Radio Tracking of Dispersing Yellow Bellied Marmots*

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Abstract

Movement of yearling yellow bellied marmots was studied by radio tracking. The equipment developed for this study is described and consists of a surgically implanted transmitter, two types of direction finding antennas and an inexpensive receiver. The results suggest that a river forms a barrier to movements, dispersing animals use burrows of greater separation then resident animals, and dispersion results in a net movement of more than a kilometer from the original colony.

Introduction

Dispersal is the movement of an individual from its place of birth to its place of reproduction. It is an active process which results in the spacing of individuals. Dispersal distance is a static description of one aspect of dispersal. It is the straight line distance between the place of birth and the place of reproduction, regardless of other movements (Howard, 1960).

The information presently available allows some generalizations to be made about the process. First, it most commonly involves young animals (Dice and Howard, 1951; Errington, 1962; Howard, 1949) Second, the distribution of dispersal distances is bimodal; within a species there are long distance dispersers and short distance dispersers (Blair, 1960; Howard, 1949; Johnston, 1956; Nice, 1937). Third, dispersal often involves movement from a favorable habitat through less favorable areas again to a favorable habitat. Finally, the individuals that successfully disperse and reproduce are the agents of what is normally referred to as gene flow.

Dispersal in birds has been studied by banding. Recapture data on marked birds give the main support to the generalizations above. Dispersal of mammals has received comparatively little attention. That little is known concerning dispersal of individual mammals is not surprising. Many mammals are small, short-lived and noctural and the logistic problems of implementing a study of their dispersal are considerable.

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Yellow-bellied marmots (*Marmota flaviventris*) are relatively large (about 3 Kg), long lived (up to 6 years), diurnal mammals and their colonial organization greatly facilitates their study. Although common in the Rocky mountains, the species has received little study. Armitage (1962, 1965) has described in detail the social and reproductive behavior of the species. Other aspects of yellow-bellied marmot biology have been touched on by Pattie (1967).

Mark and recapture methods have provided much information on the movements of animals; however, while the recapture of a marked individual in a new place may mark the end of a dispersal path, such information gives little insight into the pathways and movements of the animal between the time of release and the time of recapture. Further, successful application of mark and recapture techniques require that the movements of marked animals fall within an arbitrarily assigned trap grid of the study area. That the animal will wander outside the assumed area or that it will be missed by traps or other detection means lends further uncertainty to the method. The use of telemetry, by attaching a radio transmitting beacon to selected individuals, allows the animal to be located at will regardless of its movements within a large area. The disturbing factors of periodic trap confinement are avoided as well as the need for prior assumptions about behavior. Telemetry seemed to us to be a worthy technique in the study of dispersal in the yellow-bellied marmot.

The preliminary requirements of a tracking system that would permit locating the instrumented animal at will were a transmitter of sufficiently small size and weight (15 cc and 40 grams) to permit surgical implantation, transmitter life of 1 to 3 months, transmission range of at least 100 meters, and a receiving system that can identify the individuals by their transmitting frequency and determine the direction of the received signals.

Tracking System

To increase the likelyhood of successful location of all instrumented animals, the system must first be capable of detecting very weak signals. The detection of weak signals is limited by noise arising from both the environment and the receiving equipment. The use of a narrow receiver bandwidth increases signal-to-noise ratio provided the transmitter frequency falls within the receiver passband. This condition, in turn, requires a stable and known transmitter frequency and precise receiver tuning. Once detected, the bearing from which the signal is coming necessitates some form of directional receiving antenna to permit locating the position of the animal.

Transmitter. Specified channels for individual identification, and frequency stability permitting the use of narrow band receivers, was provided by using quartz crystal control of transmitter frequency. Since a continuous signal was not needed for direction finding, intermittent pulsing of the transmitter, so that it was off most of the time, gave a considerable extension of battery life. Our design, Figure 1, is an adaptation of Cochran and Lord's (1963) crystal controlled oscillator but uses the self-pulsing scheme of Rawson and Hartline (1964).

The critical component of the unit was the quartz crystal. Third overtone crystals in the HC-18/U case, similar to those commonly used in Citizen's Band equipment, but processed for our band of 26.500 to 26.650 MHz, tended to have rather high resistances (greater than 30 ohms). This required use of transistors with a rather high amplification factor for reliable operation. For uniform performance from one unit to the next, each crystal was matched to a transistor of appropriate gain so that self-pulsed oscillation continued for supply voltages down to 1.00 volt. This gave maximum usage of the battery energy as well as con-

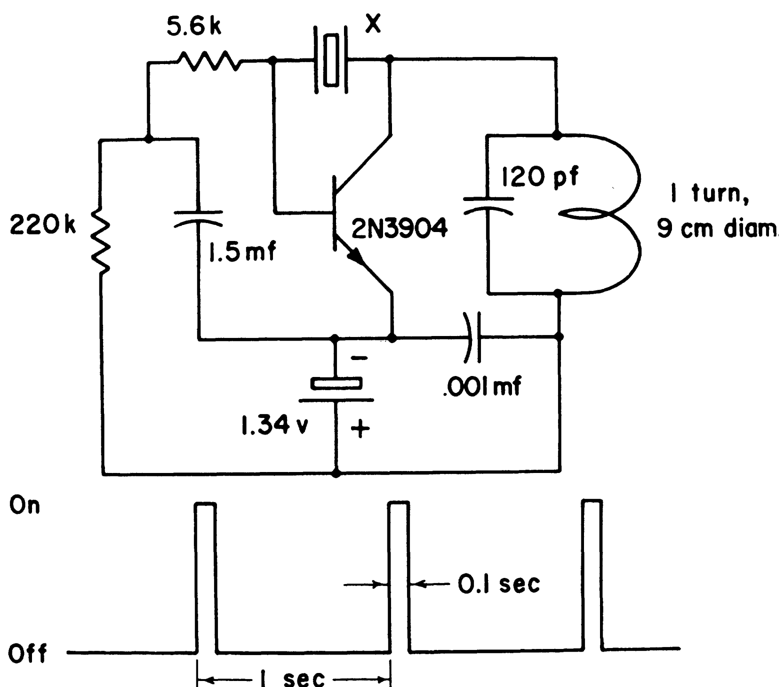

Figure 1. Circuit diagram of the transmitter. X is a third overtone crystal between 26.500 and 26.650 MHz. The duty cycle graph represents the collector current of a few microamperes during the off-phase and 2 to 4 milliamperes during the on-phase.

siderable immunity from oscillator interruption by inadvertant tank circuit detuning.

The self-pulsing timing resister and capacitor in the base bias circuit were selected for an off-time of 0.5 to 1.0 second and an on-time of .05 to 0.1 of a second for a 10:1 duty cycle. The transistor on-current of 2 milliamperes and an off-current of only a few microamperes, produced an average current drain of 0.2 of a milliampere. When powered with the RM 640 mercury cell of 500 milliampere-hour capacity, a theoretical life of 2500 hours or 15 weeks was expected. In practice, about half the theoretical life was obtained.

Radiation was from the resonant tank circuit inductance. Radiation efficiency was strongly dependent upon the area enclosed by the wire loop forming the inductance. The loop was made as large as possible while still permitting surgical implantation. A 9 cm diameter loop was found to be satisfactory for marmots. The loop was resonated on each transmitter by selecting a fixed silver mica capacitor value that permitted self-pulsed oscillation at the lowest supply voltage for the transmitter. For this tuning procedure, the lossy dielectric medium in which the transmitter would operate was simulated by placing the loop around an Erlenmyer flask filled with 0.9% saline.

The transmitters were implanted in the peritoneal cavity. Implantation required protecting the animal from toxic and foreign body reactions induced by the transmitter. This required at least two materials, since, as yet there is no one material that can do both. First, the transmitter components were encased in epoxy cement within a glass capsule to seal out moisture. (Later models were made in a flat form and covered on the two large surfaces with glass microscope cover slips.) Then, after removing all sharp edges, the units were coated with medical-grade silicone rubber to make them biologically inert. The radiating loop was vinyl insulated stranded wire inside medical-grade silicone rubber tubing and held in a circular form by one unshorted turn of piano wire. The weight of a completed unit was between 30 and 35 grams, of which 8½ grams was accounted for by the RM 640 battery.

Receiver. The high signal-to-noise ratio required for weak signal detection was obtained, in part, by using a narrow bandwidth receiver. This, in turn, required accurate tuning to assure that the signal would be in the receiver pass-band. These two criteria, along with low cost and ease in construction formed the basis for design.

The tracking receiver, Figure 2, used the crystal-controlled, broad band converter and tunable intermediate frequency amplifier scheme that is now standard practice in communication receiver design. With this method the incoming signal within the 150 kHz wide band starting at 26.500 MHz was heterodyned against a crystal oscillator at 25.500 MHz, producing a signal at the first intermediate frequency within the band of 1.000 to 1.150 MHz. Tuning to the specific signal frequency was then accomplished by a second conversion with the aid of a tunable local oscillator, covering the range of 1.455 MHz to 1.605 MHz. This second local oscillator converted the signal to a second intermediate frequency of 455 kHz. This double conversion system made possible reasonably stable tuning by placing the tunable local oscillator at a lower frequency. The signal was then converted to an audible signal at about 1 kHz by a product detector and beat frequency oscillator.

The foundation of the receiver was a modified AM broadcast radio. The Heath Model GR-24 (Heath Company, Benton Harbor, Michigan), available in kit form, was large enough in size to provide room for accessory circuits, and used silicon transistors for a wide temperature range operation. Removal of the loud speaker and audio output stage, since only earphones were to be used, provided needed room for inclusion of the additional circuits. The amplitude modulation detector was replaced by a product detector (Stoner and Earnshaw, 1963) and a crystal controlled beat frequency oscillator to allow detection of continuous wave signals. A higher degree of selectivity in the intermediate frequency pass band was obtained with regeneration by simply replacing the normal neutralizing capacitor with a slightly larger one and adding a regeneration control in the emitter return. The original tuning range of the Heath radio was reduced so that the 150 kHz wide telemetry band occupied the full dial range. This required reduction of the tuning capacitor size by removing all but 3 rotor plates and padding the tuned circuits with fixed capacitors. At this point one then had a highly selective cw receiver that tuned from 1.000 to 1.150 MHz.

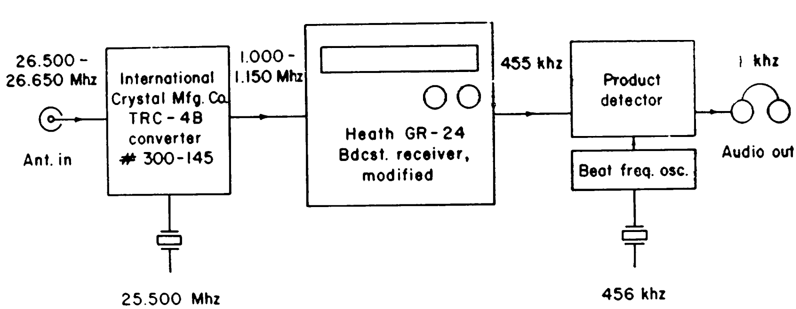

Figure 2. Block diagram of the tracking receiver. See text for Heath GR-24 modifications.

An International Crystal TRC-4B (International Crystal Mfg. Company, Oklahoma City, Okla.) converter was placed in the space liberated by removal of the speaker and output stage. A 25.500 MHz local oscillator crystal in the converter produced the desired output frequencies from the 26.500 to 26.650 MHz inputs. A slightly improved signal-to-noise ratio was obtained by replacing the radio frequency amplifier and mixer transistors with selected 2N588's or 2N1742's, and carefully retuning for optimum signal-to-noise ratio.

The resulting receiver was easily tunable to within less than 1 kHz of a given frequency and a 0.1 microvolt signal from a 50 ohm source produced a 12 db signal-plus-noise-to-noise ratio. This ratio could be increased to 17 db when the regeneration was advanced for the narrowest bandwidth that could be obtained just short of oscillation. Little frequency drift or gain change was noticed over a temperature range from -10° to $+40^\circ$C. The 6 D-cell batteries would power the unit for about 400 hours when used a few hours a day.

Antennas. It is characteristic that for portable antennas there is a conflict between precision in direction finding and signal capture sensitivity. A large antenna is desired for maximum sensitivity since weak signals are the rule in animal tracking. The directivity pattern of a large antenna is quite susceptible to distortion by interaction with nearby conducting objects, such as wires, instruments, people or proximity to ground. Therefore, it is generally recommended that the circumference of a direction finding loop antenna be less than .08 wave lengths (Anon., 1964). Such small loops, while providing accurate bearing information, are quite inefficient for detecting weak signals.

Our initial direction finding antenna system employed a loop antenna similar in design principle to that published by others (Cochran, 1966). The loop was made larger in circumference than .08 wave lengths to increase sensitivity despite some compromise in directional accuracy. Two sharp nulls, 180° apart, were obtained when the plane of the loop was at 90° to the bearing of the signal. There was no way, however, with the loop alone, to determine from which of two directions the signal was coming, i.e., which of the two nulls was the correct one. By combining an omnidirectional vertical antenna with the loop, Figure 3, and adding its signal to that of the loop in proper phase and amplitude, one of the two sensitivity lobes was cancelled, yielding a single, broad null in the direction of the arriving signal. Our addition of the sense antenna to the loop greatly facilitated animal location by providing the means for making certain that one was always proceeding toward the animal and not away from it. Phase and amplitude adjustments, Figure 4, were made by resistor and capacitor elements in the base of the antenna system.

When animals were widely dispersed the limited reception range of the loop required a great deal of random hiking to increase the probability of locating an animal. A larger, higher gain antenna sufficiently directional to reveal the approximate direction of the incoming signal, permited searching a much larger area from a given point.

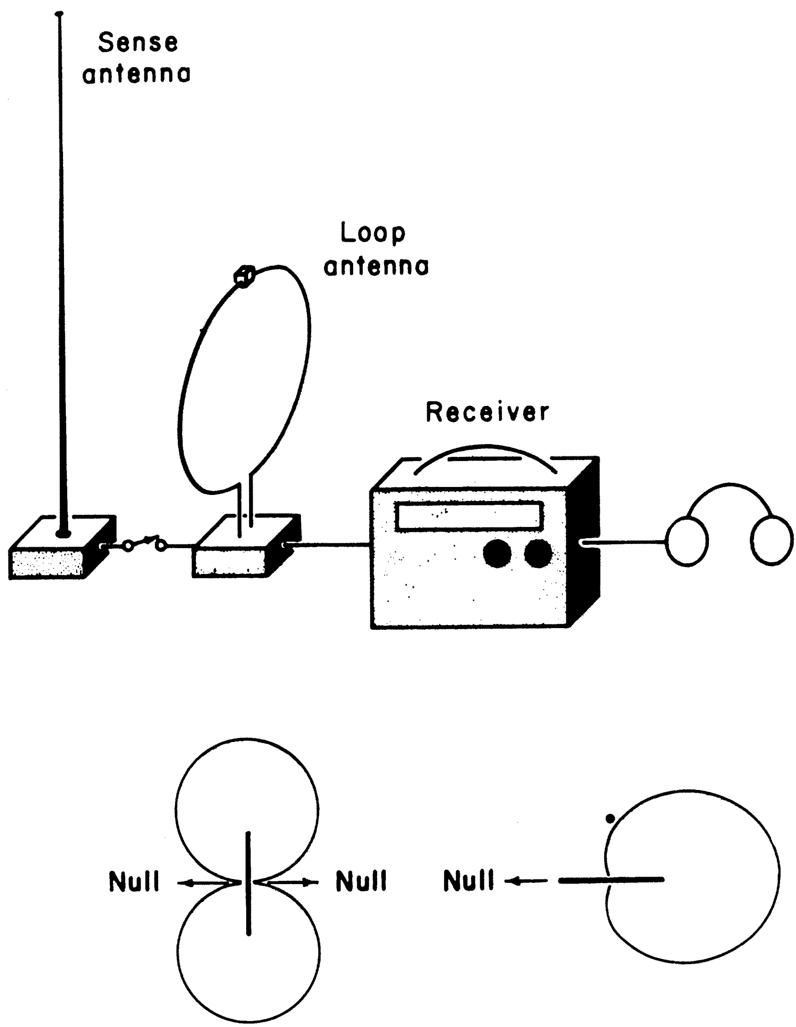

Figure 3. Loop and sense antenna tracking system. The horizontal plane directional sensitivity of the loop alone is shown at the lower left, while that of the loop combined with the sense antenna is at the lower right.

Our extended range search system, Figure 5, used a shortened 2-element parasitic or Yagi antenna. Antennas of this type are unidirectional and normally use elements approximately ½ wave in length. Since this is rather ungainly for portable use at 26.5 MHz, where the element lengths would be nearly 6 meters long, physically shorter elements were used. The elements were made electrically ½ wave long by placing inductances, Figure 6, in the dipole centers. While not as efficient as the full size antenna, it still enjoyed 14 db greater sensitivity than the loop antenna. To further aid in portability, the elements were made from telescoping Citizen's Radio whip antennas. The entire unit could be disassembled into a pair of 30 cm rods (the collapsed elements) and a 1 meter walking stick (the pole and boom).

Study Area and Methods

The study area is situated in the Elk mountains in the vicinity of the town of Gothic, Colorado, site of The Rocky Mountain Biological Laboratory on the upper reaches of the East River, Figure 7. The valley which runs NW to SE is about one-half mile wide and is divided by the river. Marmots were studied at seven colonies in this area.

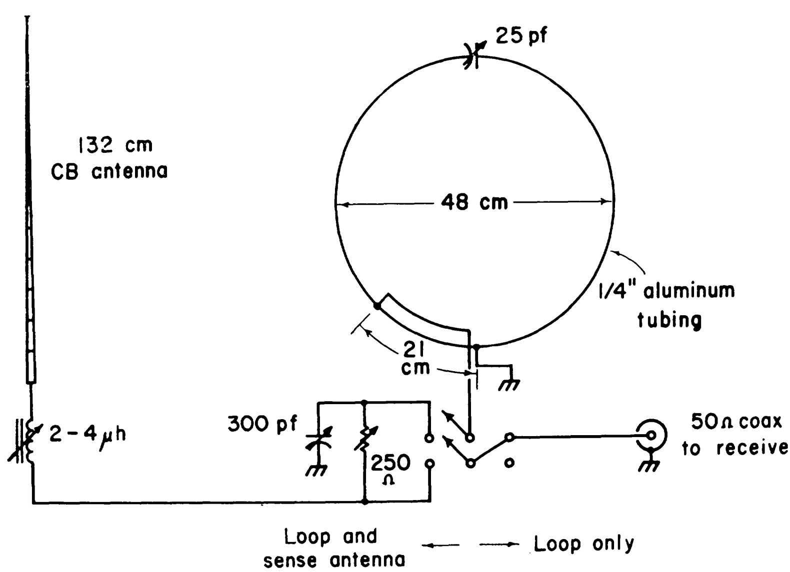

Fig. 4. Diagram of sense and loop antenna and the phase and amplitude adjusting components. Tune up is done by first resonating the loop alone for maximum signal strength at 26.575 MHz with the 25 pf capacitor. Then ,after switching in the sense antenna, the variable inductance, 300 pf capacitor, and variable resistor are adjusted until a combination is found that provides a single null over the range from 26.500 to 26.650 MHz. The variable inductance is the least critical element.

Marmot colonies were typically composed of a single resident adult male, 1 to 8 adult females, and some number of non-reproductive individuals (yearlings and young). Young first appeared above ground about the first week in July. A typical colony was located on a talus slope surrounded by meadow. Stands of blue spruce, aspen and willows were adjacent to most colonies.

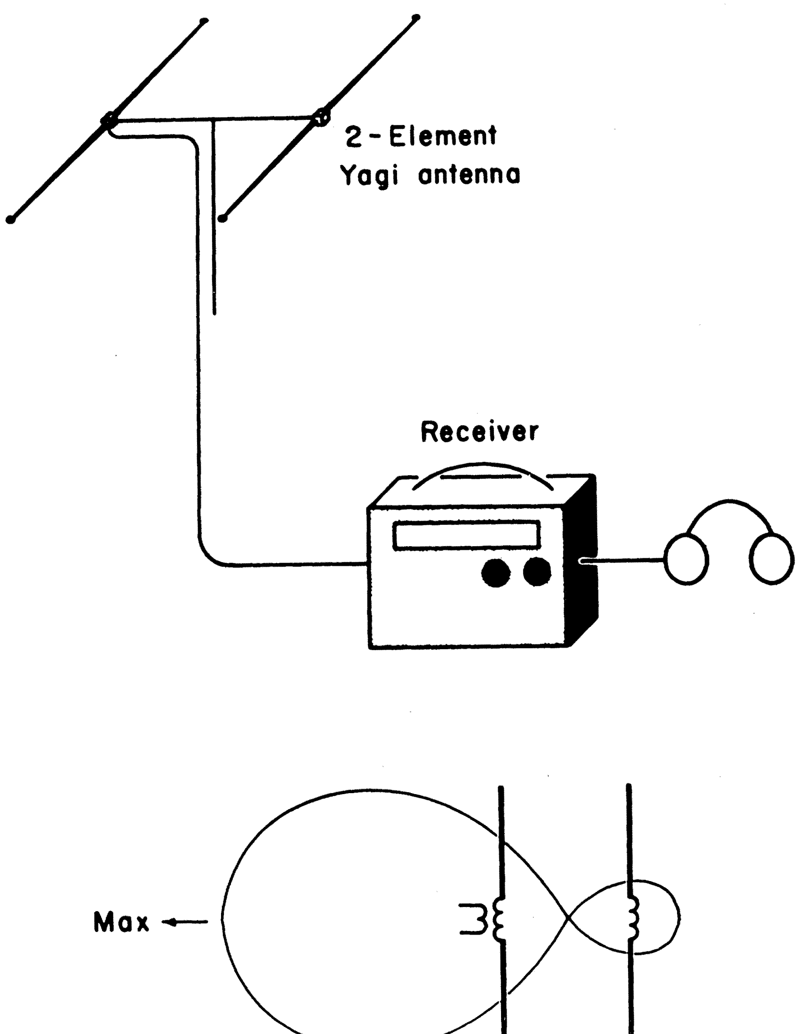

Figure 5. Extended range tracking system. The horizontal plane directivity pattern of the 2-element beam antenna is shown below. A front to back ratio of 5 to 1 can be obtained by proper adjustment of the antenna elements

Yearlings were trapped with National (National Live Trap Co., Tomahawk, Wisc.) live traps, baited with rolled oats. Placement of traps was determined by visual observation of activities of the marmots in the colonies, and by the presence of fresh feces around burrow entrances. Upon capture, each animal was marked with a pair of numbered, metal ear tags and given a distinctive dye mark for visual recognition. Animals which were to be equipped with transmitters were returned to the laboratory for surgical implantation. Each marmot was anesthetized with pentabarbital sodium and a transmitter, after rinsing

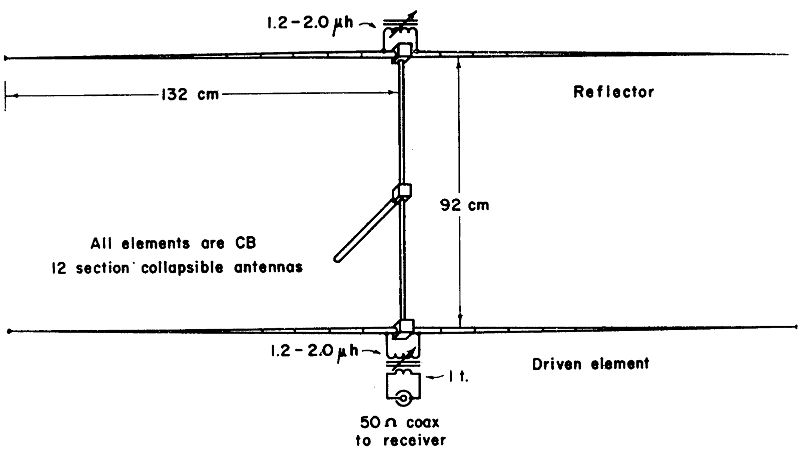

Figure 6. Diagram of the 2 element beam antenna. The inductances are adjusted for maximum front to back ratio.

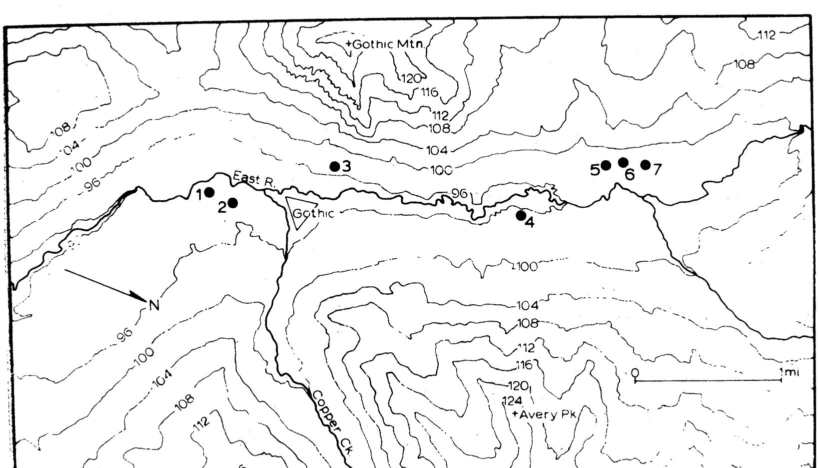

Figure 7. Topographic map of the study area in the Elk Mountains of South Central Colorado. Lines of elevation are shown in hundreds of feet.

in 70% ethyl alcohol, was inserted in the peritoneal cavity through a ventral midline incision. The transmitter was sutured to the belly wall at four places. The incision was closed in layers and the animal was released into a colony within 24 to 72 hours.

After release each animal was located daily before noon and before dusk. The general procedure was to first check for the presence of the animal at his last location with the aid of the loop antenna. The existance of an extremely strong signal indicated that the animal was still there. If a weak signal was heard its direction was determined with the aid of the loop and sense antenna and the new location found by homing on the signal source. If no signal was received, the two-element beam was used to scan a larger area about this location. If a signal with this larger antenna was then received, its general direction was noted and the receiver was reconnected to the loop. By walking in the indicated direction the signal was soon detected and again location determined by homing. If no signal could be heard with the beam antenna at the first listening point, exploration was begun of areas away from this point, in a direction that either the individual or other animals had apparently been moving. At 100 meter intervals the beam was erected and the surroundings scanned. The number of such scannings was limited by available daylight and the number of other animals yet to be located.

Results

In two summers of radio-tracking, we have equipped 12 yearlings with implanted radio transmitters (Table 1). Of these 12, 10 were

Table 1. Dates of release and duration of tracking for all yearling marmots who were radio-tracked during the course of this study.

Name	Sex	Colony No.	Year released	Date of release	Date last located	Fate
Un	M	4	1966	26 – VII	23 – VIII	D[1]
428	F	4	1966	26 – VII	23 – VIII	R[2]
444	M	4	1966	26 – VII	23 – VIII	P[3]
710	M	1	1967	10 – VII	4 – VIII	D
714	M	1	1967	10 – VII	18 – VIII	D
702	M	4	1967	8 – VII	30 – VIII	D
704	M	4	1967	8 – VII	9 – VII	D
722	M	4	1967	8 – VII	25 – VIII	R
724	M	4	1967	8 – VII	18 – VII	D
536[4]	M	5	1967	18 – VII	5 – VIII	P
716	M	5	1967	5 – VII	20 – VIII	R
514[4]	F	7	1967	6 – VII	5 – VIII	D

[1] Dispersed from the colony into which it was released.
[2] Remained in the colony as a resident for the duration of the summer.
[3] Moved just outside the home-range of the resident male after release into the colony.
[4] This individual was born into the colony from which it was tracked. All other individuals are introduced animals taken from some other place.

experimental animals that were introduced into our colonies. In 1967, Figure 7, two yearling males were released into colony 1; 3 yearlings were introduced into colony 4 in 1966 and 4 others were released there in 1967; 1 yearling was introduced into colony 5 in 1967. Three of the introduced individuals and 1 resident remained in the colonies where they were relseased for the duration of the summer. All other individuals dispersed.

In Figures 8 and 9 the distances between burrow sites used by dispersing animals and between burrow sites used by resident animals are presented. The mean distance between burrow sites of dispersing yearlings was 84.2 m. The mean distance between burrow sites used by residents was 50.3 m.

The orientation of movements of dispersing yearlings is summarized in Figure 10. Figure 11 summarizes the orientations of movements of resident animals.

In Table 2 the locations of the radio-tracked individuals are given. The tallies for the categories listed reflect differences in habitat utilization between residents and dispersing yearlings. The colonies studied in the Gothic area were associated with meadows. Trees may have been present, but they were usually at the edge of the colony. Also found were vantage points such as fallen logs or large rocks. Dispersing individuals usually were found in meadow only while they were still in the colony.

At those places where it was possible to excavate a burrow occupied by a dispersing yearling, a grass-lined nest was found.

Discussion

The extent to which the behavior of the marmots was affected by the presence of the transmitter is not known. Some effect must be assumed. A yearling female equipped with a faulty transmitter 1966 was

Table 2. Residence sites used by dispersing and resident marmots. D = Dispersing animal. R = Resident animal.

	Spruce		Aspen		Willows		Meadow		Other	
	D	R	D	R	D	R	D	R	D	R
Fallen Log	7	--	--	--	--	--	2	1	--	--
Rock Outcrop	1	--	--	--	--	--	1	7	2	--
Stump	2	--	--	--	--	--	--	--	--	--
Base of Tree	1	5	--	1	--	--	2	.	--	--
Burrow	8	--	--	2	--	--	9	4	2	--
Out in Open	1	--	--	--	--	--	3	--	--	--
Don't Know	--	--	--	--	5	--	--	--	--	--
Totals	20	5	0	3	5	0	17	12	4	0

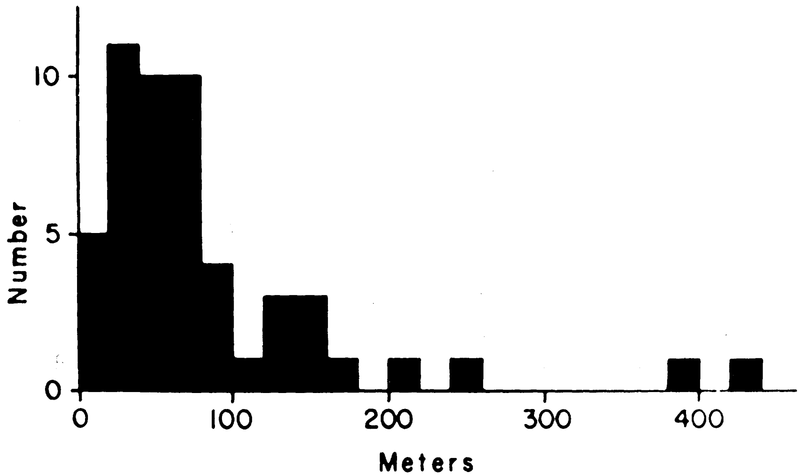

Figure 8. Distances between burrows used by dispersing yearlings.

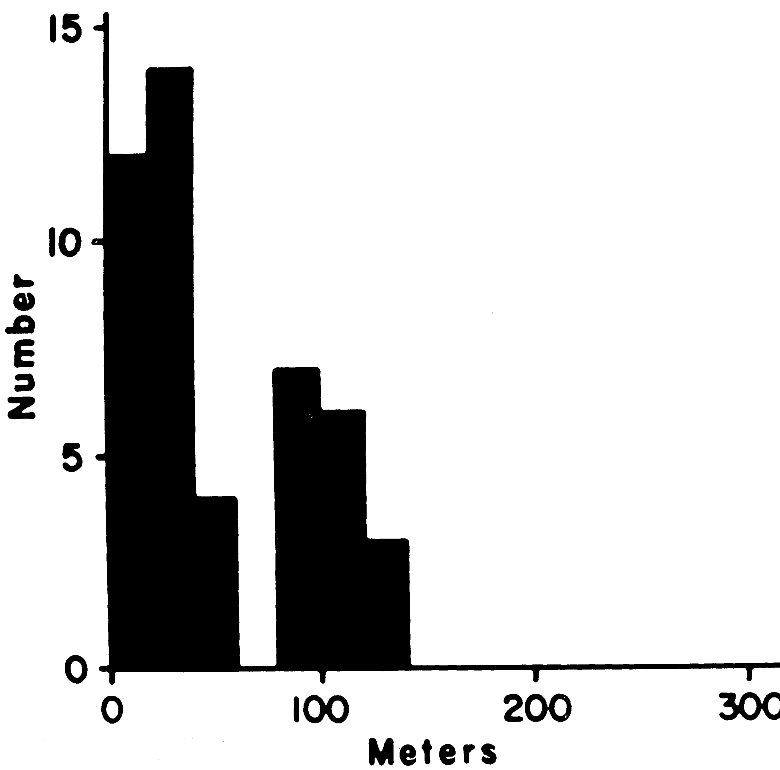

Figure 9. Distances between burrows used by resident yearlings.

recovered as a resident adult in her home colony in 1967. She did not produce a litter, although all of the other adult females in the colony did.

The tracking results are based primarily on yearlings introduced into colonies on the east side of the valley (colonies 1, 4). As a result, the direction of many of the recorded movements was toward this side of the valley. The orientation of these movements suggest that the river or its associated habitat was a barrier to the movements of marmots. Few movements were parallel to the major NW to SE axis of the valley, although many were directed due north or due south.

The movements of resident yearlings showed no predominant direction (Fig. 11). This is not surprising as the movements recorded for these individuals were between burrows within a colony and would not be expected to show orientation to a particular direction.

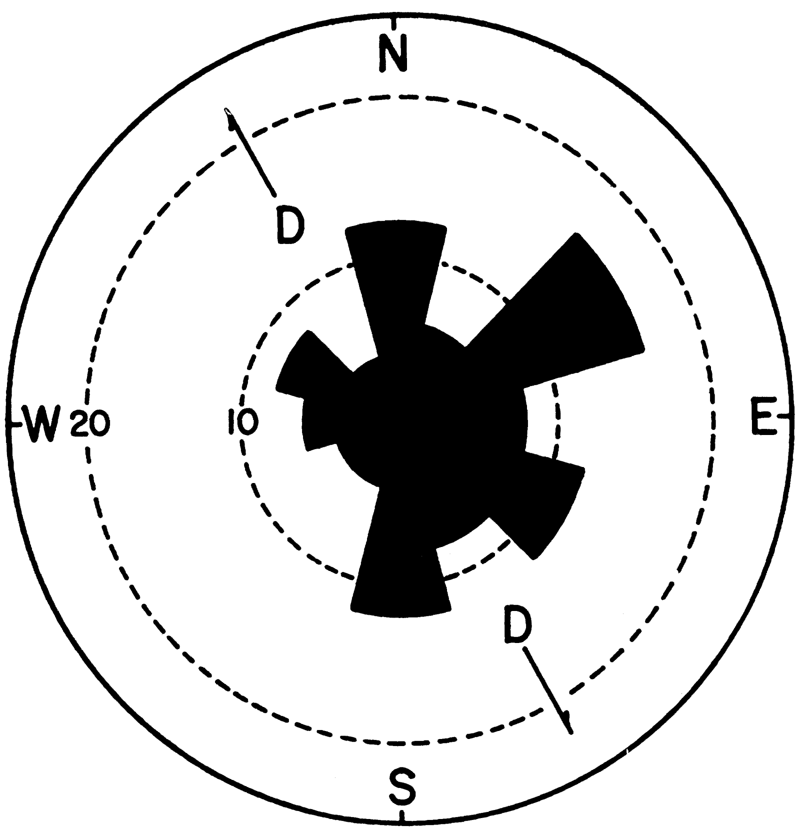

Figure 10. Orientation of movements of dispersing yearlings. The class intervals are 30° wide. D indicates the direction of the main axis of the valley. The percent of all movements in any interval is shown by the darkened portion of the figure.

Two animals were located in the same burrow, outside of colony 4, on different dates. They arrived at this burrow from different directions. Two other animals (710 and 714) followed the river south out of Colony 1. The similarity of movements of these individuals may indicate that there are a limited number of suitable pathways into and out of a colony.

The distances moved by dispersers between the times they were located show some tendency to be bimodal (Fig. 8). This distribution is skewed to the left, in part, for technical reasons. It was easier to locate individuals that had moved only 100 meters or so than it was to find an individual that had moved over 400 meters in the same time period. As a consequence, the distribution of movements of dispersers appears more like that of the residents (Fig. 9) than was expected.

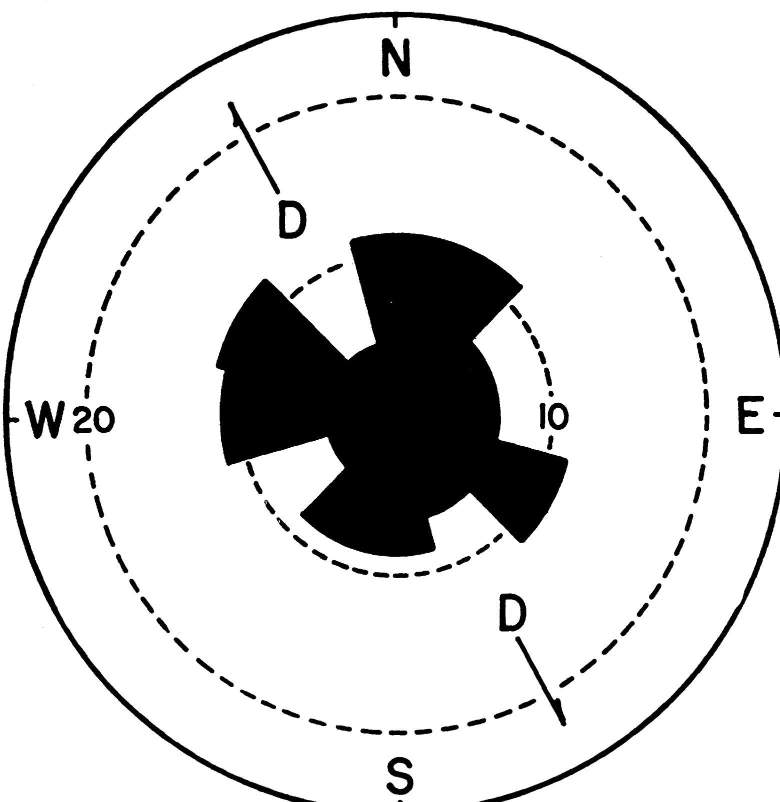

Figure 11. Orientation of movements of resident yearlings. Interpretation is as in Figure 10.

More locations were found for resident animals than for dispersers. The distance between locations of dispersers was not only greater than for residents, but also, introduced environmental factors, such as topography and vegetation, that attenuated the signals from the transmitters. While the line-of-sight reception range was up to 1 kilometer, through dense vegetation it could be reduced to little over 100 meters. The ability of dispersers to elude us, once they left the vicinity of the colony, suggests that dispersal is a long range phenomenon, greater than a kilometer.

Had the study of dispersal of yellow-bellied marmots been implemented solely by conventional trapping methods, similar data on distances moved and direction of movement would probably have been collected. To do this an extensive trapping effort would have been required; however, even the most extensive trapping effort would not have revealed information on places used by dispersing individuals. Such information was routinely collected using radio tracking methods.

The major shortcoming of the system, as developed for this study, was inadequate reception range for reliable tracking of dispersing animals. Were the range twice that available, many more locations could have been found. As little can be done to increase the radiated field strength of the transmitters at this frequency, improvements in reception distance must come as a result of improved receiver design. This could be obtained by increased signal-to-noise ratio through reduced bandwidth, which in turn, will require more precise tuning to the transmission frequencies.

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