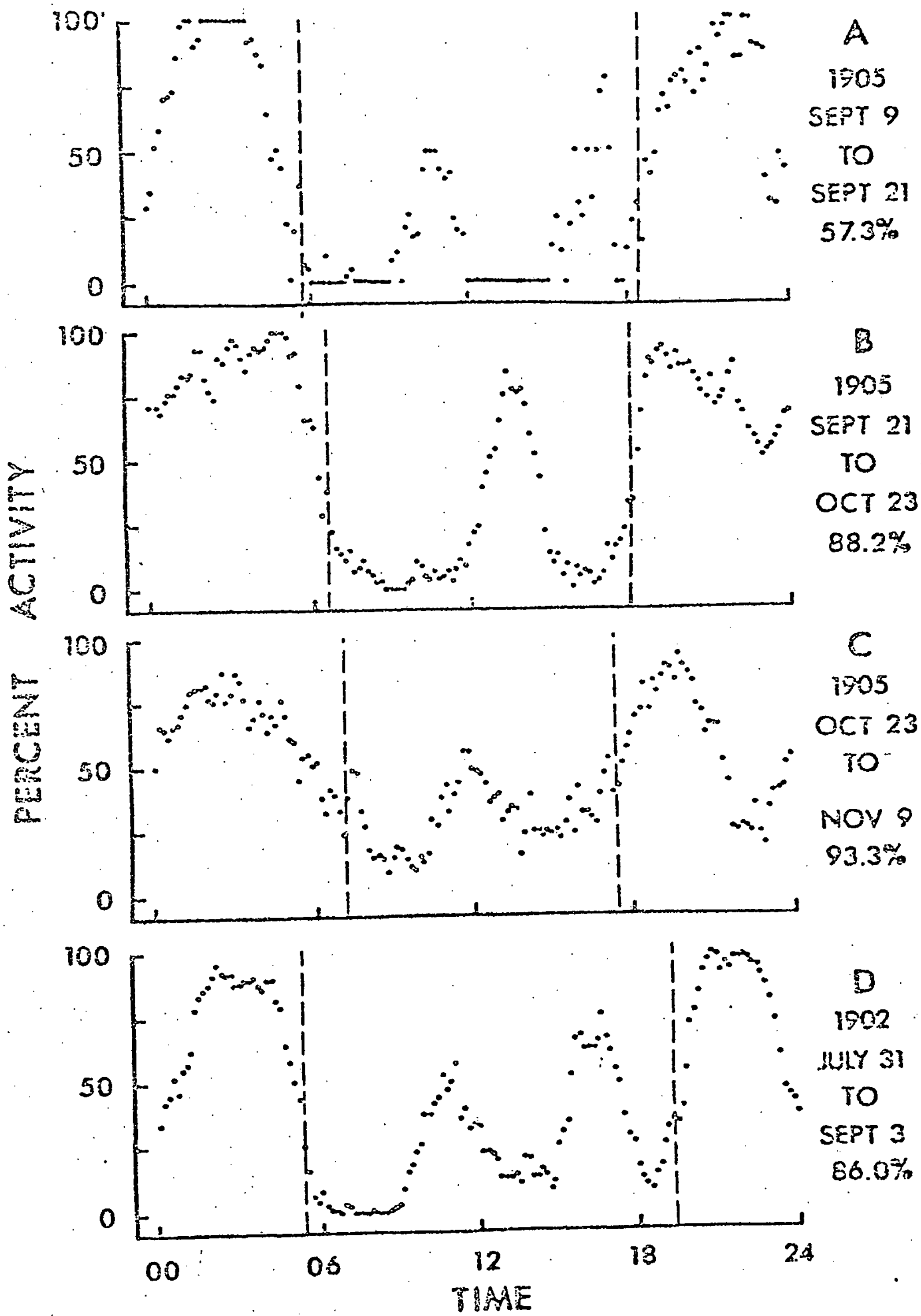
Inspection of the activity periods presented in Figures 2 through 4 reveals that at certain times there were progressive day-to-day changes in onset or cessation times of activity. An example of this was the onset of early morning activity of 1905 (Fig. 3) for the nights of September 29 and 30 through October 4 and 5. This activity period began, respectively, 23, 12, 20, 40, and 23 minutes earlier each night. At other times onset or cessation could be progressively later. Most commonly, the range of time change involved was 20 to 50 minutes.

These data were inspected for relationship to astronomical stimuli. Only the moon has daily changes of this magnitude—it rises and sets an average of 50 minutes later each day. However, no relationship with moonrise or moonset was found. At certain times darkness-related periods began before sunset or ended after sunrise for variable numbers of succeeding days. No relationship with cloudiness before sunset or after sunrise was apparent.

Radio signal reception on 12 of the 16 animals monitored by the automatic telemetry system was not continuous, mainly due to location of the muskrats with respect to the antenna towers and occasionally due to malfunctioning of equipment. Because of these discontinuities in the records, data from all 16 animals were analyzed by a computer program which calculated percentage of activity during 10-minute intervals over a period of days. For example, a 10-day period of data for the 10-minute interval of 0000 hours to 0010 hours contains 100 minutes. The program accumulated minutes of activity, resting, and unknown (caused by discontinuities in the record) for a given animal; subtracted unknown from 100, and calculated the percentage of known time that the animal was active. Output was plotted showing average peaks and troughs of activity for a 24-hour period as summarized from data from each 10-day period. These plots are presented in Figures 5 through 7 and Appendix A. This program also gave percentage activity per 24 hours over the period of days chosen.

Figures 2 through 4 show daily activity periods while Figures 5 through 7 mainly demonstrate times of activity peaks. Activity periods (as in Fig. 2 for 1902) then show up as activity peaks (as in Fig. 5D). In the following discussion the assumption is

Figure 5. Activity pattern of muskrat 1905 from September 9 to November 9, 1969 and muskrat 1902 from July 31 to September 3, 1969. Dots show the percent of time the animal was active for any given 10 minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.



PERCENT ACTIVITY
TIME
00
06
12
18
24
0
50
100
A
1905
SEPT 9
TO
SEPT 21
57.3%
B
1905
SEPT 21
TO
OCT 23
88.2%
C
1905
OCT 23
TO
NOV 9
93.3%
D
1902
JULY 31
TO
SEPT 3
86.0%

Figure 6. Activity patterns of muskrats 1915, 1916, 1917 and 1918 for varying intervals from October 31 to November 21, 1969. Dots show the percent of time the animal was active for any given 10 minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.

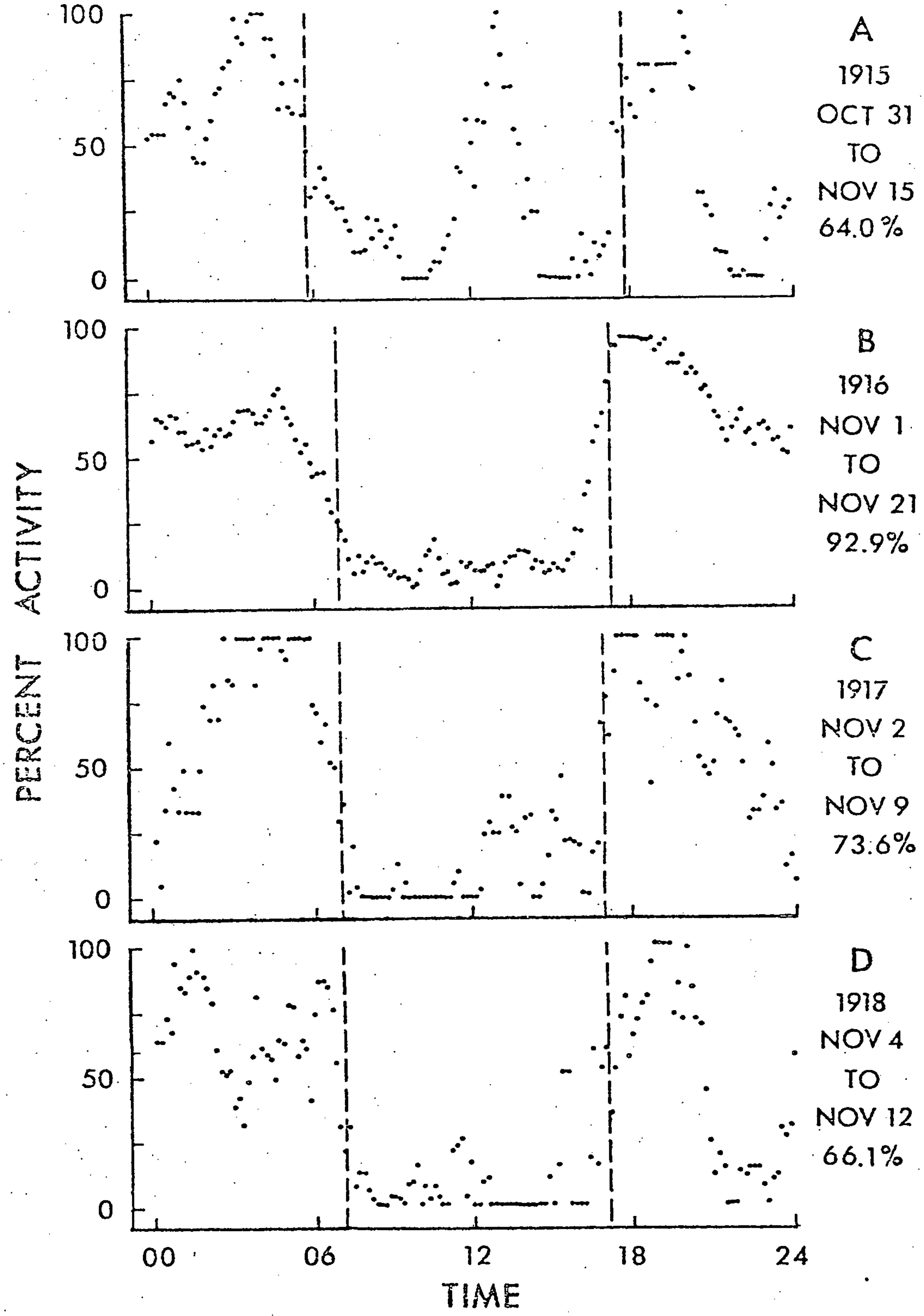
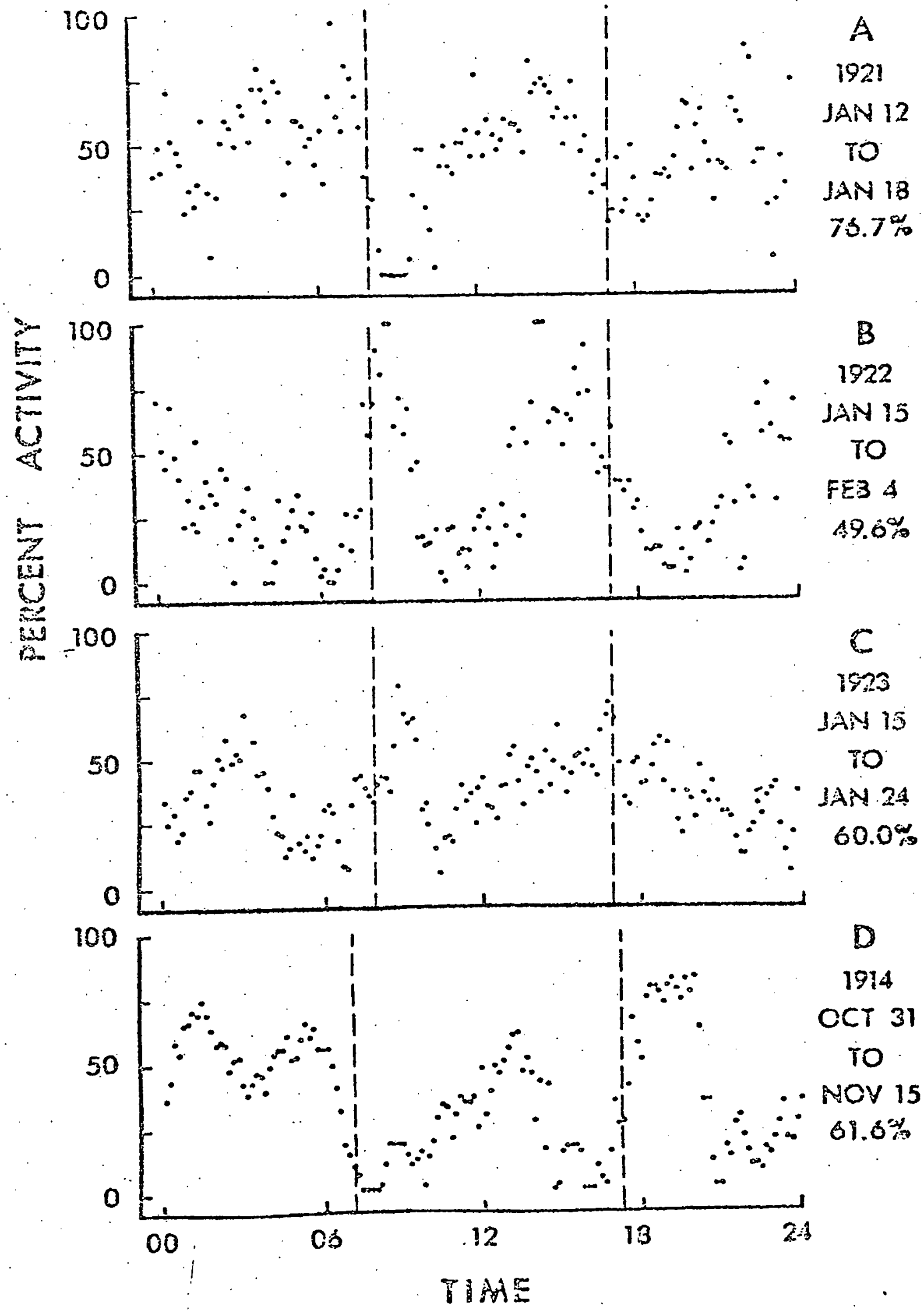

100
50
0
A
1915
OCT 31
TO
NOV 15
64.0 %
B
1916
NOV 1
TO
NOV 21
92.9%
C
1917
NOV 2
TO
NOV 9
73.6%
D
1918
NOV 4
TO
NOV 12
66.1%
PERCENT ACTIVITY
00
06
12
18
24
TIME

Figure 7. Activity patterns of muskrats 1921, 1922, 1923 and 1914 for varying intervals from 1969-1970. Dots show the percent of time the animal was active for any given 10 minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.



PERCENT ACTIVITY
100
50
0
A
1921
JAN 12
TO
JAN 18
76.7%
B
1922
JAN 15
TO
FEB 4
49.6%
C
1923
JAN 15
TO
JAN 24
60.0%
D
1914
OCT 31
TO
NOV 15
61.6%
00
06
12
18
24
TIME

made, for example, that three activity peaks indicate three activity periods.

The number of activity periods per 24 hours appears to change as the season progresses. Two darkness periods and two daylight periods were common in late summer and early autumn. By autumn only one daylight period occurred and in some cases no daylight activity periods were noted in late autumn and early winter.

For example, muskrat 1902 had four activity periods per day through August (Figs. 2 and 5D). Muskrat 1905 had a similar pattern from September 9 through September 19, but this abruptly shifted to three on September 20 and remained at three until at least October 25 (Figs. 3 and 5A,B).

Muskrats 1916, 1917, and 1918 exhibited the two period pattern in November with very little daylight activity (Figs. 6B-D), but two other animals which were concurrent, 1914 and 1915, had three period patterns (Figs. 6A and 7D).

Data on four other muskrats, limited by poor reception, covered approximately the same time period as those in Figures 2 through 6. These data also suggest a seasonal decrease in number of activity peaks (Appendix A).

Only three animals were monitored by the automatic system in winter due to difficulties in trapping and poor reception from muskrats in the Peterson Marsh area. Each animal had three activity peaks, but the peaks were spread over the 24-hour period, were less distinct and there was less correspondence in time of peaks among animals (Fig. 7A through 7C). Variability in the activity patterns shown may be due to limited data on each animal.

In order to numerically evaluate changes in activity of the four animals in Figures 2 through 4, activity periods were classified according to time of occurrence. Generally, daylight periods occurred in late morning and late afternoon and darkness periods occurred in the evening and again during early morning hours. Difficulties were sometimes encountered in placing certain activity periods in one of the four time classes. Evening periods that began before sunset or early morning periods that ran after sunrise were placed in darkness time classes. Occasionally, mostly during darkness, there were three periods where normally two occurred. In these cases the third period was lumped with the nearest activity period.

The duration of daylight activity periods, when they occurred, varied depending on the time of day, but showed a remarkably uniform pattern when averaged for two week periods (Fig. 8D). Late afternoon activity periods were about 110 minutes long from August 1 to October 31, but decreased in November (Fig. 8A). Late morning periods increased from a mean of 79 minutes in early August to a mean of 145 minutes in early November (Fig. 8B). After about November 15, late morning activity did not occur. However, this period contains data from only one animal for five days. Total minutes of activity during daylight (Fig. 8C) decreased from late August through November, as did the mean number of daylight activity periods (Fig. 9).

Figure 8. Activity of muskrats 1902, 1905, 1912 and 1916, combined, during daylight from August 1 to November 30, 1969. Numbers in parentheses indicate number of periods in sample.

A. Mean duration of late afternoon activity period.

B. Mean duration of late morning activity period.

C. Mean number of minutes of activity during daylight.

D. Mean duration of all daylight activity periods combined.

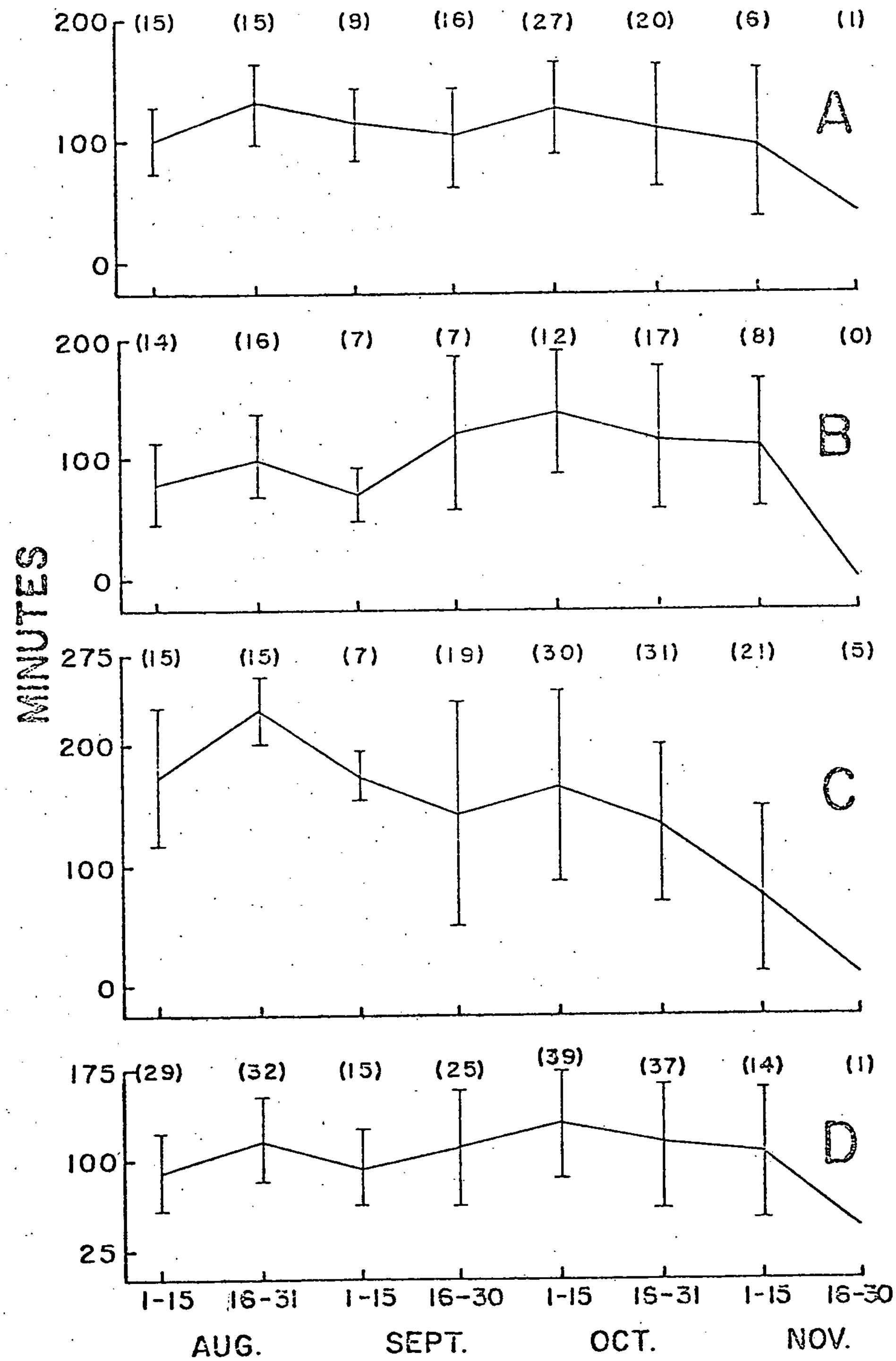
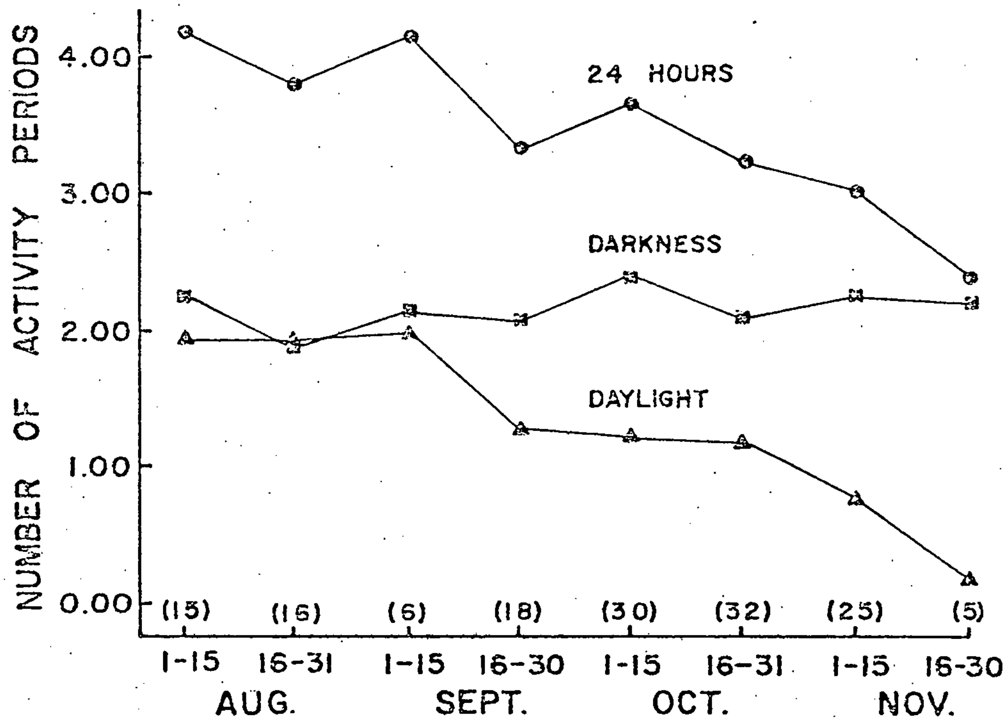

MINUTES
200
100
0
(15) (15) (8) (16) (27) (20) (6) (1)
A
200
100
0
(14) (16) (7) (7) (12) (17) (8) (0)
B
275
200
100
0
(15) (15) (7) (19) (30) (31) (21) (5)
C
175
100
25
(29) (32) (15) (25) (39) (37) (14) (1)
D
1-15
16-31
1-15
16-30
1-15
16-31
1-15
16-30
AUG.
SEPT.
OCT.
NOV.

Figure 9. Mean number of activity periods: per 24 hours, daylight, and darkness for muskrats 1902, 1905, 1912 and 1916 from August 1 to November 30, 1969. Sample sizes in muskrat days are given in parentheses.



NUMBER OF ACTIVITY PERIODS
4.00
3.00
2.00
1.00
0.00
24 HOURS
DARKNESS
DAYLIGHT
(15)
(16)
(6)
(18)
(30)
(32)
(25)
(5)
1-15
16-31
1-15
16-30
1-15
16-31
1-15
16-30
AUG.
SEPT.
OCT.
NOV.

Mean duration of all darkness activity periods increased about one hour over the study period (Fig. 10C). The early morning darkness period was generally longer than the evening period (Fig. 10A, B). Mean number of minutes of activity during darkness increased through the study period (Fig. 11) from 425 in early August to 640 by late November. However, the number of activity periodsduring darkness did not show a corresponding increase (Fig. 9). This suggests that the muskrats increased the length of their activity periods during darkness as the length of the night increased rather than increasing the number of activity periods during darkness. This is in marked contrast to their response to shorter day length; i.e. elimination of daylight activity periods rather than a shortening of period length.

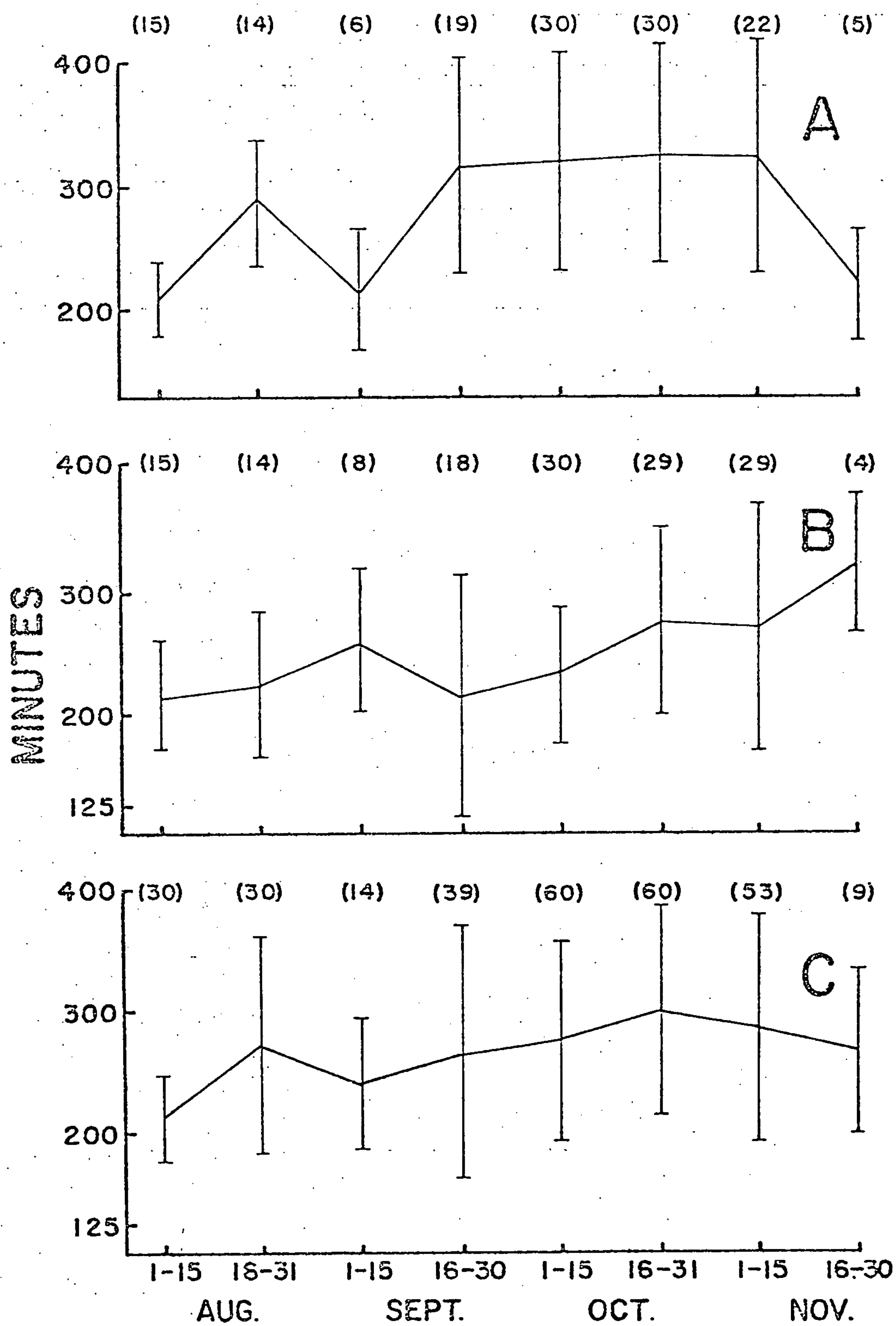
Figures 8 through 11 involve only those four animals that yielded nearly continuous data. Total activity per 24 hours was calculated for the other 12 muskrats even though data were not complete. Mean activity per 24 hours for all 16 animals is presented in Figure 11. A pronounced increase in activity during August and a decrease in late October and November is indicated. Even though no data are available to show patterns of activity prior to August, one can speculate that the increase in August and continued high levels of activity in September and October represent the period of preparing for winter; i.e. food storage and house construction. The decrease corresponds to onset of winter at this latitude, which is characterized by low temperatures and

Figure 10. Activity of muskrats 1902, 1905, 1912 and 1916, combined, during darkness from August 1 to November 30, 1969. Numbers in parentheses indicate number of periods in sample.

A. Mean duration of early morning darkness activity period.

B. Mean duration of evening darkness activity period.

C. Mean duration of all darkness activity periods, combined.



A
B
C
MINUTES
400
300
200
125
(15) (14) (6) (19) (30) (30) (22) (5)
(15) (14) (8) (18) (30) (29) (29) (4)
(30) (30) (14) (39) (60) (60) (53) (9)
1-15 16-31 1-15 16-30 1-15 16-31 1-15 16-30
AUG. SEPT. OCT. NOV.

Figure 11. Mean number of minutes of activity during darkness for muskrats 1902, 1905, 1912 and 1916 from August 1 to November 30, 1969. Numbers in parentheses indicate muskrat days in sample.

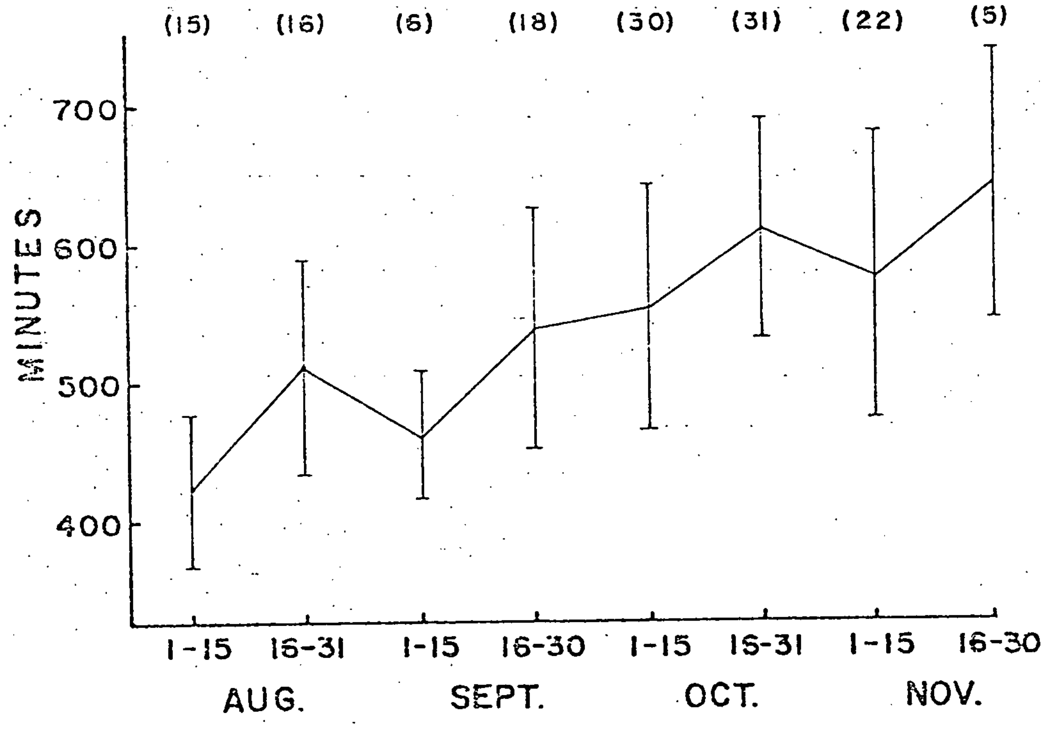
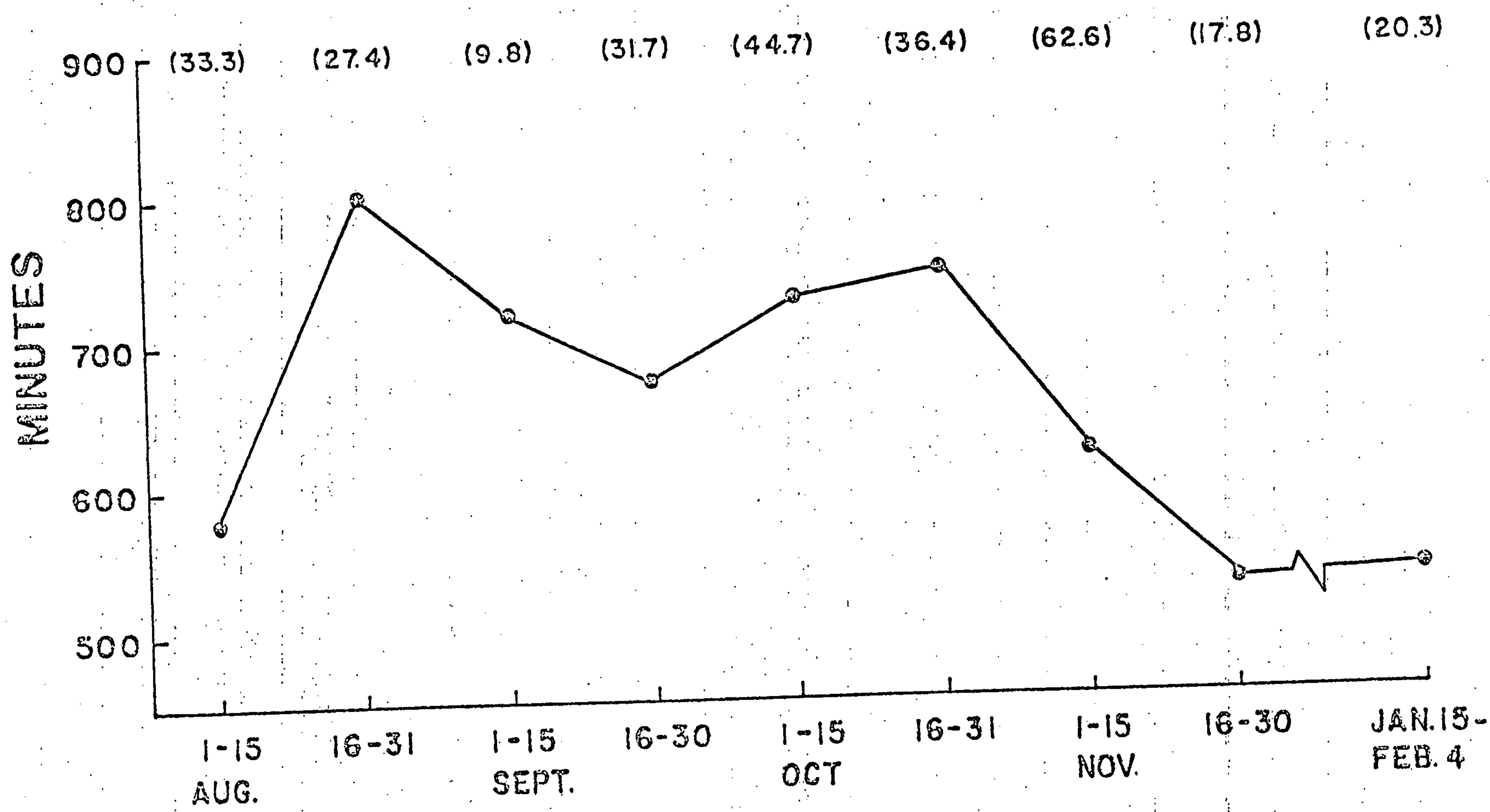

(15)
(16)
(6)
(18)
(30)
(31)
(22)
(5)
700
600
500
400
MINUTES
1-15
16-31
1-15
16-30
1-15
16-31
1-15
16-30
AUG.
SEPT.
OCT.
NOV.

Figure 12. Mean number of minutes of activity per 24 hours from August 1, 1969 to February 4, 1970. Numbers in parentheses indicate muskrat days in sample.



MINUTES
900
800
700
600
500
(33.3)
(27.4)
(9.8)
(31.7)
(44.7)
(36.4)
(62.6)
(17.8)
(20.3)
1-15
AUG.
16-31
1-15
SEPT.
16-30
1-15
OCT
16-31
1-15
NOV.
16-30
JAN.15-
FEB. 4

short days. Muskrats are no longer able to gather food or build houses after the marshes and streams freeze, and consequently reduce their total daily activity.

MOVEMENTS

Location data on muskrats were obtained in three areas: Cedar Creek, the Peterson Marsh, and the marshy shore on the west side of Fish Lake. A portion of Cedar Creek, .66 mile straight line distance or 1.5 miles of creek, was in the high accuracy area of the telemetry system (Heezen and Tester 1967). Muskrats outside this area and those on the marsh and Fish Lake were located with portable tracking receivers.

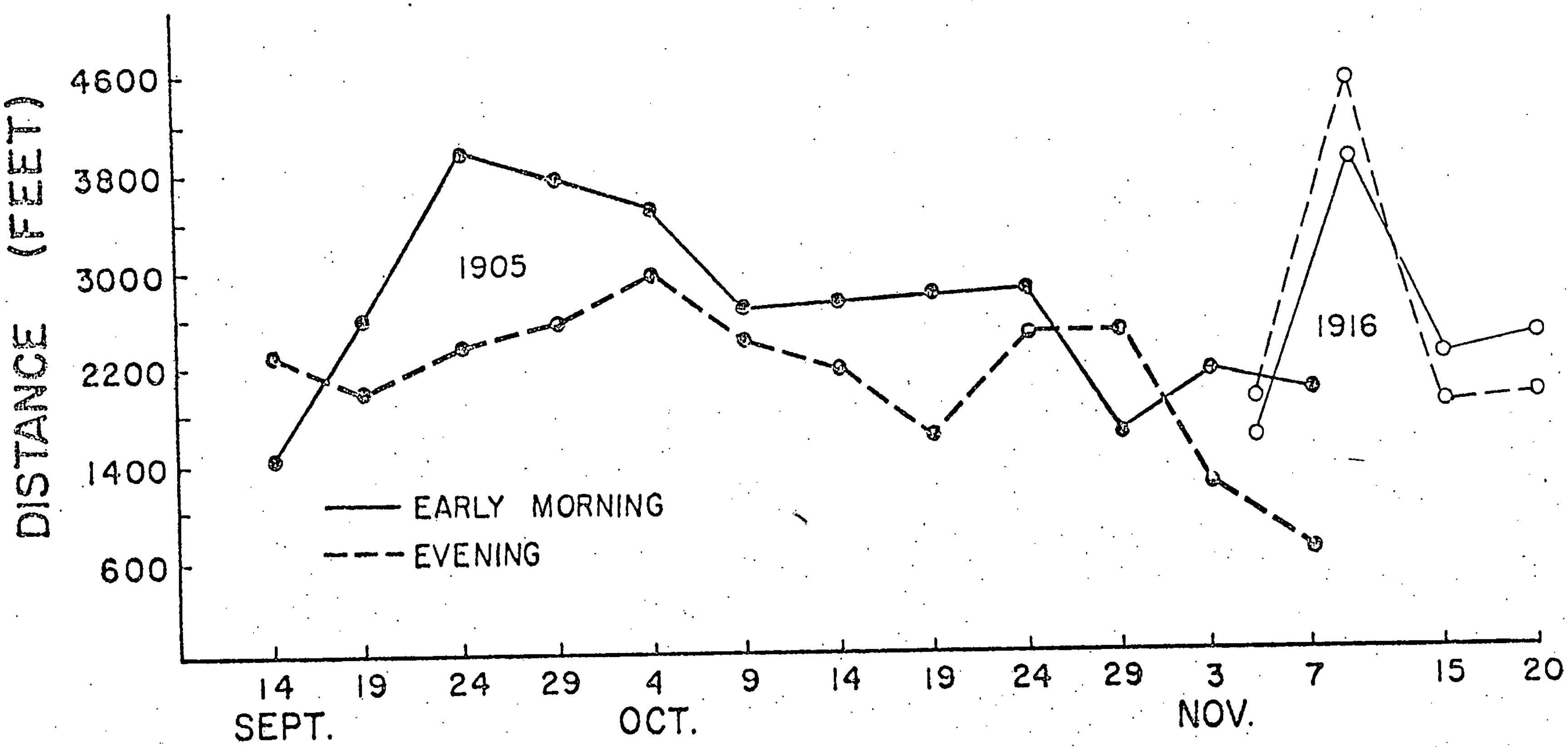
Two muskrats lived wholly within the high accuracy portion of the creek and four others used it at certain times. To evaluate movement patterns of the two muskrats in the high accuracy area, fixes were plotted whenever the animals moved along the creek. Movements were described by measuring distances moved and length of creek used during each activity period (Figs. 13 through 16). On occasion an animal would have the same fix throughout an activity period. Due to the inherent system error of 200 feet in this area of Cedar Creek, minimum movement was arbitrarily set at 200 feet. The distance moved figure would therefore be minimal because movements within a 200 foot area would not be included.

In order to use this method of evaluation, the assumption was made that muskrats were not traveling overland and that movements were all or nearly all confined to the creek. Some evidence supports this assumption. First, fixes plotted during a trip follow sharp bends in the creek quite closely. Second, field observation failed to disclose overland muskrat paths across creek meanders. Muskrat sign found away from the creek was in sedge mat areas where springs entered and was generally not more than 30 yards from the creek. Third, telemetry system fixes occurring away from the creek were distributed evenly within the error zone on either side of the creek. Occasionally, a fix placed the animal further from the creek; however, fixes immediately before or after did not confirm movement to these locations. In a few instances travel away from the creek did occur. These movements are described below.

Data in Figures 13 through 15 separate movements made during each of two nightly activity periods in the same manner as the activity analysis. Distance traveled by 1905 (Fig. 13) was generally greater during the early morning activity period than during the evening period. However, when rate of travel is computed, a figure that takes into account activity period length, the patterns are more similar (Fig. 14). A close similarity existed between activity periods for length of creek used (Fig. 15).

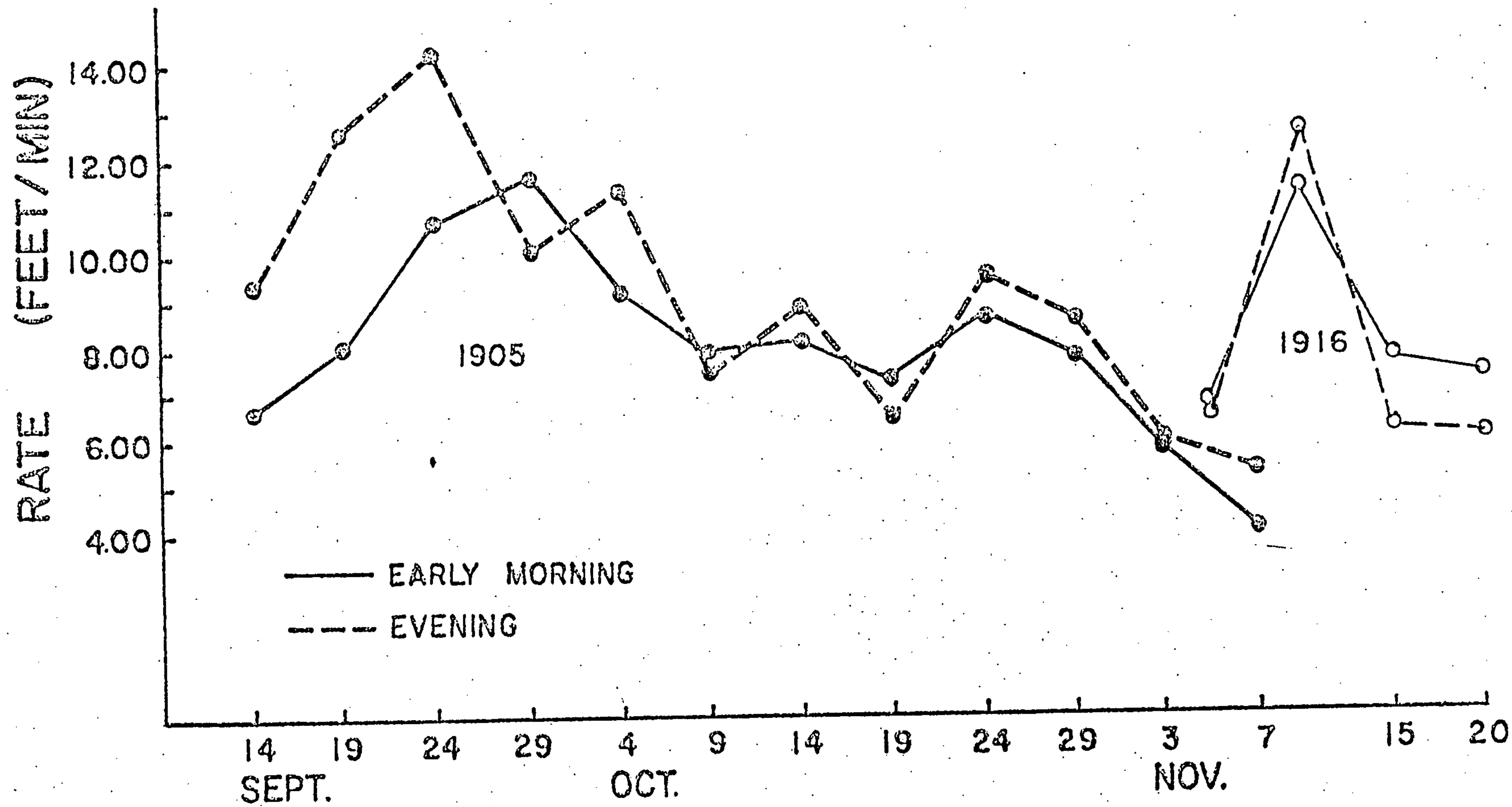
When night totals for 1905 are considered (Fig. 16), distance traveled and length of creek used were at a high level from about September 19 to October 4 and were declining to low levels when monitoring terminated. The initial increase began about the same

Figure 13. Distance traveled per nightly activity period for muskrats 1905 and 1916 from September 9, 1969 to November 20, 1969. Distances are 5-day means.



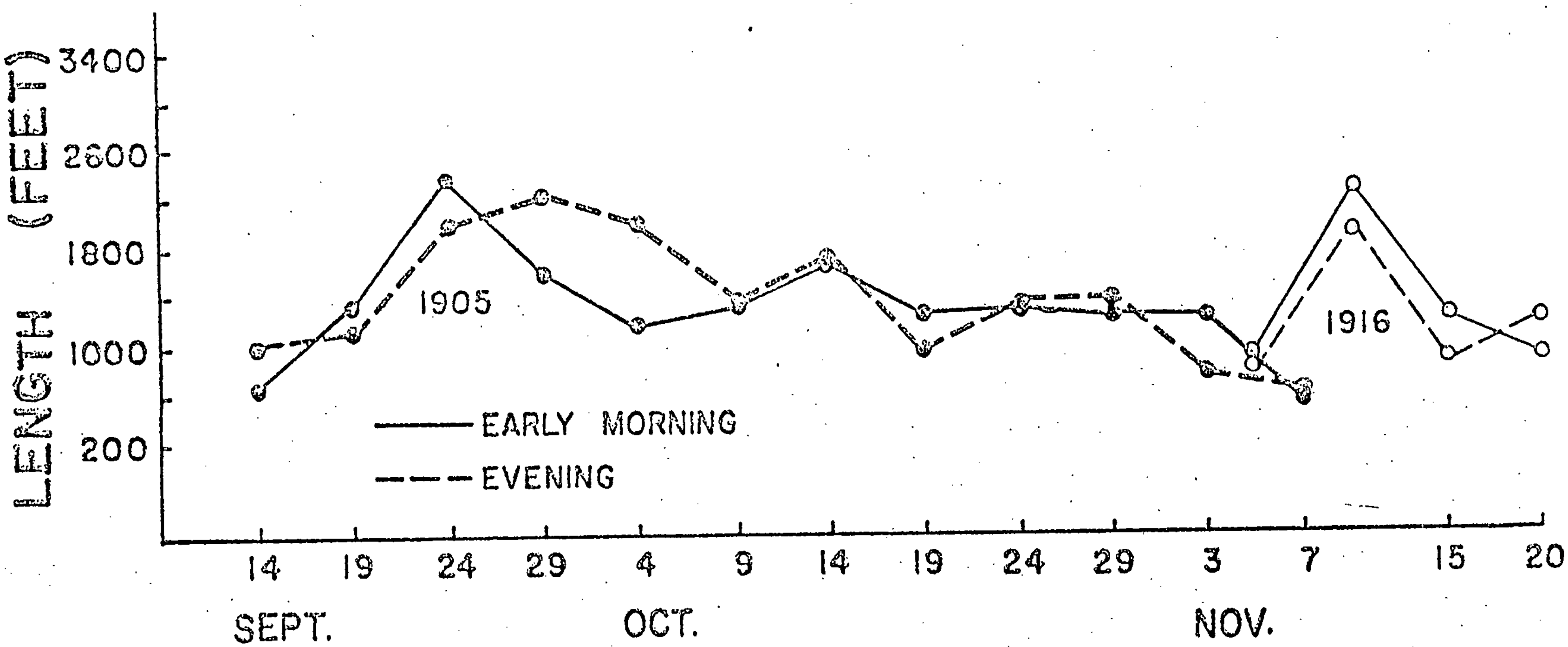
DISTANCE (FEET)
4600
3800
3000
2200
1400
600
1905
1916
EARLY MORNING
EVENING
14
19
24
29
4
9
14
19
24
29
3
7
15
20
SEPT.
OCT.
NOV.

Figure 14. Rate of travel per nightly activity period for muskrats 1905 and 1916 from September 9, 1969 to November 20, 1969. Rates are 5-day means.



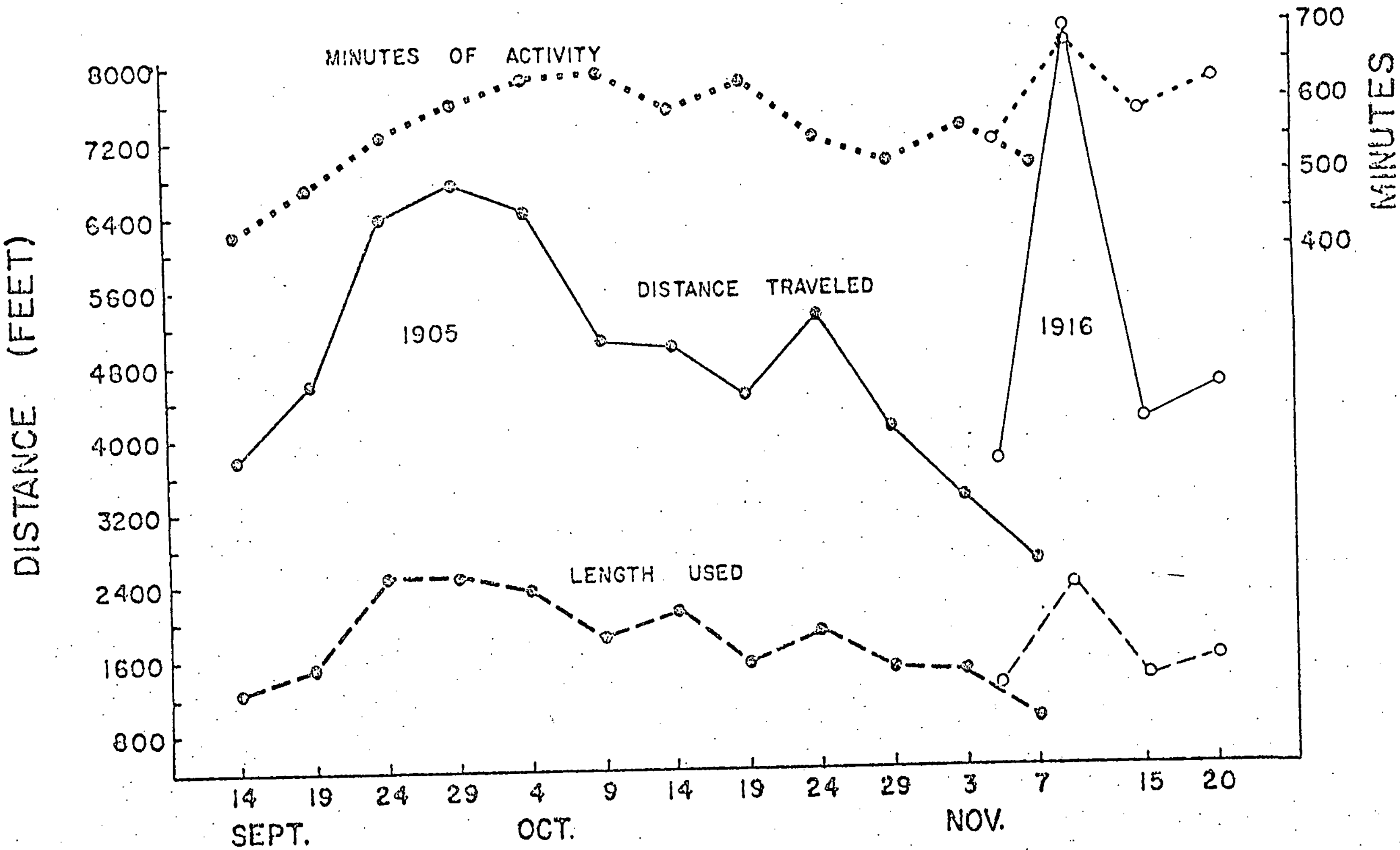
RATE (FEET / MIN)
14.00
12.00
10.00
8.00
6.00
4.00
1905
1916
EARLY MORNING
EVENING
14
19
24
29
4
9
14
19
24
29
3
7
15
20
SEPT.
OCT.
NOV.

Figure 15. Length of creek used per nightly activity period for muskrats 1905 and 1916 from September 9, 1969 to November 20, 1969. Lengths are 5-day means.



LENGTH (FEET)
3400
2600
1800
1000
200
1905
1916
EARLY MORNING
EVENING
14
19
24
29
4
9
14
19
24
29
3
7
15
20
SEPT.
OCT.
NOV.

Figure 16. Minutes of activity, distance traveled, and length of creek used for animals 1905 and 1916 from September 9, 1969 to November 20, 1969. Figures are night totals and are 5-day means.


MINUTES OF ACTIVITY
DISTANCE TRAVELED
LENGTH USED
1905
1916
DISTANCE (FEET)
MINUTES
8000
7200
6400
5600
4800
4000
3200
2400
1600
800
700
600
500
400
14 19 24 29 4 9 14 19 24 29 3 7 15 20
SEPT.
OCT.
NOV.

time that one daylight period was dropped (see Fig. 3). Minutes of activity, while increasing until October 9 and generally decreasing thereafter, did not show an obvious relationship to distance traveled or length of creek used.

Data for muskrat 1916 also showed very little difference between activity periods (Figs. 13 through 15). Figures were similar to those of 1905 except for the first five days of November when a marked increase occurred. No explanation of this was immediately apparent. However, weather may have had an influence. Average hourly night temperatures were 38°F or higher from the nights of November 4-5 through November 10-11. Five-day means are used in Figures 13 through 16. When individual nightly figures for distance traveled, length of creek, and minutes of activity are examined, distance traveled and length of creek used by 1916 were high from November 4-5 through November 12-13. Minutes of activity per night were high from November 5-6 through November 12-13. However, 1905 showed an increase in the three parameters only on November 5-6. Movement data for 1905 from September and October showed no apparent relationship to temperature or other weather factors. It is felt that the November data for 1916 are not conclusive.

It was not possible to analyze movements during daylight periods in the same manner as the darkness periods. Movements during daylight were often short and thus location data were not as reliable because system error could account for a larger portion of the observed movement. Therefore, data were analyzed by plotting fixes over varying numbers of days. Maps showing areas where activity occurred are presented in Figures 17 through 19 for 1905 for the period September 9 to November 9. Major activity areas are those where fixes were concentrated and show where the animal spent most of its time while active. While the overall length of creek used remained approximately the same, the center of night activity moved to the north during the latter part of September (Fig. 17). Resting areas were nearly the same for daylight and darkness periods. Daylight movements were much more confined and also shifted to the north.

Another area shift occurred in mid-October when 1905 began using two areas at night; one of which was located in the southern part of its home range (Fig. 18, 19). This appeared somewhat habitual in that 1905 made nightly trips downstream and back in about the same number of minutes each night. By November no single area was used more than any other at night. Daylight movements were within the same area used at night and in November they were split into two centers (Fig. 19).

Animal 1916 had a somewhat similar pattern in November; i.e. no essential change in total area but a shift in degree of use from one ten-day period to the next (Fig. 20).

Denning or places where resting occurred were not confined to one specific place for either animal, although 1905 used one creek bend more than any other and 1916 had two rest locations. From September to November 1905 used eight different resting locations. In two instances, during mid-October, this animal used resting locations during daylight that were not used during darkness.

Figure 17. Home range of muskrat 1905 from September 9 to September 27, 1969. Horizontal hatching is resting locations for the period September 9–16; vertical hatching for the period September 18–27.

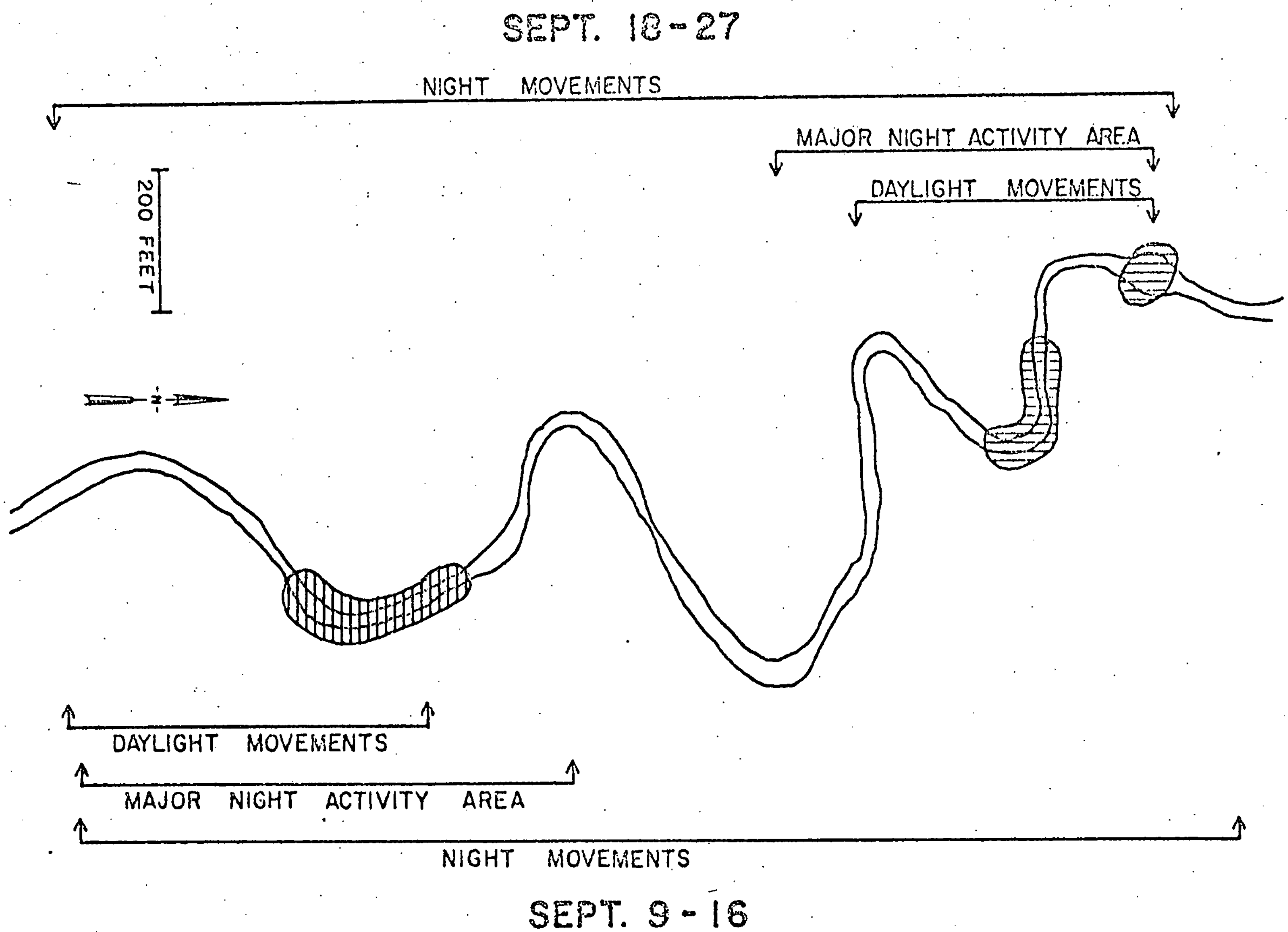

SEPT. 18 - 27
NIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
DAYLIGHT MOVEMENTS
200 FEET
N
DAYLIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
NIGHT MOVEMENTS
SEPT. 9 - 16

Figure 18. Home range of muskrat 1905 from September 28 to October 19, 1969. Horizontal hatching is resting locations for the period September 28 to October 9; vertical hatching for the period October 10-19.

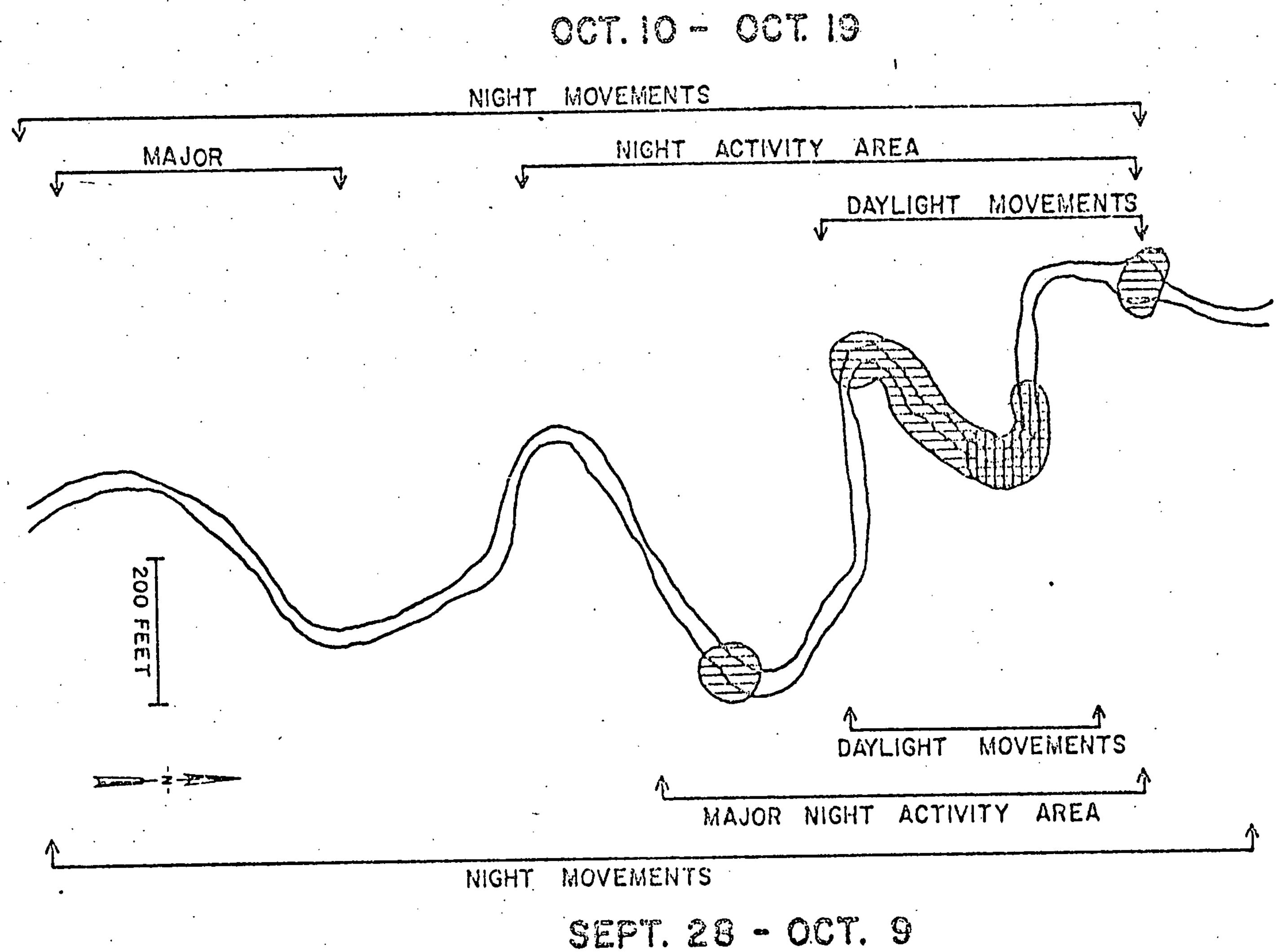

OCT. 10 - OCT. 19
NIGHT MOVEMENTS
MAJOR
NIGHT ACTIVITY AREA
DAYLIGHT MOVEMENTS
200 FEET
N
DAYLIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
NIGHT MOVEMENTS
SEPT. 28 - OCT. 9

Figure 19. Home range of muskrat 1905 from October 19 to November 8, 1969. Horizontal hatching is resting locations for the period October 19-27; vertical hatching for the period October 28 to November 8.

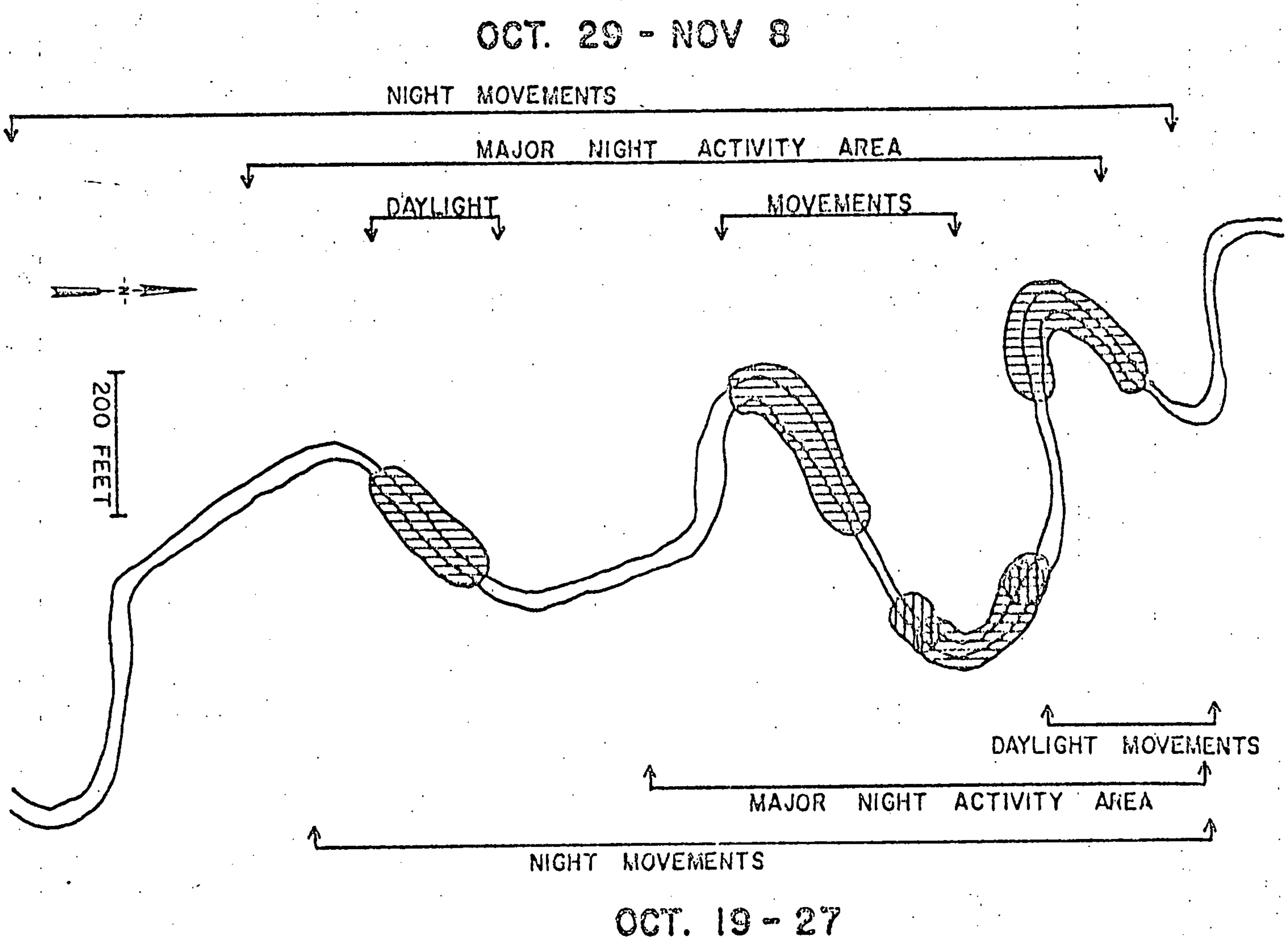
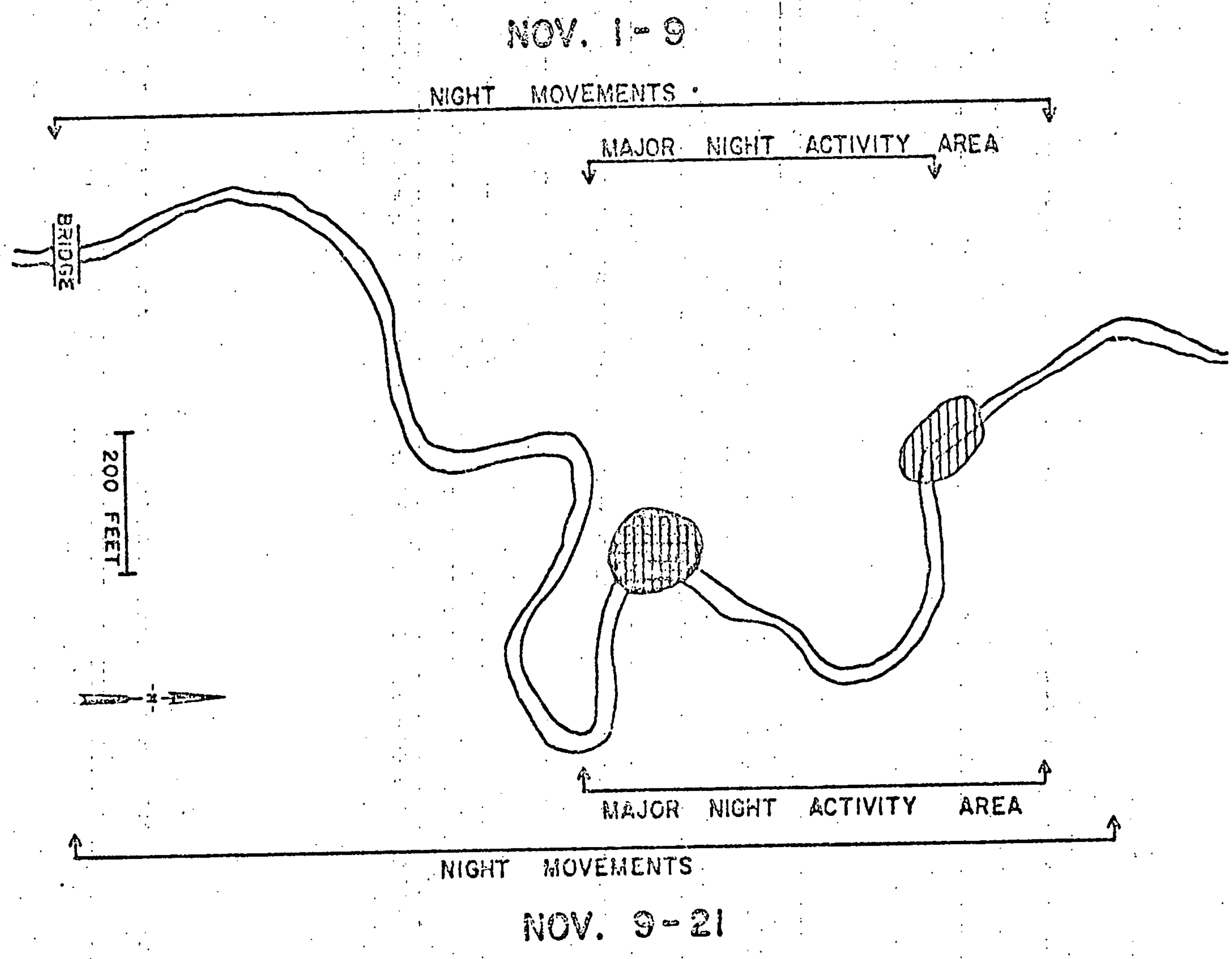

OCT. 29 - NOV 8
NIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
DAYLIGHT
MOVEMENTS
N
200 FEET
DAYLIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
NIGHT MOVEMENTS
OCT. 19 - 27

Figure 20. Home range of muskrat 1916 from November 1 to November 21, 1969. Vertical hatching is resting locations for the period November 1-9; horizontal hatching for the period November 9-21.


NOV. 1-9
NIGHT MOVEMENTS
MAJOR NIGHT ACTIVITY AREA
BRIDGE
200 FEET
MAJOR NIGHT ACTIVITY AREA
NIGHT MOVEMENTS
NOV. 9-21

Resting areas were determined from the automatic telemetry system and therefore could not be described as a den or burrow. However, when animals were occasionally checked during rest they were always found in burrows.

It is useful to compare Figure 16 and Figures 17 through 20. Lengths of creek used by the two muskrats as described in Figures 17 through 20 remained nearly the same while they were monitored, about 2700 feet, except for 1905 during one period (Fig. 19). The section of creek used changed little during the monitoring period. These maps best describe the home range of the animals. If 2700 feet can be considered home range size from September 9 to November 20 then "length used" in Figure 16 is a measure of degree of use of the home range over the time period. Muskrat 1905 was using most of its home range from about September 19 to October 4 and 1916 from November 5 to November 10.

Location data on five muskrats outside the high accuracy area were not accurate enough to permit detailed analysis. Four of these, 1901, 1902, 1903, and 1907, were near the south boundary of CCNHA and locations were recorded periodically with portable equipment. Telemetry system data were, however, useful in determining approximate limits of home ranges. Movements of these four animals were confined to a 2000 foot section of creek. Within this section is an artificial cut-off meander, formed during road building. Animals 1901, 1902, and 1903 were trapped in this meander and used it extensively. When this portion of the creek is included, the length of creek used was 2400 feet. This is comparable to the lengths of creek used by 1905 and 1916 (Fig. 16).

Use of resting areas by these four animals was also similar to 1905 and 1916. Since these animals were often checked with a portable receiver, specific den use was known. Each used several dens, especially in the meander. Movements of muskrat 1903, a young female, were more confined to the meander than those of any other animal.

Another muskrat, 1917, which could be monitored part of the time by the telemetry system, moved into an area not easily accessible with portable receivers. Incomplete data indicated use of a length of creek between 1600 and 2600 feet. More than one resting area was used.

A rough estimate can be made of available creek habitat based on knowledge of the type of habitat that was used by muskrats. This would include water surface, banks and preferred portions of adjacent sedge meadows. It would probably be within the range of .8 - 1.2 acres per 1000 feet of creek in the study area. Using this estimate, home range size for 1905 and 1916 would be from 2.2 to 3.2 acres.

Movements made within home ranges by muskrats on the Peterson Marsh were not extensive enough for the telemetry system to monitor. Fish Lake muskrats were beyond range of system monitoring. Because of these two factors locations were determined by the use of portable receivers whenever possible. Table 2 presents data on

Table 2. Lodge use by muskrats on Peterson Marsh and Fish Lake.

Animal Number	Number of Locations	Number of Lodges Used by Animal	Number of These Lodges Used by Other Animals	Number of Other Animals Using at Least One of These Lodges During the Same Time Period
1912	18	3	3	4
1913	11	3	3	4
1914	5	2	2	4
1915	8	3	3	4
1918	5	2	2	4
1921	5	2	1*	1
1922	12	1	1*	1
1923	3	1	0	0
1925	25	1	1	3
1926	32	2	2	3
1927	4	2	2	3
1928	8	2	2	3
1929	17	3	1*	1

*Animals without transmitters

lodge use and possible relationships among animals. Lodges were defined as muskrat constructions protruding substantially above the marsh or ice surface. Push-ups, small piles of vegetative matter pushed up through cracks and holes in the ice, are not included in this definition.

Most animals used more than one lodge, and lodges generally were used by more than one animal during the same time period. An exception to the former occurred during January and February of 1970 when animals 1922 and 1923 remained at the lodge where originally trapped until they died (see Table 1). On two occasions two transmittered muskrats were found together in a lodge.

Lodges in the Peterson Marsh were concentrated in deeper areas along the ditches, and those used during October and November by the first five animals in Table 3 were within a four acre area. Neither fixes from the telemetry system nor those obtained with a portable receiver showed these animals outside this area. It follows that the home ranges of these muskrats were smaller than four acres.

Animals 1925 through 1929 were monitored during February, March, and April. Most of their lodges were within the pool adjacent to Fish Lake. Animals were seldom far from the lodges they were using. When discovered out of lodges they were commonly found within dense cattail stands and occasionally in the pool. Beginning in March, the muskrats were out of lodges more frequently and were seen in the vicinity of push-ups. Some new push-ups were constructed along the pool edge about this time.

DISPERSAL AND HOMING

Movements outside normal ranges are summarized in Table 3. Of the 14 known movements, four were initiated by animals carrying transmitters. Data were gathered on the other 10 by visual observation, tracking, and placement of transmitters on animals that were already dispersing.

Seven movements occurred between August 20 and November 17, 1969. Water levels dropped at the beginning of this period. The entrance to a bank den used by 1903 was exposed between August 20 and August 25. This animal moved downstream on August 20.

Muskrat 1910 was trapped in a dry ditch connecting the Peterson Marsh and Cedar Creek while dispersing. Animal 1911, caught near the northern end of the study area, began dispersal-type movement the same day it was released. It remained at the release point from 1200 to 2100 hours, when it began moving. By 0150 hours on September 24 it had moved 8200 feet downstream. It remained active in a confined area until 0700 when it moved south out of system tracking range. By 2045 the muskrat had moved back into the reception area and by 2200 it was located 4200 feet upstream. It continued activity for one hour more after which the radio signal disappeared. Reception resumed 1.5 hours later and did not indicate movement. The transmitter was subsequently located but not recovered in deep water in a bend in the creek.

Telemetry system data indicated that 1905 left the creek on two occasions. On October 16 it began overland travel at midnight

Table 3. Dispersal type movements of muskrats, Cedar Creek Natural History Area, from September 1969 through April 1970.

Muskrat Number	Date Moving	Manner of Observation	Origin	Distance Traveled	Fate
1903	Aug 20	Transmitter	Creek	3/8 mile +	Traveled downstream, signal lost
1905	Oct 15	Transmitter	Creek	1000 feet	Left creek, went east, back to Creek about 5 hours later
1905	Oct 23	Transmitter	Creek	2400 feet	Left creek, went to Cedar Bog Lake, back to Creek 19 hours later
1907	Nov 12	Tag recovery	Creek	2-1/2 miles	Dog kill at farm
1910	Sept 22	Transmitter*	Pet. Marsh	1/2 mile +	Died at release point
1911	Sept 23	Transmitter	Creek	2-1/3 miles +	Traveled downstream, back upstream, fate unknown, possible predation
1920	Nov 17	Transmitter*, tracking	Pet. Marsh	2 miles	Died, possibly exposure
Observed	Jan 25	Visual, tracking	Pet. Marsh	1 mile	Reached Cedar Bog Lake, possibly survived

Table 3. Continued.

Muskrat Number	Date Moving	Manner of Observation	Origin	Distance Traveled	Fate
Observed	Mar 20	Tracking	Pet. Marsh	1/2 mile +	Left Peterson Marsh, went to Fish Lake Marsh, possibly survived. Entered snow in cattails near other muskrats
Observed	Mar 29	Visual tracking	Pet. Marsh	1-1/4 mile +	Left Peterson Marsh, went to Cedar Creek, possibly survived
1928	Apr 9	Tag recovery	Fish Lake Marsh	1/2 mile	Crossed Fish Lake, later killed by car on road adjacent to Fish Lake
1930	Mar 30	Transmitter*, tracking	Pet. Marsh	1-1/4 mile	Found at Cedar Creek Lab, placed in Cedar Creek, killed by mink two days later
Observed	Apr 5	Tracking	Pet. Marsh	1/2 mile +	Track lost after 1/2 mile over-land on sand road
1931	Apr 9	Transmitter*, tracking	Probably Pet. Marsh	2 miles +	Reached Grass Lake, possibly survived

*Known to be dispersing when transmitter was placed on the animal.

and moved east toward Cedar Bog Lake, a boreal-type bog lake surrounded by tamarack (Larix laricina), and white cedar (Thuja occidentalis) until 0300. At this point, when it was about 1100 feet east of the creek (about halfway to the lake), it reversed its direction and returned, arriving at 0450.

On October 24 at 0150 this animal again left the creek from the same point as on October 16. At 0305 it was at the easternmost point of the October 16 trip. By 0400 it had arrived at Cedar Bog Lake, a distance of 2200 feet from the creek. The muskrat made one trip around the lake in about 1.5 hours and ended activity at 0630. A one hour activity period with no location change occurred in the afternoon. At 1830 the muskrat left the west side of the lake, returned by nearly the same route, and arrived at the creek by 2100. Habitat along most of the route was alder, tamarack, and white cedar. Activity period times were not abnormal during either trip.

An unusual movement by a muskrat on January 25 was observed in detail. Light snow had fallen on a crust that morning and tracking conditions were ideal. The CCNHA Resident Manager, Alvar Peterson, informed me at 1215 that a muskrat was passing his residence. Subsequent backtracking, observation, and tracking revealed the muskrat's route. It had left a small lodge on the Peterson Marsh after the snow had stopped falling at 0930 and arrived at Cedar Bog Lake about 1415. Spoor indicated that the animal had entered cover at two places near the lodge before beginning movement. The straight-line distance from the lodge to the lake was one mile; the muskrat traveled about 1500 feet more than this. The weather was mild, about 30°F at noon.

Several other features of this travel were interesting. The muskrat did not enter heavy ground cover after leaving the cattails near the lodge, even though it passed within inches of holes into snow-covered grass clumps, until it arrived at Cedar Bog Lake. There it immediately entered a natural hole into a grass clump. Springs covered with snow were present at the lake edge. Three portions of its route followed man-caused features: a row of red pines (Pinus resinosa), a ditch and road, and a trail to Cedar Bog Lake. The route meandered very little, except for the first 200 yards after the animal had entered the white cedars surrounding the lake.

Six muskrats moved in March and April during the onset of warm weather. Complete thawing of ice occurred in the Peterson Marsh about April 15. These movements were similar to the spring dispersal described by many authors (Beer and Meyer 1951, Erickson 1963, Mathiak 1966, and Spruegel 1951). However, as seen in Table 3, some of these animals came from the Peterson Marsh and may have been forced to move out by poor habitat conditions.

It was possible to visually observe the behavior of three animals during dispersal. These animals appeared quite alert in that they occasionally paused, sat up, and moved their head back and forth as if sniffing the air and/or looking around. Other evidence of alertness was seen in the case of 1931 which traveled along a road on April 9 and 10. At one point, this animal jumped off the road into a clump of grass as a marsh hawk passed over. It stayed hidden in the grass for about six hours until dusk. By the next morning it had arrived at the edge of a grassy lowland containing water from melting snow. Twice, when closely approached with the portable receiver, the muskrat was found motionless and flattened out under cover. It stayed at the edge of the lowland for two days and then moved deeper into the lowland, arriving during the night of April 12-13 at Grass Lake, a marshy lake south of the CCNHA that contained good muskrat habitat.

At least six of the 13 muskrats had a tendency to follow roads during overland travel. Spoor showed that in most cases a muskrat began following a road as soon as the flat surface was encountered, although sometimes ditch travel preceded this.

Two muskrats were experimentally displaced upstream after being trapped. Animal 1907 was trapped at the southern end of the study area and released 7100 feet upstream at a bridge at 1800 hours on September 18, 1969. This is a straight-line distance of 4300 feet. In the first 48 hours after release it moved within an 1800 foot section of the creek around the release point. During the night of September 20-21 it made a 3600 foot trip upstream from the bridge. Movements during the following night were in the vicinity of the bridge. At about 2000 on September 22 it began moving rapidly downstream at the onset of evening activity and arrived in the vicinity of the original capture point about 2200, having traveled about 7000 feet.

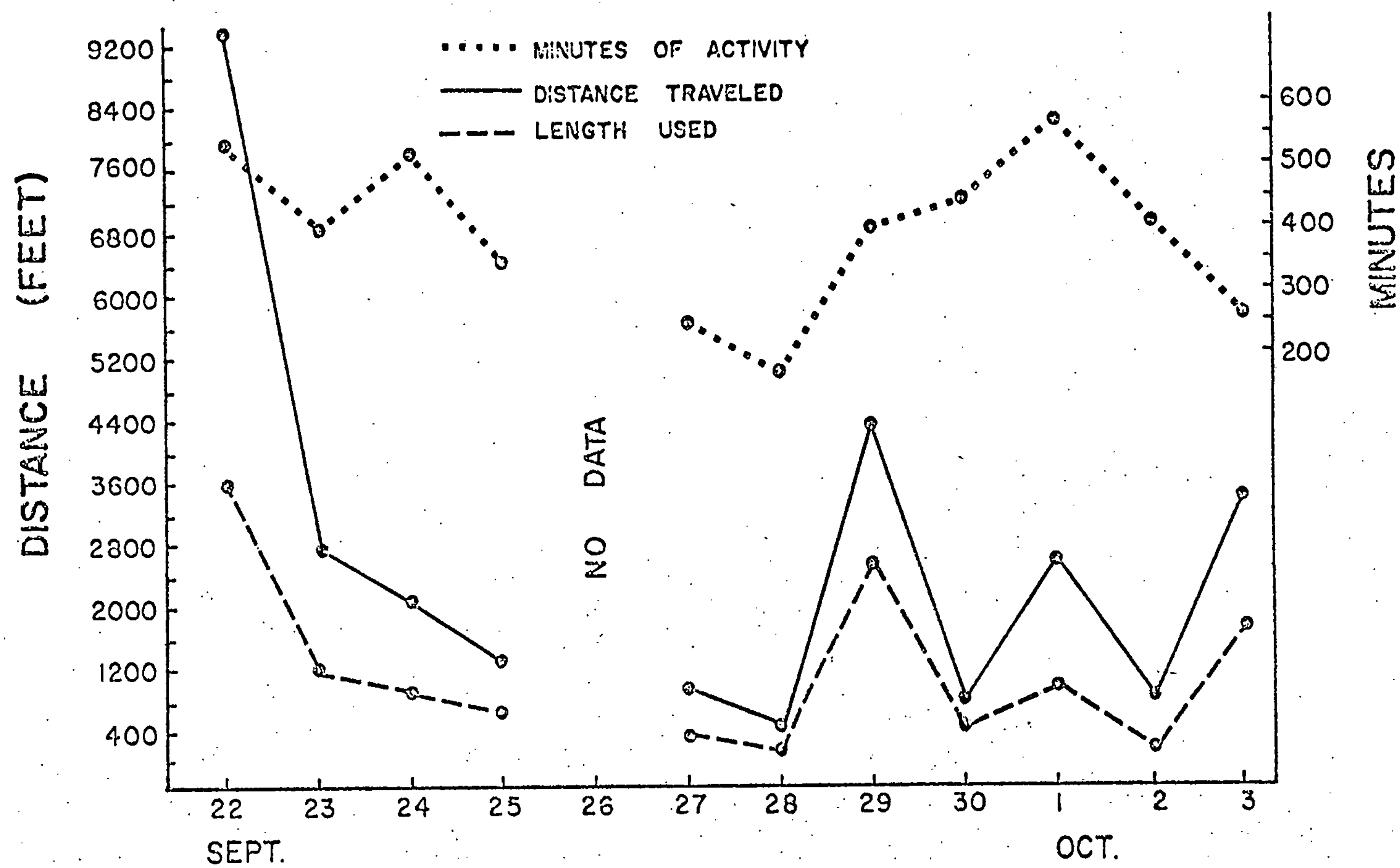
On September 24, 1907 was recaptured and released at 0930 at a point 9800 feet upstream. It remained in this area until 1900, then moved downstream. By 2215 it had returned to the point of capture. The most rapid travel was at the beginning of the trip when a distance of 3500 feet was covered in 36 minutes.

No weight change occurred between captures. The second release was within the area encountered by the muskrat during the trip upstream on the night of September 20-21. Daily activity periods occurred at normal times during the displacements.

Muskrat 1909 was caught September 22 in the same place as 1907 and was also released at the bridge. It remained near the bridge until October 4 when it returned to the vicinity of the original capture; the return trip beginning at 1230 and ending at 1600. On the night of October 5-6 it moved about 1000 feet into a sedge meadow connected to the creek and remained there until killed by a mammalian predator, probably a fox, about October 10.

Data on this muskrat before it returned downstream (Fig. 21) indicate lesser amounts of nightly activity, distance traveled, and length of creek used compared with other muskrats. Daylight activity was greater (see Appendix A, Fig. 3) but daylight movements were largely confined to a small area as in other muskrats.

Figure 21. Movements and activity during darkness of muskrat 1909 after displacement from September 22 to October 3, 1969.



MINUTES OF ACTIVITY
DISTANCE TRAVELED
LENGTH USED
DISTANCE (FEET)
9200
8400
7600
6800
6000
5200
4400
3600
2800
2000
1200
400
MINUTES
600
500
400
300
200
NO DATA
22
23
24
25
26
27
28
29
30
1
2
3
SEPT.
OCT.

MORTALITY AND PREDATION

Mortality became an important factor during the study and three main contributing factors appeared: handling, predation, and habitat conditions.

Death in traps and during handling occurred in three instances. Early death after release appeared directly related to handling in four animals (Table 1). Factors that increased the possibility of handling mortality were poor condition, holding overnight, and age; young or old animals were more susceptible. In five of the seven instances of early death one or more of these circumstances was present.

In other cases handling may have been a factor in early death but was not the direct cause. For example, data on 1906 and 1911 indicate probable death one and two nights, respectively, after release. Activity records showed unusual and rapid movement for a short period of time after which the signal was lost. Reception resumed several hours later with no activity. Both transmitters were located in deep water and mud at sharp bends of the creek and neither was recovered. Predation, as suggested by the unusually rapid movement, may possibly have occurred.

Predation became important on the Peterson Marsh in late fall. After snowfall and freeze-up in late November sign indicated that mink (Mustela vison) were present. On December 2 the remains of four muskrats were found in a large lodge in a shallow part of the marsh. Three of these carried transmitters, 1913, 1914, and 1918, and were partially or wholly eaten; the fourth was mostly decomposed but apparently intact. Data indicate dates of death of the transmittered muskrats as November 30, 15, and 26 respectively. The oldest kill was nearly consumed, with only a few bones and hair left; the hide, skull, hindquarters, and intestine of 1918 remained; and only part of the neck and chest of 1913 had been eaten.

During December and early January mink sign was very abundant in the marsh. Muskrat tracks also were found in the snow and entry holes in the ice were found near lodges. Mink sign consisted of numerous tracks throughout the marsh and burrows around bases of lodges.

By the middle of January mink sign became uncommon. Three probable mink kills were found in January; one was 1923. The transmitter and a few muskrat hairs were found buried deep within a lodge. The remains of the other two muskrats were found in lodges that were opened for trapping purposes. The lodges were frozen and time of death was unknown.

Mink sign was observed occasionally in the Peterson Marsh and Fish Lake until the spring melt. During March and April there was an increase in mink visitation of Fish Lake. On March 3 a muskrat kill and several mink scats were found next to a lodge in a collapsed snow tunnel uncovered by melt. This lodge and another about 200 feet away were frozen and had small mink-sized holes in several places.

Red fox (Vulpes fulva) sign was common on the marsh and Fish Lake throughout the winter. On most occasions foxes appeared to inspect lodges, but did not dig into them. The remains of a muskrat, 1922, were found February 3 on top of the snow 75 yards from the lodge it had occupied the previous day. The lodge was not molested. The condition of the remains indicated a fox had killed or found it dead. In early March a fox or small dog (Canis familiaris) had dug into a lodge and tunnel system on Fish Lake. A fox scat containing muskrat remains was found on top of this lodge.

Other mammalian predators in the marsh and Fish Lake areas through the winter, as indicated by sign, included dog, short-tailed weasel (Mustela erminea), domestic cat (Felis domestica), and raccoon (Procyon lotor). A raccoon dug into a frozen lodge on Fish Lake in early March.

During the cold months lodges were judged to be unoccupied if the interior was frozen when opened or froze after a trap was put in place. In most cases a muskrat's presence was discovered on the first few nights after trap placement. Plugging of the trap hole was very common, especially on the colder nights, if muskrats were present. Lodges opened for trapping that showed no activity gradually frosted up inside or froze immediately. They probably contained no muskrats during the trapping.

Eight of 18 lodges on the Peterson Marsh were vacant by January 6. By the end of February traps had been placed in 13 of the lodges and five muskrats had been captured, all from three lodges. Possible activity was noted in two of the five other lodges. The muskrats that were captured came from lodges in the deep part of the Peterson Marsh.

Trapping results on the Peterson Marsh during January and February lead to the conclusion that heaviest mortality or emigration occurred before January 1.

In late March and early April examination of lodges throughout the marsh revealed no clear evidence of muskrat presence. The interiors of several lodges had been reworked since January and February but were frozen. It appeared as if a muskrat had visited the lodge but had not remained. However, four and probably five muskrats dispersed from the marsh in early spring (Table 3). Backtracking of one muskrat led to a small lodge, not previously discovered, containing a small cavity in chewed cattail stalks and mud.

There were seven lodges on the western shore of Fish Lake; five large and two small. Three of the large lodges contained muskrats through early spring. The two that were apparently opened by mink and frozen were in shallow water along the shore.

Peterson Marsh and Fish Lake were checked for lodges in the fall of 1970. Only one lodge was found on the marsh and this was constructed on the spot where the three mink-killed muskrats were found on December 2, 1969. Four lodges on Fish Lake were constructed on top of 1969 locations and two were on new sites.

HABITAT USE

While phytosociological characteristics of habitats used were not measured, certain facets of this use became apparent. Muskrat dens were more numerous in bends of Cedar Creek. Food cuttings were almost always found in the sedge mat areas until late October. Use of these areas was terminated in November. Some use may have occurred under snow later in the winter. After snowfall and freeze-up muskrat sign was found only on ice edges and on floating platforms of sedges projecting into the creek.

Lodge location in relation to water depth was unclear on Peterson Marsh. Construction took place during September and October and was concentrated in the deepest part of the marsh in and near the ditches. However, some lodges were constructed in peripheral shallow areas after water levels had dropped.

Lodges on Fish Lake were located at edges of cattail stands and in shallow water within cattail stands along the main shore.

Evidence was found during the winter that muskrats made use of snow tunnels on the ice. On January 29, 1970 a lodge on the edge of Fish Lake had an ice-lined hole to the exterior leading to a snow tunnel around the base of the lodge. At least four tunnels led away in the direction of nearby cattails. The tunnels were about five inches in diameter and the tunnel floor was a groove in the ice about one-half inch deep. On February 1 a fresh tunnel in the snow was started but not extended. It became very cold after this and the exterior opening was plugged and not opened again.

Three other tunnel systems were found at push-ups. One of these was used by muskrat 1925 which was trapped in a large lodge across the pool. The muskrat moved to the push-up the day after being trapped and was found there from February 7 to March 2. This push-up, which was under about three feet of snow, had three tunnels leading into cattails. The two other push-ups were also in cattails at the other end of the pool. Another muskrat, 1927, was located once in each of these. One push-up, freshly enlarged on March 25, had three tunnels leading from it; the other had two. Snow melt at this time revealed tunnels leading in a meandering course to about 40 feet from the latter push-up.

On March 3, during a melt, sign indicated that a dog or fox had been digging into a tunnel system adjacent to a lodge on the edge of Fish Lake. This system, which appeared similar to the one found on January 29, had five tunnels. The interior of the tunnels was crusted and in some places ice-lined. The lodge was frozen and open at the time. A search was made during snow melt in late March but no other tunnel systems were found on the Peterson Marsh or Fish Lake. Melt may have obscured sign.

DISCUSSION

Muskrats on the three study areas were exposed to different habitat and environmental conditions. Cedar Creek muskrats were located in a more stable habitat with extensive old burrows and apparently secure winter habitat. This situation was similar to that described by Errington (1941) for certain stream dwelling muskrats in Iowa. However, lack of food along the creek probably resulted in a low density of animals.

Peterson Marsh muskrats had abundant food and water until late August when favorable habitat began shrinking due to dropping of water levels. Errington (1963) states that muskrat response at these times is concentration in areas with deeper water. Muskrat food cuttings had been noted in all parts of the marsh earlier in the summer. Lodge construction apparently reflected the muskrat concentration in the deeper part of the marsh.

Evidence for early winter loss of muskrats was strong. Lodges that contained muskrats in October and early November were frozen in late December and early January. Errington (1963) mentioned that muskrat sign outside lodges in the winter is indicative of the animals being in a precarious position and susceptible to mink predation. This situation apparently began with the onset of winter in 1969. However, since food was abundant and freezing had not affected its availability an emergency situation did not exist. Possibly the muskrats that moved in from dryer parts of the marsh did not become well-situated by freeze-up and therefore were vulnerable.

By late January ice in the marsh had reached into the mud. Muskrats captured were underweight and were probably being subjected to a shortage of food. An emergency situation appeared to exist at this time.

Muskrats were present on the western shore of Fish Lake through the winter. The major difference in habitat compared with the marsh was the availability of water around and/or under lodges. However, two lodges, mentioned with reference to being opened by mink, were in shallow areas and provided a good contrast with those in the nearby pool. Errington (1943) reported, however, that evidence of mink boring into lodges does not necessarily mean predation. Indications were that muskrats used only lodges that were at water-cattail edges through the winter. Early lodges in less desirable areas may have been abandoned in preference to these.

Errington (1943, p. 865-871) observed snow tunneling by muskrats but attributed it to transient or poorly situated animals and to emergencies. Snow tunneling apparently was done by the best situated animals in the present study and tunnels were used extensively over a period of time.

Movements of muskrats have been described by many authors (Errington 1963, Erickson 1963, Shanks and Arthur 1952, Seabloom 1958, Mathiak 1966). Home ranges in marshes were generally considered to be small. This study indicates that daily movements in marshes became more and more restricted as fall progressed and winter began. Home ranges were smaller than four acres.

Muskrats on Cedar Creek seemed to have quite large home ranges. However, a rough area estimate of creek habitat showed that creek and marsh home ranges were comparable. The boundary of either end of the home range appeared to be fixed but intensity of use within varied. The fact that areas containing food were not extensive probably influenced size of home range.

Unusual movements from the study areas cannot be fully explained by the data. Some dispersal occurred when water levels fell and den entrances were exposed. However, Errington (1963), in discussing response to drought, mentioned the muskrat's ability and tendency to modify burrows to reflect water levels. Several feet or more of water were available in Cedar Creek and since banks in most places were vertical to the stream bottom, new entrances could easily have been made. Three of four animals dispersing from the creek in the fall were young. It is possible that these animals had not yet become established.

The two movements away from the creek by 1905 are less easily explained. This animal was in good habitat and the location data indicated a well-defined home range and movement pattern. After each return the animal showed no change in its activity pattern or movement.

Peterson Marsh animals that left in the fall were not under emergency conditions, but may have dispersed due to concentration of animals and the resulting strife, as reported by Errington (1963) for muskrats under similar conditions in Iowa. Dispersal during the winter and early spring contributed to the near depopulation of the marsh and was probably due to adverse conditions.

Behavior during dispersal was interesting. Muskrats throughout their range are exposed to conditions that make overland travel commonplace for the species. The alertness, aggressiveness and routes of travel of the animals possibly indicate an evolutionary response to the common occurrence of this exposure to nonaquatic environments.

Survival of dispersing animals is also interesting. The distance between habitats suitable for muskrats in the area surrounding Cedar Creek is usually small. The muskrat that left Peterson Marsh in late January, under very adverse conditions, arrived at open water at Cedar Bog Lake where it probably would have been able to obtain food and cover until spring. Two other muskrats that left the marsh later also arrived at suitable muskrat habitat. The greatest period of danger for the muskrat might then be during the time required for it to become established in the new aquatic environment rather than the period of actual dispersal.

Road mortality is often mentioned in discussions of muskrat migrations and dispersals (Mathiak 1966). The inclination of muskrats to follow roads probably makes this phenomenon highly visible.

The effect of the transmitter on the animal could not be fully determined. However, other than some scratching while recovering from ether, animals did not appear to be distracted by the collar. They were observed swimming well and no abrasions or wearing of fur were found after three months, the longest that a transmitter was carried.

Early death in some animals is felt to be due to stress from trapping, handling and anesthesizing. Seabloom (1958) reported termination of trapping due to progressive weakness of the animals in areas where muskrats were successively recaptured and Shanks and Arthur (1952) found deaths due to trapping.

From trapping and handling experience during this study it is felt that traps should be checked at 4-6 hour intervals during both day and night. Ether should not be used as an anesthetic even though it was used with success in this study. Muskrats have recently been successfully anesthesized with metofane (S. Pierson, personal communication). No evidence of holding of breath was observed with this drug.

Activity patterns of the muskrat during late summer followed a polyphasic rhythm similar to that described by Saint-Girons (1966) for arctic mammals with major peaks of activity during darkness. However, there was a partial loss of this pattern as fall progressed and a bimodal pattern began developing. Similar bimodal patterns have been reported for other species (Aschoff 1966).

Aleksuik and Frohlinger (1971) demonstrated that growth in muskrats was slowed down during midwinter and hypothesized that increase in the size of the heart and lung was a response to hypoxic conditions in the muskrat's environment. Activity data from this study indicate that amount of activity falls off rapidly in late November and at the same time, there is a change in periodicity of activity. The few data collected by the automatic system on midwinter behavior indicate low activity levels and poorly defined peaks similar to those found by Stebbins (1971) in deer mice. Muskrats during this time, if they remain in the lodge or under the ice, are in nearly complete darkness. Field checks in January and february, although on only three animals, showed very restricted movements.

A comparison of activity data (Fig. 9) and movement data for 1905 and 1916 (Fig. 12 through 14) reveals little difference between the two nightly activity periods except that the early morning period was generally longer. However, daylight activity was different from darkness activity in that movements were more confined. This may only indicate that the animal was doing the same things during daylight but within a small area.

The change in activity patterns from late summer to winter may reflect the change from the summer reproductive period to a fall period of preparation for winter and to an inactive maintenance existence in the winter. For example, activity during August, characterized by four regular activity periods per 24 hours, may have some relationship to territoriality. Activity periods occurring irregularily over 24 hours later in the fall and especially in the winter may reflect the increasing amount of time spent within lodges and dens or under snow where food and cover are the main concerns.

Other factors that may influence activity and movement patterns are sex and age, relationships between animals, and habitat. The influence of weather factors on activity rhythms and movements could not be determined in this study. If a relationship exists it probably is complex and varies seasonally. Further investigations are needed to evaluate these potential influences. On CCNHA, stream habitat appears to provide the best site for future studies because of the accuracy of both location and activity data and the relative stability of habitat. In addition, the linear nature of the stream with its restricted food sources provides a somewhat simpler habitat in which to investigate interactions between muskrats and their environment.

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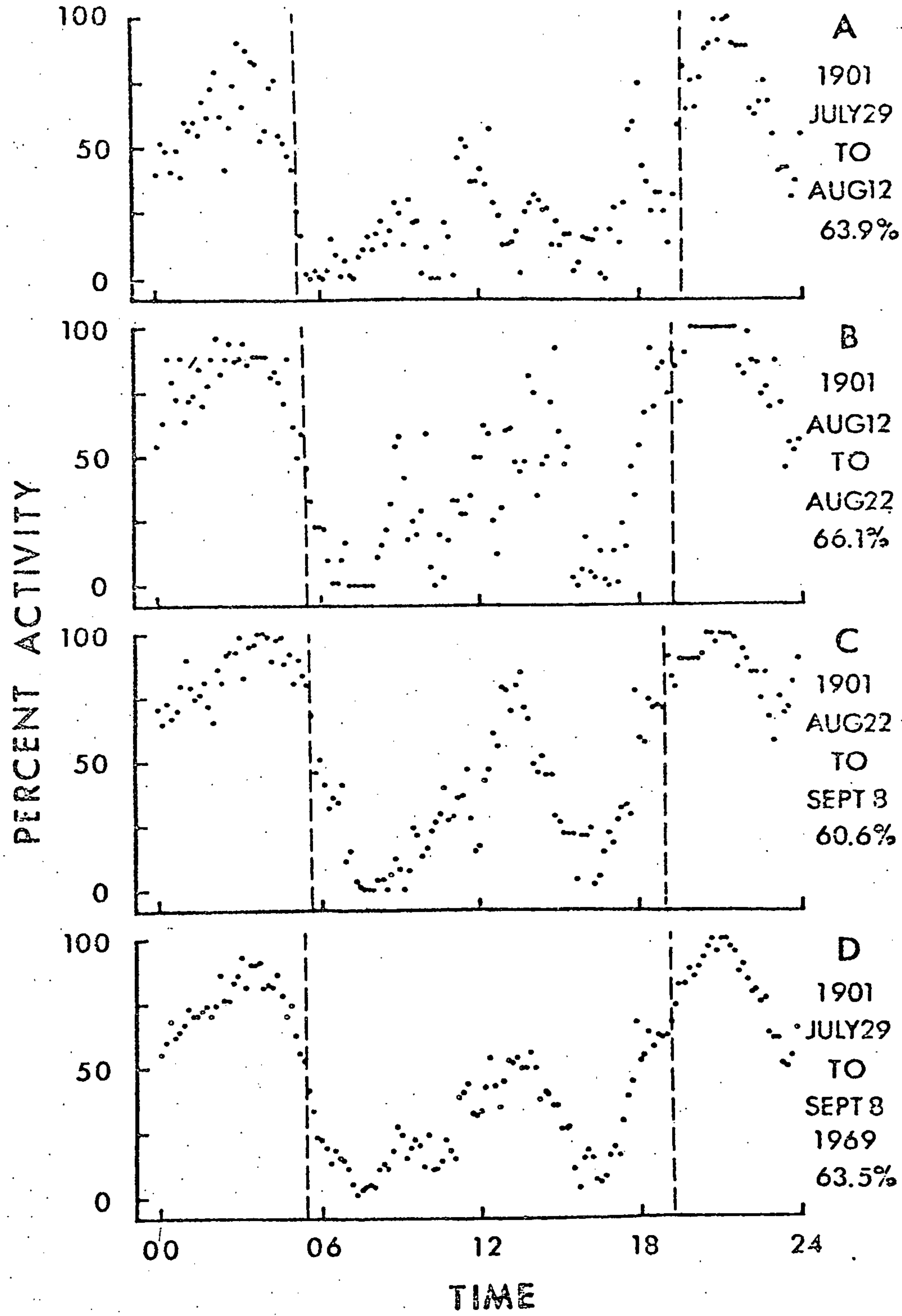
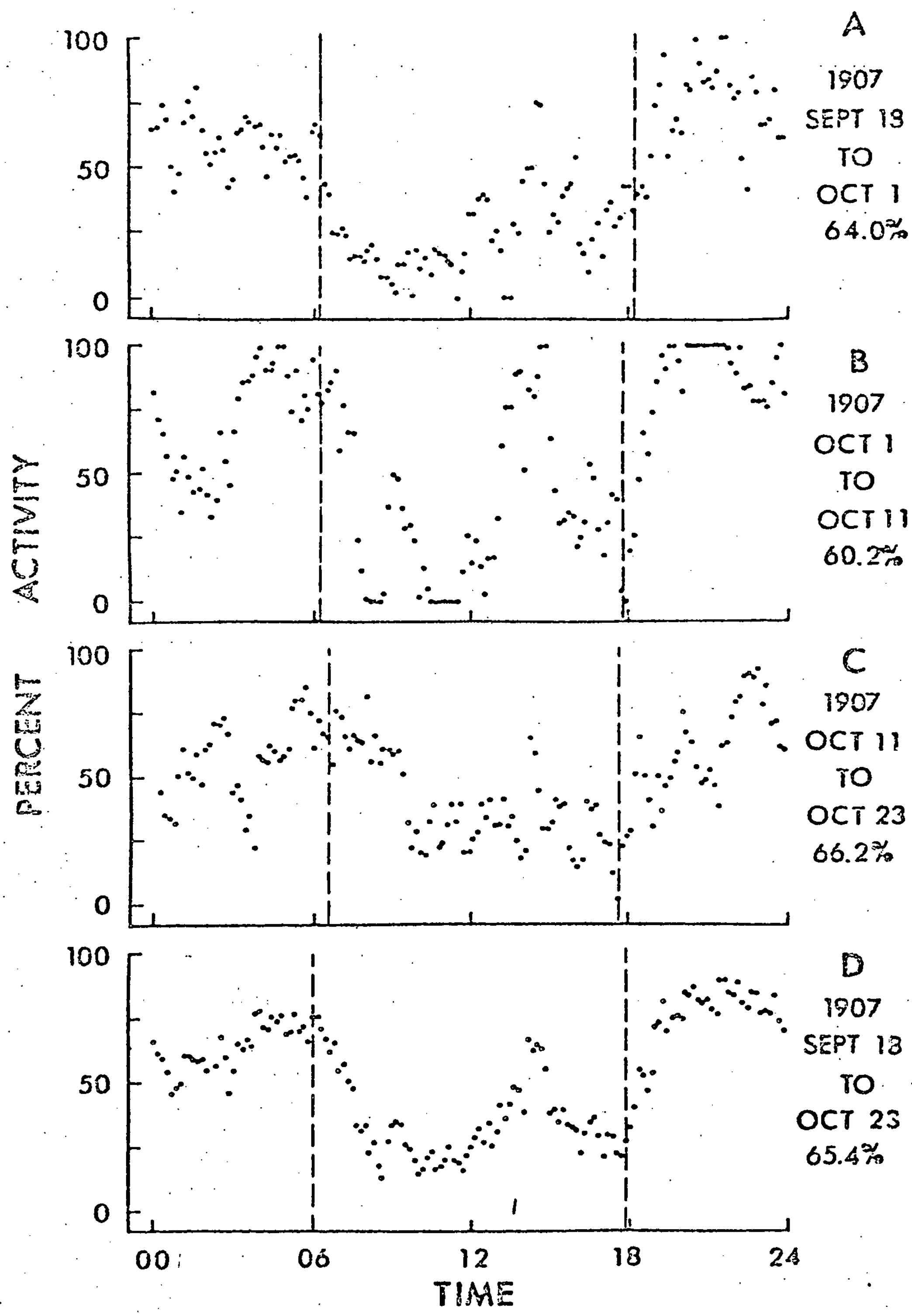
Appendix A – Figure 1. Activity pattern of muskrat 1901 from July 29 to September 8, 1969. Dots show the percent of time the animal was active for any given 10-minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.



PERCENT ACTIVITY
100
50
0
A
1901
JULY29
TO
AUG12
63.9%
B
1901
AUG12
TO
AUG22
66.1%
C
1901
AUG22
TO
SEPT 8
60.6%
D
1901
JULY29
TO
SEPT 8
1969
63.5%
00
06
12
18
24
TIME

7

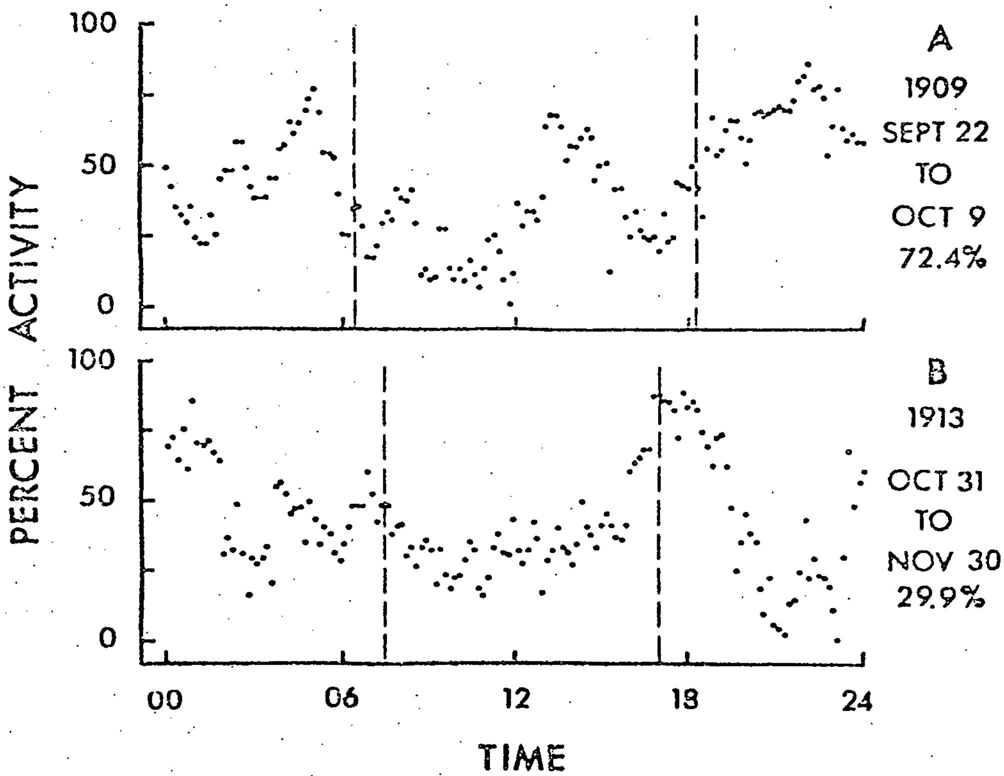
Appendix A – Figure 2. Activity pattern of muskrat 1907 from September 18 to October 23, 1969. Dots show the percent of time the animal was active for any given 10-minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.



A
1907
SEPT 18
TO
OCT 1
64.0%
B
1907
OCT 1
TO
OCT 11
60.2%
C
1907
OCT 11
TO
OCT 23
66.2%
D
1907
SEPT 18
TO
OCT 23
65.4%
ACTIVITY PERCENT
100
50
0
00
06
12
18
24
TIME

Appendix A - Figure 3. Activity pattern of muskrat 1909 and 1913 from September 22 to November 30, 1969. Dots show the percent of time the animal was active for any given 10-minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.

Appendix A - Figure 3. Activity pattern of muskrat 1909 and 1913 from September 22 to November 30, 1969. Dots show the percent of time the animal was active for any given 10-minute interval during the 24 hours. The percentages indicate amount of time animal was monitored during the period. Dashed lines show approximate time of sunrise and sunset.



PERCENT ACTIVITY
100
50
0
A
1909
SEPT 22
TO
OCT 9
72.4%
100
50
0
B
1913
OCT 31
TO
NOV 30
29.9%
00
06
12
18
24
TIME