Researches on Population Ecology

Vol. 14, No. 1 July, 1972

THE REMOTE SENSING APPROACH TO CENSUSING

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Res. Popul. Ecol. (1972) **14**, 36—57.

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INTRODUCTION

Population censusing continues to be a methodological problem in ecology, particularly for inconspicuous, mobile animals which are spaced over a large area. Whereas most censusing has depended upon capturing such animals, an approach based upon sampling without capture may serve better in many situations.

The advantages of non-capture censusing, as reviewed in detail by MARTEN (in press a), are that:

(1) The population is sampled with a minimum of disturbance.
(2) Multiple sampling of each individual in the population generates samples large enough for precise estimates, even with difficult-to-trap species or low population densities.
(3) Sampling bias, so common with trapping, may be avoided.
(4) Population density is measured directly, making unnecessary a computed boundary strip to determine the area censused.
(5) Measurement of density has high resolution in time and space.

MARTEN (in press a) has already applied the non-capture approach in censusing deer mice (*Peromyscus*), sampling by means of tracks on smoked cards. The basic principle of mark-recapture was employed, where the proportion of known, marked mice in the total population was reflected simply in the proportion of all tracks which were marked.

Presented below is a feasibility study of non-capture sampling by means of electronic remote sensing. Deer mice are detected by electronic cables lying on the ground, which register whenever a mouse crosses anywhere along their length. It is supposed that, for a given level of activity, the amount of cable-crossing by mice is proportional to the average density of occupancy along the length of the cables. This should apply regardless of the particular spatial configuration of the cables, whether they are along a single line or concentrated in one area.

Such cables effectively exploit the potential advantages of non-capture sampling:

(1) The sample size from lines is greater than from discrete points. A mouse can avoid discrete detection points, but it must cross lines if it moves

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throughout its home range at all.

(2) Cables are not at all similar to traps and therefore most effective at avoiding sampling bias.

(3) Electronic cables can record continuously, collecting information on population fluctuations at any time scale, and with a minimum of labor.

Electronic remote sensing is not yet developed to the point of a fully operational field technique, and this paper is only able to explore the potential of the approach. Presented first are several different sampling schemes. Then are described electronic detection devices which were designed to actually collect samples in the field, using cables lying on the ground.

A number of questions arise regarding the effectiveness of the electronic cables and whether the patterns of mouse activity satisfy the sampling assumptions of different sampling schemes. The questions are listed and lead to a field study designed to answer them. The field study employs different detection devices and sampling schemes all in the same area to facilitate comparison. An evaluation of each of the sampling schemes and devices follows in the conclusions section, as well as a general assessment of censusing by electronic remote sensing and suggestions of further developments toward a practical field technique.

Sampling Schemes

Removal method

A removal method, which does not require marking mice, is the simplest way to census a population. Assuming that the level of activity is the same on successive nights, the population is monitored to determine the level of activity each night. Mice whose activity falls entirely within the monitored area are then trapped and removed.

The drop in activity the next night is due to the absence of a known number of mice, providing a basis for estimating the remaining portion of the population.

$$\hat{U} = u\left[\frac{\Delta U}{\Delta u}\right] \qquad (1)$$

where $\hat{U}$=the estimated population remaining after removal

u=the nightly number of detections of mice after removal

ΔU=the number of mice removed

Δu=the drop in nightly detections of mice due to removal.

A first order approximation to the standard error is

$$s(\hat{U}) = \hat{U}\sqrt{\frac{(2u+\Delta u)\ (u+\Delta u)}{u(\Delta u)^2}}\ . \qquad (2)$$

Mark and sample

Assuming all the activity of marked mice falls within the monitored area,

$$\hat{U} = u\left[\frac{M}{m}\right] \qquad (3)$$

where $\hat{U}$=the estimated unmarked population

u=the number of detections of unmarked mice

M=the known number of marked mice

m=the number of detections of marked mice.

The standard error is

$$s(\hat{U}) = \hat{U}\sqrt{\frac{1}{u}+\frac{1}{m}} \quad . \tag{4}$$

The estimate $\hat{U}$ is in "mouse equivalents"; i. e., if only a fraction of an unmarked mouse's activity falls within the monitored area, it contributes only a fraction toward the total estimate $\hat{U}$.

In practice, mice are detected electronically and interrogated for an electronic marker. Note that it is not essential to detect each time a mouse crosses a cable. The number of detected crossings need only be large enough to provide satisfactory sample sizes of m and u. However, whether a mouse is detected should not be influenced by whether it is carrying a marker, or bias will result; hence the electronic bases for detecting mice and markers should be independent.

Once a crossing is detected, it is important to correctly classify the mouse as to whether it is marked. Failing to detect a marker once the mouse bearing it has been detected is an error leading to an overestimate of U. Registering a marker when there is none leads to an underestimate of U; this error is not likely in practice because the electronic error would have to occur right at the instant of a mouse crossing.

Much more likely is a "false count" —registering a mouse when there is none— since some environmental disturbances which the electronics interpret to be a mouse could occur at any time. Each such error, because it is interpreted to be an unmarked mouse, introduces a bias toward overestimating the unmarked population. Even if only mice are detected, it may not be possible to distinguish several species from one another, which in effect leads to a false-count problem if it is desired to census each species separately.

Time-signal approach

A "time-signal" approach may help with this problem of censusing one species in the presence of false counts and/or unmarked counts from other species. The crossings of marked and unmarked mice are recorded over a period for which the activities of some species fluctuate. The number of unmarked mice (U_i) of each species may be estimated by the multiple linear regression equation

$$u_t = a + \sum_i U_i K_{it} \tag{5}$$

where

$$\hat{K}_{it} = \frac{m_{it}}{M_i}$$

u_t = the number of unmarked counts in the census area during the t^{th} time interval

a = the average number of false counts

U_i = the number of unmarked mouse-equivalents of species i occupying the census area

m_{it} = the number of counts of marked mice of species i during the t^{th} time interval

M_i = the known number of marked mice of species i.

("Species" may be any groups, such as age or sex classes, whose activity patterns through time are distinct.)

Paraphrasing equation (5), the total count for unmarked mice during the t^{th} time interval (u_t) is the sum of the false counts (a) and the crossings of unmarked mice of each species (U_iK_{it}). u_t is the dependent variable, the K_{it} are independent variables, and the U_i are regression coefficients to be estimated.

In effect, the activity pattern through time of a particular species (perhaps the diurnal cycle or fluctuation from day to day) is observed for marked mice, establishing a "time signal", and the portion of unmarked counts which follows this signal is extracted and assumed due to unmarked mice of that species. The time signal does not have to be regular or repeating, but it is assumed that marked and unmarked mice of the same species have the same time signal and that the amount of their activity (per individual) is the same.

The $\hat{U}_i$ and $s(\hat{U}_i)$ may be calculated by the usual matrix procedures for multiple regression analysis (SEAL, 1964, Chapter 4). For the case of two species,

$$s(\hat{U}_i) \propto \sqrt{\frac{1-R^2}{1-r^2_{12}}} \qquad (6)$$

where R^2 = the multiple correlation coefficient, i. e., the proportion of variance in unmarked activity (u_t) accounted for by variation in the activity (K_{it}) of all marked species

r^2_{12} = the correlation between the activities (K_{it}) of the two marked species.

The different species' activity patterns (K_{it}) may be correlated with one another without introducing a bias in the estimates ($\hat{U}_i$), but equation (6) indicates the precision of the estimates is greater when the K_{it} are not correlated. A greater correlation can be tolerated between the several species' activities when the activities of other species are accounted for (contributing to a larger R^2), activity fluctuations are more pronounced, counts (u_t, m_{it}) are high, or the number of time intervals is large. Correlation of a species' activity with the time signal of false counts introduces a bias toward over or under estimating that species' regression coefficient, depending upon whether the correlation is positive or negative.

Since the $\hat{K}_{it}$ are random variables, not fixed as normally assumed for independent variables in regression analysis, the standard errors of conventional regression analysis are not exactly appropriate. MARTEN (1970a, p. 91) discusses several approaches to more precise estimation of time-signal standard errors. Conventional estimation of standard errors (e. g., equation 6) should suffice in most practical applications, however.

DETECTION METHODS

The three kinds of electronic detection cables to be described below were developed sufficiently for testing in the field. Two of them—the aluminum tape and acoustic cable—detect all mice (marked and unmarked) as mice, but do not always distinguish between different species of mice. The third kind of cable, an antenna which detects miniature transmitters, serves to record the cable-crossing of known, transmitter-bearing mice, thereby permitting separate sampling of the marked representatives of different species.

Either the aluminum tape or acoustic cable can be used for removal censusing. The antenna cable may be combined with either of the other two kinds of cables to implement mark-and-sample censusing.

All three kinds of detection cables will now be described. Circuit diagrams, as well as discussion of design considerations, may be found in MARTEN (1970a).

Aluminum tape

The aluminum tape consists of two parallel strips of adhesive aluminum foil attached to mylar tape 4 inches wide and 0.005 inches thick (Fig. 1, D). There is normally a low electrical conductance between the two aluminum strips because mylar is a poor conductor; but the conductance is suddenly increased when a mouse simultaneously touches both strips while stepping across the tape. This is detected electronically with less than 0.1 microampere of current passing through the mouse, well below the 5 microampere level found by conditioning experiments (GREEN, 1958) to be the detection threshold in rats.

Different kinds of animals have different resistances when stepping on the aluminum tape. The resistance of mice ranges from about 10^4 ohms in voles to 10^6 ohms in *Peromyscus* and 10^8 ohms in *Dipodomys.* Many genera seem to be quite distinct, and some species within a genus are distinct from each other. Lizards and birds have a very high resistance and cannot easily be detected; amphibians have a lower resistance than mice. Therefore, small mammals can be distinguished from other animals on the basis of their resistance, and some small mammal species can be distinguished from one another.

The aluminum tape has the advantage that both the tape and the electronics are simple and inexpensive. The effect of a mouse is the same no matter how long the tape may be, even thousands of feet.

The tape's most serious limitation is that it cannot function when objects lying across it have a total conductance much greater than the mouse to be detected; i. e., if the background conductance is high, a mouse does not have much effect. This may happen if, for example, soggy leaves are lying on the tape. The best way to

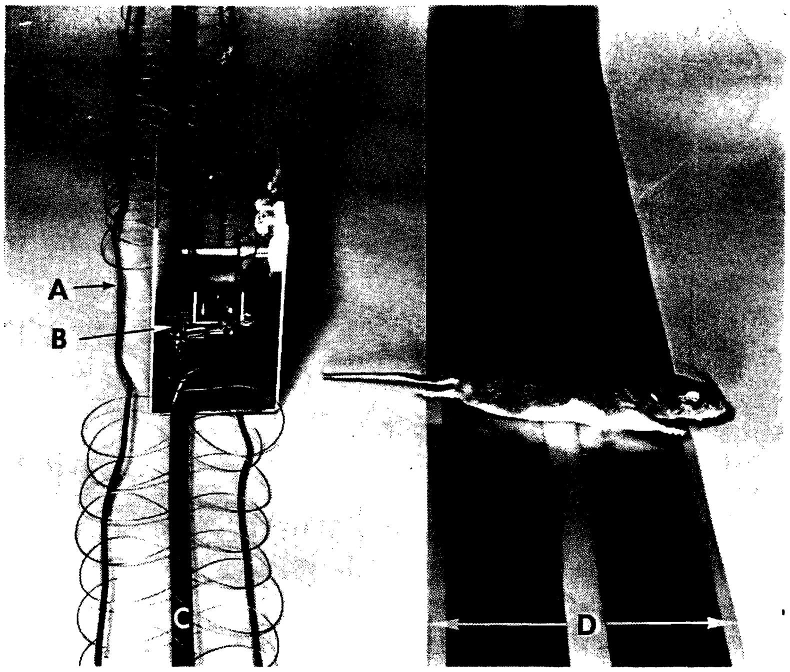

Fig. 1. Electronic remote-sensing cables. The acoustic cable (C) has a loop antenna wire (A) running its length and a phonograph cartridge (B) at intervals. The total length of the *P. maniculatus* on the aluminum tape (D) is 6 inches.

avoid this is to have a canopy above the tape, such as BIDER (1968) used over his sand track.

Several limitations of the aluminum tape result from its width. It is best placed in a straight line because of its limited lateral flexibility, and herbaceous stems must be cleared away so it can lie flat on the ground. It must be anchored if there are strong winds, the best way being to glue the bottom of the tape to the tops of stakes.

Six *Peromyscus truei* resident in an enclosure at the Animal Behavior Station, University of California, Berkeley were observed for their behavioral reactions to the aluminum tape and other remote-sensing devices. The enclosure was 30 feet square, with concrete walls, a soil substrate, and sparse herbaceous cover. Nocturnal observations were made with the aid of red lights which were left on at all times. SOUTHERN (1946) has reported that rats did not appear disturbed by far-red light, though they could detect it.

The mice were never attracted to aluminum tapes. They seemed completely unaware of the tapes when first installed, and close to 100% of their crossings were counted. Mice seldom passed under tapes, even where portions were an inch or so above the ground. They developed a habit of jumping over tapes after being exposed to them for a week, and counting efficiency dropped to about 10%. They also seemed to develop a subtle avoidance of the tapes, in that the tapes seemed to border their movements.

This contrasts with direct field observations in an Ontario forest, where *P. maniculatus* not only continued to step on tapes, but often ran along them for short distances, just as they run along logs and sticks where they apparently find easier travelling than the leaves on the forest floor. Noting that *P. maniculatus* normally runs and *P. californicus* often employs a quadrupedal hop (EISENBERG, 1962), the counting efficiency of the aluminum tape for different mouse species could vary according to their gait.

Voles (*Microtus californicus*) in the enclosure never showed any awareness of aluminum tapes, even after continued exposure.

No false counts (i. e., electronic signals indicating a mouse crossing when in fact none crossed) were observed in the enclosure.

Acoustic cable

The acoustic cable acts as an elongated treadle which produces a sound when a mouse steps upon it. It is a stainless steel tape, 1/4 inch wide and .01 inches thick, with .008 inch stainless steel wire looping back and forth through holes in the tape (Fig. 1, C). A mouse steps on the wire as it walks or jumps across, which generates a characteristic "jingle" at the site of the disturbance; the sound passes down the tape where it is heard with the ear or detected with a phonograph cartridge (Fig. 1, B).

The acoustic cable has the advantage that it is laterally more flexible than the aluminum tape, and hence more easily placed in the field; and it is not affected by wetness as is the aluminum tape. It cannot function, however, during strong winds and rains because of the intense mechanical disturbances they cause in the cable.

As with aluminum tapes, *P. truei* was never attracted to acoustic cables in the enclosure. There was a conspicuous avoidance of cables on first exposure, the mice often hopping over them or sometimes being deflected by them. The ground in the enclosure was nearly bare, and the acoustic cable disrupted the surface much more than it would in forest or chaparral, where the surface is already disrupted by litter.

However, after a week acoustic cables seemed to have no effect on the movements of mice. They sometimes gave a slight hop as they crossed but often touched the cable in doing so, resulting in a counting efficiency of about 50%. Efficiency was highest when a mouse was walking, and lowest when it was running from one part of the enclosure to another and tended to jump clear. No false counts were observed.

Transmitters

Battery-operated, pulsing transmitters of the general sort described by MACKAY (1968, pp. 78-90) were used in this study. When encapsulated in paraffin, the transmitter measures 2 cm × 1 cm × .5 cm. It weighs about a gram, most of the weight coming from the battery, which lasts about six months. The fact that paraffin can be melted away makes battery replacement easy.

Mice were anesthetized for transmitter implantation with .04 mg. of Sodium pentabarbital per gram of mouse body weight, 60% of the dosage recommended by PILGRIM and DEOME (1955) for laboratory *Mus*. Transmitters were placed in the abdominal cavity through a 1/2 inch slit in the belly, which was then closed with three stitches of silk thread. Mice were held in the laboratory for implantation no more than two days and were released into their old home ranges. None seemed encumbered by the surgical operation or the presence of the transmitter, and all were healthy for the six month duration of the study.

The transmitters were detected when within 3 inches of a loop antenna cable (Fig. 1, A). In order to reduce interference from broadcasting, the carrier frequency was 470 Kc, outside the commerical broadcast band. A key feature was capacitance-balancing the antenna (described by MACKAY, 1968, pp. 215–216), as this sharply reduces the reception of atmospheric noise and broadcasting which might otherwise be confused with a transmitter.

Transmitters were distinguished by their pulse rate. The four rates in this study were 125, 350, 600, and 1200 cps. Field tests showed that transmitters in mice always registered as the mouse crossed the antenna cable—except for the lowest pulse frequency. About seven pulses are required to register the transmitter when it passes near an antenna, and it was found a mouse carrying a transmitter of the lowest frequency could run across the antenna very fast without registering. The low-frequency channel was not normally used in the field, being kept open instead as a check for non-transmitter electronic pickup.

QUESTIONS

A field evaluation of the remote-sensing approach to censusing must answer a number of questions about mouse activity. Is activity constant enough from night to night to allow the removal method? Are the activiites of marked and unmarked mice equal, as required by the mark-and-sample method? Are there false counts which invalidate the removal and mark-and-sample methods?

If the time-signal method is to be used to deal with false counts, additional questions must be answered. Is there sufficient variation in activity through time? Is a particular time pattern of activity characteristic of the entire population? To answer all the above questions, various individuals and groups of mice in the same population were implanted with different markers (i. e., transmitters). The observations are presented in the first section of the results, which treats activity patterns.

Furthermore, for the time signal method, do the different species have time signals which are different from each other and different also from false counts? Observations on this question, based upon the activities of different species in the same area implanted with different markers, come in the next section of the results, which gives correlations between the time patterns of the different species.

An evaluation of detection devices must answer other questions. Does the equipment work properly on a large scale ? Is detection efficiency high enough to generate satisfactory sample sizes ? Are samples representative of the entire area ? The last section of the results deals with these questions by presenting correlations between different devices recording in the same area and correlations between separate spatial subsamples in the same area.

For each method, what time scale is best ? Fluctuations in activity from hour to hour and from night to night are examined throughout the results.

FIELD PROCEDURE

Ten lengths of aluminum tape, each two hundred fifty feet long, recorded in deciduous forest at Petawawa Forest Experiment Station, Ontario, Canada during the summer of 1968. They were parallel to each other and thirty feet apart. The area was also observed directly with red light on some nights, in order to gain a familiarity with the kind of activity the aluminum tape was measuring. Nearly all nocturnal activity registered on the aluminum tape was due to *Peromyscus maniculatus.*

Five lengths of acoustic cable with transmitter antenna (as in Fig. 1), each one hundred feet long, recorded in chaparral at the University of California's Russell Tree Farm (near Lafayette, California) during the summer of 1969. They were placed 30 feet apart, with four lengths of aluminum tape parallel between them.

The eight *P. truei* resident on the California site through the summer received transmitter implants at the beginning, as did two *P. californicus.* The area was trapped on only a few occasions, leaving the mice largely undisturbed. Although most of the activity of transmitter-bearing mice fell within the monitored area, mice left the area on occasions. Correlations presented below were computed from periods when this was not a complicating factor.

The first and third acoustic cables recorded separately from the second and fourth, providing a simultaneous record from two sets of cables in the same area. The sensitivities of the two sets were controlled separately and readjusted on a number of occasions, so changes of unknown magnitude in detection efficiency and level of false counts were present. Where this might complicate the analysis, only short periods of constant sensitivity were used.

Activity records for the entire period may be found in MARTEN (1970a). Detailed descriptions of the two study sities, (including maps) as well as comprehensive accounts of activity patterns there, may be found in MARTEN (in press b). The only results presented here are those aspects of activity relevent to censusing.

RESULTS

Activity Patterns

Records of individual *P. truei* carrying transmitters at the California site show several periods during the night when they are crossing the cables, separated by periods when they are not. Direct observation of *P. truei* in the enclosure and

P. maniculatus at the Ontario site again disclosed bursts of activity during the night.

If the activity of several individuals is added together, as in the transmitter records for 4 *P. truei* in Fig. 2, the discrete pulses of individual activity are not so conspicuous, but periods of greater and lesser activity still remain. A first peak tends to occur within a few hours of nightfall, and the time of a second peak, which may be very strong, is quite variable. There is usually a period of inactivity for the entire group, lasting one or two hours, somewhere between 11 p. m. and 3 a. m. This pattern is most conspicuous when averaged over many nights (Fig. 3).

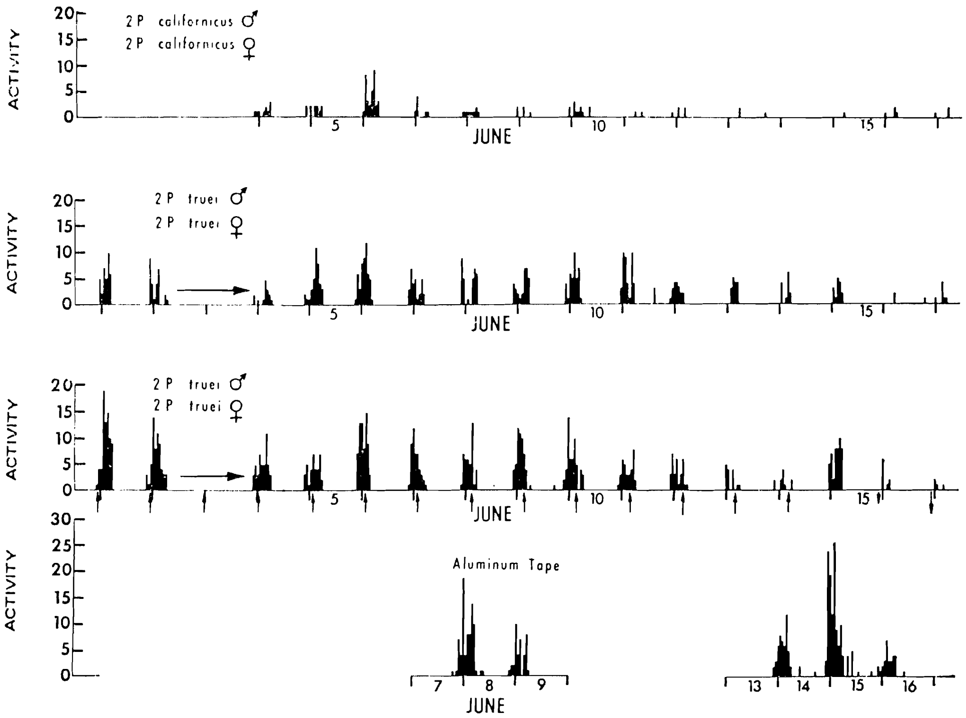

Fig. 2. Hourly counts from transmitters and the aluminum tape in California chaparral (June, 1969). An arrow across a space in the bars indicates no record for that period. The bars above the tics give the counts between 11 p. m. and midnight (Daylight Saving Time). The vertical arrows give the time of moon rise (pointing up) or moonset (pointing down). Sunrise time was about 5:45 a. m.; sunset time was about 8:30 p. m. Records labelled "*P. truei*" or "*P. californicus*" are based upon transmitters in known groups of mice.

The two groups of transmitter-carrying *P. truei* (Fig. 2) provide an opportunity to examine the uniformity of timing of activity within the population during any given night. The overall pattern for the two groups is similar on many nights (e. g., May 30-31, June 5-6, June 10-15), but rather dissimilar on some others. Even when the pattern is similar, the timing may not be exactly the same, and the statistical correlation of hourly activity between the two groups is, in fact, low (Fig. 4).

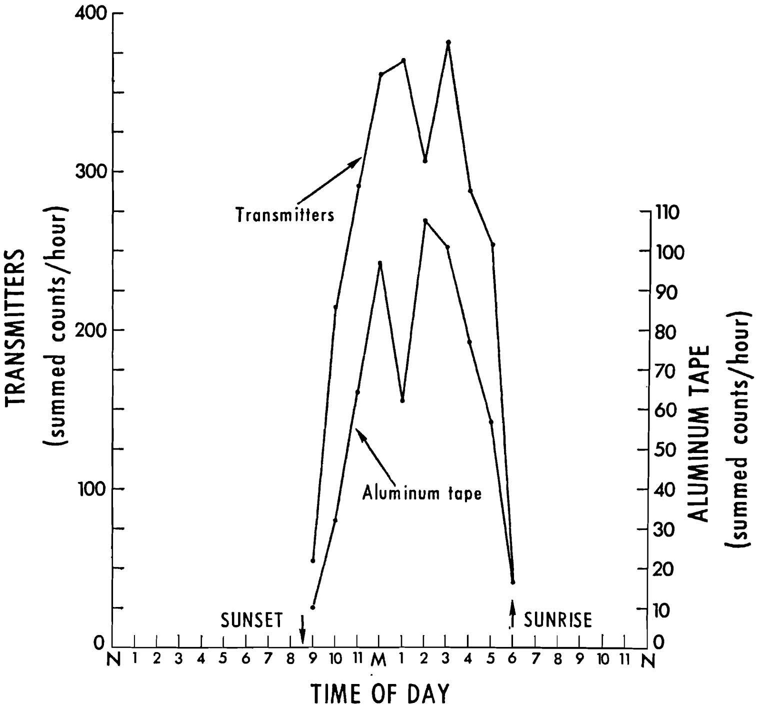

Fig. 3. Total counts for each hour of the day at the California site (May-July, 1969). Hours of the day are as defined in Fig. 2.

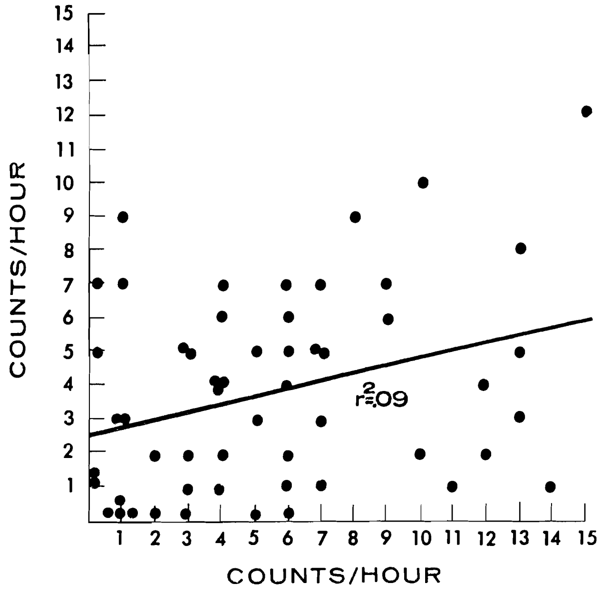

Fig. 4. Simultaneous hourly counts at the California site from two groups of transmitter-bearing *P. truei*. The points are taken from Fig. 2, June 6-12.

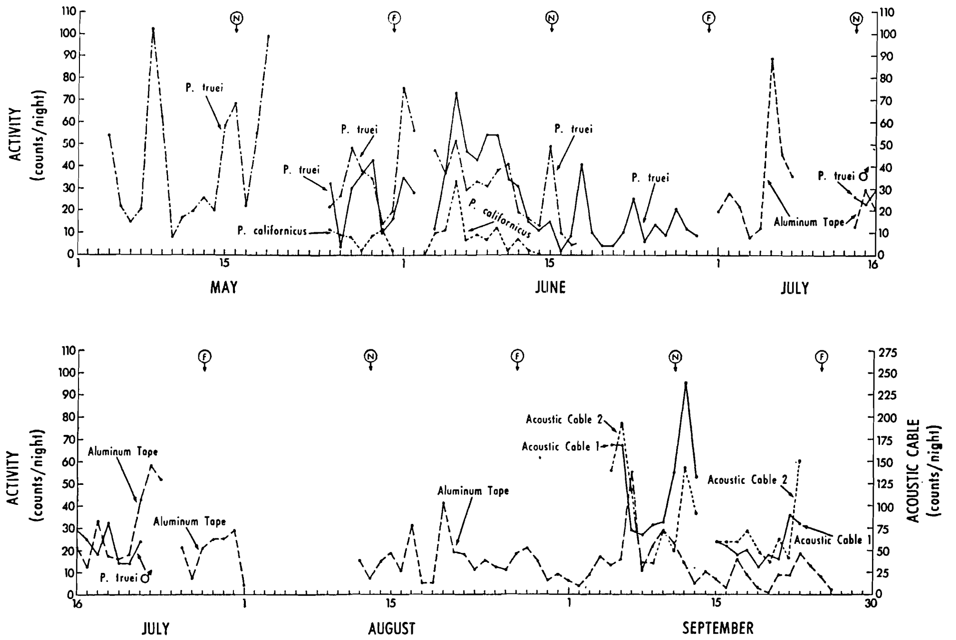

Fig. 5. Total nightly counts (8:00 p.m. to 6:00 a.m. Daylight Saving Time) for activity at the California site (1969). Circled N and F give dates of new and full moons respectively. Records labelled "*P. truei*" or "*P. californicus*" are based on transmitters in known groups of mice.

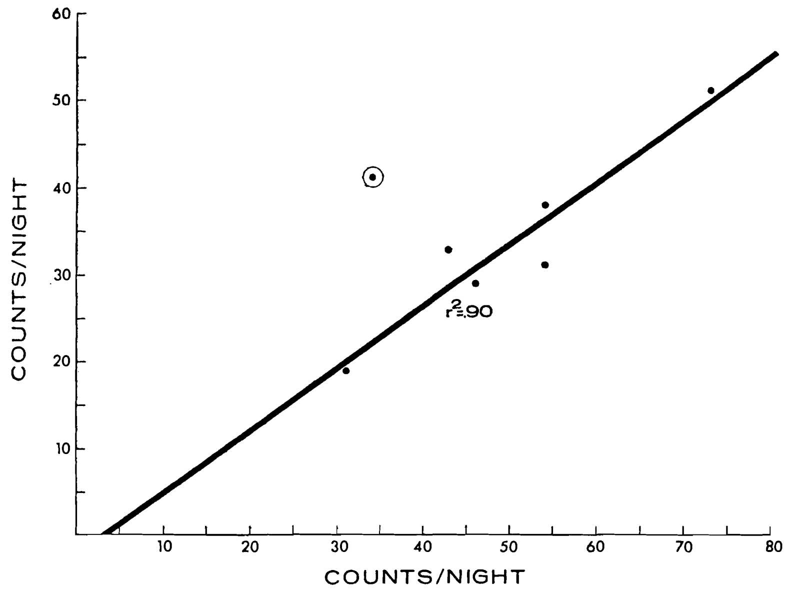

Fig. 6. Simultaneous nightly counts at the California site from two groups of transmitter-bearing *P. truei*. The points are taken from Fig. 5, June 6-12. The circled point was not included in the computation of R^2.

Total nightly activity in California (Fig. 5) showed marked fluctuations from night to night, with an average period of about four to five days. (MARTEN in press b). The two groups of *P. truei* carrying transmitters had activity patterens similar to each other from night to night, usually fluctuating exactly in phase (Fig. 5, May 25 to June 16). However, the two groups were one day out of phase at times (e. g., May 25-29 and July 14-22). The correlation between the nightly activities of the two groups was high (Fig. 6), indicating considerable uniformity from individual to individual within the population.

Aluminum tape records give the summed activity of the entire population. In Ontario the aluminum tape was registering chipmunks during the day and mice at night, with a space of several hours at dusk and dawn when nothing was registering. The aluminum tape's pattern within a night was quite similar from night to night (Fig. 7), but altered markedly through the year. In the spring (May), there are three peaks in activity each night. By early summer, activity after midnight is reduced, and activity is increasingly compressed into the early portion of the night as the summer progresses.

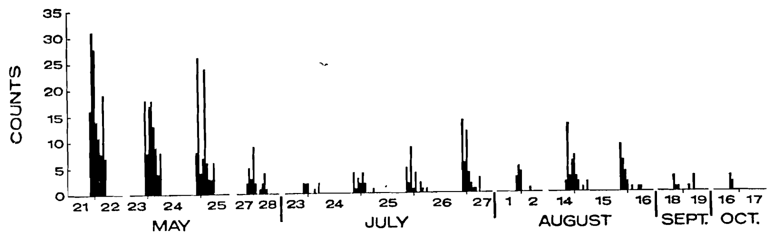

Fig. 7. Hourly counts on the aluminum tape at the Ontario forest site (1968). Hours of the day are as defined in Fig. 3. Three *P. maniculatus* were removed on May 27.

Fig. 7 illustrates how total activity on the aluminum tape at Petawawa in 1968 declined as the summer progressed, despite an increase in population density over the same period. Activity per individual therefore declined very sharply. Part of this decline could be due to mice learning to avoid the aluminum tape, but simultaneous direct observations confirmed that both individual and population activity of *P. maniculatus* did in fact decline through the summer. However, total nightly activity was often roughly the same on adjacent nights (e. g., Fig. 7, May 21-25, when activity ranged between 170 and 265 counts per night).

At the California site the aluminum tape was registering only during the night (Figs. 2 and 8). Hourly changes are not so abrupt as transmitter records, but the pulsed pattern remains, often showing itself as three peaks in the course of the night. The pulses are blurred on some nights because individuals are not in synchrony with each other, as GRAHAM (1968) found for *Microtus* in the field, which were not synchronized except at dawn and dusk. There are conspicuous night to night fluctuations on the aluminum tape (Fig. 5), with an average period of about three to four days (MARTEN in press b).

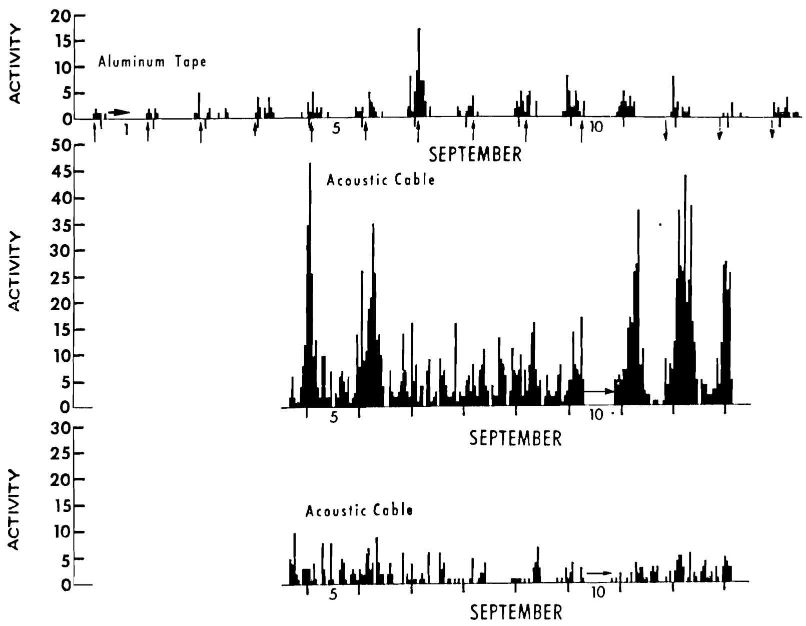

Fig. 8. Hourly counts from two sets of acoustic cables and from aluminum tapes in California chaparral (Sept., 1969). Explanation of symbols as in Fig. 2. Sunrise time was about 7:00 a. m.; sunset time was about 7:00 p. m. (Daylight Saving Time).

Comparison of species

The number of counts registered by transmitter-bearing *P. californicus* was much lower than for *P. truei*. It is not known whether the *P. californicus* were actually less active, or whether they were moving about in the branches of the chaparral more than *P. truei*, thus by-passing the antennas on the ground.

When counts are high, the pattern of *P. californicus* activity through the night (Fig. 2) is similar to that of *P. truei*, except a much greater portion of the activity consistently occurs during the hour or two preceding dawn. There are characteristically three pulses of activity during the night when counts are low, and the burst of activity before dawn turns up quite reliably even when *P. californicus* does not appear at any other time of the night.

P. californicus can follow the same night-to-night pattern as *P. truei* (e. g., Fig. 5, June 4-11).

R. BIDER has supplied unpublished data from a sandtrack in Quebec forest, the site and technique described by BIDER (1968). As the total numbers of tracks each day reflect the total amount of activity for each species, they provide additional information on night-to-night fluctuation in *Peromyscus* activity and its correlation with that of other species living in the same area.

Nightly activity of *P. maniculatus* during June to September of 1964-1969 did fluctuate some from night to night (analysed in detail by MARTEN, in press b). However, these fluctuations had a low correlation with those of two vole species, *Clethrionomys gapperi* ($r^2<.03$) and *Microtus pennsylvanicus* ($r^2<.01$, except one year when $r^2=.11$). The correlations between the two voles, which experienced strong activity fluctuations from night to night in response to changing weather conditions, were somewhat higher (r^2 ranging from .09 to .16).

Comparison of detection devices

As conditions were quite dry in California during the recording period of June to September, the aluminum tape worked well at all times. The efficiency of the aluminum tape seemed to drop through the summer season, in part because the tape eventually stretched tight on the slope, pulling itself an inch or two above depressions in the ground.

The peaks for each night (Fig. 2) are often positioned at about the same hour for both transmitters and aluminum tape. The agreement is particularly good when averaged over many nights (Fig. 3). However, the actual hourly correlation between counts from transmitters and aluminum tape is rather low (Fig. 9).

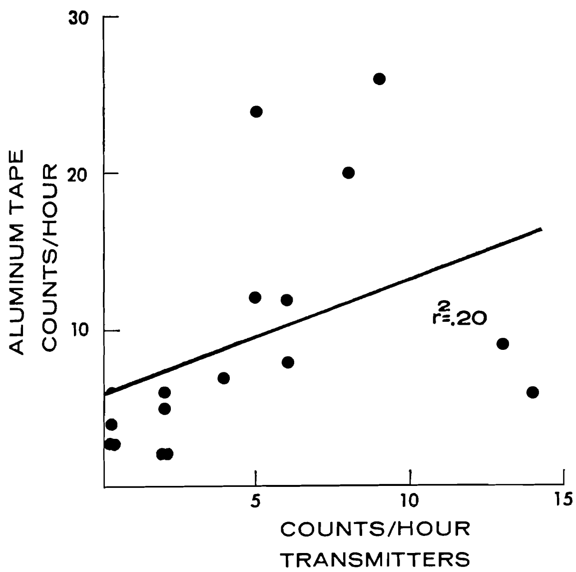

Fig. 9. Simultaneous hourly counts at the California site from the aluminum tape and all *P. truei* carrying transmitters. The points are from Fig. 2, June 14-15.

Fig. 10 illustrates the high correlation from night to night between the aluminum tape and transmitter *P. truei*. Recalling that the loop antennas detecting the transmitters were interspaced with aluminum tapes on the study plot, this high correlation

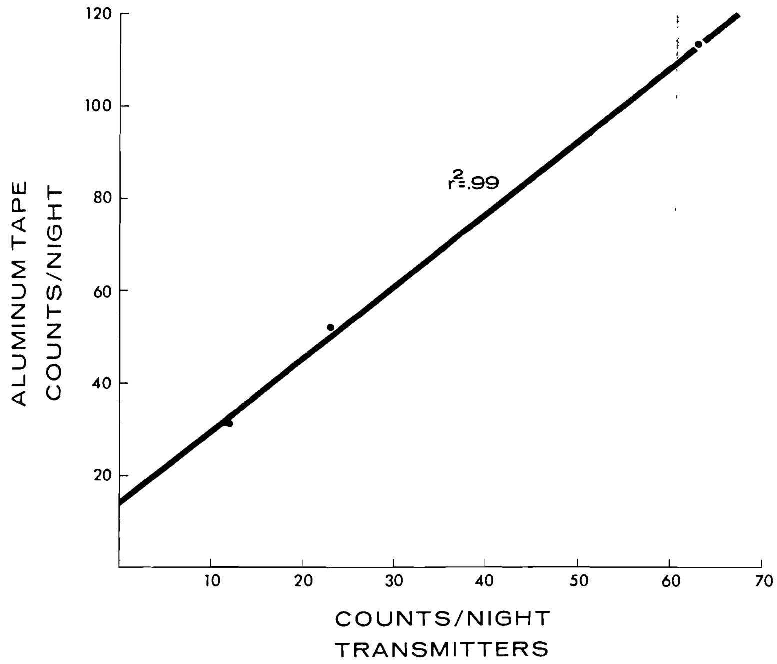

Fig. 10. Simultaneous nightly counts at the California site from the aluminum tape and all *P. truei* carrying trans mitters. The points are from Fig. 5, June 14-16.

indicates both antennas and aluminum tapes were obtaining a spatially representative sample of nightly activity in the study area. The fact that the line in Fig. 10 passes so close to the origin (i. e., a of equation (5) is small) indicates false counts were not significant on the aluminum tape; i. e., the aluminum tape was detecting primarily *P. truei.*

When a transmitter was detected crossing the antenna, the acoustic cable simultaneously detected a mouse about 50% of the time, an efficiency quite sufficient to generate adequate sample sizes. This sensitivity of the acoustic cable, though sufficient for it to respond to mice, did not cause the cable to respond to disturbances from wind.

The acoustic cable, like the aluminum tape, is intended to give the summed activity of the entire population. At the California site, the acoustic cable was registering during the day as well as the night (Fig. 8), which is not surprising considering the abundance of diurnal ground-moving birds. Even when averaged over many nights (Fig. 11), the characteristic hourly pattern of mouse activity did not show through well in the nightly portion of acoustic cable record.

The two interspaced sets of acoustic cables had a very low correlation even with one another at night on an hourly basis (e. g., Fig. 8, Sept. 5-13, $r^2=.14$, $n=80$) indicating considerable spatial heterogeneity during short periods.

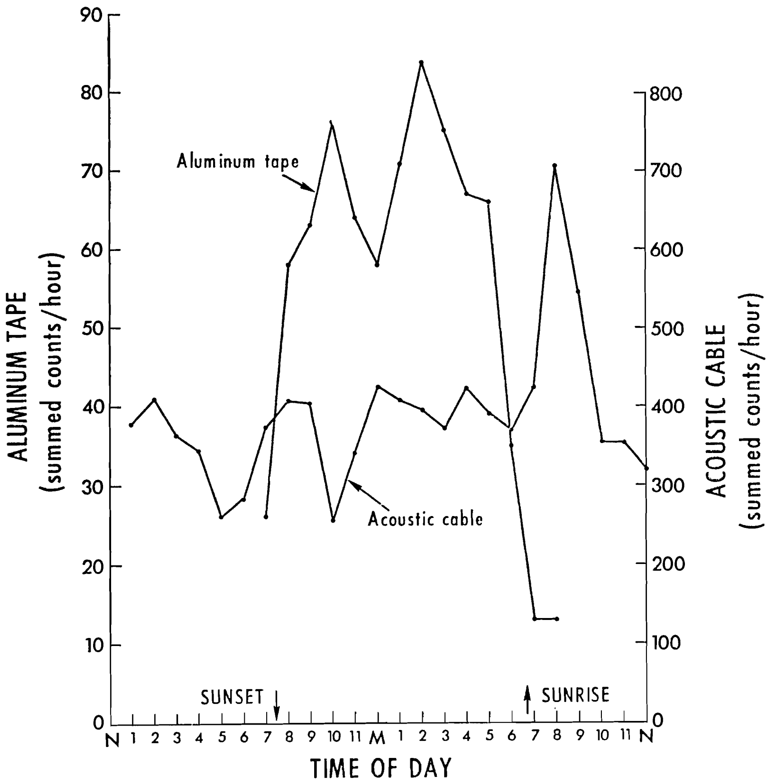

Fig. 11. Total counts for each hour of the day at the California site (August-September, 1969). Hours of the day are as defined in Fig. 3.

The two sets of interspaced acoustic cables had a high night-to-night correlation with each other during some periods (e. g., Fig. 5, Sept. 5-13, $r^2=.58$, $n=9$), but not during others (e. g., Fig. 5, Sept. 15-21, $r^2=.04$, $n=7$) when the sensitivity of one cable was too high. This indicates that, on a nightly basis, acoustic cable sampling was representative of the study area, but that the acoustic cable was responding to different things at different sensitivities.

The correlation between nightly counts on the acoustic cable and aluminum tape was sometimes fair (Fig. 5, Sept. 15-21, $r^2=.53$, $n=4$), but often low (Fig. 5, Aug. 12-17 and Sept. 8-11, $r^2=.1$, $n=12$). This, along with substantial acoustic cable counts on nights when marked mice and aluminum tape counts were low, suggests the acoustic cable was responding to something in addition to mice.

Conclusions

This study has not thoroughly validated mouse censusing by means of electronic detection, but there are some definite indications of its prospects.

Comparision of sampling schemes

If the amount of activity is more or less constant from day to day, population size may be simply approximated with the removal method, equation (1). Referring to Fig. 7, total nightly counts on the aluminum tape were about the same from May 23 to May 25, averaging 182 counts per night. The count dropped to 58 on the night of May 28 after three *P. maniculatus* were temporarily removed, suggesting the three mice were accounting for about 70% of all the activity in the 1.6 acres covered by aluminum tapes. Applying equation (1), $u=58$, $\Delta U=3$, $\Delta u=124$, and $\hat{U}=1.4$.

This population density (2.75/acre) is normal for forest *Peromyscus* during most of the year, but the 4.4 mice in the study area hardly provided a basis for estimating the population by trapping. In fact, this census was preceded by two weeks of intensive trapping without a single capture, even though the aluminum tape record demonstrated the mice were present the entire time. Remote sensing can therefore extend precise censusing to normal, low density populations instead of restricting the study of population dynamics to populations of high density and species susceptible to trapping.

However, the large variation in mouse activity from night to night observed in California indicates it is sometimes essential to run a calibration based on the activity of marked mice (i. e., the mark and sample method). It also appears that false counts sometimes rule out simple estimation of $\hat{U}$ from equation (3). The intercepts in Fig. 9 and 10 indicate the level of false counts, i. e., a in equation (5). The fact that the intercepts are significantly greater than zero indicates false counts were present at the California site—only a few on the aluminum tape and many on the acoustic cable.

This means in practice that time signals must be exploited (equation 5) if remote sensing is to be used for censusing. Recalling equation (6), population estimates from the time-signal approach are most precise when the activities of marked species provide clear and distinct time signals whose patterns account together for most of the time pattern of unmarked detections.

Evidence from the California site indicates activity within a night does not always provide a reliable basis for the time-signal approach. The pattern within a night is different for different species (r_{12} is small), as is desired, but the behaviour of a particular population during a particular night, on an hourly basis, is neither precise nor uniform for all individuals within the population. Different individuals may be active at different times from one another, particularly during the middle of the night when the population is not synchronized by sunset or sunrise. Different parts of the home range may be used at different times, so that even with hundreds of feet of detecting cable, the sample in any particular hour may not be representative of activity. In contrast, the time signal within a night for the Ontario population was more clearly defined than in California, sufficiently so to permit time-signal censusing.

Changes in total activity from night to night provide a more reliable basis for the time-signal approach. The changes are large enough to provide a discernible signal, and they are uniform throughout the population. Different kinds of mice, e. g. voles and deer mice, have different time signals (r_{12} small) which allow equation (5) to estimate each separately, even though the electronic mouse detector does not distinguish between them. The different signals are based on different reactions to night-to-night fluctuations in weather and different inherent periodicities, characteristically four days in deer mice (MARTEN, in press b).

The time signals of closely related species in the same area may not differ sufficiently to permit separate estimation of each. For example, *P. truei* and *P. californicus* had a similar pattern of activity from night to night (r_{12} large).

To get an idea of how well the time-signal approach might work in practice, equation (5) can be applied to two marked groups of *P. truei*, imagining one of the groups to be unmarked. For this special case, equation (5) reduces to

$$u_t = a + U\frac{m_t}{M} \quad . \tag{7}$$

Using the data in Fig. 6 and regarding counts on the horizontal axis as the m_t and on the vertical axis as the u_t, the known number of mice in the "marked" group is $M=4$. The linear regression estimate is $\hat{U}=2.9$, very close to the three mice actually in the "unmarked" group. False counts (a, the intercept of Fig. 6) are near zero, as they should be in this case; and the correlation (R) is large, indicating a high precision for the estimate $\hat{U}$.

Comparison of detection devices

Considering the performance of different techniques for detecting mice, the aluminum tape was the most successful. It is inexpensive and detected mice reliably in several different field situations. Fig. 10 illustrates the time-signal equation (7) applied to an aluminum tape record, with transmitters regarded as marked counts and aluminum tape regarded as unmarked counts. An actual estimate could not be computed because the aluminum tape and antenna were operating contiguously, but unfortunately not in the "detection-interrogation" scheme required to record the m_t and u_t properly. However, the counts in Fig. 9 are undoubtedly proportional to the proper values, and the high correlation (R) suggests a population estimate would have been precise.

The acoustic cable was designed to avoid the limitation of the aluminum tape to dry conditions; but its performance was disappointing because too many things other than mice were being counted in the field test, even though this was not a problem in the enclosure test. This is evidenced by the poor agreement between acoustic cable and aluminum tape (Fig. 11), contrasted with the good agreement between aluminum tape and transmitter records (Fig. 3). However, the acoustic cable seemed to operate reliably, and it could well be useful in other situations.

A capacitance proximity detector has numerous potential advantages over the mouse detection systems used in this study. It is simply a wire lying on the ground which detects whenever a mouse passes within several inches. The proximity detector has the advantage that a wire is easily placed in the field. A wire is a minimal intrusion in the mouse's habitat and cannot be crossed without detection. No physical contact is necessary, in contrast to the aluminum tape and acoustic cable.

A pilot proximity detector was assembled for this study (described in MARTEN, 1970a, p. 73-76). The small effect of a small animal like a mouse could not be detected with a wire more than 100 feet long, though larger animals could be detected with even longer wires. The wire was much more sensitive when attached to inch-wide tape, the effect of a mouse stepping on the tape (and displacing the wire slightly) being much greater than its proximity alone.

A possible disadvantage of the proximity detector is that it may be very non-specific. Enclosure observations showed it responding only to mice, but it was not tested on a full scale in the field, and some other animals may have a similar effect to mice.

The one marking system tested (i. e., transmitters) worked well, though less expensive markers would be required for routine use in the field. The ideal electronic marker would be inexpensive and detectable anywhere along a cable; it would allow several different kinds of marks and last a long time. "Passive" transmitters (MACKAY, 1968, p. 259-276) may offer the most potential; some have simple and inexpensive circuitry, different transmitters can be tuned to different frequencies, and there is no battery to run down.

Additional Errors

A limitation of remote sensing, which also pertains to trapping, is that only the accessible portion of the population is censused. The aluminum tape was used with an enclosure population of about 70 *Microtus californicus*, yielding several thousand counts per day. The population was then trapped and aluminum tape counts dropped to 1% of their original level, even though an additional 10% of the population, all juveniles, was subsequently captured.

Though the commonly recognized errors of trap censusing—due to small sample size or bias in sampling marked animals—can be reduced to negligible proportions by the non-capture approach, another source of error must also be considered. Two portions of the same population may experience similar activity fluctuations from night to night, but slightly out of phase. If the marked and unmarked portions of the population are behaving this way, the ratio of their activities in any one night may be quite out of proportion to their numbers, though not consistently in any one direction.

This, then, is a random error due to violation of sampling assumptions. It sets a minimum below which the total error cannot be reduced, no matter how small the standard error and bias. This error is probably insignificant when averaged over many nights, but it is potentially large for a census based only upon one or two nights, particularly if the population is small. It is undoubtedly prominent in trapping too, though not so easily detected as in remote sensing.

Because unknown errors can nullify any censusing method, it is recommended that all of the non-capture methods be combined with the removal test proposed by MARTEN (1970b, in press a). If equations (3) or (5) correctly estimate a known decrement in the unmarked population (due to removal or marking), the population estimates may be considered reliable.

SUMMARY

A non-capture approach to censusing offers the possibility of (a) increasing sample sizes, thereby increasing precision, and (b) removing the bias so frequently associated with trapping. Sampling schemes analogous to removal and mark-recapture trapping were tested in the field, using electronic remote sensing as the means for sampling mice.

The activity of *P. maniculatus* in Ontario forest and *P. truei* and *P. californicus* in California chaparral was observed directly and monitored electronically. A conductance device (the aluminum tape) and a "treadle" device (the acoustic cable) were used to detect mice; and miniature transmitters were used as markers. The aluminum tape proved more selective than the acoustic cable in registering mice. However, because an electronic mouse detector may register things other than the species being censused, it was suggested the unmarked population be estimated by extracting a "time signal" from unmarked activity which correlates with a known time signal of marked mouse activity.

Peromyscus activity was pulsed through the night, with different individuals not in tight synchrony and a slight depression in overall activity in the middle of the night. The time pattern of *P. truei* activity within a night was different from that of *P. californicus.*

P. truei had conspicuous fluctuations in total nightly activity, with a period of about 4 days, the entire population usually being in phase. Night-to-night fluctuations in vole tracks in Quebec (unpublished data from R. BIDER) had low correlations with *P. maniculatus* tracks in the same area.

The time signal of *P. truei* activity within a night was not uniform enough within the population for censusing by electronic remote sensing. Activity was sufficiently variable from night to night, as well as uniform within the population, to provide a characteristic night-to-night signal for censusing.

ACKNOWLEDGEMENTS : Duncan MCNEIL (Barringer Research, Toronto) and Leonard KLEBINOFF (Canadian Radio Control Electronics, Toronto) contributed to the design and construction of the acoustic cable and transmitter detection systems. The miniature transmitters were obtained from Robert GOODMAN (Franklin Research Institute, Philadelphia). R. S. MACKAY generously made his laboratory available for the early stages of transmitter experimentation. Simon CARRIER, Gary STEWART, and Kenneth KEAGAN assisted with the field work in Ontario. Janet BARNABE (Biometrics Unit, Canadian Forestry Service) did computer programming. Figures were prepared by the

Graphics Unit of the Canadian Forestry Service. Roger BIDER (MacDonald College, Quebec) supplied valuable unpublished data from his forest sandtrack. Charles Krebs made helpful suggestions on the manuscript. Particular thanks are due to my academic supervisor, William LIDICKER, and to my colleagues in the Canadian Forestry Service, Donald MACLEAN, Jag MAINI, and Peter RENNIE, for their continuing support of this work. The initial stages of this project were supported by Atomic Energy Commission Grant ♯ AT (11-1)-34.

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遠隔検知法による個体数推定

G. G. MARTEN

ネズミ類などの個体群調査において，捕獲という操作なしに個体数を推定する方法を確立することは，推定の偏りをなくし精度の高い推定値を得るための１つの望ましい方向であると考えられる。ここでは *Peromyscus* 属の３種のネズミ（*maniculatus, truei, californicus*）を対象として電子記録装置による遠隔調査技術の適用を試み，種々の角度からその有効性を検討した。テストした装置は，調査区内でのネズミの通行をアルミはくテープ上での電気抵抗の変化としてとらえるものと，"acoustic cable" を用いて振動として検知するものの２つである。どちらの場合も当然対象種以外のネズミや他動物に対しても反応するので，推定に先立ってその種固有の時間的な反応パターン（"time signal"）を明らかにしておく必要がある。そこで上記３種についてこの "time signal" の種ごとの特徴を比較，記載した。