RADAR OBSERVATIONS OF BIRD MOVEMENTS ALONG THE ARCTIC COAST OF ALASKA

WARREN L. FLOCK

SIX DEW (Distant-Early-Warning) radars, located along the northern arctic coast of Alaska, have been used to observe bird movements. The DEW radars, operating in the upper portion of the L frequency band (wavelengths near 23 cm), comprise a chain which extends from Alaska eastward across the Canadian Arctic and Greenland and terminates in Iceland. The northern arctic coast of Alaska is characterized by large low areas of tundra, and the Alaskan radars are all located at only slight elevations above sea level. From west to east, the radar locations and their DEW designations are Pt. Lay (LIZ-2), Wainwright (LIZ-3), Pt. Barrow (POW-Main), Lonely (POW-1), Oliktok (POW-2), and Barter Island (BAR-Main). These locations are shown in Figure 1.

The initial purpose of the investigation reported here was to determine if the DEW radars could provide useful information about the eider migration along the coast, and this question appeared to be answered in the affirmative after the first year of observations (1969) at Pt. Barrow and Lonely. The general trend of the northern arctic coast of Alaska is east-west, and bird migration is predominantly parallel to the coast, the eiders migrating to the east in the spring and to the west after about the middle of July. The well-known summer eider migration past Pt. Barrow can be observed readily visually and has been described by Murdoch (1885), Thompson and Person (1963), and Johnson (1971). It was estimated by Johnson that 95 percent of the birds migrating past Pt. Barrow in July-August are eiders and that 95 percent of the eiders are King Eiders (*Somateria spectabilis*) and 5 percent are Common Eiders (*Somateria mollissima*). At Oliktok in 1971 it was discovered also that there is a significant summer migration to the east in the direction opposite to that of the eiders. In addition, extensive east-west migrations not believed to involve eiders were recorded in the spring of 1972 at Oliktok. The concept of migration along the northern arctic coast that has developed from the studies is considerably more complex than the picture envisaged in the earlier stages.

The use of radar for bird study is well known by now (Eastwood, 1967; Myres, 1970), but each radar differs in technical characteristics or location or both from others, and the only way to determine for certain what bird movements a particular radar will detect is to actually observe and record its radar echoes. Following a short preliminary inspection of the Pt. Barrow radar in 1967, longer visits were made to Alaskan DEW radars during parts

Monk Parakeet *(Myiopsitta monachus)*. A recent colonizer in eastern North America. Painting by Murrell Butler.

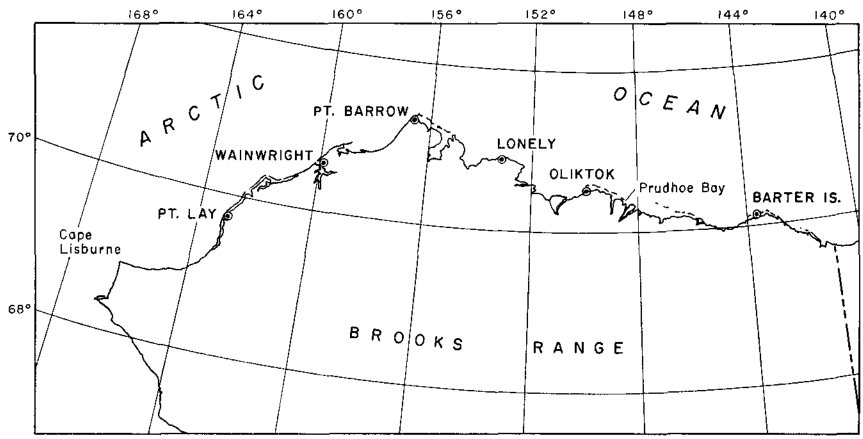

FIG. 1. Map of northern arctic coast of Alaska, showing radar locations.

of late July and early August in 1969, 1970, and 1971 and in late May–early June in 1972. The data reported represent the first use of DEW radars for the study of bird movements. Similar data have also been obtained by the author by utilizing radars of the Alaskan Air Command at Cape Prince of Wales (Flock, 1972), Cape Romanzof, and Cold Bay. The Alaska investigations through 1971 were part of a larger program of analyzing the role that radar can play in reducing the hazard of collisions between birds and aircraft.

PROCEDURES

The radar scopes at all six sites were observed visually and photographed by use of a Polaroid camera. In addition data were obtained from an automatic 35 mm camera, utilizing 100 foot reels, at the Pt. Barrow radar site. During test runs from 24 September to 27 October 1968 and from 11 to 29 June, 1969, most automatic-camera exposures were for one antenna rotation except when some time exposures were obtained accidentally. After that time the automatic camera took successive 5.6-minute time exposures. This latter type of record was obtained for 27 days in 1969 (during 8 August to 8 September), 72 days in 1970 (during 27 May to 5 October), and 64 days in 1971 (during 2 August to 5 November). Altogether about 40,000 frames of 35 mm film and 420 Polaroid prints (mostly 5.6-minute time exposures also) were exposed and examined. Radar displays showing 20 or 40 nautical mile (nmi) ranges were used generally, but some use of the 80 nmi range was made as well. One time exposure alone allows a 180° ambiguity as to direction, but the ambiguity can be resolved by watching individual targets on the radar screen or by examining successive time exposures. When a figure legend lists an eastward movement, for example, the illustration itself does not show if the movement was to the east or west and the eastward notation is based on notes written when the photograph was taken or comparison of successive frames on 100 foot reels.

The 35 mm films were studied by use of a microfilm viewer. For most of the days when time exposures were available, the numbers of tracking targets were counted for the hours of 02:00, 05:00, 08:00, etc. ADT, these being times when weather data were available from Barrow. The target directions were also recorded, and the numbers of targets with headings in each 10° interval were tabulated, an example being shown in Table 1.

One additional numerical illustration of the possibilities of the radar data is included in this paper. For certain times or periods the numbers of targets counted were used to obtain estimates of the numbers of birds crossing a line extending 40 nmi in opposite directions from the Pt. Barrow site. The numbers of targets counted (the sums of eight counts spaced three hours apart) were used to determine target densities, the average speed of the targets was somewhat arbitrarily taken as 40 knots, and it was assumed that the average target consisted of 80 birds, on the basis of data supplied by Johnson (1971). [Example, using figure from Table 2: Total of 220 targets for the eight hours considered divided by eight gives 27.5 targets on the radar screen on the average during the day considered, on an area of $\pi(40)^2 \cong 5000$ nmi^2, corresponding to a density of 27.5/5000 or 0.0055 targets/nmi^2. In one hour (0.0055) (40 knots) (80 nmi) = 17.5 targets cross a line 80 nmi in length centered at the radar. (17.5) (80 birds per target) = 1400 birds/hr and (1400) (24) = 33,600 birds/day.]

The tilt angles of the DEW antenna beams are adjustable. Fortunately the low tilt angle needed for recording echoes from birds at low altitudes was not inconsistent with normal operational requirements. A beam of low tilt angle was available at Pt. Barrow when continuous records were made and, at least temporarily, as needed at the other sites as well. Thus it is believed that the radars were capable of recording migrations taking place at quite low altitudes at the times most of the data were taken.

OBSERVATIONS

On the first trip to DEW sites between 22 July and 1 August 1969, the radars at Pt. Barrow and Lonely were observed to record at least a significant fraction of the eiders migrating past them. Radar echoes at these sites are especially numerous when many migrating eiders are seen visually. The visit to Lonely on 29 July 1969 coincided with a major eider movement that was very obvious and spectacular, both visually and on the radar (Fig. 2). Radar

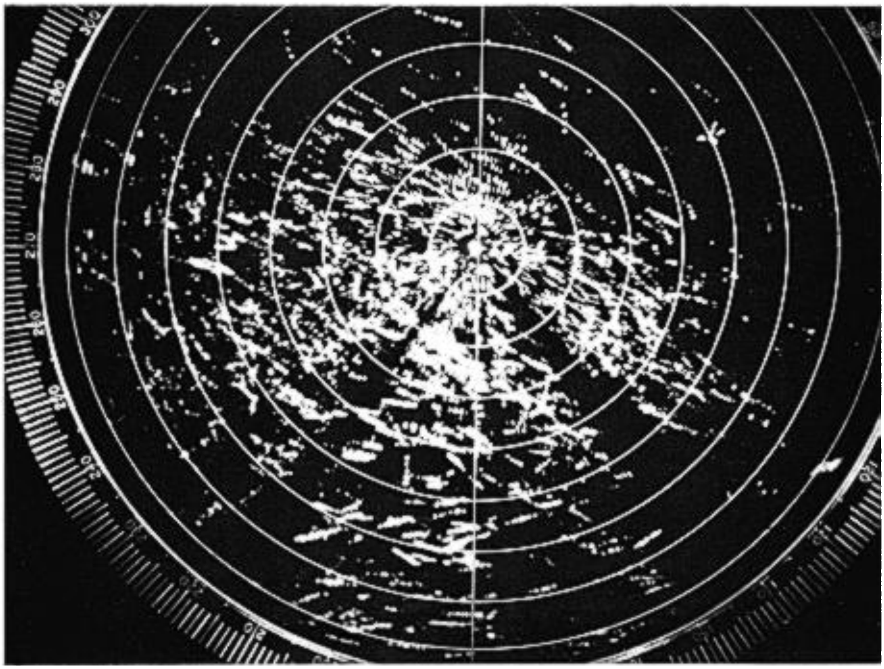

FIG. 2. POW-1 radar screen, Lonely, Alaska, 00:34 ADT, 30 July 1969. Five-minute time exposure, 40 nmi range, echoes moving NW.

echoes were recorded at distances beyond 40 nmi to the south of the site. Observers at Pt. Barrow also reported heavy eider movement that night.

Winds during much of the latter part of July, 1969 were strong and from the west and not favorable for the westward migration of eiders past Pt. Barrow and Lonely. However late on 26 July 1969, the wind speed at Barrow was reduced to about 4 knots at a time when the wind was blowing from a direction of 220°. Considerable movement was observed visually and on the POW-Main radar that night. On the following two days the wind directions and speeds were less favorable, but the wind shifted to the northeast (to come from a direction of 60°) in the late evening of 29 July 1969. It was at this time that the major migration shown in Figure 2 took place. A calculation of numbers passing the Lonely radar at the time of Figure 2, utilizing the method described under Procedures, gave a result of 8000 birds per hour, based on a count of 157 targets.

Between 27 July and 5 August 1970, observations were made at Point Barrow and Lonely again and also at Wainwright, about 70 miles to the west of Barrow. Figure 3 shows the Pt. Barrow screen on 30 July 1970 at a time

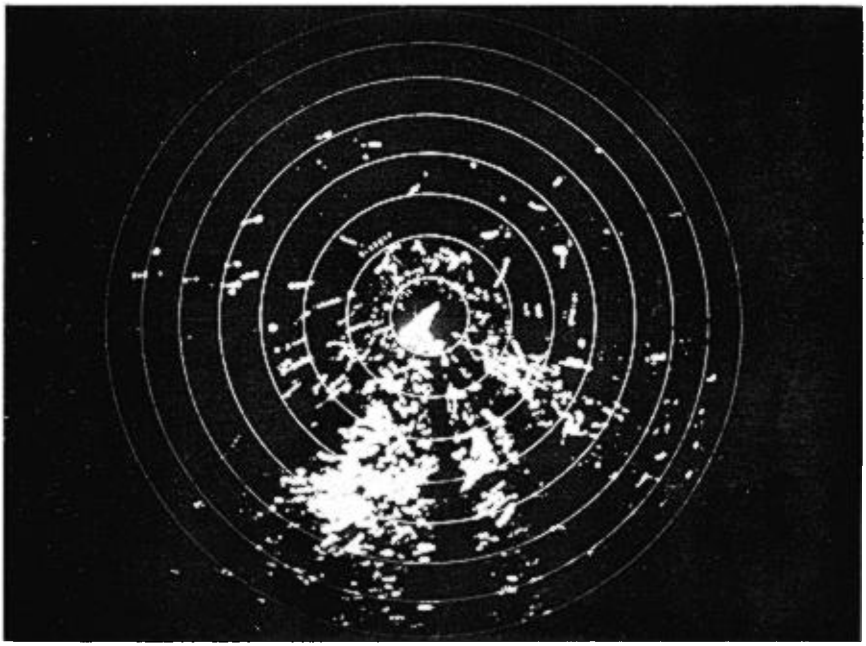

FIG. 3. POW-Main radar screen, Pt. Barrow, Alaska, 21:05 ADT, 30 July 1970. Five-minute time exposure, 40 nmi range. The overlapping echoes 10 to 30 nmi to the south are caused by birds moving W.

when westward overland migration was taking place in the area 10 to 30 nmi to the south of Pt. Barrow. At Lonely considerable movement to the south of the site was seen on the radar screen again, as in 1969, but migration was less evident visually. One reason for visiting Wainwright was to determine if significant overland migration took place there, perhaps between the general areas of Lonely and Wainwright and to the south of Point Barrow. At Wainwright, however, the migration is typically between 5 and 10 nmi offshore, consistent with the statement of local resident, Bill Patkotak, as to where the eiders are known to migrate.

In 1970, Johnson (1971) studied the eider migration at Point Barrow visually, and automatic-camera photography of the Point Barrow radar was requested by the writer so that simultaneous radar and visual data would be available. The radar and visual data were correlated in general (in that periods of intense movement as indicated visually were also periods of intense movement as indicated by the radar). However the radar and visual data could not be correlated in detail (not precisely as to location or numbers and not on a flock by flock basis) as the DEW radars, like other long-range

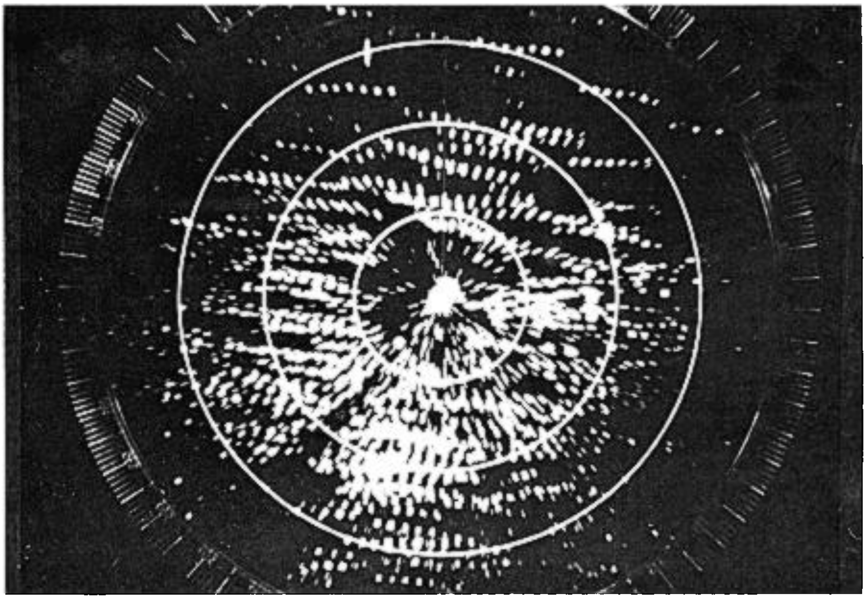

FIG. 4. POW-2 radar screen, Oliktok, Alaska, 21:15 ADT, 2 Aug. 1971. 5.6-minute time exposure, 20 nmi range, echoes moving E.

surveillance radars, do not give satisfactory coverage within the first few miles and the visual observations were made about a mile from the radar.

In 1971 the three active DEW radar sites in Alaska that had not been inspected previously were visited between 26 July and 16 August. The observations at Barter Island and Oliktok were of particular interest in that they showed predominant eastward migration during the visits to these locations (27 July to 3 August). This movement was aided by a west wind and took place at a rather high altitude. Movement was greater over the land to the south of the sites than over the water. It was not possible to see these birds visually with binoculars or the unaided eye, and it is not known what species are involved. Figure 4 is an illustration of the Oliktok radar screen during this period. Photographs taken at Barter Island were similar.

Some eastward movement was also seen at Pt. Lay in August 1971, and some of these birds arrived from the direction of Siberia. At Pt. Lay, however, most echoes were of birds that were proceeding in a southerly direction. In the area of Pt. Lay the coast trends north-south and the birds traveling to the south there were generally off shore and presumed to be mostly eiders which had been following the coastline from the east.

The first spring visit by the writer to a DEW site was made at Oliktok

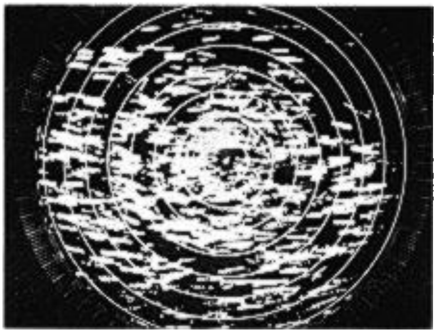

FIG. 5. POW-2 radar screen, Oliktok, Alaska, 20:05 ADT, 28 May 1972. 5.6-minute time exposure, 40 nmi range, echoes moving E.

from 27 May to 5 June 1972. This location was chosen because of the proximity of the Oliktok radar to the Prudhoe Bay oil area and because of the interest of Bureau of Sport Fisheries and Wildlife personnel and others in the area. Both the tundra and ocean were frozen and covered with snow throughout the time of the visit but echoes from the birds showed profusely on the radar screen. The wind was from the east most of the week, but on 28 and 29 May there was a period of west wind. Bird movement tended to correspond to the wind direction, but not entirely. A very heavy movement towards the east took place with the favorable west wind on 28 and 29 May (Fig. 5). Westward movement tended to dominate otherwise, but at times there was movement towards the east in opposition to the east wind, especially on 4 June when the opposing wind was slight and especially in an area from 20 to 50 nmi to the south of the radar site. This region to the south showed on the radar screen as an important corridor for east-west migration. The rise in height of the ground to the south may tend to make the birds in that region conspicuous on the radar. Another feature of interest of the radar record was that birds were observed to approach the coastline from the north, or from over the Arctic Ocean, on 29 and 30 May (Fig. 6).

Visibility was generally rather poor during the period at Oliktok, a low ceiling being the principal limiting factor, and few migrating birds were seen visually. Jaegers, flying to the east a few at a time, were the most common bird actually seen flying purposely in a given direction. The low ceiling also limited observation from aircraft as well as from the ground. J. Larry Haddock and James Bartonek of the U.S. Bureau of Sport Fisheries and Wildlife visited Oliktok from 2 to 5 June and attempted to identify the source of the radar echoes by aircraft flights in the vicinity. On 3 June, an effort was made to direct their aircraft to particular bird targets but practical

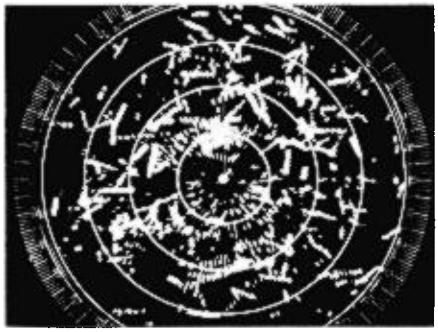

FIG. 6. POW-2 radar screen, Oliktok, Alaska, 09:00 ADT, 30 May 1972. 5.6-minute time exposure, 20 nmi range. Visual monitoring of the radar screen at this time indicated that a large percentage of the echoes shown were approaching the coastline from over the Arctic Ocean.

difficulties were encountered. On 4 June, the aircraft landed on two lakes to the south and observations of birds were made from the lakes. The observers saw a number of geese, jaegers, and shorebirds, which were probably indicative of what some of the migrating birds were or had been, but a large percentage of their observations were of birds so close to the ground that it is doubtful that the radar received echoes from the same individual birds.

By the time of the return flight from Oliktok to Pt. Barrow on 5 June, water was flowing over the ice at the mouth of the Colville River, and large numbers of White-fronted Geese (*Anser albifrons*) were seen in the Colville delta area. These birds were also seen regularly in small numbers (10–16) at Oliktok itself. Other birds which were seen at Oliktok regularly or in significant numbers and could have caused radar echoes included the Whistling Swan (*Olor columbianus*), Parasitic Jaeger (*Stercorarius parasiticus*), Pomarine Jaeger (*Stercorarius pomarinus*), Glaucous Gull (*Larus hyperboreus*), Am. Golden Plover (*Pluvialis dominica*), Ruddy Turnstone (*Arenaria interpres*), Dunlin (*Calidris alpina*), and Semipalmated Sandpiper (*Calidris pusillus*). Two pairs of swans were regularly at the site and apparently intended to nest there. A flock of 12 Snow Geese (*Chen caerulescens*) was seen at Oliktok on 2 June.

The birds cluttered the Oliktok radar scope quite seriously at times, and it was difficult to detect or follow small aircraft in the cluttered areas. Echoes from birds were detected at ranges at great as 75 nmi.

AUTOMATIC-CAMERA DATA FROM PT. BARROW

Spring Migration.—Only limited automatic-camera data are available concerning the spring migration, and they were for late May and the month

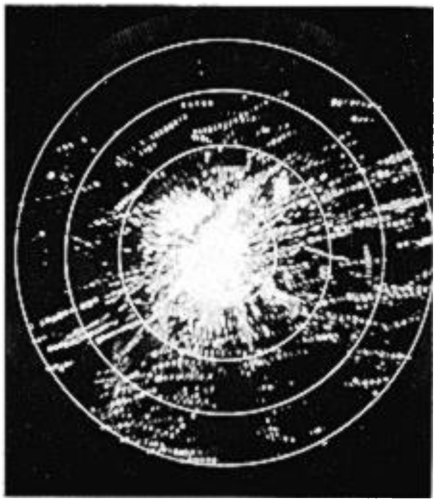

Fig. 7. POW-Main radar screen, Pt. Barrow, Alaska, 20:15 ADT, 11 June 1969. About eight-minute time exposure, 20 nmi range, echoes moving E-NE.

of June. Time exposures were obtained on 11 June 1969 and from 27 May 1970 through most of June, 1970. Migration continues into June, as shown in Figure 7, which also shows the very interesting feature that birds are proceeding generally in a direction of about 70° (measured clockwise from geographic north). The same general directions are also shown in the June 1970 records. Headings were commonly in the 60° and 80° range from 27 May to 17 June, though in very slight numbers on 8–10 June, when westward movement predominated. A 40 nmi sweep was used in 1970, and targets were often seen over the ocean to the north-east at ranges of 25 nmi and greater.

Summer Westward Migration.—No sharp dividing line appeared between the spring and summer migrations in 1970, and there was no time when birds were not moving. No data were obtained from 17 to 25 June 1970, and mixed or alternating east-west movements were recorded from 25 June to 6 July. From that date on, migration to the west predominated.

The birds taking part in the summer migration past Pt. Barrow generally follow along the shore or the offshore islands from the southeast as they approach the area of the point. They commonly have a heading of about 290° as they approach and gradually change direction to achieve a heading of about 250° to the west of Pt. Barrow. This route takes the birds quite far out over the ocean to the west, as they would need a heading of about 225° to follow the coastline closely to the west of Barrow. The overwater route followed is shorter and more direct than one close to the shore west of Barrow and is

TABLE 1

NUMBERS OF TARGETS HAVING DIRECTIONS WITHIN SPECIFIED ANGULAR LIMITS

1. 26 Aug. 1969		2. 28 Aug. 1969	
Angular Range	Number of Targets	Angular Range	Number of Targets
0°–220°	10	0°–220°	10
220°–240°	1	220°–240°	3
240°–250°	1	240°–250°	12
250°–260°	4	250°–260°	12
260°–270°	13	260°–270°	34
270°–280°	21	270°–280°	47
280°–290°	32	280°–290°	25
290°–300°	43	290°–300°	19
300°–310°	44	300°–310°	12
310°–320°	25	310°–320°	4
320°–330°	19	320°–330°	2
330°–340°	10	330°–340°	1
340°–350°	2	340°–350°	0
350°–360°	1	350°–360°	0

consistent with the offshore migration observed at Wainwright. Some data on the summer migration past Pt. Barrow for late August, 1969 are shown in Tables 1 and 2.

Some caution is needed in interpreting Table 1, as birds approaching from the east are more readily detected than those leaving to the west, so that data may be weighted towards the approaching birds. Another complication is that some birds bypass Pt. Barrow itself by migrating overland in the area to the south of the point. Much data of the type shown has been accumulated,

TABLE 2

ESTIMATED NUMBERS OF BIRDS PASSING PT. BARROW
(Assuming an average speed of 40 knots and 80 birds per flock)

Day (Aug. 1969)	Number of Targets	Direction of Movement	Estimated No. of Birds
25	220	SW	33,600
26	500	NW	76,500
27	475	NW	72,500
28	495	W	75,500
29	465	W	71,000
			Total ≅ 329,000

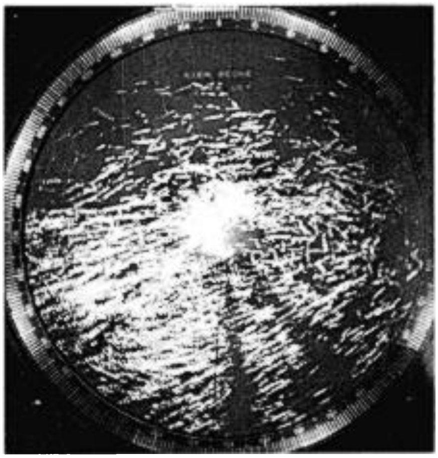

FIG. 8. POW-Main radar screen, Pt. Barrow, Alaska, 00:40 ADT, 7 Oct. 1970. 5.6-minute time exposure, 40 nmi range, echoes moving W-SW.

but it is practical to include only a few illustrations at this time. A second paper concentrating primarily on numerical summaries and analyses would be appropriate at a later date.

Summer Eastward Migration.—The photographs taken at Barter Island and Oliktok in the summer of 1971 (Fig. 4) drew attention to an eastward migration of unknown species that were flying too high to be seen visually. Automatic-camera data from Pt. Barrow also showed eastward migration at about the same time, specifically on 3–6 August 1971 when eastward movement predominated, on 2 August when westward and eastward movement were comparable, and on 7 and 8 August when westward movement predominated but eastward movement was also evident. The winds were from the west and strong (greater than 17 knots at Barrow) from 1 to 5 August 1971. Very little westward movement of eiders was observed during this period. The films for 1969 and 1970 also show some eastward movement at the general times of the more obvious westward summer migration.

Fall Migration.—Migration is conspicuous on the radar films into the first week of November 1971 after which no radar data are available. Migration was quite intense in the first week of October in both 1970 and 1971, as shown in the example of Figure 8. A cold spell took place during the first week of October 1970, and a mass exodus of birds took place then. Some birds were reported to have died of starvation and cold. The temperature dropped below 0°F (to -2°F) on 7 October for the first time in the fall of 1970, and the temperature was about 2°F at the time of Figure 8. The birds were then flying with a slight favoring wind (6 knots towards 230° at 04:00 ADT at Barrow, Alaska).

DISCUSSION

The radar record suggests that some of the late-migrating birds in spring (as in Fig. 7) fly directly from the region of Pt. Barrow to some of the Canadian Arctic islands (Manning, Höhn, and Macpherson, 1956; Parmelee, Stephens, and Schmidt, 1967). The evidence is not conclusive but these birds may well be eiders. It appears that some of the birds which migrate past Pt. Barrow and nest near Oliktok may stay rather far out over the ocean after passing Pt. Barrow and may rest on open leads, before heading south to nesting areas (Fig. 6). The peak of the spring eider migration past Pt. Barrow is reported by Johnson (1971) to take place in May, but few eiders were seen at Oliktok between 27 May and 5 June 1972. The lakes at that time were frozen and the eiders which frequent the lakes later in June were not present. Eiders returning from the Canadian islands and other locations east of Pt. Barrow follow the coastline of Alaska as they approach Pt. Barrow from the east. No radar echoes have been seen to approach from far out over the ocean to the east. The summer migration of the eiders at Pt. Barrow has received the greatest attention from both the native Eskimos who hunt the eiders and from previous investigators. It is the male eiders that migrate first to the west in the summer. These male birds leave the breeding grounds as soon as laying starts (Delacour, 1959). By mid-August females begin to predominate in the migration past Pt. Barrow, and young birds migrate past Pt. Barrow at still later dates in September and October.

A limitation of conventional surveillance radars is that they are incapable of identifying bird echoes as to species. About the only occasion for which the identity of bird echoes can be established with reasonable certainty is when essentially only one species (or genus) is believed to be migrating in significant numbers in a certain area, on the basis of visual observations. The early summer eider migration along the coast as recorded by the Pt. Barrow, Lonely, and Wainwright radars seems to fall in this category. Radar observations in these areas near the coast correspond generally in number and location with visual reports of eider movements and there is no good evidence of major westward migration of other species during the early summer migration of the eiders. Some eiders fly low over the water, or over the land near the water, but others fly higher and the higher birds, at least, should be detectable by a radar beam having the low tilt angle employed. For example at Lonely on 30 July 1969 (Fig. 2), some eider flocks almost collided with a tracked vehicle crossing the tundra while it was estimated that others might have been as high as 1000 feet. The writer is of the opinion that the DEW radars mentioned do at least a reasonable job of monitoring the eider migration along the Arctic Ocean coastline and believes that the majority of radar echoes recorded near the coastline during the summer westward migration are due to eiders.

The case of the radar echoes observed as much as 40 nmi south of the coastline at times of peak eider migration near the coast is very interesting but difficult to assess. As eiders are commonly believed to fly only at low altitudes near the coastline, suggestions that some of the inland birds are eiders have met with general skepticism. Neither the literature or personal discussions with native Eskimos or biologists with experience in Alaska, however, provide very clear or convincing evidence one way or the other on this question or suggest clearly what other birds are migrating at these times.

Factors favoring the eider hypothesis in situations like that depicted in Figure 2 are the same as those stated above for believing the echoes near the coastline are eiders plus the fact that eiders are commonly seen flying over land south of Lonely and near the natural gas well near Barrow. This latter location is only about 5 miles from water but even that distance is significant and there is no reason to believe all eider movement ceases immediately south of that point, especially when a major large-scale movement is taking place. In addition the fact that some eiders have been seen visually at moderate heights at Lonely, such that they might be detectable by radar at a considerable distance, needs to be emphasized. Also whatever the inland birds were in cases like Figure 2, they were migrating in synchronism in time and space with the coastal eiders, displaced to the south but with no clear gap in between, which suggests that they might have been eiders themselves. Of the possibilities other than eiders, Black Brant (*Branta nigricans*) are perhaps the most likely. The writer leans towards the eider hypothesis for dates as early as that of Figure 2, but the evidence is not convincing and the identity of the inland migrants must be considered to be unresolved.

In the case of the fall migration past Pt. Barrow, birds other than eiders must be responsible for many of the echoes. Oldsquaw (*Clangula hyemalis*), Black Brant and loons are among the other birds that migrate in the fall. The identity of most of the migrants observed with the Oliktok radar between 27 May and 5 June 1972 cannot be established definitely but White-fronted Geese must be prominent among the birds moving west, especially in the case of some of the echoes which seemed to terminate in the Colville delta area. Frank Bellrose (pers. comm.) has suggested that the birds moving east on 28 and 29 May may have been Black Brant and that Snow Geese and Whistling Swans may have been important sources of westward moving echoes. Some Snow Geese migrate to Wrangel Island via Cape Prince of Wales (Flock, 1972), but others apparently travel to Wrangel Island via the Mackenzie Valley and the northern arctic coast of Alaska. The identity of the summer migrants traveling east at Oliktok and Barter Island in 1970 is not known but it can be conjectured that they were shorebirds which later headed to the south along the Mackenzie River Valley.

The vertical coverage of a radar is a function of antenna beamwidth, antenna tilt angle, meteorological conditions, and range. Surveillance radars tend to have broad vertical beamwidths such as to provide little information about target altitudes. Thus only qualitative statements about altitudes can be made about most of the observations reported here. There is very clear evidence, however, that the DEW radars commonly detect birds which are so high that they cannot readily be seen visually. At Barter Island and Oliktok in the summer of 1971, for example, the radar showed birds passing directly overhead, when the antenna tilt was sufficiently high to preclude most ground clutter. In these particular cases it can be estimated roughly that some of the birds were at altitudes near 10,000 feet. At no time were these birds seen with binoculars or the unaided eye, though the sky was clear. A carefully planned program of visual observations at such times using fixed telescopes (Gauthreaux, 1970) might, however, result in sightings.

Radar can provide accurate flight directions quite readily, although there are always a fairly large number of targets which cannot be tracked or followed from one frame to the next. Radar is less well suited for providing numbers of birds, but procedures have been devised for particular situations (Nisbet, 1963; Gauthreaux, 1970). The radar record for Pt. Barrow has numerous gaps and for that reason alone is not capable of providing an accurate total number of migrants. Also a careful study of techniques for determining numbers, using DEW radars, has not yet been made. However it is clear that the Pt. Barrow and other DEW radars can monitor movements over a much larger area than visual observers, and the radar record shows that many birds migrate over the water to the north of Pt. Barrow and overland to the south of Pt. Barrow. One approach to estimating numbers by radar would be to use data on flock sizes from visual observations. Johnson (1971) reports average sizes of 91, 82, and 43 for conditions of favorable, neutral, and unfavorable winds. Thompson and Person (1963) report a mean flock size of 105.

Using a number of 80 birds per flock, estimates of the numbers of birds passing Pt. Barrow were made for the period of 25–29 August 1969, as shown in Table 2. Dividing the daily fourth column figures of Table 2 by 24 and averaging gives an average hourly rate of 2740 birds/hr for the five day period. Johnson (1971) reported figures from visual observations at Pt. Barrow on a weekly basis. His maximum movement was 1100 birds/hr for the week of 23–30 July 1970, and he quoted 500 per hour for the week of

23–30 August 1970. Unfortunately, there is no one entire week of good radar data which can be compared with Johnson's figures, but the radar figures are significantly higher than those that he quotes. The Duck Camp location at Pt. Barrow, where the visual observations have been made, is an excellent location for visual studies of migration, and large numbers of eiders pass close by it. As a rough guess, however, it appears that three or four times or more as many birds migrate past the entire Pt. Barrow area as can be seen at Duck Camp.

CONCLUDING REMARKS

The DEW radars are capable of continuously monitoring bird migration along the northern arctic coast of Alaska and presumably elsewhere along the DEW chain as well. Thus these radars can be utilized on a multipurpose basis. Cameras which are permanently installed on scopes in the maintenance areas are suitable for this purpose. Radar can provide continuous coverage of bird movements in overcast and over a much greater volume of space than visual observers. This latter point is illustrated by the fact that radar detected movement at distances up to 75 nmi from the DEW sites and also detected high flying birds which could not be seen visually.

The use of the DEW radars has shown a number of features of bird migration along the arctic coast, in addition to the rather well documented westward migration of eiders past Pt. Barrow after the middle of July. Some of the other birds fly higher and make larger radar echoes than do the eiders (Fig. 5). The picture of bird migration in Alaska that has been developed over the years by visual observations and banding operations includes many of the interesting and important characteristics of migration in the area, but the radar data show impressive migratory movements which have gone largely unseen by man. Banding recoveries suggest but do not positively establish the identity of the birds participating in some of these movements, as they only very roughly indicate possible migration routes. Radar data are essential to any attempt to adequately describe bird migration in Alaska.

The positive identification of the radar echoes appearing profusely on the DEW radar screens is a difficult problem at the present time. Work is proceeding at Boulder on radars for recording amplitude and Doppler signatures of bird echoes for identification purposes (Konrad, 1968; Schaefer, 1968). A principal feature of the signatures is modulation at the wingbeat frequencies, and the latter vary inversely with wing lengths (Greenewalt, 1960). Eventual development of such signature radars in Alaska, for identification of echoes detected by surveillance radars, would be advantageous.

Radar studies of birds in the Arctic are pertinent at this time because of the interest that has developed in the Arctic because of oil discoveries, etc., (Fish and Wildlife Service, 1971). In this respect, radar can assist in the function of environmental monitoring (of bird activity). It would seem highly appropriate to monitor bird activity by radar, especially perhaps at Oliktok near Prudhoe Bay or at Pt. Barrow, to obtain a record of how bird numbers and activity are affected over a period of time by man's activities or natural causes.

SUMMARY

Radar records of bird movements along the northern arctic coast of Alaska appear to document the westward summer migration of eiders past Pt. Barrow, Wainwright, and Lonely. In addition the records show a sometimes heavy fall westward migration that persists into November at Pt. Barrow. An extensive spring east-west migration and a high-altitude eastward summer migration have also been observed by radar at Oliktok, near Prudhoe Bay east of Pt. Barrow.

At the time of the summer westward eider migration, identification of radar echoes as due to eiders was based on correlation with visual observations and on the fact that no major westward migration of other species is known to take place then. In the other cases positive identification by visual or other means was not accomplished. The spring migration at Oliktok was complex in nature, presumably involved at least several species, and took place at a time of heavy overcast when the ocean and tundra were frozen and covered with snow. The summer eastward migration recorded at Oliktok took place at a sufficiently high altitude that it could not be seen visually by naked eye or binoculars in clear weather.

The results reported represent the first application of DEW radars to the study of bird movements.

ACKNOWLEDGMENTS

The work was supported through 1971 by Research Grant 68-1377 from the Air Force Office of Scientific Research. The 1972 trip was financed by the Smithsonian Institution and Air Force contract F44620-67-C-0063. I wish to express my thanks to Colonel William R. Menzie, Commander, 4785th Air Base Squadron, Department of the Air Force, to Colonel Robert O. Gruetzemacher (former commander), and to their staffs for their help in arranging the visits to the DEW sites and the recording operations at Pt. Barrow. Also, I thank the radicians, station chiefs, and other personnel of ITT Arctic Services, Inc., for their assistance. Special mention in this respect should be made of Mr. William Newman, Lead Radician, POW-Main, at the times most of the automatic camera data were obtained. The fine cooperation received from Mr. John F. Schindler, Director, Dr. Max C. Brewer, former director, and the staff of the Naval Arctic Research Laboratory, Barrow, Alaska, is much appreciated. Finally, the assistance of Mrs. Terry Cormack, in analyzing the data from the POW-Main radar, was essential to the completion of the work.

LITERATURE CITED

Delacour, J. T. 1959. The waterfowl of the world. Volume 3. Country Life Ltd., London.

Eastwood, E. 1967. Radar ornithology. Methuen & Co. Ltd., London.

Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior, 1971. To have and to hold, Alaska's migratory birds. U.S. Government Printing Office, Washington, D.C.

Flock, W. L. 1972. Radar observations of bird migration at Cape Prince of Wales. Arctic, 25: 83–98.

Gauthreaux, S. A. 1970. Weather radar quantification of bird migration. Bioscience, 20: 17–20.

Greenewalt, C. H. 1960. Hummingbirds. Doubleday and Co., Inc. Garden City, N.Y.

Johnson, L. L. 1971. The migration, harvest and importance of waterfowl at Barrow, Alaska. Unpubl. M.S. thesis. Univ. Alaska, Fairbanks.

Konrad, T. G. 1968. Radar as a tool in meteorology, entomology, and ornithology. *In*, Proceedings of the Fifth Symposium on Remote Sensing of the Environment. Willow Run Labs., Univ. Michigan, Ann Arbor.

Manning, T. H., O. E. Höhn, and A. H. Macpherson. 1956. The birds of Banks Island, Natl. Mus. Canada Bull. 143.

Murdoch, J. 1885. Birds. *In*, P. H. Ray, Report of the International polar expedition to Point Barrow, Alaska. U.S. Government Printing Office, Washington, D.C.

Myres, M. T. 1970. The detection of birds and insects, and the study of bird movements, with radar. Proceedings of the World Conference on Bird Hazards to Aircraft, 2–5 Sept. 1969: 501–519, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa.

Nisbet, I. C. T. 1963. Quantitative study of migration with 23-centimetre radar. Ibis, 105:435–460.

Parmelee, D. F., H. A. Stephens, and R. H. Schmidt. 1967. The birds of southeastern Victoria Island and adjacent small islands. Natl. Mus. Canada Bull., 222.

Schaefer, G. W. 1968. Bird recognition by radar. A study in quantitative radar ornithology. *In*, The problems of birds as pests. Academic Press, London.

Thompson, D. Q., and R. A. Person. 1963. The eider pass at Point Barrow, Alaska. J. Wildl. Mgmt., 27:348–356.

DEPARTMENT OF ELECTRICAL ENGINEERING, UNIVERSITY OF COLORADO, BOULDER, COLORADO 80302, 1 AUGUST 1972.