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SUMMARY

A portable radar unit was used to locate and monitor two honeybee drone congregation areas (DCA's) in the West Campus area of the University of Kansas, Lawrence, Kansas. Drone flight activity was observed by radar over a 3-day period. On July 3, 5 and 6, 1985, drones were flying between 1545 and 1815 h. Flight activity at DCA's, as seen on the radar screen, was recorded on 16 mm black and white film. This film was evaluated to locate the DCA's in relation to features of the terrain, establish the diameter and height of the DCA, record the number of drones per cubic meter of space in the DCA, and observe the influence of caged queens and wind on drone flight activity. Radar, although limited in some areas because of terrain and man-made interferences, will be useful in further studies of the mating biology of honeybees.

INTRODUCTION

Honeybee (*Apis mellifera* L.) drones are produced by established colonies on a seasonal basis in response to optimal protein nutritional status in the colony (TABER and POOLE, 1974) and are known to have definite flight times (HOWELL and USINGER, 1933). They fly to specific aerial locations called « drone congregation areas » (DCA's) (MÜLLER, 1950 ; ZMARLICKI and MORSE, 1963 ; RUTTNER and RUTTNER, 1965). Although precise information on the size, shape and dynamics of flight of drones within DCA's is not known, the following generalizations (RUTTNER, 1974) have emerged from the studies of ZMARLICKI and MORSE (1963), RUTTNER and RUTTNER (1965, 1966, 1968), STRANG (1970), TRIBE (1982), TAYLOR (unpublished data). (1) Drones appear to assemble at the same locations year after year ; (2) The DCA's exist even when a queen is not present ; (3) Drones respond with greater intensity to queen pheromones when flying within the congregation area ; (4) Pursuit of queens by drones declines as queens move away from a congregation area ; (5) Flight altitude of the drones within a congregation area is inversely related to wind velocity ; and (6) Drones locate DCA's quickly and appear within DCA's on their first mating flight.

These observations suggest that drones assemble and seek mates at locations where specific physical features are found (although BUTLER and FAIREY, 1964, do not agree). VAN PRAAGH (1983) has hypothesized that DCA's are associated with areas of uniform optical properties. Thus far, no features of terrain or wind patterns have been shown to be consistently associated with DCA's. Patterns of features associated with DCA's may have eluded investigators because it has not been possible to precisely define the spatial configuration of DCA's or the vertical and horizontal movement of drones within them. All the assessments of DCA's reported in the literature have been based on observations made using caged or tethered queens (or queen pheromone) suspended from poles or lines within the DCA's (GARY, 1963). The difficulty with this technique is that drones are attracted from some distance (TRIBE, 1982) downwind of the queen. Because of the intensity of this behavioral response to queen pheromones and shifting wind velocities and directions, it is difficult for the observer to define the borders of the DCA's and the relative densities of drones at different elevations within them.

Radar has been used to record and study insect and bird movement (GLOVER *et al.*, 1966 ; SCHAEFER, 1968 ; SCHAEFER, 1976 ; LARKIN *et al.*, 1980 ; LINGREN *et al.*, 1982) and insect aggregations over specific geophysical features (REYNOLDS and RILEY, 1979). RUTTNER and RUTTNER (1966) suggested that radar might be useful in tracking honeybee drones but the techonology available to them at that time was inadequate. In this paper we will describe the results of studies in which we successfully located and documented drone activity in DCA's with the use of radar. We were also able to assess drone activity in a three-dimensional volume of space in the absence and presence of tethered queens. The potential utility and some limitations of this technique are discussed.

MATERIALS AND METHODS

Prior to this study, drone congregation areas at the University of Kansas (West Campus) in Lawrence, Kansas had been located, and the activity within them assessed using caged queens attached below drone traps (TAYLOR, 1984) suspended from helium-filled balloons. The landscape is generally rolling and consists of several fields bordered by well-defined woods or tree lines (Fig. 1). The studies were conducted on July 3, 5 and 6, 1985. The drone flight period generally occurred between 1545 and 1815 h. The weather was clear and warm (approx. 32 °C during drone flight) with light, variable breezes. On July 6, there was a light breeze (< 2 km/h) from the west.

To assist in the biological aspects of the studies, caged queens were suspended below a helium-filled balloon. Visual observations were made by O.R. TAYLOR who maneuvered the balloon and queens and therefore was directly below the DCA and also by G.M. LOPER who was near the radar unit using a 21X power telescope. The queens were alternately raised, lowered and raised again, or the balloon was walked 80 m from the center of the DCA, and after 10 minutes, it was walked back into the DCA. Radar observations and filming were continuous.

Assessment of insect activity was made using an X-Band marine radar operating at 9.4 gigahertz, with a pulse length of 50 nanoseconds and a pulse repetition rate of 3400 hertz. The unit has a 1.22 m diameter, parabolic antenna which forms a pencil-shaped beam 1.65° wide. This beam was rotated about a vertical axis at a 3 second rotation rate. Distance and direction of individual insects was displayed on a short persistence cathode ray tube (CRT). Electronic « anti-clutter » suppression was used as necessary to discriminate between insect targets and terrain features such as trees. A 16 mm camera was mounted above the CRT which took black and white time-lapse pictures every 3 seconds. Still pictures were also taken with a 35 mm camera mounted over the radar screen. The radar antenna was electronically linked to a balloon tracking theodolite. As an operator optically tracked the caged queens with the theodolite telescope, the radar beam followed the up and down movements of the cage. At other times activity was measured by disengaging the theodolite and manually adjusting the elevation of the radar beam. Estimates of drone density were based on visual counts of targets on the black and white film of the CRT and prior radar calibrations as described by SCHAEFER (1976) and DRAKE (1981). Densities at several altitudes were integrated to obtain total insects within the DCA.

The film was evaluated to determine (1) the location of the apparent center of drone activity and the widths of the major and minor axis of the DCA, (2) the upper and lower limits of drone activity in the DCA, (3) the three dimensional volume in which the drones were flying above ground, (4) the influence of wind direction on drone flight activity, (5) the influence of the presence of queens on drone flight activity, and (6) the number of drones per cubic meter in the DCA.

RESULTS

On July 3 to 6, several locations for the radar unit were tested and the best viewing angles were determined. Several DCA's near the apiary could not be observed with radar due to interference (« clutter ») from trees, buildings, etc. (Fig. 1). Generally, the best location for observing the DCA's with radar was to locate the radar so the beam was directed uphill toward the DCA's with low shrubs or foliage between the radar and the DCA's. By positioning the radar so the beam grazed the tops of the foliage, interference from extraneous targets was minimized. The radar was located within 300 m of the DCA's to improve altitude resolution. Although drones could be detected as far as 1.1 km from the radar, the beam width beyond 300 m was too wide to study vertical distribution of drones within the DCA. The calculated effective beam width at 200 m was 8.7 m and range resolution was 7.5 m. A location was found where uninhibited viewing was available of a large DCA designated « Big Sky ». At the same radar site, a second DCA designated « Peppergrass », whose general location was known by Taylor was located precisely by radar. There was some shadowing of this second DCA by trees in the foreground (Fig. 1).

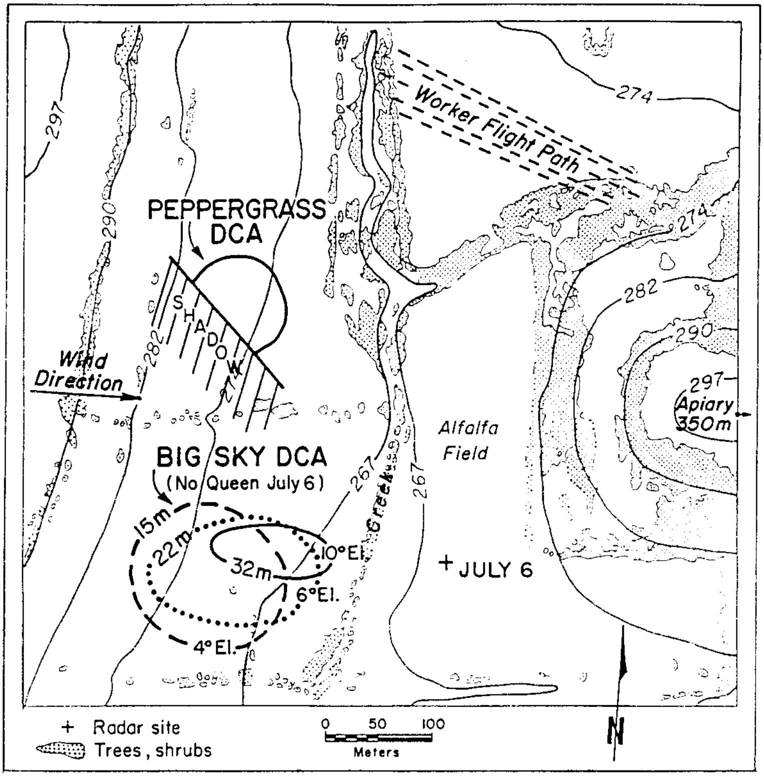

FIG. 1. — *Drone congregation areas (DCA) and worker flight paths plotted on contour map near University of Kansas, Lawrence KS, July 3-6, 1985. Ellipses represent average major and minor axis of distribution of honey bee drones detected by a radar beam pointing 4, 6, and 10 degrees above horizontal. No caged queens were present. Ellipses heights are above ground surface at ellipses center.*

Insect activity was very visible to the east, southeast, south, west, northwest, and north of the radar site. Hills with woods (NE) and individual trees (SW) blocked our view. Both honey bee worker and drone flight activity was recorded. Worker flight was recorded to the north of the radar (Fig. 1) and to the south as they were forced by the wooded hill, east of the alfalfa, to fly high enough to be detected in the radar beam.

Drone activity at the « Big Sky » DCA was filmed on July 3, 5 and 6, 1985. Drone flight began about 1545 h (CDT) and was finished by 1815 h although filming continued as late as 1844 h. Experiments using caged queens in the « Big Sky » DCA were performed intermittently on July 6 between 1600 and 1830 h. All further reference to drone activity in a DCA will describe observations at the « Big Sky » DCA.

By changing the angle of elevation of the radar dish, we were able to record drone activity at several elevations above ground. Thus, in Fig. 1, we describe the apparent outer dimensions of drone activity at 15, 22 and 32 m above ground. The center of the « Big Sky » DCA was in an open field 80 m south of an east-west tree line and 130 m west of a small creek.

When tethered queens were not in the DCA, drone activity was contained within an elliptically shaped column extending from approximately 12 m to 34 m above the ground (Fig. 1). No general flight paths to or from the apiary were seen in relation to the DCA's ; rather, the insects moved rapidly within a generally circular area. Few linear flight paths were detected within the DCA which implied considerable turning by the drones. The size and shape of the DCA at a particular altitude was constantly changing.

The number of drones tended to be greatest near the DCA center at each elevation. Since closely spaced drones could not be resolved by the radar, a statistical measure of drone distribution was not possible. Instead, the width of the drone activity along north-south and east-west directions was measured (Table 1). The DCA was nearly circular near the ground and more elliptical near the top, with the major axis aligned with the very light breeze. There was a very light breeze (< 2 km/h) from the west which may have been responsible for an apparent « leaning » of the column of drones towards the east (Fig. 1) at the higher elevations. The center of the DCA at the higher elevation was offset to the east by approximately 53 m (Table 1) as compared to the base.

TABL. 1. — *Physical parameters and drone numbers at the « Big Sky » DCA as measured by radar when caged queens were not present.* Lawrence, KS, July 6, 1985

DCA Parameter	Angle of Elevation of Radar Dish		
	4°	6°	10°
North-south width of DCA	(m)143 ± 27	101 ± 20	52 ± 19
East-west width of DCA	(m)138 ± 22	166 ± 23	118 ± 32.1
Distance to center of DCA from radar	(m)224 ± 14 (n = 33)	198 ± 12 (n = 41)	171 ± 13 (n = 20)
Height above ground [(1)]	(m) 15 ± 4	22 ± 4	32 ± 4
# of drones/radar sweep	view partially blocked by trees	17.2 ± 5.7 (n = 11)*	5.1 ± 2.8 (n = 8)
Time of Observation (CDT)		1741-1745 h	1750-1752 h

(1) Height of beam center ± 1/2 the effective width of radar beam.
* The number of 3 second sweeps from which counts were made.

The average number of drones/radar « sweep » (rotation) was 17 at 22 m and 5 at 32 m between 1741 h and 1752 h (tethered queen not present) (Table 1) and the total number of drones in the DCA above 12 m was estimated to be 25. This agrees well with the visual estimates made minutes earlier when the queens were present and we could see drones flying near the cage. Even when queens were not present in the DCA, drones could be heard but were not seen due to their low aerial density and fast air speed.

When the queens were within the DCA, the drones flew within a smaller space which rapidly expanded and contracted. The shape of this smaller area of flight tended to be elongated down-wind. Occasionally a cluster of overlapping signals on the radar screen indicated a convergence of drones within the DCA especially when the tethered queens were elevated in the DCA. This convergence of drones as detected by the radar, was correlated with visual sightings of comet-like groups of drones within one or two meters of the queens. Such comets usually broke into smaller groups and departed within 10 seconds.

When dense comets of drones were sighted near the queens, few individual drones were resolved by the radar because they were too close together. As a comet dispersed, the spacing between drones increased and individual dots reappeared on the radar screen. The size and shape of drone flight volume changed rapidly until the next comet formed. The length of time between formation of comets probably was related to wind currents and the abilities of drones to locate and fly toward a pheromone source. Drone density measurements were not made while a queen was present due to rapid variation in drone distribution.

During most observations to determine the normal flight pattern of the drones, the queens were lowered to the ground and moved to the north of the DCA. On one occasion after we observed drones near the top of the DCA (40 m), the queens were moved horizontally (and across wind) 80 m north of the DCA. The number of drones approaching the cage declined rapidly as the queens were moved out of the DCA. While the queens were north of the DCA no drones were observed at the 40 m altitude and we assume they returned to lower altitudes within the DCA. After 10 minutes the queens were returned to the DCA (still at 40 m altitude) and within 1.7 minutes drone activity around them resumed. The queens were then lowered to 25 m and additional drones were observed both visually and on the radar.

The radar detected drones at the DCA from 1545 h to 1815 h. There was a gradual increase in numbers during the first hour and gradual decrease during the last hour. The maximum number of drones observed visually near the queens at a given moment was approximately 60. The number of birds detected by the radar was insignificant and easily distinguished by speed and trajectory compared to insect targets.

DISCUSSION

Although RUTTNER and RUTTNER (1966) suggested that radar might be useful in tracking drones, this study appears to be the first test of this technique and the first to illustrate localized drone flight activity in a DCA in the absence of a tethered queen. Referring to the six generalizations concerning DCA's, we have obtained verification of numbers 2, 3, 4. Number 3 states that drones react most intensely to the queen pheromones when in the DCA. The film records showed altered drone flight behavior in a DCA when queens were brought into it as well as a sharp decline in the pursuit by drones when the queens were moved across wind and out of the DCA.

Drone activity was seen in two DCA's simultaneously, and the presence of both of the DCA's were unknown to the radar operator. Thus drone flight activity is easily recognizable on the radar screen and this suggests that radar can be used to assist in finding DCA's. The location of the radar for successful monitoring of drone activity is crucial, and some terrains combined with man-made features can make some sites difficult or even impossible for radar studies of DCA's.

The data estimating the number of drones at various elevations (July 6) suggest that the drones were present in a space which might be described as a tilted column with most drones flying near the center. The light breeze from the west may have caused the drones to drift to the east at the higher elevations. The vertical stratification of drones and the film records showing that the « center » of the DCA varies with elevation and possibly wind direction and velocity suggests that the radar can more accurately define DCA's as compared with the tethered queen methods of GARY, 1963, RUTTNER and RUTTNER, 1965 ; and STRANG, 1970.

These results are the first step towards actual documentation of the vertical distribution of drones — without the presence of queen pheromones — in a three-dimensional space.

The radar film shows that the shape of the DCA and the distribution of drones within it is constantly changing. The distinctiveness of DCA's is a function of drone density (TRIBE, 1982 ; ORT, personal observations). At high densities the number of drones moving among nearby DCA's can be so great that drones can be attracted to queens almost everywhere. These tests were made when drone density was low and when the DCA's were easily discerned. Further tests with the radar at higher densities may reveal whether the size and shape of the DCA changes with density but may also show whether drones move directly from one DCA to another or move in a less directed manner.

The use of radar will allow detailed studies of many parameters influencing honeybee mating biology and perhaps give us clues as to what factors are responsible for the selection of specific sites by drones and queens as mating areas. Additionally, as further studies are conducted, a spatial concept rather than an area concept may evolve as we take full advantage of the radar technique.

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RÉSUMÉ

CONTRÔLE ET DÉTECTION DES LIEUX DE RASSEMBLEMENT DE MÂLES D'ABEILLE À L'AIDE D'UN RADAR

Un radar portable monté sur une remorque a été utilisé pour localiser un lieu de rassemblement de mâles (LRM) d'*Apis mellifica*. Il s'agissait d'un radar de navigation à bandes X, travaillant à 9,4 gigahertz, d'impulsions 50 nanosecondes et de fréquence d'impulsions 3 400 hertz. L'unité possédait une antenne parabolique de 1,22 m de diamètre qui formait un faisceau rayonné large de 1,65°. Après des études technologiques préliminaires du 3 au 5 juillet, on a pu visualiser une activité de vol de mâles à l'intérieur d'un LRM, le 6 juillet 1985 entre 15 h 45 et 18 h 15 près de Lawrence, dans le Kansas (USA). Une caméra 16 mm montée au-dessus du tube à rayons cathodiques a enregistré des objectifs représentés par des insectes. Les estimations de la densité des mâles ont été tirées des comptages visuels sur le film, et faites pour 3 altitudes à l'intérieur du LRM (Tabl. 1). L'activité de vol des mâles a été observée à l'intérieur d'un cercle à 11 m au-dessus du sol, mais également dans les ellipses plus petites situées à 16 m et 25 m au-dessus du sol (Fig. 1). Le centre de l'activité semblait affectée par une légère brise venant de l'ouest, qui provoquait un déplacement de l'activité de vol dans le sens du vent aux altitudes supérieures (Fig. 1). Le radar peut être utilisé pour localiser et étudier l'activité de vol des mâles, là où les caractéristiques du terrain (collines, arbres, édifices) n'interfèrent pas.

ZUSAMMENFASSUNG

ÜBERWACHUNG UND ENTDECKUNG VON DROHNENSAMMELPLÄTZEN DER HONIGBIENEN DURCH RADAR

Ein tragbares Radargerät, montiert auf einem Autoanhänger, wurde dazu benutzt, um Drohnensammelplätze (*Apis mellifera* L.) festzustellen. Bei dem Gerät handelte es sich um ein X-Band Marine-Radar, das bei 9.4 Gigahertz mit einer Impulsdauer von 50 Nanosekunden und einer Impulsfrequenz von 3.400 Hertz arbeitete. Das Gerät war mit einer Parabolantenne von 1.22 m Durchmesser versehen, die

einen bleistiftförmigen, 1.65° breiten Strahl aussendet. Nach Vorversuchen zwischen dem 3.-5. Juli 1985 bei Lawrence, Kansas (USA), wurde am 6. Juli zwischen 15.45 und 18.15 Uhr die Flugaktivität der Drohnen innerhalb eines Sammelplatzes sichtbar gemacht. Individuelle Insektenkörper wurden mittels einer 16 mm Kamera aufgezeichnet, die über der flimmernden Kathodenstrahlenröhre montiert war. Schätzungen der Drohnendichte beruhten auf visuellen Auszählungen der Filmbilder ; es wurden Schätzungen der Drohnendichte auf dem Sammelplatz in drei verschiedenen Höhenschichten durchgeführt (Tabl. 1). Der Raum, innerhalb dessen Drohnenflug beobachtet wurde, war in 11 m Höhe über dem Boden durch eine Kreislinie umschrieben, aber in 16 und 25 m über dem Boden durch kleinere elliptische Flächen (Fig. 1). Das Zentrum der Flugaktivität wurde offensichtlich durch eine leichte Westbriese beeinflußt, welche die Flugaktivität in größeren Höhen in Windrichtung versetzte (Fig. 1).

Radar kann überall dort zur Auffindung und zum Studium der Drohnenflugaktivität eingesetzt werden, wo nicht Geländestrukturen wie Hügel, Bäume oder Gebäude störend einwirken.

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