

AN IMPROVED MARINE RADAR SYSTEM FOR STUDIES OF BIRD MIGRATION

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Abstract.—Mobile laboratories equipped with marine radars were used to study the intensity, altitude (above 25 m), direction, behavior and ground speed of migrating birds in Alaska, Minnesota and South Dakota. A screen to reduce clutter on the radar display resulting from echoes of surrounding vegetation and other objects was developed. Other modifications, including disengagement of the antenna motor, use of a side-lobing shield and replacement of the slotted waveguide with a parabolic antenna, improved the system's ability to obtain information on flight altitudes. New features available on radars, such as the color monitor, alarm function, echo stretch function and plotting function, improved the radar system's ability to obtain information on movements of birds.

UN SISTEMA MEJORADO DE RADAR MARINO PARA ESTUDIAR LA MIGRACIÓN DE AVES

Sinopsis.—Se utilizaron laboratorios móviles equipados con radares marinos, para estudiar la intensidad, altitud (sobre los 25 m), dirección, conducta y velocidad de aves migratorias en Alaska, Minnesota y Dakota del Sur. Se desarrolló un cedazo de pantalla para reducir disturbios en el radar como resultado del eco de la vegetación y de otros objetos. Otras modificaciones, que incluyeron el desacoplar el motor de la antena, y el remplazo de la guía de ondas por una antena parabólica, mejoraron la capacidad del sistema para obtener información de la altura de vuelo. Dispositivos nuevos disponibles para el radar, tales como monitores a color, y funciones de alarma, eco y representación gráfica, mejoraron la capacidad del radar para obtener información sobre el movimiento de las aves.

Radar has been an important tool in ornithological research for more than four decades. It has been used to detect birds when the possibility of visual observations was limited, such as at night, in clouds, and during very light snowfall. Even during conditions of good visibility, high-flying or distant birds that often are missed by visual observers can be detected by radar. Several types of radar have been used to study movements of birds, including weather radars, air traffic control radars and marine radars (Able 1985, Eastwood 1967). Marine radars probably are the easiest to operate and are the least expensive to purchase. For these reasons, as well as their high resolution, short minimal range, portability and availability, the use of marine radars in ornithological studies has increased in recent years (Gauthreaux 1985a,b; Kerlinger and Gauthreaux 1984, 1985; Korschgen et al. 1984; Williams 1984; Williams et al. 1972). We present information on recent technological improvements in marine radars, and the modifications we developed to improve the performance of radar in our studies of bird migration in Alaska, Minnesota and South Dakota from 1987 to 1990.

STUDY SITES

We used mobile laboratories equipped with marine radars at six locations in Alaska, Minnesota and South Dakota. The study sites in Alaska were in the east-central part of the state, near the communities of Tok (63°20'N, 142°59'W) and Gakona (63°08'N, 145°13'W). Both sites are relatively flat and forested, but are surrounded by mountainous terrain. The two study sites in South Dakota were in the northeastern corner of the state, near Amherst (45°45'N, 97°58'W). One of these sites is flat and the other is situated in rolling hills; both sites are in largely agricultural areas with few trees. The two study sites in Minnesota were in the northwestern part of the state, near Thief River Falls (48°07'N, 96°30'W) in a flat mosaic of farmland, shelterbelts, woodlots and wetlands.

DESCRIPTION OF RADAR LABORATORIES

Each of the mobile laboratories consisted of two small marine radars mounted on a cab-over camper on a four-wheel drive pick-up truck (Fig. 1). One of the radars (surveillance) scanned the area around the lab and was used to obtain information on flight paths, migration intensity and ground speeds of migrating birds. The second radar (vertical) was modified to measure altitudes of flight. Each lab was powered by a 5-kW generator or by four 6-volt (golf cart) batteries linked in series. When fully charged, the batteries could power the lab for approximately 14 h.

Surveillance radar.—The surveillance radar (Furuno Model FCR-1411, Furuno Electric Company, Nishinomiya, Japan) was a standard marine radar transmitting on 9410 MHz (X-band) through a slotted waveguide 2 m long; the peak power output is 10 kW. The cost of this radar was approximately \$12,000 (US) in 1990, excluding installation. This radar can be operated at a variety of ranges, from 0.5 to 133 km. Pulselength can be set at 0.08, 0.6 or 1.0 μ s, depending upon the range setting used (the shortest pulselength was not available for ranges greater than 5.6 km). At the shorter pulselengths, picture definition is improved, while at longer pulselengths, the detection of echoes is improved. This radar has a digital, color display with several useful features including color-coded echoes (to differentiate the strength of return signals), on-screen plotting of previous echoes (thus depicting flight paths) and true north correction for the display screen. A plotting function records the position of a target at selected intervals (15 or 30 s, or 1, 3 or 6 min) (Fig. 2). As a target is plotted at fixed time intervals, ground speed is directly proportional to the distance between consecutive points and can be estimated with a hand-held scale. An alarm function can be set to ring when targets above a certain strength level appear on the screen. At ranges greater than 5.7 km, the echo stretch function can be used to magnify the echoes of small targets, which sometimes appear as small dots.

Whenever radar energy is reflected from the ground and other objects that surround the radar unit, an echo (referred to as ground clutter)



FIGURE 1. The mobile radar lab: a. surveillance radar, b. vertical radar.

appears on the screen. Ground clutter can be caused, for example, by field stubble as little as 0.5 m high.

At the Alaska study sites, ground clutter was reduced by using the radar unit in locations closely surrounded by trees. The closest fringe of trees acted as a radar fence, shielding the remaining forest from the radar. Thus, only a small area of ground clutter was observed in the center of the display screen. (For further discussion of radar fences, refer to Eastwood 1967, Skolnik 1980 and Williams et al. 1972.)

As the use of trees as a radar fence was not an option at the more open Minnesota and South Dakota sites, we developed the ground clutter reduction screen, which shielded the lower edge of the surveillance radar beam and thus eliminated much of the ground clutter. This screen was constructed of a hinged sheet of 3-mm-thick aluminum sheet metal; the bottom sheet was bolted onto the lower edge of the antenna face at a 90° angle (Fig. 3). Threaded adjustment screws were used to raise or lower the outer edge of the screen, making it possible to remove the ground clutter by setting the lower edge of the effective radar signal a few meters above the ground. Each screen cost approximately \$300 for materials and labor.

Another modification that reduced ground clutter was elevation of the forward edge of the radar antenna by insertion of a 50-mm-high wooden shim under it. The shim elevated the angle of the antenna (and thus the radar beam) by approximately 10°; to increase the beam beyond 10°, one

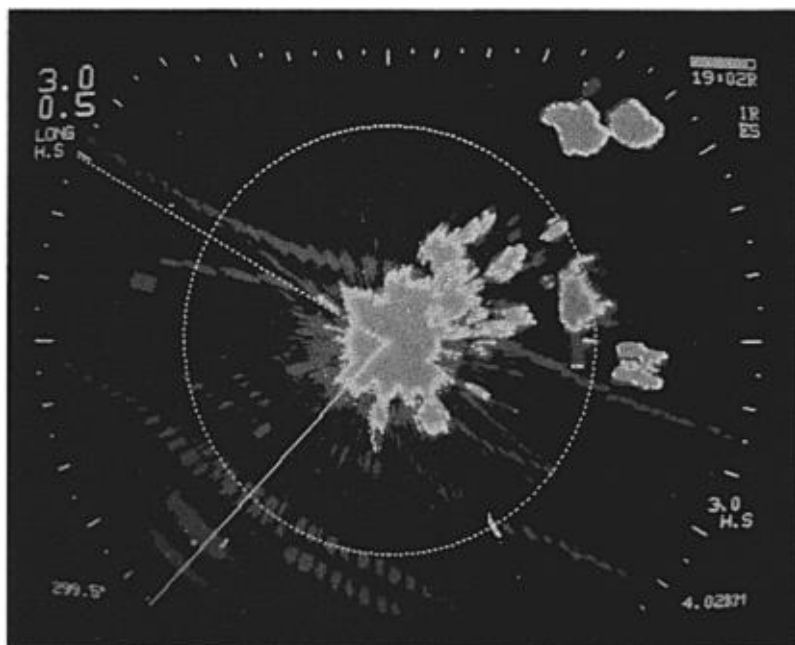


FIGURE 2. The surveillance radar display with plotted echoes of swans (*Cygnus* spp.) flying from southeast to northwest (note that the screen is oriented so that north is up). The large, irregular blotches are ground clutter. The adjustable, dashed ring has a radius of 4.02 km (noted in lower, right corner of screen). The dashed, straight line (oriented at 299.5°, see lower, left corner of screen) can be moved to determine flight direction.

could permanently twist the waveguide that connects the antenna with the remainder of the scanner unit or insert a waveguide rotary joint or a section of twistable-flexible waveguide (available from Space Engineering Corp., St. Petersburg, FL).

Vertical radar.—The vertical radar (Furuno Model FR-8050) was a standard marine radar that was modified by replacing the slotted waveguide with a 0.6-m-diameter parabolic dish. This radar also transmits at 9410 MHz, with a peak power output of 5 kW. Cost of this unit was approximately \$8000 (US), excluding installation. The radar can be operated at various ranges from 0.5 to 89 km and has a digital, eight-level, monochrome display. Pulselength can be set at 0.08, 0.3, 0.6 or 1.0 μ s, depending upon the range setting used (the shortest pulselength was not available for ranges greater than 2.8 km). A plotting function records the position of a target either continuously or at intervals (30 s, or 1, 3 or 6 min), and an alarm function can be set to sound when targets above a certain strength level appear on the screen. Interference rejection circuitry could be activated, allowing for simultaneous operation of the vertical and surveillance radars.

Following the advice of Gauthreaux (1985a,b), we mounted the vertical

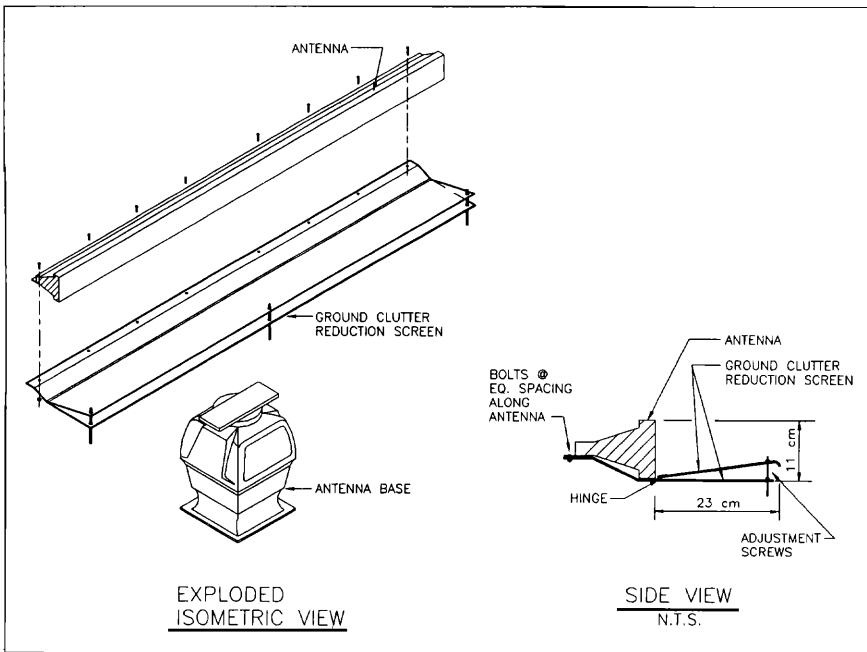


FIGURE 3. An exploded isometric view of the surveillance radar antenna, ground clutter reduction screen and antenna base, and a side view of the ground clutter reduction screen and surveillance radar antenna.

radar antenna on a hinged assembly that enabled us to swing the antenna from a vertical position (for horizontal sampling) to a horizontal position (for sampling flight altitudes directly above the radar laboratory). We also used Gauthreaux's method of preventing excessive scattering of radar energy from the antenna by installing a tight-fitting collar of aluminum flashing approximately 100 cm high around the antenna.

In an unmodified system, the display screen shows only a thin, illuminated line that does not move. As birds pass through the radar beam, the targets appear along this line only as bright spots that are easily missed. We modified the system by positioning the plate that holds the antenna motor by approximately 10 mm off-center, so that the gears between the motor and antenna were disengaged, thereby allowing the motor to turn while the parabolic dish remained stationary. With this modification, targets formed large areas or circles that are less easily missed (Fig. 4).

RESULTS AND DISCUSSION

Surveillance radar.—We conducted simultaneous visual and radar observations during daylight hours in Alaska. Visual observations were made by an individual equipped with binoculars and a spotting scope, either

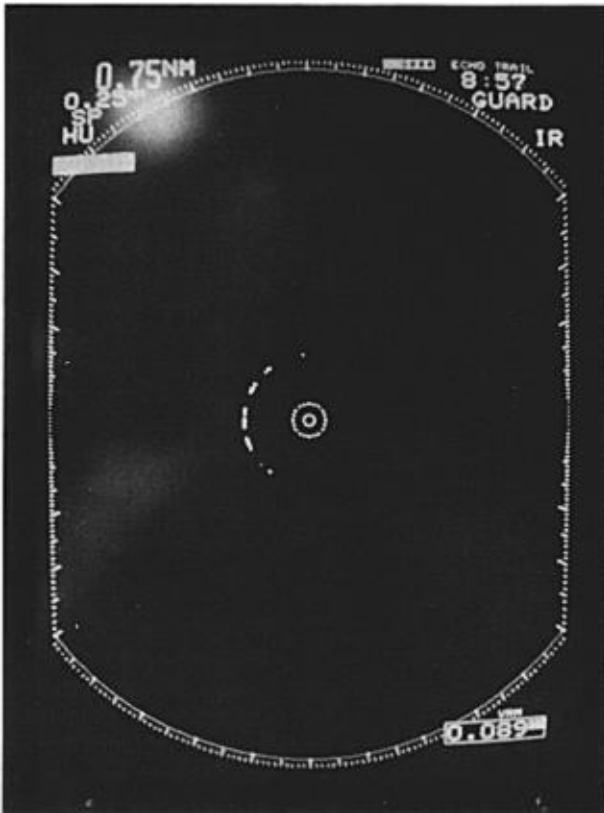


FIGURE 4. The vertical radar display with plotted echo (the broken arc) of a Great Blue Heron (*Ardea herodias*) flying at 324 m above ground level. Note that the adjustable, dashed ring (currently at 89 m, see lower right part of screen) can be used to measure flight altitude.

from the lab or from a 7-m high tower located 150 m away. Maximal distances of detection of birds by the surveillance radar depended on body size, flock size, flight profile, atmospheric conditions and the range of the radar setting. At the shorter range settings (e.g., 1.4 or 2.8 km), individual small passerines were detected up to 1 km. Individual small passerines usually were not detected by the radar at range settings greater than 2.8 km, even if the birds were within 1 km, because, as range is increased, radar sensitivity decreases.

Tight flocks of passerines could be detected on the 5.7-km range setting, however, and on many occasions we detected flocks of birds on the radar well before we could see or identify them visually (Table 1). Flocks of waterfowl and Sandhill Cranes (*Grus canadensis*) routinely were detected at up to 7 km, which was near the limit of the display screen at the 5.7-

TABLE 1. Distances of detection of bird species (individuals and flocks) by radar in Alaska, South Dakota and Minnesota. Note that all species except for the raptors generally were in flocks and that the radar range setting used was 5.7 km, but the actual limits of the display screen at that setting is 7.4 km.

Species	Distance detected (km)			n (targets)
	Mean	SD	Maximum	
Tundra Swan (<i>Cygnus columbianus</i>)	3.9	1.3	7.4	67
Trumpeter Swan (<i>Cygnus buccinator</i>)	4.0	1.7	7.1	23
Unidentified swan (<i>Cygnus</i> spp.)	4.4	1.4	7.4	156
Greater White-fronted Goose (<i>Anser albifrons</i>)	4.0	1.6	7.4	39
Snow Goose (<i>Chen caerulescens</i>)	2.6	0.8	4.7	25
Canada Goose (<i>Branta canadensis</i>)	3.5	1.3	6.8	70
Unidentified goose	3.8	1.3	7.1	110
Mallard (<i>Anas platyrhynchos</i>)	3.0	1.1	4.5	10
Northern Pintail (<i>Anas acuta</i>)	2.5	0.8	4.6	21
Unidentified duck	3.5	1.4	7.0	92
Bald Eagle (<i>Haliaeetus leucocephalus</i>)	2.2	0.6	4.2	33
Northern Harrier (<i>Circus cyaneus</i>)	2.0	0.6	4.1	57
Sharp-shinned Hawk (<i>Accipiter striatus</i>)	2.0	0.5	3.2	22
Red-tailed Hawk (<i>Buteo jamaicensis</i>)	1.9	0.6	3.3	22
Rough-legged Hawk (<i>Buteo lagopus</i>)	2.0	0.6	3.3	29
Unidentified hawk (<i>Buteo</i> spp.)	2.3	0.7	4.1	75
Sandhill Crane (<i>Grus canadensis</i>)	4.9	1.9	7.4	72
Unidentified shorebird	2.0	0.4	2.9	12
Franklin's Gull (<i>Larus pipixcan</i>)	2.9	1.0	5.2	46
Common Raven (<i>Corvus corax</i>)	2.3	0.8	5.0	36
Unidentified blackbird	2.8	0.8	4.3	14
Unidentified passerine	2.0	0.4	2.7	25

km range setting (echoes on the sides of the display screen could be seen farther than 5.7 km, because the screen was wider than it was tall). Individual soaring hawks (*Buteo* spp.) were detected up to 4 km away. Therefore, like Gauthreaux (1985a), we used the 5.7-km range setting to study movements of larger birds and the 1.4-km range setting to study movements of passerines.

The ground clutter reduction screens were useful additions to the labs and allowed sampling in open, flat situations where it was impossible to find natural radar fences. Use of the screen at one of the Minnesota study sites removed 27% of the ground clutter on the radar display at the 5.7-km range setting and 68% of the ground clutter at the 1.4-km range setting (Fig. 5). Use of this screen also reduced clutter at the other sites in Minnesota and South Dakota, although the reduction was not quantified. The adjustable angle of the screen enabled us to use the lab in a variety of terrains. Care had to be taken in adjusting the screen angle, however, for, although ground clutter was reduced as the angle was increased, the chance of missing low-flying birds also increased. Through field testing at each site, we were able to adjust the screen angle to reduce ground clutter caused by crops in the nearby fields, yet still detect targets

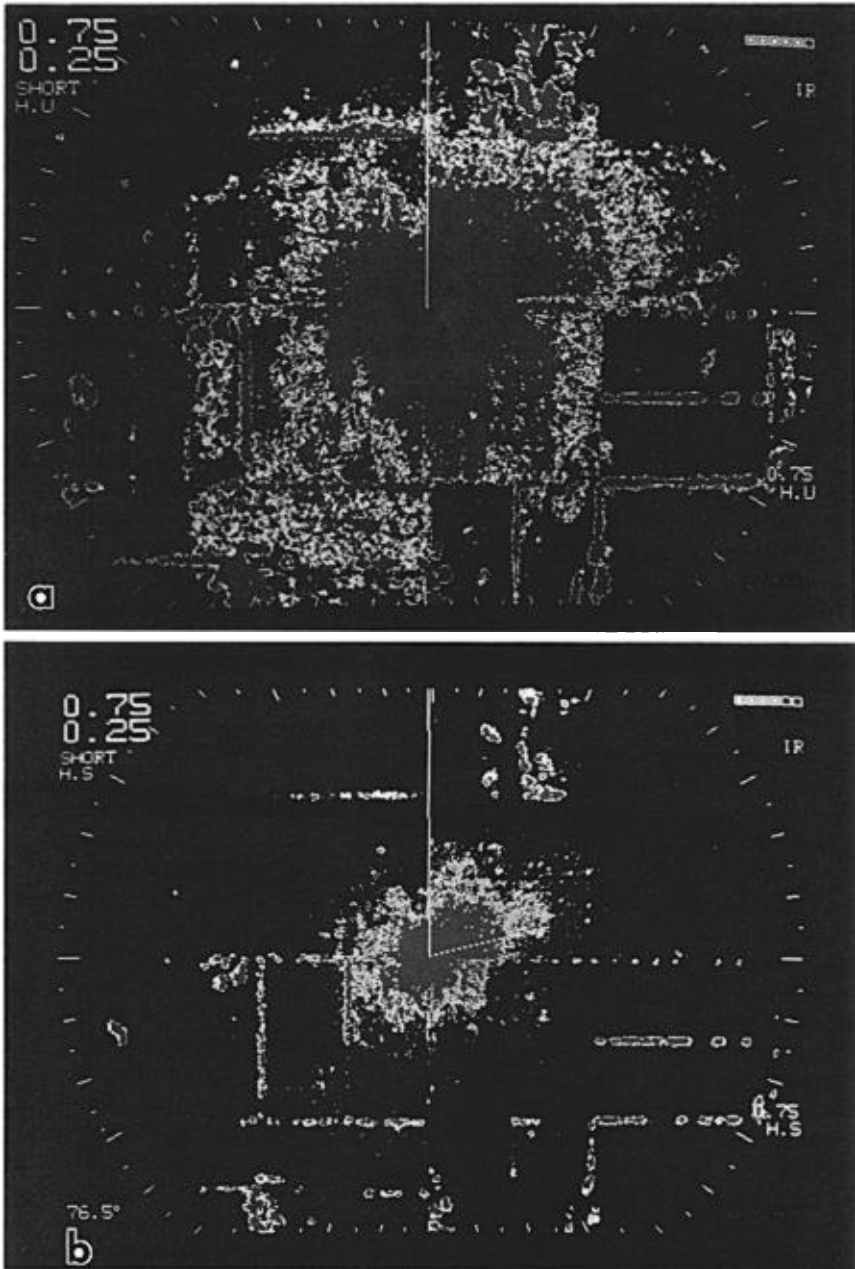


FIGURE 5. Comparison of the surveillance radar display with and without the ground clutter reduction screen at the 1.4-km range setting at a study site in northwestern Minnesota. a. without the screen, b. with the screen. The white heading line that runs

only a few meters above ground level. Note that the clutter screen did not undergo any rigorous laboratory testing; its effects on radar performance were tested only by making practical adjustments in the field.

In addition to our modifications, recent advances in the technology of marine radars contributed substantially to the performance of our units. For example, the color display and the echo stretch function of the surveillance radar reduced eye strain, compared with the traditional monochrome display. These features were particularly valuable because of the long periods spent observing the display.

The plotting function eliminated the need to photograph the radar screen to record movements of birds. Photography was necessary with older marine radars because the target image faded with time (Eastwood 1967). On our radars, the target image, which was bright blue on a background of black, was erased only after the data were recorded on data sheets by hand. The plotting function also reduced eye strain by eliminating the need to watch the display constantly and simplified the estimation of ground speeds. The optimal plot interval for our studies was 15 s.

It can be difficult to record data by hand during periods of exceptionally heavy migration, even with the plotting function. The system could be improved further by the development of an electronic interface between the radar and a computer, for automatic data collection.

Vertical radar.—The vertical radar was able to monitor flight altitudes of individual small passerines from 25 m above ground level (agl) to at least 600 m and probably up to 1 km agl; large birds and flocks of passerines could be detected at higher altitudes (Table 2). Note that the values reported in Table 2 are restricted to daytime observations of birds that were close enough to spot and identify. We frequently observed targets at higher altitudes that we knew were passerines or waterfowl, even though there was no visual confirmation, either because we heard them or identified them to species group with surveillance radar. We normally used the 1.4-km range setting on the vertical radar because it offered the best compromise between sensitivity and aerial coverage.

Through visual observations, we determined that the vertical radar was capable of detecting insects. We reduced this problem by slightly decreasing the gain setting, but some of the large insects (dragonflies and large beetles) undoubtedly were still detected. It was not possible to decrease the gain any further without missing birds, however.

The side-lobing shield reduced the zone of ground clutter in the center of the radar display from approximately 100 to 25 m, making it possible to sample down to that lower altitude. Replacement of the slotted wave-

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from the center to the top of each display is 1.4 km long. The series of dots (telephone poles) running east-west through the centers of the displays and other linear features (fences and road berms) form "maps" of the study area.

TABLE 2. Altitude of flight (in m) of bird species (individuals and flocks) observed during daylight hours by vertical radar in Alaska, South Dakota and Minnesota. Note that all species except for the raptors and passerines generally were in flocks.

Species	Mean	SD	Mini- mum	Maxi- mum	<i>n</i> (targets)
Snow Goose (<i>Chen caerulescens</i>)	178	135	30	486	31
Canada Goose (<i>Branta canadensis</i>)	246	259	81	706	5
Mallard (<i>Anas platyrhynchos</i>)	187	81	42	301	13
Unidentified duck	204	126	52	619	40
Sharp-shinned Hawk (<i>Accipiter striatus</i>)	165	138	69	527	11
Sandhill Crane (<i>Grus canadensis</i>)	576	346	266	1080	5
Unidentified shorebird	310	128	104	463	6
Franklin's Gull (<i>Larus pipixcan</i>)	163	109	64	411	19
Barn Swallow (<i>Hirundo rustica</i>)	127	175	46	592	9
Lapland Longspur (<i>Calcarius lapponicus</i>)	57	24	30	102	10
Common Grackle (<i>Quiscalus quiscula</i>)	99	40	58	147	6
Unidentified blackbird	108	38	55	162	11
Unidentified passerine	84	48	30	191	14

guide with a parabolic antenna reduced the width of the radar beam from 25° to approximately 12°. This reduced the unavoidable error in altitude measurements caused because radar measures the "slant range" of targets, which means that the altitude of a bird flying through the edge of the beam is overestimated by an amount proportional to the width of the beam (Skolnik 1980). Disengaging the antenna from its motor made it much easier to see targets on the display screen and to measure their altitudes. Finally, the alarm and plotting functions made it possible to collect data on flight altitudes continuously without having to watch the display continuously; the radar technician could record the data at his or her convenience and then erase the target echoes. When bird movements were particularly heavy, however, we did not use the alarm function, as it sounded nearly continuously.

Despite our modifications and improvements, information on height of nocturnal flights of birds below the level sampled by the vertical radar (25 m) remains difficult to collect. The hinged assembly upon which the vertical radar antenna was mounted allowed us to sample lower elevations over water bodies or smooth, snow-covered fields by orienting the antenna horizontally. Over any other surface, however, ground-clutter echoes from vegetation or an uneven ground surface obscured the display screen. To our knowledge, a marine radar system that samples flight altitude below 25 m over anything but water or a snow-covered field has not been developed (Gauthreaux 1985a,b; Korschgen et al. 1984). We are attempting to modify our radar antennas with screens that would enable us to sample flight altitude below 25 m in a variety of habitats. In the interim, we will use a night-vision scope to sample these lower altitudes.

The mobile radar lab described herein is relatively inexpensive, is available "off-the-shelf" (with simple modifications), can be operated

without extensive training, is portable and has a short minimal range and high resolution. Other radar systems have some advantages for studies of bird migration: weather radar can monitor migration over relatively large areas, airport surveillance radar eliminates ground clutter and tracking radar can provide precise information on flight behavior (altitude, direction, speed) of individual migrants and has some identification capability via wingbeat signature (Able 1985, Eastwood 1967, Skolnik 1980). Those systems, however, generally are more expensive, less portable, require more training to use and are less available to the ornithologist than our system. For these reasons, we believe that our marine radar system is the best alternative to other systems and is well-suited for ornithological studies. Future advancements in radar technology and techniques promise further benefits to ornithology.

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