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# AN EVALUATION OF FOUR TELEMETRY SYSTEMS FOR WILDLIFE INVESTIGATIONS[1]


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## INTRODUCTION

When studying many large wild mammals in their natural environment, problems arise locating individuals and obtaining information about them without significantly altering their behavior. Telemetry equipment has recently been developed for use on large mammals, but all too often biologists tend to use that equipment most readily available rather than equipment suited to the needs of their particular study. The primary purpose of this study was to find a telemetry system suitable for use on coyotes. Coyote behavior as well as most predator behavior is quite secretive and nocturnal to a large extent, so a telemetry system was needed which would provide maximum range with good directional characteristics and high reliability.

The objectives of this study were to field test telemetry equipment such that might be used in subsequent mammal studies and to make an objective comparison of the transmission and reception characteristics of several types of transmitter collars and receivers. The range of four transmitters was tested and compared as a function of three terrain situations. Transmitters were tested for line of sight transmission at ground level, through brush, trees and other small natural obstructions, line of sight transmission from a high point (aircraft) to ground level, and transmission over natural obstructions such as hills and ridges. The distance the transmitter signal was audible over 90° of a 180° rotation of the receiver antenna was also compared for the various transmitters and receivers. The systems were further compared for their directional characteristics and the angular resolution of each system was determined.

Upon completion of these tests, the systems were evaluated as to their practical application in wildlife investigations. The system deemed most appropriate for the current coyote study was further evaluated and monitoring sites established on the study area.

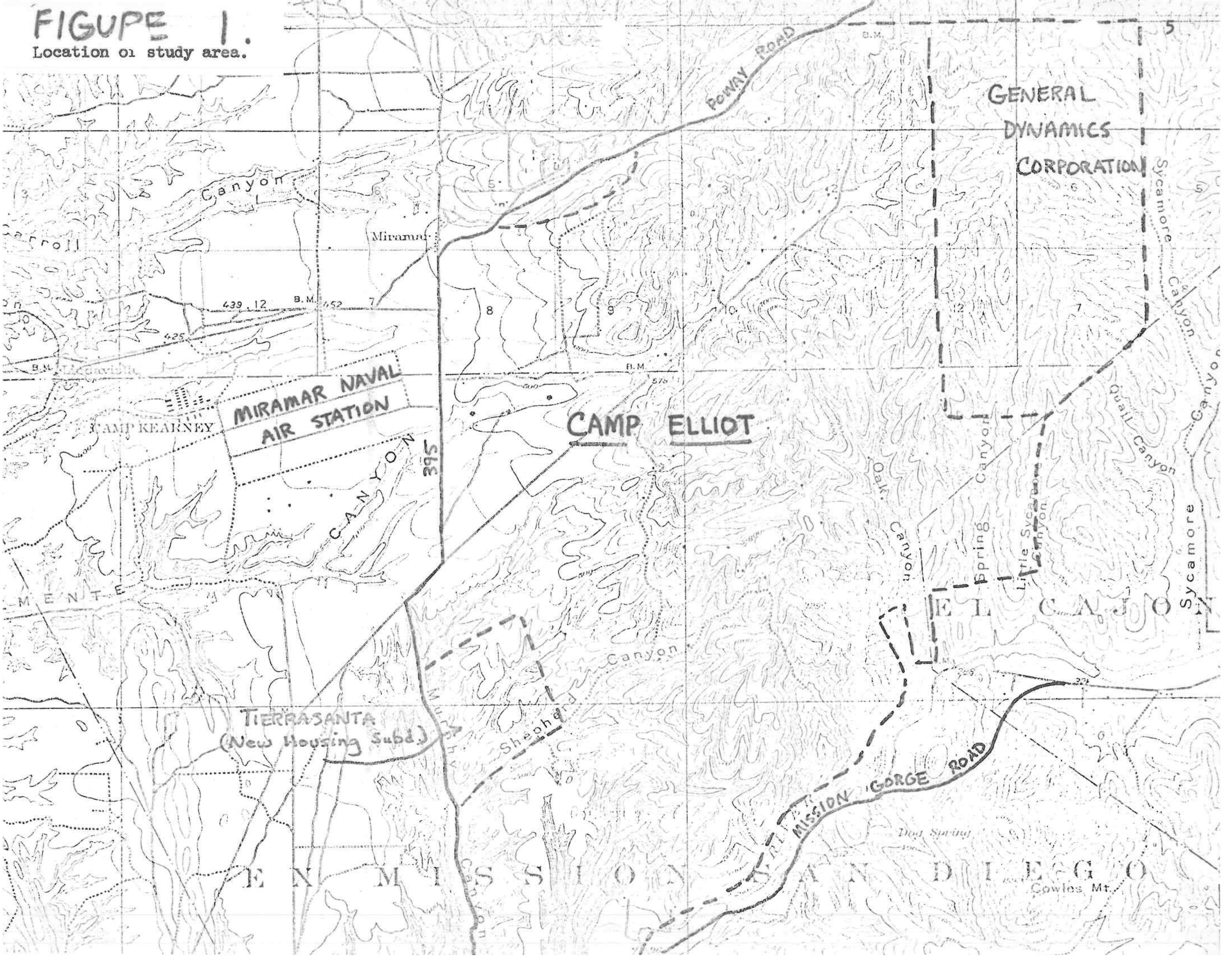
Telemetry studies in the past have relied upon information and equipment from previous studies, but little has been done in the area of comparing different transmitter-receiver systems. For this reason, this study was conducted to evaluate similar telemetry systems over the same type of terrain and determine the system most suitable for use on coyotes.

## DESCRIPTION OF THE STUDY AREA

This study was conducted on Camp Elliot, an inactive United States Marine Base presently under the command of Miramar Naval Air Station, which is situated adjacent to the west boundary of Camp Elliot. Camp Elliot and the study area are located approximately five miles north of San Diego on Highway No. 395. Approximately 10,000 acres lie within Camp Elliot. Camp Elliot is enclosed by Highway No. 395 and Murphy Canyon Road on the west, Poway Road on the north, General Dynamics Corporation property and San Diego County property on the east, and Mission Gorge Road on the south (Figure 1). The elevation in this area varies from approximately 400 feet in the valleys to 1292 feet above sea level, atop Fortuna Mountain, the highest point within Camp Elliot. The testing was done primarily in the valleys and along numerous ridges ranging in elevation from 800 to 1000 feet.

The study area is typically a coastal sage plant community with chaparral vegetation appearing on the north slopes and in shaded canyons. The area lacks natural free water, with the only water available in the form of man-made reservoirs. The vegetation found in the valley bottoms and shaded canyons consists primarily of California live oak, (Quercus agrifolia), sycamore (Platanus racemosa), willows (Salix gooddingii), red willows (Salix laevigata) and tree tobacco (Nicotiana glauca). The north slopes of the ridges are dominated by chamise (Adenostoma fasciculatum), scrub oak (Quercus dumosa), laurel-sumac (Rhus laurina), monkey-flower (Mimulus guttatus), black sage (Salvia mellifera), purple sage (Salvia leucophylla), and white sage (Salvia apiana). A few scattered remnants of eucalyptus groves are also found on the northern slopes. The south-facing slopes and lower elevation flats are dominated principally by coastal sagebrush (*Artemisia palmeri*), buckwheat (*Eriogonum fasciculatum*), buckbrush (*Ceonothus cuneatus*), California lilac (*Ceanothus thyrsiflorus*), and red-berry buckthorn (*Rhamnus crocea*). There are some large areas of grassland also found in the study area which are not limited to the valleys and flats, but also found on slopes and ridges.

FIGUPE 1.
Location o1 study area.



## METHODS AND MATERIALS

Four neck-collar transmitters were obtained as well as three receivers. Three of the collars were low-frequency transmitters in the Citizen's Band range of 11 meters. One collar was a high-frequency transmitter at 159.435 MHz. Of the three receivers used, one, the Ocean Applied Research FR-206 receiver, was adapted to receive all three of the low-frequency transmitters. The Ocean Applied Research ADFS-210 Visual Display receiver was used only with the OAR transmitter; additional crystals could be added for use with other transmitters. The Johnson Messenger 350 receiver was used with Johnson and Davidson transmitters as well as the high-frequency transmitter from Wildlife Materials. Specifications on transmitters and receivers are listed in Table 1.

The different systems (transmitter-receiver) were tested simultaneously to keep the amount of variation due to climatic differences at a minimum. The tests were conducted over the same terrain for each system. When one receiver was stationary and the transmitter moved, this procedure was used for all the systems tested on that day. A dog was used to carry the different collars and each was placed on the dog at known distances from the receiver. During each test all the receivers being used were operated with ear-phones on a headset by the same individual. This was done to eliminate differences known to exist between individual's hearing abilities.

The line of sight transmission at ground level, through brush and trees, was conducted in several of the longer valleys found on Camp Elliot as well as along some of the ridges. The transmission over natural obstructions was conducted by placing the collars, one at a time, on the dog in a narrow canyon approximately 300 feet lower in elevation than the surrounding terrain. The line of sight test from a high point to ground level was accomplished by the use of a helicopter, but this test was done for only the Ocean Applied Research telemetry system. Results were obtained from the California Department of Fish and Game on the air to ground ranges of both the Johnson and Davidson transmitters using the Johnson Messenger 350 receiver and these were compared to the OAR system.

During each test the system in operation was also tested for its angular resolution and these confidence intervals were recorded for various distances up to the maximum range of the system. These null angles were then plotted against the distance between the transmitter and receiver.

Each test was repeated at least three times and the results reflect the mean values of these trials. The range distances were calculated from receiver and transmitter positions fixed on a topographical map of the area.

Upon completion of the initial testing the system deemed most suitable for use on the current coyote study was set up on Camp Elliot and proposed monitoring sites were established.

TABLE 1.

Specifications on transmitters and receivers were as follows:

Transmitters

1. Ocean Applied Research - AB 224 - LP
San Diego, California 92121

frequency - 25 MHz, crystal controlled

output - 250 milliwatts.

antenna - electrostatic dipole, omni-directional signal.

size - 1000 grams.

packaging - water-proof, "coyote-proof" and adjustable for growth.

battery life - 6 months; replaceable.

cost - $250/unit.

comments - overall size can be reduced to 600 grams without effect on range or life.

2. A. R. Johnson - mountain lion collar
Moscow, Idaho

frequency - 32 MHz, crystal controlled

output - 100 milliwatts.

antenna - copper loop, exposed.

size - 465 grams.

packaging - epoxy enclosed transmitter and batteries.

battery life - 6 months; non-replaceable.

cost - $55/unit.

comments - antenna loop size adjustable.

Table 1. (continued)

3. Davidson Company - deer collar
   Minneapolis, Minnesota

   frequency - 31 MHz, crystal controlled

   output - 100 milliwatts.

   antenna - copper loop, epoxy covered.

   size - 350 grams.

   packaging - collar, transmitter and batteries are epoxy covered.

   battery life - 10-11 months; non-replaceable.

   cost - $85/unit.

   comments - antenna loop size is critical for proper tuning.

4. Wildlife Materials - Big game collar - deer
   Carbondale, Illinois 62901

   frequency - 150 MHz

   output -

   antenna - whip, nylon covered.

   size - 250 grams.

   packaging - nylon-web collar, epoxy covered transmitter.

   battery life - 1 year; replaceable.

   cost - $66/unit.

   comments - expandable to allow for growth.

<u>Receivers</u>

1. Ocean Applied Research - Finders Receiver FR-206
   San Diego, California 92121

   reception - 11 meter transmitters; 8 crystal controlled channels.

   antenna - 16 inch square, tuned magnetic loop with a 20-inch electro-static whip

   power - 8 AA penlight batteries/20 hours.

Table 1. (continued)

| | | |
|---|---|---|
| controls | - | On-Off volume control, local-long distance switch, antenna sense switch, channel selector. |
| packaging | - | durable metal case, shielded antenna. |
| cost | - | $500/unit. |
| comments | - | designed for hand use in field, can be used as mobile unit. |

2. Ocean Applied Research - Automatic Direction Finder System ADFS-210
San Diego, California 92121

| | | |
|---|---|---|
| reception | - | 11 meter transmitters; 10 crystal controlled channels. |
| antenna | - | loop array - two 8 by 10 inch fixed loops mounted atop a 22 foot vertical whip. |
| power | - | operates from any 12 VDC source or internal battery pack. |
| controls | - | On-Off volume control, channel selector, video display adjustments. |
| video display | - | 3-inch cathode ray tube with compass rose graduated every 5° from 0 to 360°. |
| packaging | - | aluminum, splash-proof sealing. |
| cost | - | $4100/ unit. |
| comments | - | available in high frequency, VHF and VHF bands; adaptable for either mobile or fixed usage. |

3. E. F. Johnson - Messenger 350 - Model 242-0154
Waseca, Minnesota

| | | |
|---|---|---|
| reception | - | 11 meter transmitters, 12 channels. |
| antenna | - | 12 inch circular aluminum loop mounted atop a 2 foot mast. |
| power | - | operates from any 12 VDC source. |
| controls | - | On-Off volume, radio frequency gain, channel selector, manual tuner. |
| packaging | - | metal case. |
| cost | - | $500/unit. |
| comments | - | basic unit designed for mobile use, but available with battery pack for hand use; adaptater used for high frequency transmitters. |

## RESULTS AND DISCUSSION

### Range

The range of the telemetry systems compared varied depending upon the type of transmission. Line of sight transmission at the ground level which was directed through brush, trees and other small natural obstructions gives a good index for typical tracking ranges in a coastal sage or chaparral community such as that found along the coast in southern California. The results of this test are shown in Table 2. The OAR collar showed a range of 4.6 miles when the FR-206 receiver was used and 3.0 miles with the ADFS-210 receiver. However, since the OAR transmitter has a 250 milliwatt output as compared to the 100 milliwatt output of the A. R. Johnson and Davidson Co. transmitters, a correction factor is necessary to objectively compare these ranges. The correction factor was obtained by using the square root of the factor by which the power output was increased, as the factor by which the range will be increased. Since the OAR transmitter has 2.5 times the power output of the A. R. Johnson and Davidson transmitters, the range should increase by a factor of 1.581. This factor was used in Tables 2, 3, and 5. When this correction factor was applied to the results of the OAR transmitter tests, the ranges were reduced to 2.9 miles for the FR-206 receiver and 1.9 miles for the ADFS-210 receiver.

Comparing the results of this test shows the OAR transmitter has the greatest range of the transmitters tested. However, this was only found with the FR-206 receiver. The OAR visual display receiver began losing the signal at 2.0 miles and at 3.0 miles the visual image was too weak to read. The A. R. Johnson transmitter had a maximum range of 2.7 miles with the Johnson 350 receiver and 2.3 miles with the OAR FR-206 receiver. This disparity between receivers was probably due to improper tuning of the FR-206 receiver which lacks the manual tuning control found on the Johnson receiver. The Davidson transmitter had a 2.2 mile range using the Johnson 350 receiver as compared to 2.0 mile range with the FR-206 receiver. Here again, the manual tuning is what probably accounts for this difference.

The collar from Wildlife Materials was subjected to the same conditions for this test as the other transmitters and the maximum range for this high-frequency transmitter was only .7 miles. This difference in range as compared to the other transmitters is due to the characteristics of high-frequency radio waves which exhibit some distortion and loss of penetration when transmitting through brush and other foliage. Factory specifications for this transmitter indicated a range of 2 miles, but results of this test indicate this would be possible only under favorable conditions with a perfect line of sight transmission.

Comparisons show the A. R. Johnson transmitter has 22.7% more range than the Davidson transmitter, while the OAR transmitter using the FR-206 receiver with the corrected range value has 31.8% more range than the Davidson transmitter and 7.4% more range than the A. R. Johnson transmitter. These comparisons were made using values obtained with the Johnson 350 receiver for both the A. R. Johnson and Davidson transmitters. When the range of these three transmitters are compared using the FR-206 receiver, the OAR transmitter had 45% more range than the Davidson transmitter and 26% more range than the A. R. Johnson transmitter.

Objectively comparing the OAR ADFS-210 receiver to the other receivers is difficult, considering this is a visual display receiver while the others are audio receivers. However, since the system is being compared, the ADFS-210 showed 34.5% less range than the FR-206 receiver when both were used with the OAR transmitter. The A. R. Johnson/Johnson 350 system had 42%

more range than the OAR/ADFS-210 system while the Davidson/Johnson 350 system ranged 15.8% farther.

The low-frequency transmitters showed 4.1, 3.85, and 3.1 times more range for the OAR, A. R. Johnson, and Davidson collars respectively than the high-frequency transmitter from Wildlife Materials.

TABLE 2. Range: Line of sight transmission at ground level, through brush, trees and other small natural obstructions.

| Transmitter | Receiver | Maximum Range (miles) |
|---|---|---|
| OAR | FR-206 | 4.6 (2.9)* |
| OAR | ADFS-210 | 3.0 (1.9)* |
| A. R. Johnson | Johnson 350 | 2.7 |
| A. R. Johnson | FR-206 | 2.3 |
| Davidson | Johnson 350 | 2.2 |
| Davidson | FR-206 | 2.0 |
| Wildlife Materials | Johnson 350 | .7 |

*Corrected range - This is the range of the OAR transmitter corrected to the same power output as the A. R. Johnson and Davidson transmitters:

$$\text{Corrected Range} = \frac{\text{Max. Range}}{\sqrt{\frac{250 \text{ mw}}{100 \text{ mw}}}}$$

The range of transmission over natural obstructions was appreciably less than the ranges for line of sight transmission at the ground level. The range tests over natural obstructions were conducted by placing the collars on the test animal in a canyon 300 feet lower in elevation than the surrounding ridges. The results of this test (Table 3.) indicate a 2.9 mile range for the OAR transmitter using the FR-206 receiver while the ADFS-210 only worked up to 1.9 miles. However, these results are considerably reduced when corrected for similar power output as the other transmitters. Using the corrected range as a basis for comparison, the OAR/FR-206 had the greatest range of 1.8 miles, 30% greater than the 1.2 range found with the ADFS-210, 20% more range than the A. R. Johnson/FR-206, and 28.5% more range than the Davidson/FR-206. This system ranged 5.9% farther than the A. R. Johnson/Johnson 350 and 20% farther than the Davidson/Johnson 350. The OAR/FR-206 had 18 times the range of the Wildlife Materials transmitter, but this is due to the poor transmission of high-frequency transmitters over obstructions.

The Davidson transmitter had 15 times the range of the Wildlife Materials transmitter, while the A. R. Johnson had 17 times the range. The A. R. Johnson transmitter had 13.3% more range than the Davidson transmitter when both were used with the Johnson 350 receiver.

The results of this test indicate very similar ranges for the three low-frequency transmitters, all considerably greater than the high-frequency transmitter.

TABLE 3. Range: Transmission over natural obstructions.

| Transmitter | Receiver | Maximum Range (miles) |
|---|---|---|
| OAR | FR-206 | 2.8 (1.8)* |
| OAR | ADFS-210 | 1.9 (1.2)* |
| A. R. Johnson | Johnson 350 | 1.7 |
| A. R. Johnson | FR-206 | 1.5 |
| Davidson | Johnson 350 | 1.5 |
| Davidson | FR-206 | 1.4 |
| Wildlife Materials | Johnson 350 | .1 |

*Corrected range - See Table 2.

The line of sight transmission from transmitters on the ground to receivers located in aircraft was determined for the three low-frequency transmitters. This air to ground range (Table 4.) showed the OAR/ADFS-210 system 5 to 7 miles greater than either the A. R. Johnson/Johnson 350 or the Davidson/Johnson 350 system. This difference in range may be attributed to the difference in power output of the OAR transmitter as compared to the A. R. Johnson and Davidson transmitters. When the range is corrected for the OAR collar, it is reduced to 9.5 miles which lies within the approximated ranges provided by California Department of Fish and Game for the A. R. Johnson and Davidson transmitters.

TABLE 4. Range: Line of sight transmission - ground to aircraft.

| Transmitter | Receiver | Maximum Range (miles) |
|---|---|---|
| OAR | ADFS-210 | 15 (9.5)* |
| A. R. Johnson | Johnson 350 | 8-10** |
| Davidson | Johnson 350 | 8-10** |

*Corrected range - See Table 2.

**Approximate ranges as provided by California Department of Fish and Game.

As the distance between the transmitter and receiver increases, the null angle (angle in the relative position of the receiver antenna where no signal is received) will increase. This means that as the distance between the transmitter and receiver increases, the certainty with which you can pinpoint the transmitter location decreases. The maximum range of the transmitters was determined when this null angle approaches 180° in an 180° rotation of the receiving loop antenna. The maximum distance the transmitter signal is audible over 90° of the compass rose (45° on either side of the null angle) in an 180° rotation of the receiver antenna was compared (Table 5.). Using the corrected ranges for the OAR transmitter, it was determined that the OAR/FR-206 telemetry system had 10.5% more range than the A. R. Johnson/Johnson 350, 20% more range than the Davidson/Johnson 350 and 320% more or over 4 times the range of the Wildlife Materials/Johnson 350 system when transmission was line of sight at ground level. For this type of transmission the A. R. Johnson transmitted 8.5% farther than the Davidson transmitter.

When the transmission was over natural obstructions, the results (Table 5.) indicated much less difference between the low-frequency transmitters than for the line of sight transmission at ground level. The OAR/FR-206 and the A. R. Johnson/Johnson 350 had the same range of 1.5 miles where the signal was audible over 90° of the compass rose. This was 15% greater than the 1.3 mile range for the Davidson transmitter. The Wildlife Materials transmitter when transmitting over this much of a hill was unable to record a null angle of 90° or less.

TABLE 5. Directional Range: Maximum distance transmitter signal is audible over 90° of the compass rose (45° on either side of the null angle) in a 180° rotation of the receiver antenna.

| Transmitter/Receiver | Directional Range | |
|---|---|---|
| | Line of sight transmission at ground level (miles) | Transmission over natural obstructions (miles) |
| OAR/FR-206 | 3.3 (2.1)* | 2.4 (1.5)* |
| A. R. Johnson/Johnson 350 | 1.9 | 1.5 |
| Davidson/Johnson 350 | 1.8 | 1.3 |
| Wildlife Materials/Johnson 350 | 0.5 | 0.0 |

*Corrected range - See Table 2.

Directional Characteristics

The variation in signal strength was determined as a function of the orientation of the receiving loop antenna to the transmitter. This test was standardized for all of the telemetry systems by measuring this variation in signal strength at a fixed distance of one mile between the receiver and the transmitter.

Knowledge about the orientation of the receiver antenna is necessary before one should attempt any extensive tracking with a telemetry system. If a loop antenna is used, such as those described with the FR-206 and Johnson 350 receivers, the plane of the loop must be perpendicular to the direction of the transmitter to locate the transmitter. In this position no signal will be received and this is referred to as the null. Rotation of the antenna from this null position will result in the start of a signal which will increase in intensity up to 90° of rotation. Then the signal strength will diminish through another 90° of rotation until the loop is again perpendicular to the direction of the transmitter and the null is reached. As the distance between the receiver and transmitter increases, the angle of rotation about the null, where no signal is heard, will increase. This is the null angle. When the null angle approaches 180°, the maximum range of the transmitter has been reached.

During this study the orientation of the transmitter antenna was tested for variation in transmission qualities and as long as the transmitter antenna remained in the upright position, no noticeable differences in signal strength were heard with the OAR transmitter. Orientation to the direction of the receiver had no effect on the signal received; however, when inverted all of the transmitters showed a substantial loss in range, with none exceeding one mile.

The FR-206 receiver was found to have the most sensitive directional antenna. The position of the receiver is determined by using the null position of the loop. Then the receiver is rotated 90° so that it is parallel to the null axis and the antenna sense switch is depressed. The antenna sense switch adds the electrostatic whip to the magnetic loop and feeds more power to one side of the loop. If the hot side of the loop is pointed towards the transmitter, the signal strength will be greater as indicated on the signal-strength indicator than if the other side of the loop is pointed towards the transmitter. This feature enables the observer to determine the absolute direction of the transmitter on one fix of the signal.

At one mile no signal is heard with the FR-206 receiver $\pm$ 5° about the null axis. The null angle then is 10° for the OAR/FR-206 system at this distance. Since the ADFS-210 has a double loop-array antenna, the antenna orientation has no effect on the signal strength, and no null position is noted. The Johnson 350 receiver with the loop antenna can be used to determine the null axis, but in order to determine in which direction on this axis the transmitter is located, two fixes must be taken and the direction which the two null axes converge determines the position and direction of the transmitter. The Davidson/Johnson 350 system had a $\pm$ 6.5° null deflection for a 13° null angle at one mile while the A. R. Johnson/Johnson 350 is $\pm$ 6° or a 12° null angle at this distance. These null angles were recorded with line of sight transmission at the ground level.

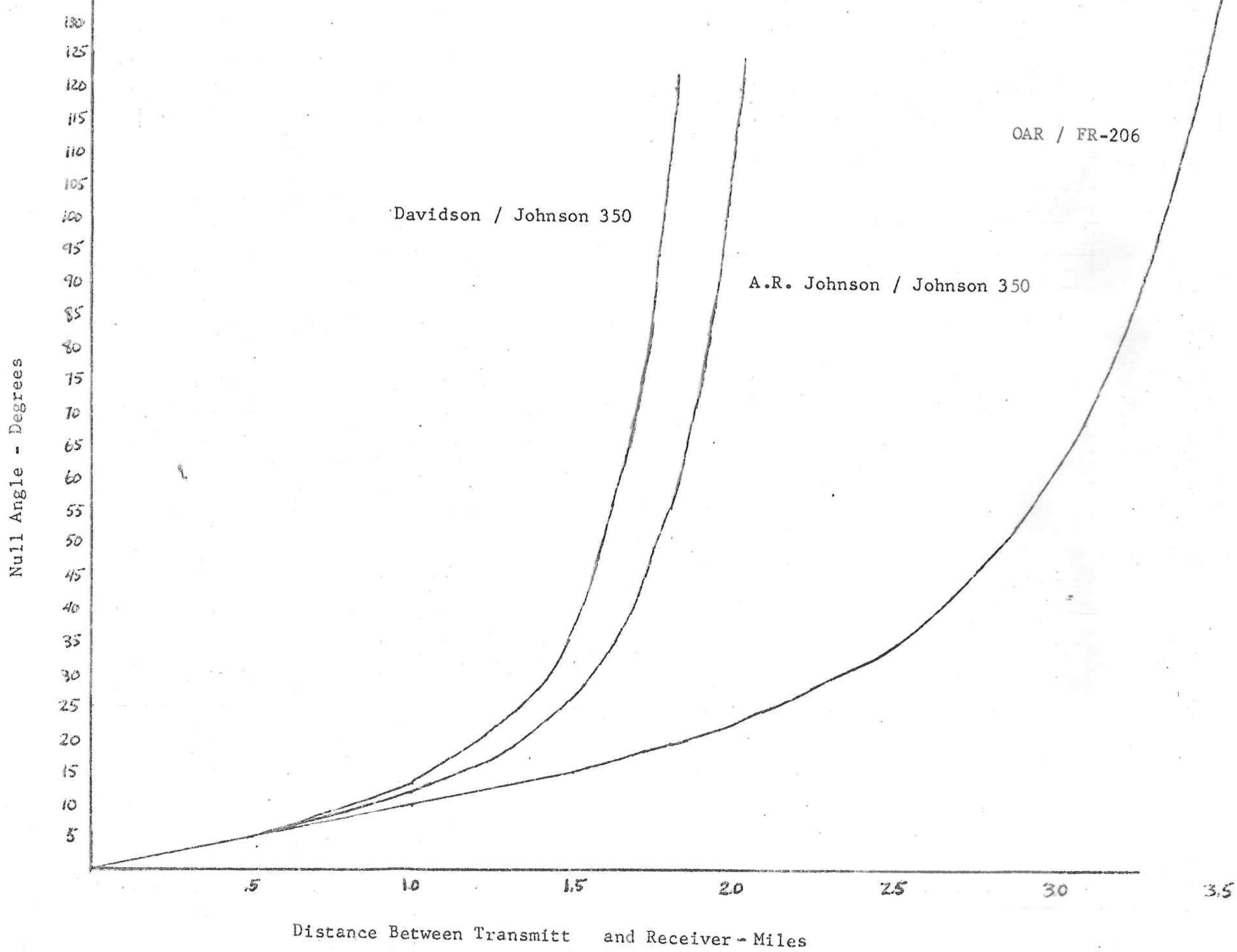
The angular resolution of a telemetry system is a useful tool when radio-tracking fast-moving animals over rough terrain. Location of the animal's position and movements are accomplished by triangulation. This technique involves pinpointing the animal's location with two or more fixes on the null axis from different monitoring sites. The convergent point of these null axes is the location of the transmitter. However, if the animal is moving during these fixes on the null axes, the true position of the animal will be impossible to obtain by simple triangulation. If the precise position is desired, then the investigator needs some method of estimation of the distance between the receiver and the transmitter at varying null angles. For this purpose, and, since coyotes are known to move about rapidly in some instances, the angular resolution of the different telemetry systems has been plotted against known distances between the receiver and transmitter. The results of these tests (Figures 2 and 3) have indicated an empirical relationship between these two parameters.

The angular resolution for the systems with line of sight transmission at the ground level (Figure 2) shows identical results at .5 mile where the null angle is 5°. The Davidson/Johnson 350 then progresses to 13° deflection at 1.0 mile, 37° at 1.5 miles, 120° at 1.8 miles and approximately 170° at 2.2 miles which is the maximum range for this system. The A. R. Johnson/Johnson 350 system showed a 12° null angle at 1.0 mile, 27° at 1.5 miles, 120° at 2.0 miles and 170° at 2.7 miles. The OAR/FR-206 telemetry system had a null of 10° at 1.0 mile, 15° at 1.5 miles, 23° at 2.0 miles, 63° at 3.0 miles, 140° at 3.5 miles and 160° at 4.6 miles.

When transmission was over natural obstructions the Davidson/Johnson 350 received no signal in 9° at .5 mile, 38° at 1.0 mile, and 170° at 1.5 miles. The A. R. Johnson/Johnson 350 was similar with 9° at .5 mile, 18° at 1.0 mile, 87° at 1.5 miles and 170° at 1.7 miles. The OAR/FR-206 system increased from 7° at .5 mile, to 12° at 1.0 mile, to 20° at 1.5 miles, to 43° at 2.0 miles, to 170° at 2.8 miles. These data are represented on Figure 3.

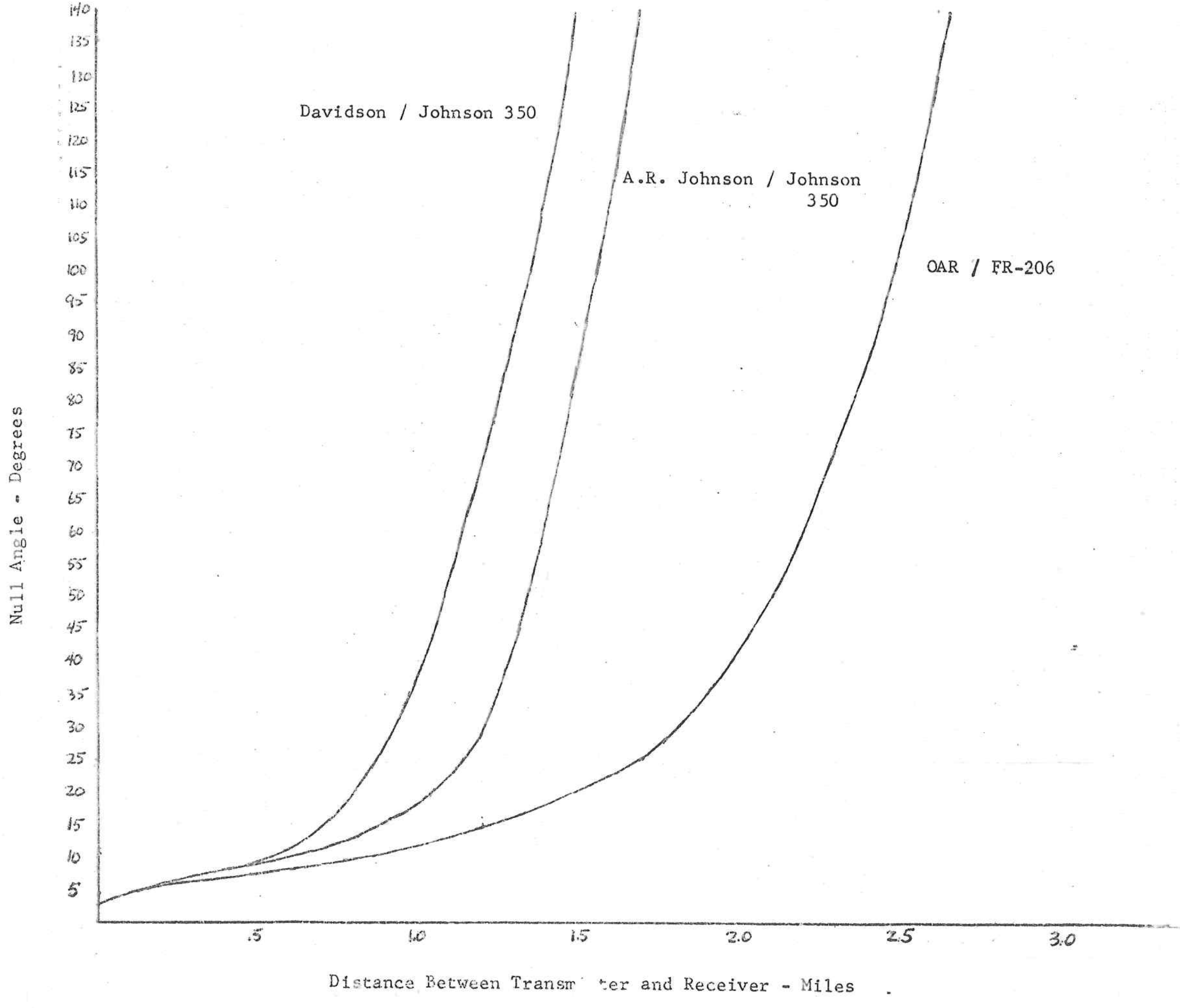
FIGURE 2.

TRANSMISSION AT GROUND LEVEL



TRANSMISSION OVER NATURAL OBSTRUCTIONS

FIGURE 3.



## Temperature

The effect of temperature upon the transmission of the transmitters was tested. The Davidson, A. R. Johnson and OAR transmitters were subjected to -10° C. in an environmental chamber and maintained at this temperature for three hours. All the transmitters functioned throughout this period and none showed any loss in signal strength. The transmitters were then immediately subjected to 43° C. and maintained at this temperature for three hours. All the transmitters functioned throughout this period and again none showed any loss in signal strength.

SUMMARY

Consideration of the telemetry systems tested has shown that the high-frequency transmitters are more adapted for transmission across open, relatively flat terrain than over terrain such as that found in the chaparral-coastal sage community here in southern California. When high-frequency transmitters in the 50-200 MHz range can be used, it is advantageous to do so because these transmitters have a much greater range to weight ratio than do the low-frequency transmitters. Interference noise is considerably less at the higher frequencies. However, if transmission is necessary through foliage and over natural obstructions, the low-frequency transmitters are better adapted. The 25-40 MHz range has excellent penetration through dense foliage and works well over large natural obstructions, such as that found on a coastal terrain. Disadvantages of the lower frequencies are the lower range to weight ratio, increased size of the transmitting antenna, making it necessary to go to a loop or a dipole antenna, and the interference noise encountered with local Citizen's Band operators.

For a comparative view of the systems tested, the advantages and disadvantages of each will be discussed. The OAR/FR-206 had the greatest range of the systems tested with 7.4% more range than the A. R. Johnson/Johnson 350, and 31.8% more than the Davidson/Johnson 350. However, when the FR-206 receiver was used with the A. R. Johnson and Davidson collars, the ranges were similar to those obtained with the Johnson 350. This would seem to indicate the difference in range lies in the transmitter rather than the receiver. With this assumption one must then consider the difference in power output of the three transmitters. This difference, although corrected for, may still be the reason for the increased range with the OAR equipment. The OAR/FR-206 system was very similar to the A. R. Johnson/ Johnson 350 when transmission was over natural obstructions. The primary advantage of the OAR/FR-206 system is the packaging of the equipment. The collar is constructed so that it is water-proof and coyote-proof. The transmitter and batteries are housed under a hard plastic housing riveted to the adjustable nylon belt collar. The transmitter and batteries are replaceable, making this unit reusable if retrieved from the animal. The disadvantage with this particular unit is its overall weight, which limits its use to only large animals. The FR-206 receiver is also well constructed and is the only receiver tested which could be readily used by hand in field investigations. Its sensitivity for directional-finding ability was superior to the Johnson 350.

The ADFS-210 receiver is well adapted for mobile use or as a fixed receiver. It provides a visual display which at low frequencies can be most useful when trying to distinguish the transmitter signal from interference noise. The range of this receiver was considerably less than either the FR-206 or Johnson 350.

The A. R. Johnson/Johnson 350 system showed greater ranges in every test than the Davidson/Johnson 350. The angular resolution of the A. R. Johnson collar was better than the Davidson. The A. R. Johnson transmitter has an adjustable loop antenna which serves as the collar. The transmitter and batteries are housed in epoxy. This unit can be tuned, to adjust to changes in antenna circumference. The A. R. Johnson has no provision to replace the batteries or the transmitter, so this makes this unit only usable one time.

The Davidson transmitter is covered with epoxy over the transmitter, batteries and antenna. The collar has very little adjustment for size and

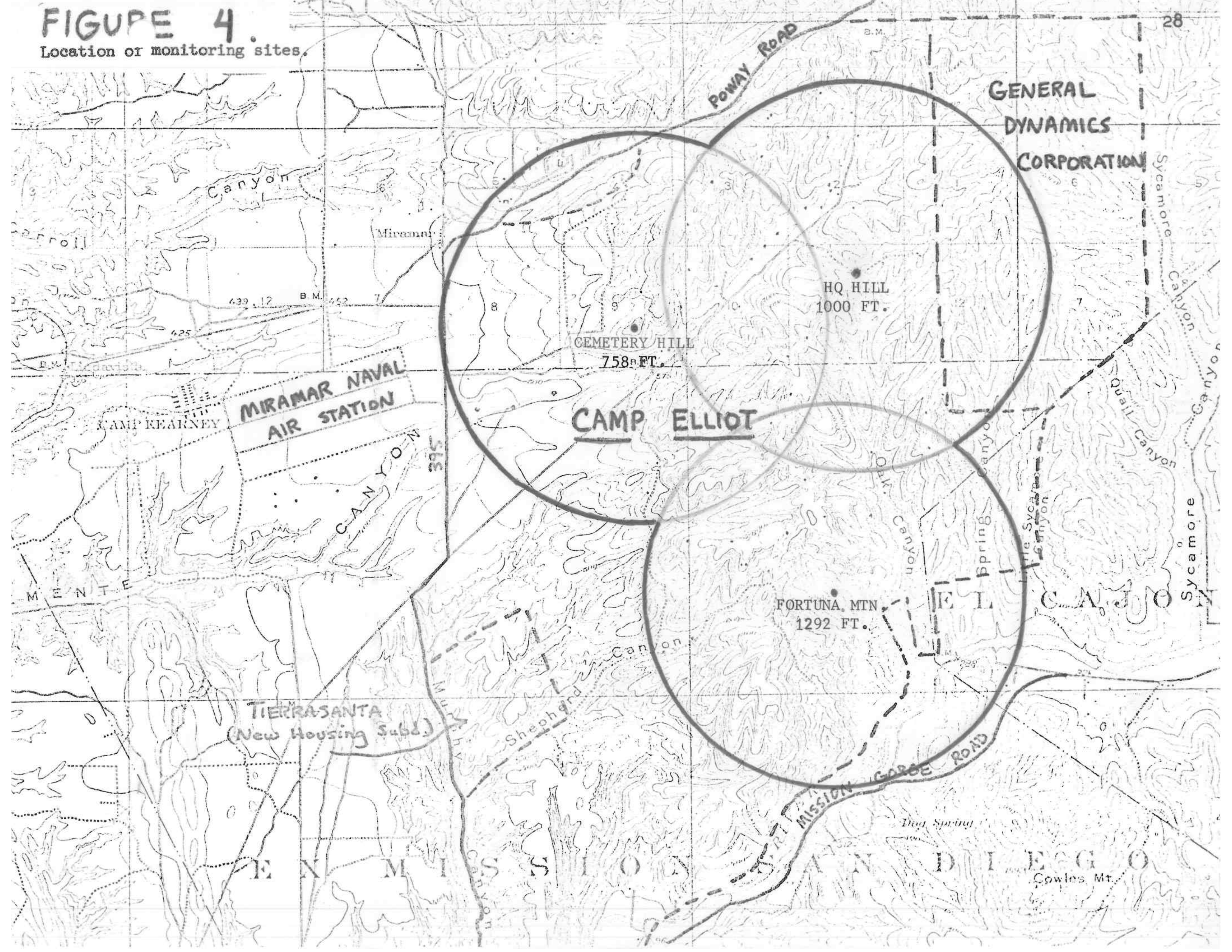
and must be filled in with epoxy when it is fitted on the animal. This makes tranquilization of the animal necessary in order to fit this collar on the neck. The transmitter is very sensitive to variation in antenna length and it is impossible to tune the transmitter to the changed antenna circumference. This unit is also only good for use one time, since it is impossible to replace batteries.

The Johnson Messenger 350 receiver is an excellent receiver with good range and angular resolution. This unit is well suited for use in a mobile unit and can be adapted for use as a hand-held receiver, although it would become bulky with extended use by hand. The Johnson 350 has a manual tuning control and it was found that more time was spent in locating a radio signal with this type of adjustment. This unit has four more channels than the OAR receiver and would work better than the FR-206 receiver in mobile units.

Monitoring sites have been established on Camp Elliot, based upon the results of this study and using 1.7 miles as the maximum expected range from any of the three sites chosen. The sites were chosen on high points with interconnecting roads, such that from each site the determined range for either the OAR telemetry system or the A. R. Johnson/Johnson 350 telemetry system over natural obstructions will overlap with each of the other two sites (Figure 4).

# FIGURE 4.

Location or monitoring sites.



## RECOMMENDATIONS

The following recommendations for further research are based upon the results cited in this report. Wildlife investigations requiring the use of a telemetry system to monitor the movements of a certain species must make certain considerations before choosing an appropriate radio-tracking system. Some of the considerations necessary are:

1. Type of Terrain. Transmission properties of the high-frequency transmitters are most adapted for relatively level country, while low-frequency transmitters are better suited to rolling hills or mountainous terrain. The low frequencies are also preferred for a foliage penetration.
2. Range. The range of a telemetry system must be chosen so that the observer can monitor the species without disturbing the animal's normal behavior.
3. Transmitter Package. The transmitter must be packaged so that the animal cannot destroy the unit and should be constructed such that normal behavior of the species will not affect transmission. For example, a transmitter suited for an Arctic aquatic species should function under extremely cold temperatures as well as be water-proof. The weight of the unit should not exceed 6% of the body weight of the animal.
4. Directional Resolution. The receiving system selected should be considered for directional resolution, with respect to the degree of resolution necessary to locate the type of animal being studied. If pinpoint accuracy is necessary, the receiving system should be able to be used by hand when the observer is approaching

the tagged animal. Further consideration should be given to the type of terrain, availability of roads, and the general behavior of the species to determine if the angular resolution of a particular receiving system will permit easy monitoring of the species.

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