Bird Migration Along the Beaufort Sea Coast: Radar and Visual Observations in 1975

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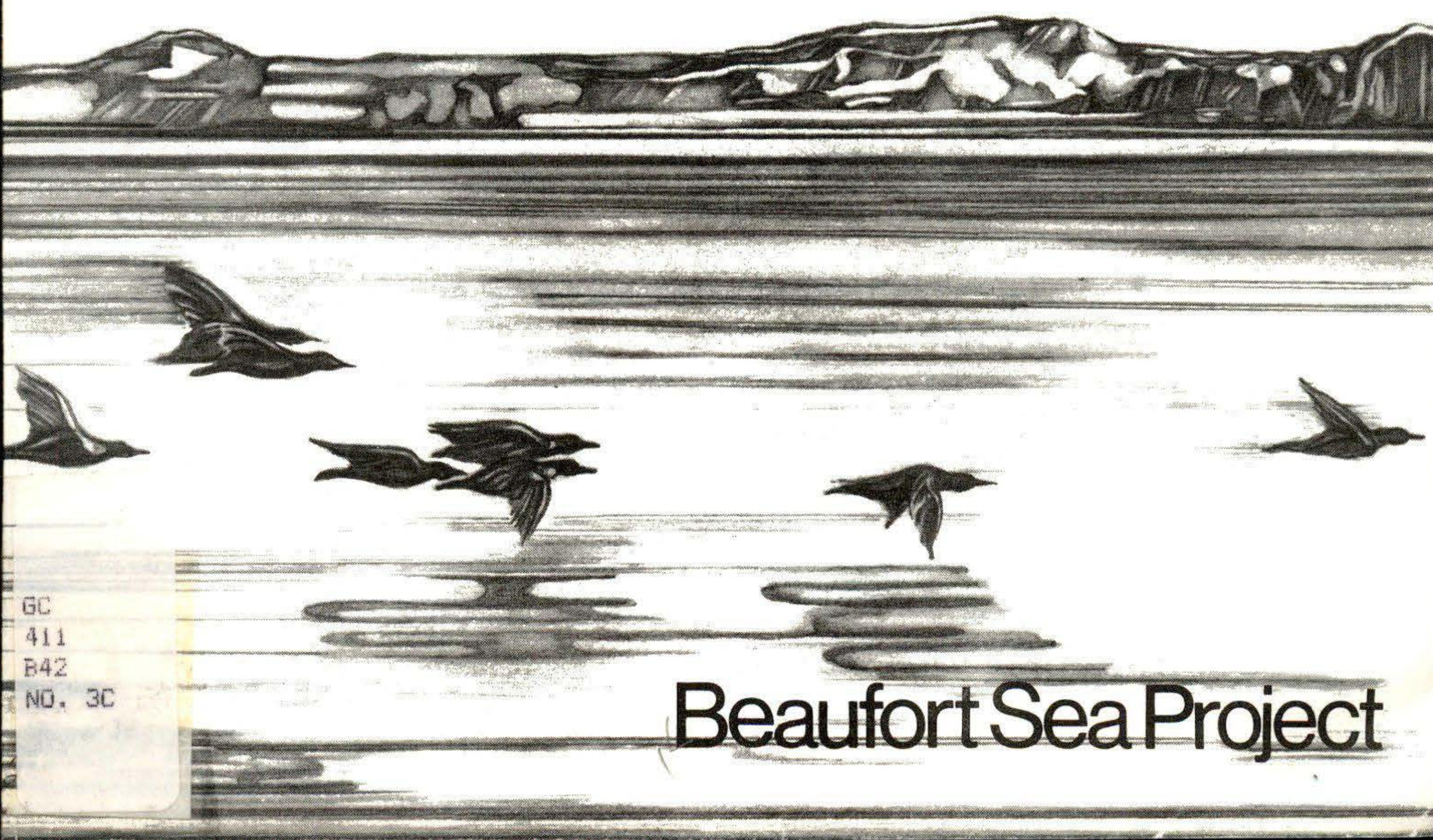

Beaufort Sea Project

BIRD MIGRATION ALONG THE BEAUFORT SEA COAST: RADAR AND VISUAL OBSERVATIONS IN 1975

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SUMMARY

Bird distribution within and the patterns and timing of movements over the south-central Beaufort Sea and northern Yukon were studied from 9 May to 9 July 1975. Three techniques were used:

1) near-continuous monitoring by the Komakuk, Y.T., DEW radar of the distribution, flight paths, and relative numbers of birds aloft within 74 km of Komakuk;

2) systematic daily observations of migrating and local birds at two sites on the Yukon coast--Komakuk and Clarence Lagoon (see Johnson *et al.* In Press); and

3) aerial surveys of lengths 326-694 km of the south-central Beaufort Sea on seven dates.

Three main classes of movement were recorded by radar: eastward, westward, and northeastward.

Birds often flew east and west more or less parallel to the coast on a broad front. Such flights often extended over the southern Beaufort Sea to the limit of detectability (55 km or more offshore) and across the width of the North Slope. However, there was usually some degree of concentration along the shore, and on some occasions few birds were aloft more than 15 or 20 km offshore. Small numbers of birds were occasionally detected flying northwest and east over the British Mountains. Until late May, both eastward and westward movement were usually of low density; thereafter, movement in both directions was denser, although still variable in density from hour to hour and day to day.

Small numbers of birds flew north and northeast across the British Mountains and North Slope and out over the Beaufort Sea. Such movements occurred intermittently throughout the study period.

Numbers detected each day by radar and visual techniques were not closely correlated, and many birds that flew parallel to the coast were too far inland or offshore to be detected visually. Radar and field observers detected different--though overlapping--components of the flow of migrants, and both techniques were necessary to document migration adequately.

Visual observations gave no indication of the identity of the few birds that moved northeast; shorebirds, Oldsquaws and perhaps Brant or eiders and scoters are suspected.

The most commonly detected eastbound species were Brant, Oldsquaws, Pomarine Jaegers (until 12 June), and Glaucous Gulls. Other species that were predominantly eastbound in spring included Yellow-billed, Arctic and Red-throated Loons, Common and King Eiders, Stilt Sandpipers, Parasitic Jaegers (until 12 June), Sabine's Gulls, and Arctic Terns. Most of the eastward

movement recorded visually occurred between 28 May and 12 June. Thereafter, radar observations continued to show eastward movement, but field observers saw few birds moving east.

Visual observations showed less westward then eastward movement. The most commonly detected westbound species were Whistling Swans, White-fronted Geese, Pintails (but see below), scoters (few seen before mid-June), and (from 13 June onward) Pomarine and Parasitic Jaegers. Visual as well as radar observations showed that significant westward movement occurred from late May to the end of the study.

Significant numbers of some species--Snow Geese, Pintails (until 7 June), Red-breasted Mergansers, many shorebird species, and Long-tailed Jaegers--were recorded moving both east and west. In the case of shorebirds, which often fly high when migrating long distances, most of the birds observed were probably involved in local flights.

Stepwise Multiple Regression Analysis showed that birds moved west in largest numbers with easterly winds and falling pressure, whereas they moved east in largest numbers with westerly winds, rising pressure and good visibility.

No birds were seen offshore during the first aerial survey on 14 May; the only open water encountered on that survey consisted of a few small cracks and holes. Small numbers of Glaucous Gulls, Brant, Oldsquaws, Yellow-billed Loons, and scoters were seen on 28 May. The largest numbers recorded on any aerial survey--about 5560--were seen on 5 June: Oldsquaws predominated (3274) but significant numbers of both Common and King Eiders, Brant, and Yellow-billed Loons were also seen. Fewer birds were seen on 15 June; again Oldsquaws predominated, with lesser numbers of eiders, Brant, and other species. On 26 June fewer individuals (390) but more species (11) were seen. On 3 and 9 July more open water was encountered, but the total numbers seen (881 and 206) were not high; Oldsquaws and scoters predominated.

No large concentrations of eiders were recorded either in the water or aloft during any aerial survey, nor were many seen migrating along the shore. The migration route between Point Barrow and Banks Island remains poorly documented, but the paucity of eiders observed offshore suggests that few landed in the central portion of the Beaufort Sea in 1975.

INTRODUCTION

The Beaufort Sea and its coastlines are important areas to many species of water-associated birds. Significant fractions of the total North American populations of a number of species are present in the Beaufort Sea area at certain times of the year; these species include the following: Yellow-billed, Arctic, and Red-throated Loons; Whistling Swans; Brant; Snow and White-fronted Geese; Oldsquaws; Common and King Eiders; Glaucous, Sabine's, and Ross' Gulls; and jaegers (Johnson *et al.* In Press). Some of these birds occur in the Beaufort Sea area only during migration; others also nest, moult, and accumulate fat reserves there.

Previous to 1970, little systematic information about the distribution and numbers of birds in and near the Beaufort Sea was available. The distribution and numbers of birds far offshore were especially poorly known.

Oil and gas were discovered in the area in the late 1960's; it was apparent that existing knowledge was insufficient to permit the necessary assessments of the impact of increased human presence and of industrial development on the birds of the Beaufort Sea. Hence, a number of studies--several of them more systematic and intensive than had been conducted in the area previously--were initiated in Alaska and Canada by governments and industry.

Information collected in 1972 and 1974 by the Canadian Wildlife Service, its contractors, and co-operating agencies is summarized in a companion report (Searing *et al.* 1976). However, in 1974, the year in which the bulk of the data on offshore distribution and movements were collected, sea-ice cover was unusually extensive and long-lasting. The degree of similarity between the results obtained in 1974 and those that might have been obtained in a more typical year was unknown. There was a particular need for more information about distribution and movements during the critical spring migration period. In spring there is little open water even in a normal year, and high mortality can occur from natural causes (Barry 1968). Furthermore, the occurrence of an oil spill into one of the few areas of open water present in spring might kill large numbers of waterbirds.

LGL Limited was contracted by the Canadian Wildlife Service to design and conduct an intensive study of spring migration in 1975 along the north coast of the Yukon Territory and across adjacent parts of the Beaufort Sea. The objectives of this study were to provide information about the following:

1. the timing, species composition, and routes of migration;
2. the offshore distribution of each species;
3. the numbers, speeds, and directions of movement of flocks of each species; and
4. the relationships between timing of migration and weather and ice conditions.

In order to gather this information, bird movements were monitored by radar on a 24 hr/day basis from early May to early July. Radar data were supplemented by data gathered during visual migration watches conducted at two coastal sites and during periodic offshore aerial surveys.

The results of these studies are presented in this report in several major sections:

1. weather, snow, and ice conditions in 1975;
2. general description of migration in 1975;
3. relationships between migration and weather; and
4. results of aerial surveys offshore.

The detailed results on a species-by-species basis are given by Richardson *et al.* (1975:145-324). They are summarized in Figures 9 and 21 and in Appendix 2 of this report, and are given in more detail by Johnson *et al.* (In Press). Except where otherwise noted, the taxonomic conventions of the American Ornithologists' Union (1957, 1973) have been followed.

STUDY AREA

Komakuk

Komakuk (or Komakuk Beach) (69°36'N, 140°11'W) is the site of a DEW radar station and is situated on the Yukon coastal plain adjacent to the Beaufort Sea about 32 km west-southwest of Herschel Island, Y.T. (Figure 1).

Immediately northeast of Komakuk is a low area containing several small semi-permanent lakes and a large mud flat associated with a creek (Fish Creek) running adjacent to a levee-like gravel bank on the coastline, which is continuous with Nunaluk Spit to the east.

A small lake (1.6 x 0.8 km) lies approximately 1.2 km south-southwest of the radar station. A small outflow stream flows north from this lake into a flooded sedge marsh that stretches about halfway to the coast. An area of low-centre polygons lies between the sedge marsh and the drier tussock tundra along the coast.

Much of the area surrounding the Komakuk DEW station is polygonized; most of the polygons have low centres that are flooded. At its interface with the gravel beach, the coastal plain abruptly drops about 8 m to sea level. The embankment along the beach near Komakuk and the area lying directly south of it are principally tussock tundra, which has a characteristic vegetation cover of *Eriophorum vaginatum* interspersed with small amounts of *Betula nana*, *Vaccinum vitis-idaea*, *Empetrum nigrum*, and *Ledum palustre*.

Clarence Lagoon

Clarence Lagoon (69°37'N, 140°46'W), approximately 23 km west of Komakuk, is a brackish reservoir that is approximately 3.5 km long and 1.5 km wide. It is fed by the Clarence River, Craig Creek, and several unnamed creeks

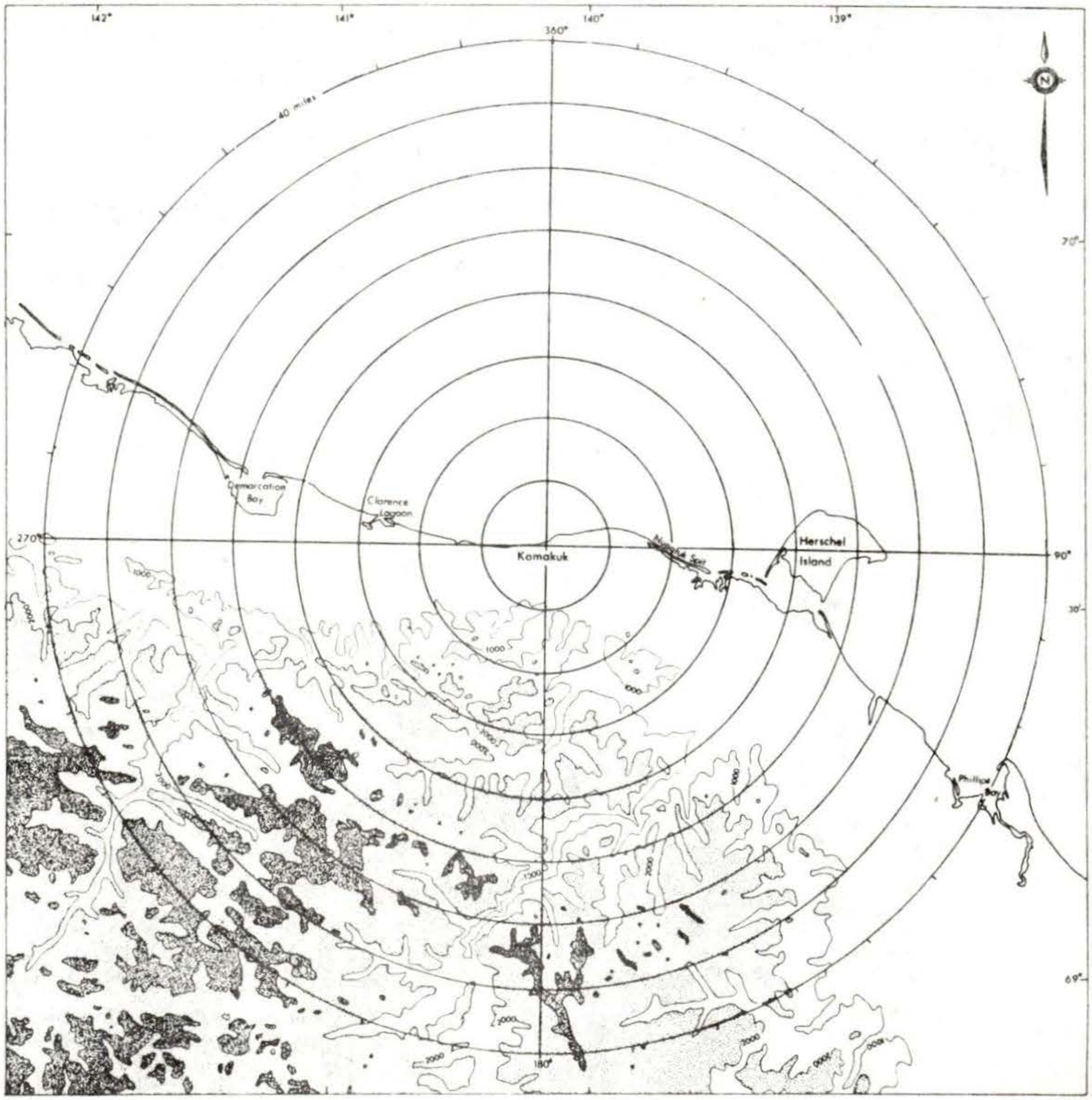

FIGURE 1. Map of the Coverage Area of the Komakuk DEW Radar. Areas above 1000 ft (305 m) elevation are demarked by a contour line; areas above 2000 ft are stippled; areas above 4000 ft are darkly stippled. Range rings are at 5 n mi (9.25 km) intervals.

(all of which originate in the British Mountains to the south) and empties into the Beaufort Sea to the north. The lagoon is contained on the north by a long, narrow gravel spit, which is interrupted on its west side by the mouth of the lagoon. The remainder of the lagoon is bordered by braided gravel river delta and wet or semi-flooded sedge tundra. The extensive low areas have a vegetation cover of sedges (*Carex* spp. and *Eriophorum* spp.), and the more restricted areas of higher physical relief have a lichen-heath vegetation cover (*Cetraria* spp., *Cladonia* spp., *Steriocaulon* spp., *Cassiope tetragona, Dryas integrifolia,* and *Empetrum nigrum*).

Approximately 1.2 km southeast of the lagoon lie two small lakes (1.0 x 0.4 km and 0.6 x 0.4 km). At the west end of the lagoon, along Craig Creek and the Clarence River, is an extensive lowland with many ponds and lakes.

In general, the terrain around Clarence Lagoon is lower-lying and has more extensive standing water than the Komakuk area.

METHODS

Radar

Radar and Filming

Radar data were recorded through time-lapse and still photography of the Plan Position Indicator (PPI) display of the Komakuk Beach, Yukon Territory, surveillance radar (69°36'N, 140°11'W). (A PPI is the standard map-like display upon which surveillance radar data are normally presented.)

Detailed specifications of the Komakuk radar are classified. In general terms, however, it is a medium-powered L-band surveillance radar. The angular and range resolution are typical of those of most air-surveillance radars. Moving Target Indicator (MTI) curcuitry was used to permit detection of birds in the presence of echoes from stationary objects; the 'MTI wedges' where birds are undetected (Richardson 1972a) were quite narrow in angular width. Except for MTI, no special circuits were used; hence, the data obtained were stable and high in quality relative to those obtained in many other radar studies of bird migration. Occasionally, however, radar performance was suboptimal; data from such periods were either omitted from consideration or recorded as being of suboptimal reliability.

Time-lapse film of the PPI display was obtained almost continuously from 12 May to 8 July 1975 at a rate of one 35 mm frame every 48 sec. During time-lapse filming, the PPI displayed an area of radius 74 km (40 n mi) centred at the radar site. Figure 1 shows the radar-coverage area and selected topographic contours.

No difficulty was encountered in distinguishing echoes from birds and from other objects. The only other types of echoes encountered were those from stationary objects, aircraft, and precipitation.

Echoes from birds and from these types of objects were easily distinguished by their size and/or speed.

Polaroid photographs of the PPI were obtained once or twice each day from 9 May to 9 July 1975. The objective of obtaining such photographs was twofold: to permit an immediate assessment of the numbers, directions, and locations of migrants and to provide a back-up to the time-lapse record. Usually, four photographs were obtained in quick succession during each session:

1. 74 km radius, one revolution of antenna;
2. 74 km radius, 6.4 min time exposure (eight revolutions);
3. 37 km radius, one revolution of antenna;
4. 37 km radius, 6.4 min time exposure (eight revolutions).

In the 'one-revolution' photographs, each bird or group of birds that was detected appeared as a single point-echo (Plate 1A, C). In the 6.4 min time exposures, each bird or group appeared as a short dotted line or, particularly on the 74 km radius photographs, as a short streak (Plate 1B, D). During the eight-revolution time exposures, the shutter was closed during the sixth revolution; hence, a bird or flock would, ideally, have appeared as a sequence of five dots, a gap, and then two more dots. The position of the gap would have revealed the flight direction. Unfortunately, birds were usually undetectable during some revolutions; as a result, more than one gap in the sequence often occurred. Nevertheless, the flight directions of at least some echoes were discernible on the Polaroid photographs or could be discerned through comparison of echo positions on pairs of photographs taken in sequence.

Movements and Times Sampled

Preliminary examination of the time-lapse films showed that migration was often detected not only along the coast and over the North Slope but also over the British Mountains, 25 to 55 km or more inland, and over the Beaufort Sea to the limit of radar detectability. Eastward, westward, and northward or northeastward movements were common in each of these areas. Hence, the characteristics of east, west, and north or northeast movement were recorded separately at each of three locations--about 30 km inland over the British Mountains, over the North Slope and coast, and approximately 20 km offshore over the Beaufort Sea.

The characteristics of bird movements detected by radar were recorded from the time-lapse films at 3-hr intervals: 00:00, 03:00, 06:00, ..., 18:00, and 21:00 YST.

PLATE 1. Examples of Single-sweep and Eight-sweep Polaroid Photographs of the Komakuk Radar Display. All photos were obtained between 03:41 and 03:57 YST on 2 July 1974. Analysis of time-lapse radar films for the same period showed a density of 5.3 (on the zero to eight scale) east-southeast movement over the Beaufort Sea and coast and a simultaneous west-northwest movement at lower density (4.3 coastally; 2.3 20 km offshore).

The display radius is 40 n mi (74 km) in A and B, with a circle at radius 25 n mi (46 km). The display radius in C and D is 20 n mi (37 km), with circles at 5 n mi (9 km) intervals.

A and C show one revolution of the Antenna; B and D show eight revolutions, with the shutter closed during the sixth revolution. Thus, in A and C each flock (or, within a few miles, each single bird) that was detected appears as a single 'dot' echo, whereas in B and D each bird or flock appears as a streak or a line of dots, sometimes with a gap near the end toward which the bird or flock was moving.

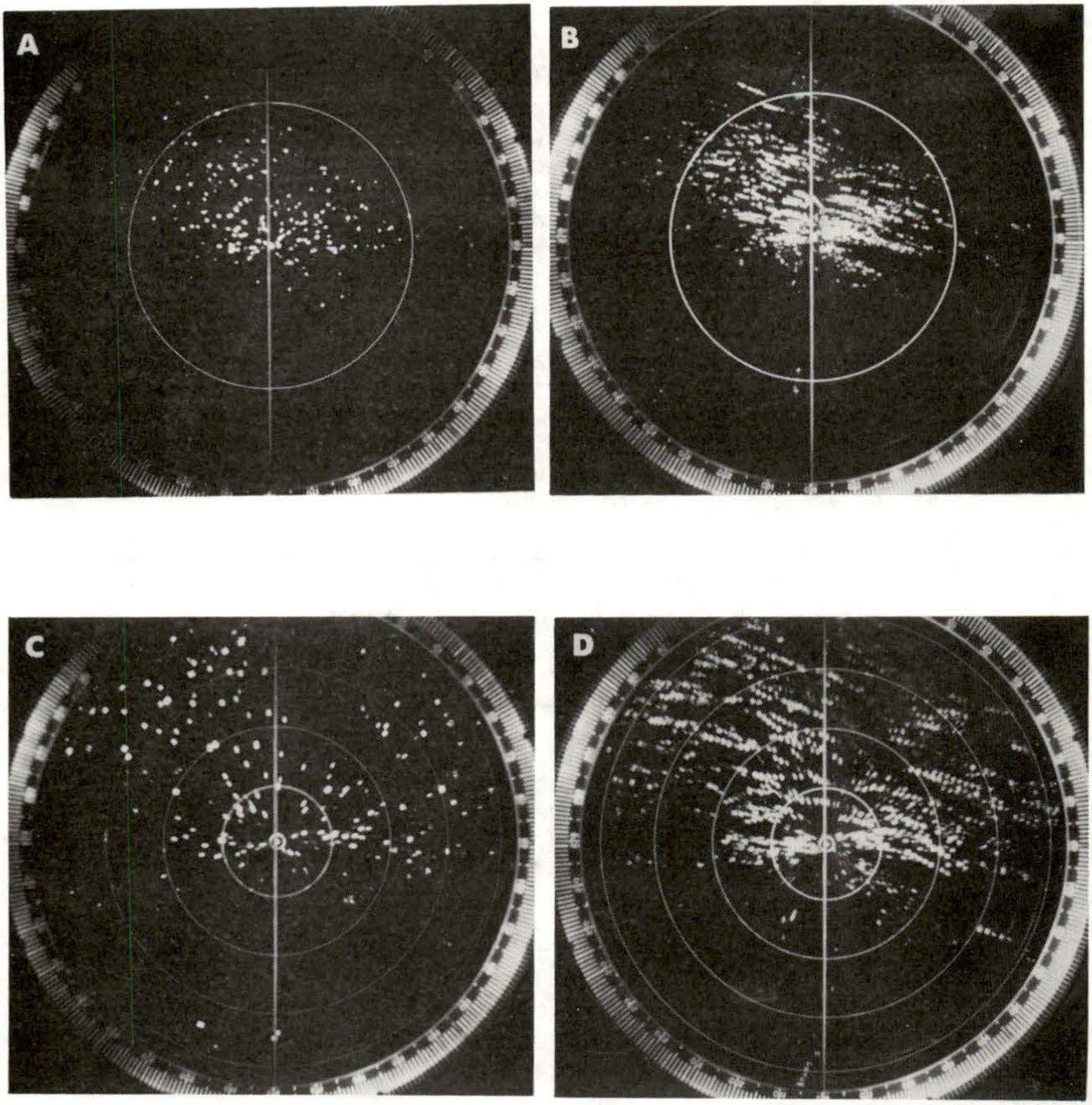

PLATE 1. Examples of Single-sweep and Eight-Sweep Polaroid Photographs of the Komakuk Radar Display.

Quantification of Numbers Aloft

Ordinal Scale

The standard zero to eight ordinal scale of migration volumes used in Canadian radar studies (e.g., Richardson 1972a: Figure 6) was used to record the amount of migration of each class (east, west, north or northeast) at each sampling place and time*. Most data were obtained from the time-lapse films. However, on occasions when time-lapse film was not obtained, densities were estimated from Polaroid photographs if they were available and interpretable (i.e., if flight directions were discernible).

A scale value of zero represents no migration; four represents moderate density migration (e.g., as in a typical shorebird or waterfowl flight over southern Canada); and seven represents a dense migration (e.g., as in a passerine movement over southern Canada during a night with favourable weather). Similar scales have been used in most radar studies of migration in Europe and in some studies in the United States. The advantages of this approach over direct counts of echoes are the following:

1. A scale value can be assigned more quickly than echoes can be counted, especially if it is necessary to count echoes on moving film rather than on single frames.

2. A realistic scale value can often be assigned in situations when it is impossible to count echoes accurately (see below).

The disadvantage of the zero to eight scale is that it is ordinal in nature. Absolute numbers are not determined directly, and standard parametric statistical procedures are inapplicable unless their assumptions are carefully checked.

Counts

In this study, the limitations of the ordinal scale were overcome by standardization. The Migration Traffic Rate (groups/10 km of front/hr) was determined at some but not all sampling times and was compared with the preassigned zero to eight scale values.

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*No cases of density seven or eight migration were encountered in this study. In practice, the scale was subdivided to the level 0.0, 0.3, 0.7, 1.0, 1.3, 1.7, ... in order to record small but discernible hour-to-hour or place-to-place differences in the number of birds aloft. This practice does not imply that migration volume can be assessed in an absolute sense with an accuracy of better than 1.0 units.

On most days, an attempt was made every 6 hr (i.e., at alternate sampling times) to count the numbers of echoes involved in each type of movement (east, west, north) at the three sampling areas (inland, coastal, offshore). Counts were not possible for every type of movement at every 6-hr interval; counts usually could not be made on occasions when the film registration was imprecise, when echo from precipitation was present, or when large numbers of migrants with divergent flight directions were present at the same place and time. Nevertheless, over 600 counts were obtained.

We recorded the number of echoes crossing within a 1-hr period a line oriented perpendicular to the mean flight direction and of length 10 km on the scale of the PPI display. The counts were made while the time-lapse film was viewed at a rate of about 3.75 frames/sec on a Steenbeck editing machine. At 3.75 frames/sec, the film representing a 1-hr period was viewed in 20 sec. Lines 10 scale km in length were marked onto the viewing screen in the appropriate location and with the appropriate orientation. Care was taken to position the lines well away from the MTI wedges.

On a few occasions, counts were made at locations other than the three standard ones in order to obtain a more complete record of the total quantity of migration across the area. The same 'echoes/10 km of front/hr' method was used.

It is emphasized that both methods of recording migration volume from radar--the zero to eight ordinal scale and the counts--recorded the number of discrete echoes from birds. An echo may represent only one bird (although a single bird is unlikely to be detected if it is more than a few kilometres away), or it may represent a flock of either a few or of many birds.

Appendix 1 presents the analysis of relationships between counts and zero to eight scale values. In summary, the relationship was strong (Spearman rank r = 0.978) but non-linear. Well over 95% of the assigned zero to eight scale values were within one unit of the 'correct' value. Thus, the zero to eight scale was sufficiently repeatable to be useful as a way of recording migration volume. Table 1 presents the approximate Migration Traffic Rates (in groups/10 km of front/hr) corresponding to each integer value on the zero to eight scale.

Quantification of Tracks and Speeds

The average flight directions of the birds involved in each of the three classes of migration (east, west, north or northeast) were recorded at 3-hr intervals in each sampling area (inland, coastal, offshore). These directions were estimated to the closest 10° by eye from the time-lapse film.

TABLE 1. Relationship Between the Zero to Eight Ordinal Scale of Migration Volume and Counts of Birds or Flocks per 10 km of Front per Hour*.

ZERO TO EIGHT SCALE VALUE	AVERAGE COUNT (Echoes/10 km Front/Hr)
0	0
1	6
2	13
3	20
4	34
5	80
6	> 200

* based on Appendix 1

The flight paths of samples of the echoes involved in certain exemplary movements and in certain movements of special interest were recorded in more detail. As the moving film was displayed on the screen of the viewer, the path of an echo was traced onto a sheet of transparent plastic placed over the screen. The film was run back and forth until the paths of the desired number of echoes had been traced. The duration of each tracing was recorded using a stop watch; this information and appropriate scaling information permitted calculation of speeds.

Other Information

For each type of movement (east, west, north or northeast) at each sampling time, the degree of concentration along the coast and the maximum distance offshore at which birds were detectable were recorded. Verbal notes were made to record any unusual characteristics of the flights that were noted (e.g., curved courses, birds detectable unusually far inland, echoes of unusually great intensity, echoes breaking away from or joining a concentrated stream along the shoreline, birds concentrating near the foothills rather than along the shoreline, behaviour near precipitation, rapid changes in numbers aloft).

Migration Watches

Migration watches were conducted from 9 May until 9 July at the following two sites on the Beaufort Sea coast: the Komakuk Beach, Y.T., DEW station; and Clarence Lagoon (69°37'N, 140°46'W), which is located 23 km west of Komakuk. At each site, two observers shared a daily schedule of watches (see Johnson *et al.* In Press, for more details concerning the migration watch methods).

Data were coded in the field on standard forms specially designed for keypunching. After being key-punched and key-verified, data were checked for coding errors through use of a validation program. Data gathered at the two sites were initially analyzed separately and were subsequently combined when appropriate. For each site, daily tables were produced showing, for each species sighted during each 2-hr period of the day, the rate at which birds were recorded in each of three categories: birds moving east (30°-150°), those moving west (210°-330°), and those either moving north or south or not showing any directional tendency. From these tables, the rate of migration of each species--averaged over all the hours of observation during each day--was calculated for each of the three directional categories (*east*, *west*, and *other*); these daily migration rates were plotted separately for each site to form the main summary description of the visual observations. In addition, the data from each site were tabulated by 10-day periods in order to show the number of birds of each species recorded per hour by hour of the day, by flight altitude, by habitat, by distance from shore, by flock size, and by direction of flight (in 20° categories).

Komakuk Beach

The observation post at this site was established at the top of an 8-m high embankment extending along the Beaufort Sea coast. Visibility beyond 180 m was obstructed between azimuths 130° and 170° by the buildings and radar apparatus of the DEW site. Pressure ridges on the sea ice approximately 5 km offshore obscured the observers' view of low-flying flocks farther than that offshore.

The orientation of the coastline in the Komakuk area is west-southwest (250°) to east-northeast (70°). South of the coast, the tundra is well-drained and, with the exception of a lake approximately 1.15 km^2 in area and located 1.2 km southwest of the observation post, has little surface water. The terrain slopes upward to the foothills of the British Mountains, located 10 km to the south. From 3 June until the end of the study, there was a lead of open water approximately 5 km north of the Komakuk site; many of the observations made during June and July were of birds associated with this lead.

Because of their other duties, the observers stationed at Komakuk were each responsible for only one migration watch of 2 or 3 hr/day. Watches were conducted on 56 days and during a total of 218 hr. Most of the watches were conducted within the time periods 05:00-08:00, 10:00-14:00, and 16:00-21:00 Yukon Standard Time (YST).

At this site, watches were frequently conducted by both observers together; at such times, one observer monitored offshore bird movements and the other inland movements. The telescope was used more extensively when two observers were present, and it is probable that these two-man watches resulted in more efficient coverage of a larger area than did the one-man watches.

At Komakuk, field observations were recorded on a portable tape recorder. Use of this recorder enabled the observers to watch continuously without lowering their eyes to record data by hand.

All bird sightings at Komakuk were ultimately recorded on the above-described data forms. For purposes of analysis, birds that were possible migrants were separated from those that were local residents on the basis of the behaviour notes recorded with each observation. Birds that were in sustained flight and that maintained an eastward or westward course were included in the migration analysis; those that landed, took off, or were sitting, and those engaged in territorial behaviour were included in the *others* category (with birds flying north or south).

Clarence Lagoon

The observation post at this site was established at the northeast corner of Clarence Lagoon, at the base of the sand and gravel spit (3 km in length) that separates the lagoon from the sea. The post was at the top of the coastal embankment, which rises approximately 3 m above sea level. Observers had a clear field of view to the south, but extensive pressure ridges approximately 1.6 km offshore seriously restricted observations of birds flying low over the sea ice.

At this site, the orientation of the coastline is from west-northwest (290°) to east-southeast (110°). Most of the tundra near the observation post is low-lying and has numerous small creeks and extensive sedge marshes. Approximately 3 km^2 of the lagoon was visible from the observation post. The coastal plain south of this site is approximately 13 km wide. A small area immediately seaward of the lagoon entrance (3 km west of the observation post) began to thaw in early June and remained open for the rest of the study; with the exception of this area, little open water was visible from the Clarence Lagoon site.

Each of the observers at the Clarence Lagoon site conducted two migration watches daily--except early in the study when there was little bird movement. Four 3-hr watches were originally scheduled between the hours of 02:00 and 18:00 YST. However, because the clock used as the time standard at Clarence Lagoon gained approximately 4 min/day, the actual times at which migration watches were conducted shifted toward earlier hours until 16 June, after which a time signal was broadcast daily by radio from Komakuk. Observations were conducted on 58 days and during a total of 523 hr.

Almost all the watches at Clarence Lagoon involved only one observer per watch period. Data were recorded in a field notebook. Because this method of recording required the observer's full visual attention, effective observation time was significantly reduced during periods of intense migratory movement.

At Clarence Lagoon, all birds observed were classified as *probably migrant*, *probably local*, or *status uncertain*. These classifications were based on several criteria, including behaviour and the observer's knowledge of local movement patterns. In the cases of birds classed as *migrant* or *uncertain*, full details of behaviour and habitat were recorded; however, in the cases of birds classed as *local*, no detailed notes were recorded. Before analysis, the migrant status data were reclassified on the basis of the same behavioural criteria applied to data gathered at Komakuk. According to this process, some of the birds originally categorized as *migrants* were classified as *local*; but those originally classified as *local* could not be reclassified because the relevant behaviour parameters were not recorded.

Effects of Differences in Techniques

For most species, the net effect of differences in techniques between Komakuk and Clarence Lagoon was to reduce the apparent migration rates calculated for birds observed at Clarence Lagoon relative to to such rates for birds observed at Komakuk. Qualitatively, however, the data from the two sites are generally in close agreement (i.e., with respect to beginning, end, and peak dates of migration).

Aerial Surveys

Aerial surveys of the Beaufort Sea were conducted on seven dates: 14 and 28 May; 5, 15, and 26 June; and 3 and 9 July. Except for the 14 May survey, which was flown between 10:00 and 13:50 YST, all surveys were conducted between 16:47 and 22:53 YST. A De Havilland Twin Otter (DHC-6) was used for each survey; an altitude of 30 to 46 m and a speed of 114 to 192 km/hr were usually maintained.

During all seven surveys, two observers (one seated on each side of the plane) were situated on the second seat behind the cockpit. The same two observers were responsible for the systematic observations on all seven flights. Each observer sat in his position during the entire survey. Additional observers were on board for the first and last surveys. During the first survey, an additional observer was seated on the right-front (co-pilot) seat; and during the last survey, two additional observers were each seated immediately in front of one of the regular observers.

The following technique was used during each survey: the plane was flown offshore for a maximum distance of 240 to 280 km north of the coast but, more importantly, it was flown along any leads that were encountered. This strategy was based on the assumption that the largest numbers of birds would be found in areas of open water. General ice conditions during each survey are described in the 'Results'.

The objective of surveys was to locate concentrations of birds rather than to systematically survey a defined portion of the Beaufort Sea. Hence, the results cannot be used as a basis for an overall estimate of density or of absolute numbers in areas other than those surveyed.

The flight paths of the aircraft during each survey are shown on maps contained in the 'Results' section. These paths were determined through combination of the following techniques:

1. reference to known landmarks;
2. consideration of aircraft heading, air speed, flight duration, and estimated wind drift; and
3. occasional distance and bearing 'fixes' obtained by radio from the Komakuk and Shingle Point DEW radars, usually when a major alteration in course was made.

In order to obtain radar fixes, it was often necessary to fly at altitudes well above standard survey height; flight at such altitudes was not only time-consuming but occasionally interrupted the continuity of the surveys. Radar fixes, therefore, were obtained infrequently. Sections of the flights during which the aircraft flew above standard altitude are marked on the above-mentioned maps.

Aircraft equipped with Global, Omega, or inertial navigation systems were not available.

Despite all attempts to navigate accurately, transect locations, especially those far offshore, are probably inaccurate by as much as 20 km in certain instances.

During each survey, the flight path was subdivided into transects. The start and end points of transects were usually locations where there were major changes in course or where ice conditions changed markedly. Long, straight transects over areas of uniform habitat were subdivided arbitrarily to facilitate tabulation of data. A transect was defined as a strip 400 m wide--200 m on each side of the aircraft.

For each individual or group of birds or mammals seen, the following information was dictated into a portable tape recorder: species; number of individuals; numbers by age and sex class, when determinable; whether the birds were on or off transect; habitat category; behaviour category. Descriptions of ice conditions and navigational information were recorded intermittently throughout the flights. During surveys along interfaces between open water and ice or the coast, the aircraft was positioned within 150 m of the interface to permit a clear view of both habitats.

The survey route was chosen on the following bases:

1. satellite photographs (NOAA visible spectrum and occasionally ERTS) of ice conditions in the Beaufort Sea[1];
2. reports of ice conditions obtained through daily radio contact between the Komakuk radar operators and British Airways airliners, which flew both northeast and southwest approximately 34,000 ft (10,350 m) over the Beaufort Sea and which crossed the coast above Komakuk Beach DEW station at approximately 18:30 YST;
3. reports provided on survey dates by our survey pilots while they were *en route* (at 1500 m altitude) from their base in Inuvik to Komakuk Beach;
4. reports provided by other light aircraft that were conducting surveys in the study area;
5. ice conditions encountered during the surveys.

After the surveys were completed, one observer transcribed data to coding forms to permit efficient key-punching and computer tabulation. Coded data were then checked by another observer and later by computer through use of a validation program that identified impossible or improbable situations. After correction of errors, the data were tabulated on a transect-by-transect basis by a second computer program. Table 2 shows, as an example, the tabulation of data gathered during one transect survey.

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[1]The most recent of the photographs available prior to each flight were used; these photographs were approximately 7 to 10 days old.

TABLE 2. Computer Tabulation of Transect Number 7 on the 5 June 1975 Aerial Survey†.

```
AERIAL SURVEY TABULATION        TRANSECT NUMBER    7        DATE 75/ 6/ 5        2213 HOURS TO 2235 HOURS
                                                                                 IN  NA  MIN TIME PERIODS

      TRANSECT                  LOCATION                AIRCRAFT                 INTERFACE               WEATHER                      SURFACE

TYPE:   14 -LINEAR           WATERBODY #   0       TYPE:     TW OTTER       CODE:             1     CLOUD COVER:     10      LAND:         999 % SNOW
LENGTH:      45.0  MI        ISLAND    #   0       HEIGHT:   110 FEET       SIDE NEAR               WIND SPEED:   17 MPH      SEA :            3 % ICE
WIDTH:    440  YARDS         SITE      #   0       SPEED:    120   MPH        EDGE:         LEFT    WAVE HEIGHT:   2 FEET     LGE LAKES:   999 % ICE
                                                   DIRECTION:               DISTANCE:   3600 YD   AIR TEMP: 99    DEG F     PONDS:       999 % ICE
                                                                                                                          SEA ICE:        NA
REMARKS:                                                                                                                              MELTWATER
```

NAME	TOTAL NUMBERS FRONT # 99	R REAR # 51	L REAR # 52	GRAND TOTALS TOTAL SEEN	PER MILE	PER SQ MILE	INDIVI-DUALS	# OF PAIRS	FAMILY GROUPS OCCUR-RENCES	NUMBER SEEN	OTHER GROUPS OCCUR-RENCES	NUMBER SEEN
YELL.-BILL. LOON	0 0	0 0	10 0	10 0	0.22 0.0	0.89	0	0	0	0	2	10
OLDSQUAW	0 0	816 620	160 900	976 1520	21.69 33.78	86.76	1	1	0	0	39	973
COMMON EIDER	0 0	279 0	2 0	281 0	6.24 0.0	24.98	0	0	0	0	3	281
KING EIDER	0 0	97 0	6 0	103 0	2.29 0.0	9.16	0	1	0	0	7	101
PARASITIC JAEGER	0 0	1 0	0 0	1 0	0.02 0.0	0.09	1	0	0	0	0	0
SEAL SP.	0 0	8 0	0 0	8 0	0.18 0.0	0.71	1	0	0	0	1	7
TOTAL BIRDS	0 0	1193 620	178 900	1371 1520	30.47 33.78	121.87	2	2	0	0	51	1365
TOTAL MAMMALS	0 0	8 0	0 0	8 0	0.18 0.0	0.71	1	0	0	0	1	7

```
       1ST 3 COLUMNS                                        NEXT 3 COLUMNS
*    REDUCED VISIBILITY          ONLY 1 OBSERVER OR 1 OF 2 PRIME OBSERVERS HAS IMPOSSIBLE VISIBILITY
**   IMPOSSIBLE VISIBILITY       ONLY (OR BOTH) PRIME OBSERVERS HAS IMPOSSIBLE VISIBILITY
***  FULL - TIME
```

† Information coded 99 or 999 (see air temperature and surface cover) refers to "unknown" classifications. In the 'Total Numbers' and 'Grand Totals' columns, a pair of numbers are listed for each species; the upper number represents the number of animals seen on transect (within 200 m of the aircraft) and the lower number represents those seen off transect.

WEATHER AND PHENOLOGY OF ENVIRONMENTAL INFLUENCES DURING 1975

The two most critical factors that affect the timing and success of breeding of birds in Arctic regions are the timing of snow melt in tundra areas and the timing of ice melt both at sea and on inshore waterbodies. The presence or absence of snow cover affects the timing of movement onto the nesting areas, and hence, the duration of the period available for nesting (Linduska 1964; Barry 1967). Snow and ice cover are primarily influenced by temperature, insolation, and wind, which are themselves influenced by snow cover and sea-ice cover. The melting of snow is also related to topography; for example, flat tundra areas retain their snow cover longer than areas of sloping terrain that receive the incident rays of the sun more directly. From mid-May onward, the sun does not set at this latitude, and although the influence of the sun is stronger at midday, when it is in the southern sky, this influence is felt throughout the 24-hr day.

During the migration watches at Komakuk and Clarence Lagoon, observers made hourly records of temperature, wind direction, wind speed, cloud cover, visibility, percent snow cover, percent sea-ice cover, and precipitation. DEW-line personnel at the Komakuk radar site recorded meteorological data every 6 hr; records of ceiling, visibility, precipitation, fog, barometric pressure, temperature, wind speed and direction, cloud cover, and the relative humidity were extracted from their observations.

Snow Cover and Temperature

The effect of insolation on snow, ice, and temperature is modulated by cloud cover. Regardless of the air temperature, thick cloud cover inhibits snow melt during the Arctic spring (Barry 1967). During this study, extensive cloud cover (8/10 or more) occurred 64% of the time at Komakuk.

The decrease of snow cover is also dependent upon the depth of winter snow accumulations and the effect of wind on these accumulations. By the time this study was initiated, the wind had compacted snow on the Yukon North Slope into a hard layer up to 1 m thick over much of the tundra and into drifts over 6 m deep along the embankment overlooking the sea beach.

In early May 1975, the mean daily temperature rose sharply from approximately -12°C to a peak of -1.8°C on 7 May (Figure 2). This unusual early rise in temperature stimulated the initial snow melt on the tundra, and, in combination with the sublimation effect of the high wind, it began to reduce the snow layer. On 13 May, the temperature dropped and ranged between -10 and -7°C until 22 May, when it began a rise that eventually brought the mean daily temperature above freezing on 29 May. During this time, strong winds blew alternately from the west and the east.

No extensive area of snow-free tundra was present until 31 May. The last day the mean daily temperature was below freezing was 4 June. As soon as above-freezing temperatures prevailed, the snow cover disappeared rapidly from the tundra. At Komakuk, the snow cover decreased from 95% to 50%

FIGURE 2. Climatic Variables and Number of Bird Species Seen Each Day.

LEGEND

A. Peak of Whistling Swan movement (westbound)
B. Peak of Brant movement (eastbound--two peaks)
C. Peak of Baird's Sandpiper movement
D. Peak of Pectoral and Semipalmated Sandpiper movement
E. Peak of Pintail movement (westbound)
F. Peak of Red Phalarope movement (eastbound)
G. Peak of Pomarine Jaeger movement (eastbound)
H. Peak of Arctic and Red-throated Loon movement (eastbound)
I. Peak of Oldsquaw movement (eastbound)
J. Peak of Pomarine Jaeger movement (westbound)
K. Peak of scoter movement

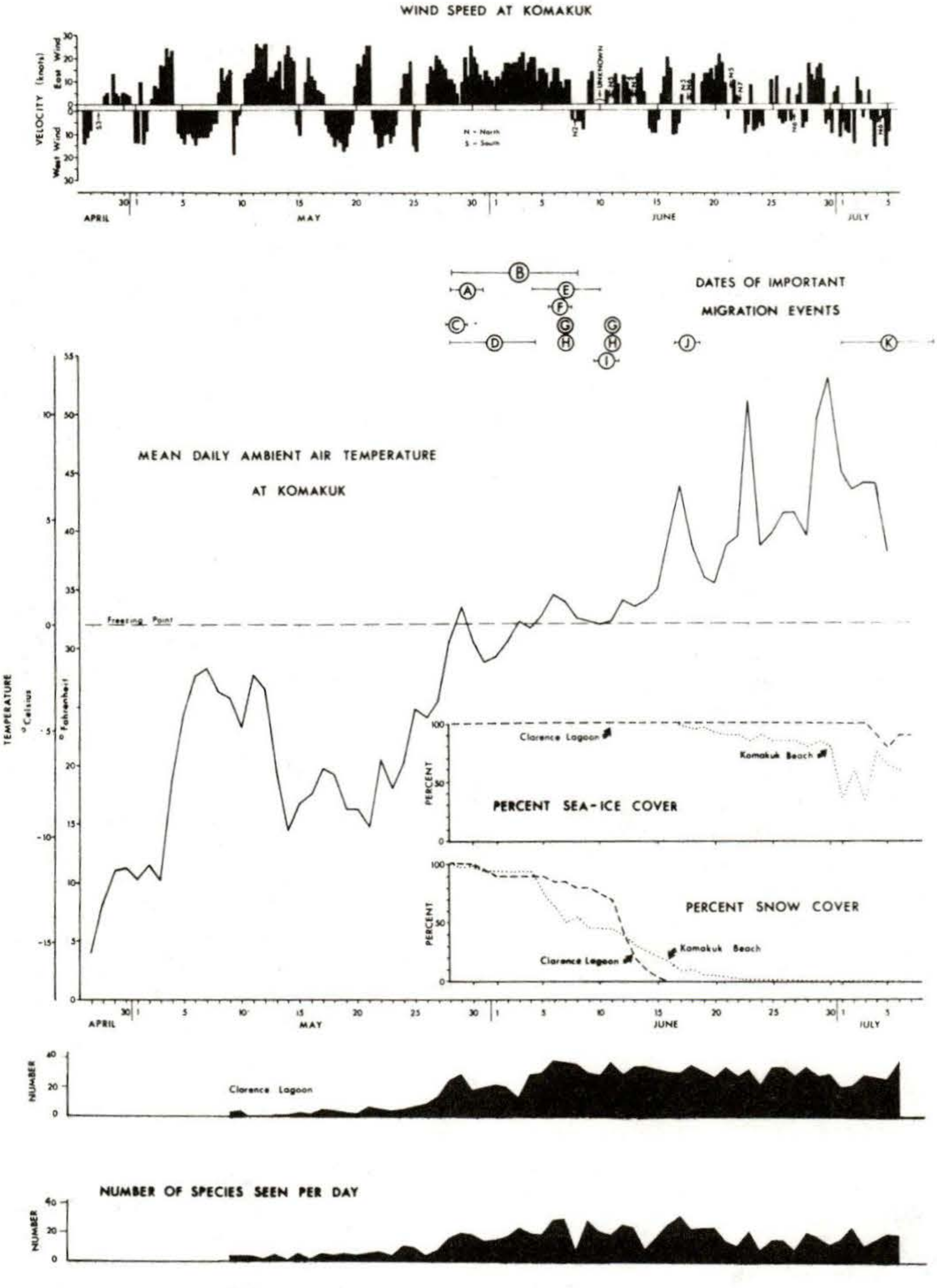

FIGURE 2. Climatic Variables and Number of Bird Species Seen Each Day.

between 4 and 7 June. By 15 June, there was only 10% cover at this location, and after this date only trace amounts remained in depressions. At Clarence Lagoon, snow cover decreased from 90% to 70% between 5 and 11 June, and by 16 June snow had completely disappeared (Figure 2).

The period of snow melt coincided with the period of arrival, nest initiation, and commencement of laying of most bird species. During the 1975 study season, there were no periods of inclement weather after nest initiation. On the Yukon North Slope, the summer season of 1975 was without any unseasonal climatic phenomena and was sufficiently moderate to provide excellent breeding conditions for most Arctic birds.

The mean daily recorded temperature averaged about 4°C during the normal incubation period of many species (between 15 June and 5 July). On two days (23 and 30 June) the mean daily temperature was above 10°C; these high temperatures, in combination with the 24-hr insolation periods that were unhampered by solid cloud cover, increased the amount of heat absorbed by the tundra.

Ice Cover

The appearance of areas of open water in the Beaufort Sea is critical to many species of waterbirds during their spring migration and prebreeding activities (Myres 1958; Barry 1974).

An area of open water in the Amundsen Gulf during 1975 was evident in satellite photographs taken as early as 15 April. This polynya, which remains open throughout many winters (Barry 1974), was probably open throughout the winter of 1974-1975. Another large area of open water projected out from the Chukchi Sea past Point Barrow and into the Beaufort Sea; this area was evident in satellite photographs taken as early as 15 May. An interface between the shorefast ice and the seasonal pack ice within 16 to 80 km of the coast stretched more or less continuously between Amundsen Gulf and Point Barrow; periodically, leads would open up along this interface. These leads often froze over again or closed because of shifting winds.

On 21 April an ERTS satellite photograph showed a substantial lead located approximately 48 km north of Komakuk; this lead was at least 97 km long and lay along a west-southwest to east-northeast axis. On 14 May, when a an aerial survey was conducted in this area, the lead had closed completely; there were, however, a few small cracks and holes in the pack ice offshore (see Plate 6A in 'Aerial Survey Results' section) and a small polynya near the edge of the fast ice northwest of Herschel Island. On 17 May, some open water was present in Clarence Lagoon; this open water was the result of run-off from the Clarence River. On 19 May, a small area of open water appeared in the sea ice off the mouth of the lagoon.

At Komakuk, a large lead was present offshore near the edge of the fast ice on 5 June (see Plate 7). However, there was solid ice cover immediately offshore until 16 June. On this date, a large lead opened a few miles offshore and a few small cracks were seen within a few hundred metres of the beach (see Plate 8A). A small amount of open water was seen offshore at Clarence Lagoon on 22 June (Figure 2).

According to Burns (1973:127), 'In general, the break-up proceeds from south to north, starts approximately one week after the mean temperature exceeds 32°F, and is caused by rising temperatures, warm water moving northward and the melting of snow cover.' River water running into the Beaufort Sea, especially from the Mackenzie River, accelerates break-up (Gill 1974).

The appearance of the lead just offshore from Komakuk on 16 June coincided with a rapid rise in mean daily temperature from 2°C on 15 June to 6.5°C on 17 June. The presence of this shore lead was strongly influenced by the large areas of open water that extended east from the Mackenzie Delta region to Amundsen Gulf and north from this region to Prince Patrick Island (see Plate 8A). This large expanse of open water gradually extended westward toward Herschel Island, and by 25 June extensive open water that was continuous with the open water to the east was present within 2 km of Komakuk (see Plates 8B and 9A).

On 29 and 30 June, the mean daily temperature rose quickly to a high of 11.9°C; on the evening of 30 June, during light rain and dense fog, the ice along the shore at Komakuk moved out to sea and left a shore lead several hundred metres in width. When this lead opened, flocks of male White-winged and Surf Scoters, male Oldsquaws, and some loons appeared near shore. At this time, there was still very little open sea water near Clarence Lagoon. At Komakuk, a moderate west wind that coincided with a rapid drop in temperature closed much of the shore lead. Large amounts of floating ice continued to move in and out of this shore lead until the end of the study period (9 July).

At Clarence Lagoon, more extensive areas of open water began to appear in the sea ice around 5 July. The lagoon itself opened completely on 1 July, and the remaining ice was blown to the west shore by an east wind.

Wind

The air masses that influence the North Slope create almost constant winds that alternately blow from the west and from the east (west winds are defined here as those from directions between 225° and 315° and east winds as those from directions between 45° and 135°). The wind in this region seldom blew from the north and virtually never from the south (Figure 2). The winds were generally quite strong and often gusted to over 50 km/hr. Occasionally, there were calm periods, but these were generally short lulls during which the wind shifted direction.

The wind blew predominantly from the east during most of May and early June; during this period, however, it periodically shifted to the west. Long periods during which east winds prevailed occurred between 10 and 18 May and between 26 May and 8 June (Figure 2). The latter period corresponded to that of major spring migratory bird movement. After 8 June, wind velocity became very inconsistent; the wind shifted almost daily until the end of the study.

RESULTS AND DISCUSSION

General Description of Migration

Results of visual observations conducted near the coast indicated two main directions of migration: eastward and westward. The radar confirmed that most migrants moved east or west more or less parallel to the coast. However, the radar also revealed a third group of migrants: birds that moved northeast across the British Mountains, across the North Slope, and out over the Beaufort Sea (Figure 3). This third type of movement occurred frequently but usually included far fewer flocks than did typical eastward or westward movements.

The following three subsections describe these three types of movements as revealed by visual observation and radar monitoring. Later sections will give the results of the aerial surveys. Species-by-species summaries of all relevant data are given in Johnson *et al*. (In Press).

Eastward Migration

Seasonal Variations in Numbers

Eastward migration was detected by radar on almost every day during the study period (Figure 4). However, fewer birds moved east during most days in mid-May than during most days later in the season. On some occasions early in the study period, only a few flocks were detectable at any one time in the radar-coverage area (of several thousand km^2). Later in the season, over a thousand eastbound groups of birds were occasionally detectable in this area at one time.

When observations were terminated on 9 July, the volume of eastward migration, as detected by radar, had not begun to decline; it seemed, in fact, that this volume was still increasing (Figure 4). The most intense and most prolonged eastward movement of the season was recorded from 3 to 8 July.

The seasonal patterns of variation in numbers of birds detected during visual migration watches were very different. Before 27 May, the maximum rate of eastward migration during any one half-day period at either site was 12.5 birds/hr during the afternoon of 23 May at Komakuk (mostly unidentified shorebirds on this date)*. During many half-day periods previous to 27 May, no birds were seen though observations often continued over 5-hr periods within these half-days (Figure 5).

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*In order to permit direct comparison between radar and visual observations, all references to migration rates in half-day intervals refer to the periods 02:00-10:00 and 14:00-22:00 YST. Intervals with less than 60 min of visual observations are excluded from consideration.

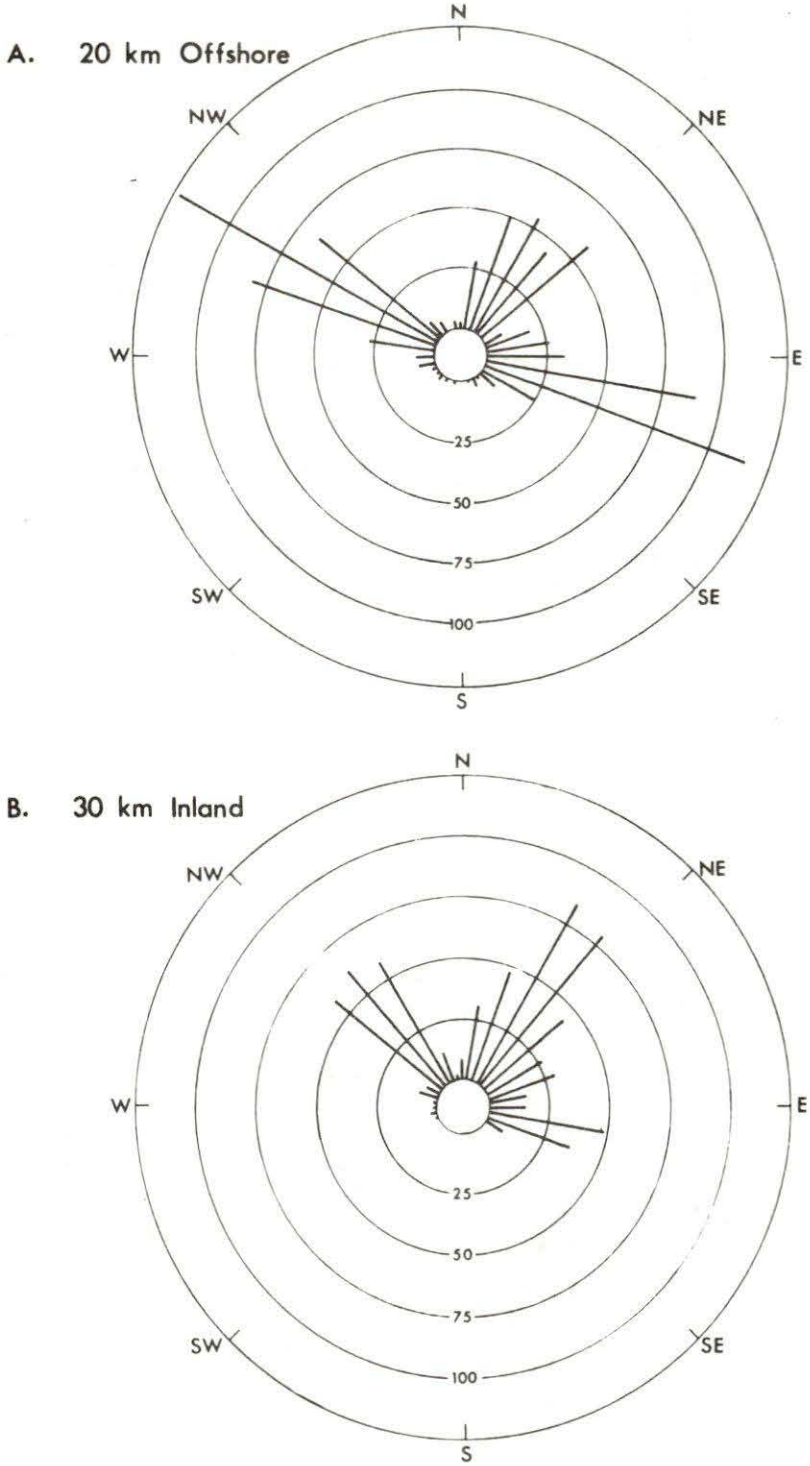

FIGURE 3. Relative Frequency of Migratory Movements in Various Directions. Data are from the Komakuk (Y.T.) radar, 9 May to 9 July 1975. The length of each radial line designates the number of 3-hr periods when movements with the designated mean direction were recorded. The frequency distribution along the coast and over the North Slope was similar to that 20 km offshore.

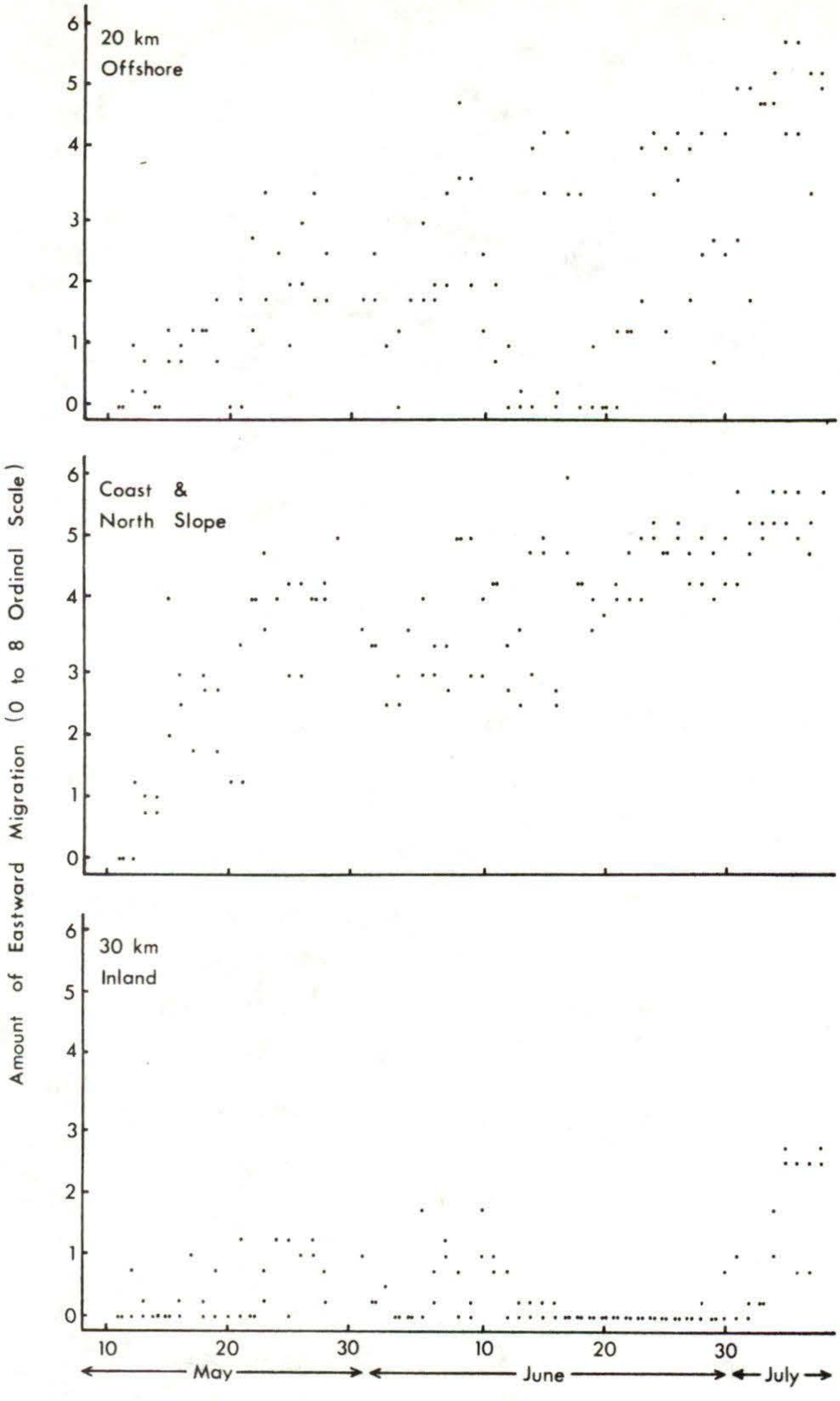

FIGURE 4. Amount of Eastward Migration Detected by Radar *vs*. Date. Migration Traffic Rates measured on the zero to eight ordinal scale (see 'Methods') are plotted for two periods each day--03:00-09:00 and 15:00-21:00 YST. (The median value for each period is plotted.)

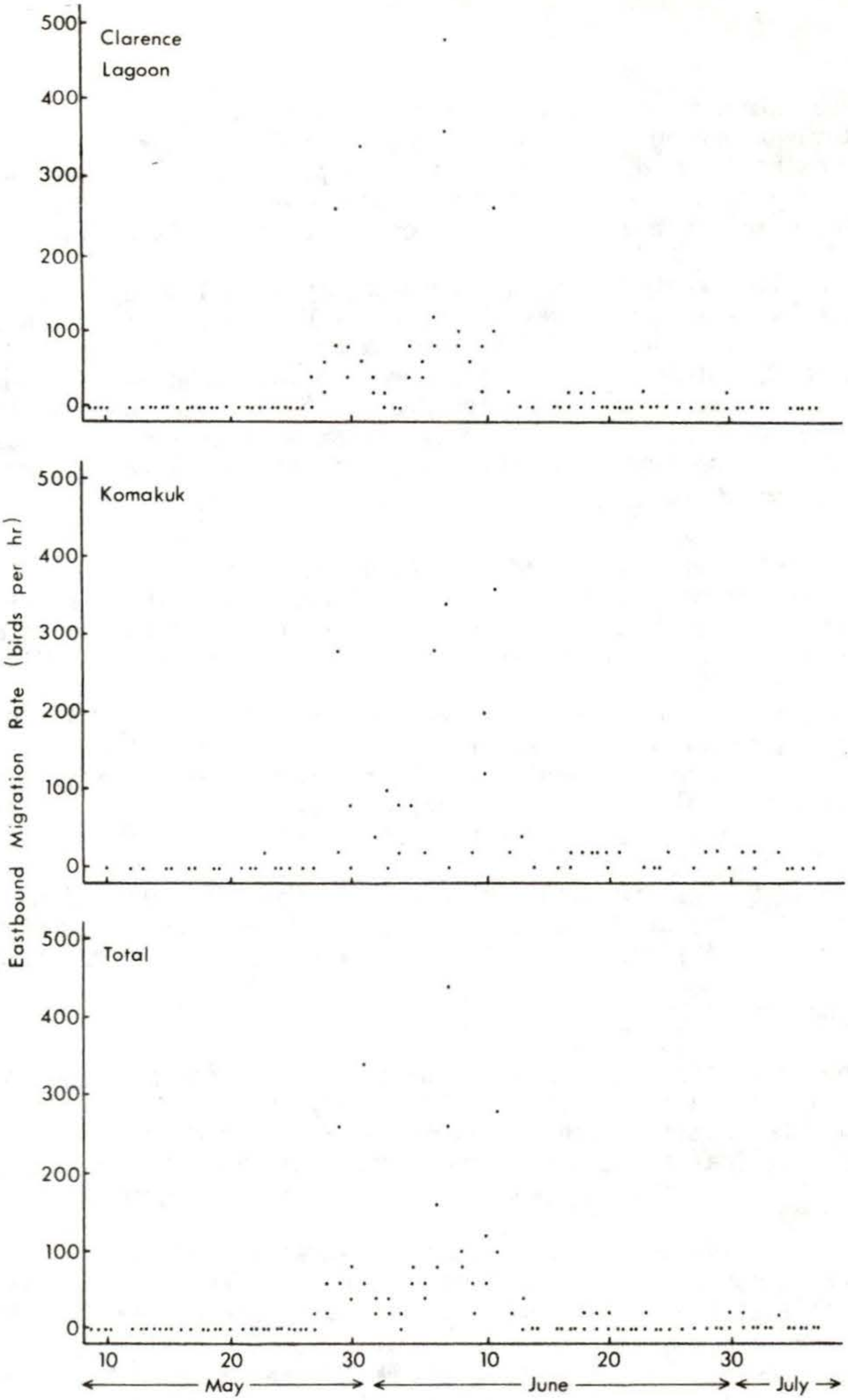

FIGURE 5. Amount of Eastward Migration Seen by Ground Observers *vs.* Date. Migration Traffic Rates in birds per hour are plotted for two periods each day--0:200-10:00 and 14:00-22:00 YST. Periods with less than 1 hr of observation and those with poor visibility (< 1.6 km) are not plotted. The 'Total' section weights the Clarence Lagoon data more heavily than the Komakuk data; weights are proportional to the number of hours of observation at the two sites.

Peak numbers were observed moving east at both Clarence Lagoon and Komakuk during the period 27 May to 13 June. Over 100 birds were seen per hour during seven half-day periods, all during the period 29 May to 11 June. Brant, Oldsquaws, and Pomarine Jaegers were the three most commonly detected species during this period.

The highest migration rate recorded by visual observations during any one half-day period was 486 birds/hr during the afternoon of 7 June at Clarence Lagoon (332 at Komakuk at the same time). Brant, Oldsquaws, and Pomarine Jaegers were the most abundant migrants on this date. Plate 2 shows the appearance of the radar on this date. It shows that the density of broad-front eastward movement was less than such movement on many other days but that there was a strong concentration of eastbound migrants along the coast.

After 13 June, eastbound migration detected visually never exceeded a maximum rate of 26 birds/hr at either site. This maximum rate occurred on the afternoon of 1 July at Komakuk; most of the birds detected on this date were Oldsquaws and unidentified shorebirds.

The sharp decline in the average volume of visually detected eastward migration during the latter part of the study period was not accompanied by a parallel decline in the numbers detected by radar either along the coast and North Slope or elsewhere (compare Figures 4 and 5). Possible reasons for this difference will be discussed after the basic characteristics of the flights have been described. It should be kept in mind throughout the following subsection that visual observations apparently revealed an incomplete and biased sample of the flow of migrants eastward parallel to the coast.

Broad-front Migration

The radar showed that large numbers of migrants moved eastward more or less parallel to the coast not only over the coast itself but also over the entire North Slope and to the limit of detectability offshore. Smaller numbers often moved eastward over the foothills of the British Mountains and over the mountains themselves.

The relative numbers of eastbound migrants over these different areas varied considerably from time to time (Figure 6*). On some occasions, the density over the coast was not much greater than the density over a wide range of distances offshore (Plates 1, 3A). On other occasions, the density along the shore was much greater than that offshore (Plate 3B). At times there were similar numbers of flocks over the

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*Appendix 2 in Richardson *et al.* (1975) gives the densities of the various categories of movement at 3-hr intervals in the same format that Figure 6 presents these data at 12-hr intervals.

coast and inland over the North Slope (Plate 3C); more commonly, there were fewer flocks inland (Plate 3B). On rare occasions, there were more flocks near the foothills than near the coast. On some days when there was much eastward migration offshore and/or over the North Slope, eastbound flocks were detected 45 km or more inland (over the British Mountains), but on other days when there was as much or more migration offshore and over the North Slope few or no eastbound birds were detectable beyond the foothills (Plate 3D *vs.* 3B). On rare occasions, more eastbound migration was detectable over the mountains than offshore (Plate 3D).

The density of eastward migration 20 km offshore was occasionally as great as that over the coast, but it was almost never greater (Figure 7A). However, because of the broad expanse of the offshore movement relative to the coastal movement, the total number of flocks (and presumably of individual birds) detected 10 to 75 km offshore was often much greater than that within 2 or 3 km of the coast (e.g., Figure 8). Furthermore, radar would have detected a larger fraction of the flocks that were present along the coast than of those that were present offshore; hence, Figure 8 probably underestimates the proportion of the birds that were offshore. Thus, during many days an observer on the coast could not have been expected to have seen a large fraction of the eastward migration that occurred across the general area of the North Slope, Yukon coast, and southern Beaufort Sea.

Species Composition of Eastward Migration

Introduction--The species composition of the eastward movements could only be determined from the visual observations. No radar-monitoring method provides sufficient information to permit identification to species from radar data alone, and in the present study the radar rarely provided sufficient information to permit separation of related groups of species.

The visual observations at Clarence Lagoon and at Komakuk provided considerable information about the species composition of the eastbound and westbound movements, but for the following seasons visual observations were inevitably incomplete and biased:

1. Visual observations were obtained at only two locations, both of which were along the coast; however, radar showed that the migrants were by no means confined to the coast.

2. The probability of detecting and identifying a bird at a specific distance as well as at the maximum distance at which any individuals of a species may be detected and identified varies with some or all of the following factors: size, colouration, frequency and loudness of calls, and the typical altitude of flight.

(Continued on page 38)

PLATE 2. Appearance of Radar Display on 7 June 1975, the Date of Peak Migration According to Visual Observations. Eight-sweep time exposures at 74 and 37 km radius are presented for 04:45 (A, B) and 15:40 (C, D) YST. At 04:45 there was northeast to east-northeast broad-front movement over the mountains, North Slope and Beaufort Sea; eastward movement along the North Slope and coast; and a *higher* density west-northwest broad-front movement with some coastal concentration. The nearly orthogonal north-east and west-northwest movements are readily distinguishable on the photographs. Large numbers of Brant (67% of total), moderate numbers of Oldsquaws (13%), and smaller numbers of Pomarine Jaegers (6%), Sabine's Gulls (3%), Arctic Terns (3%), and unidentified loons (4%) moved east over Clarence Lagoon early in the morning. Few birds were seen moving west in spite of the larger numbers of flocks detected by radar moving west than east; all of the westbound birds seen at Clarence Lagoon were Pintails and shorebirds.

By 15:40, most of the birds detected by radar as well as of those detected visually were eastbound. The movement was on a broad front over the North Slope and Beaufort Sea, but was strongly concentrated along the coast. The east-northeast and west-northwest movements that were detected in the morning had ceased. The species composition, based on visual observations, was similar to that in the morning (63% Brant, 12% Pomarine Jaegers, 10% Oldsquaws).

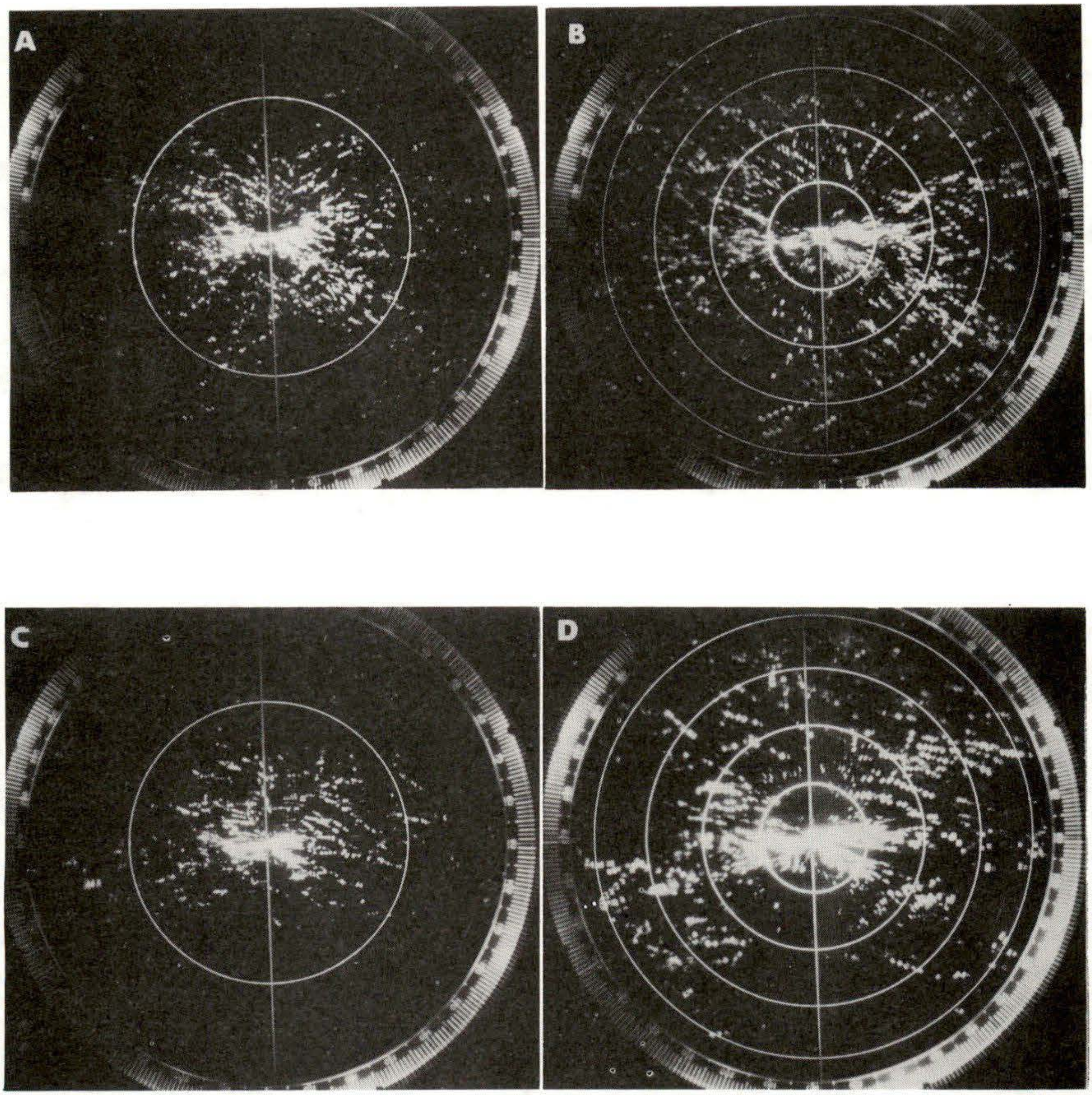

PLATE 2. Appearance of Radar Display on 7 June 1975, the Date of Peak Migration According to Visual Observations.

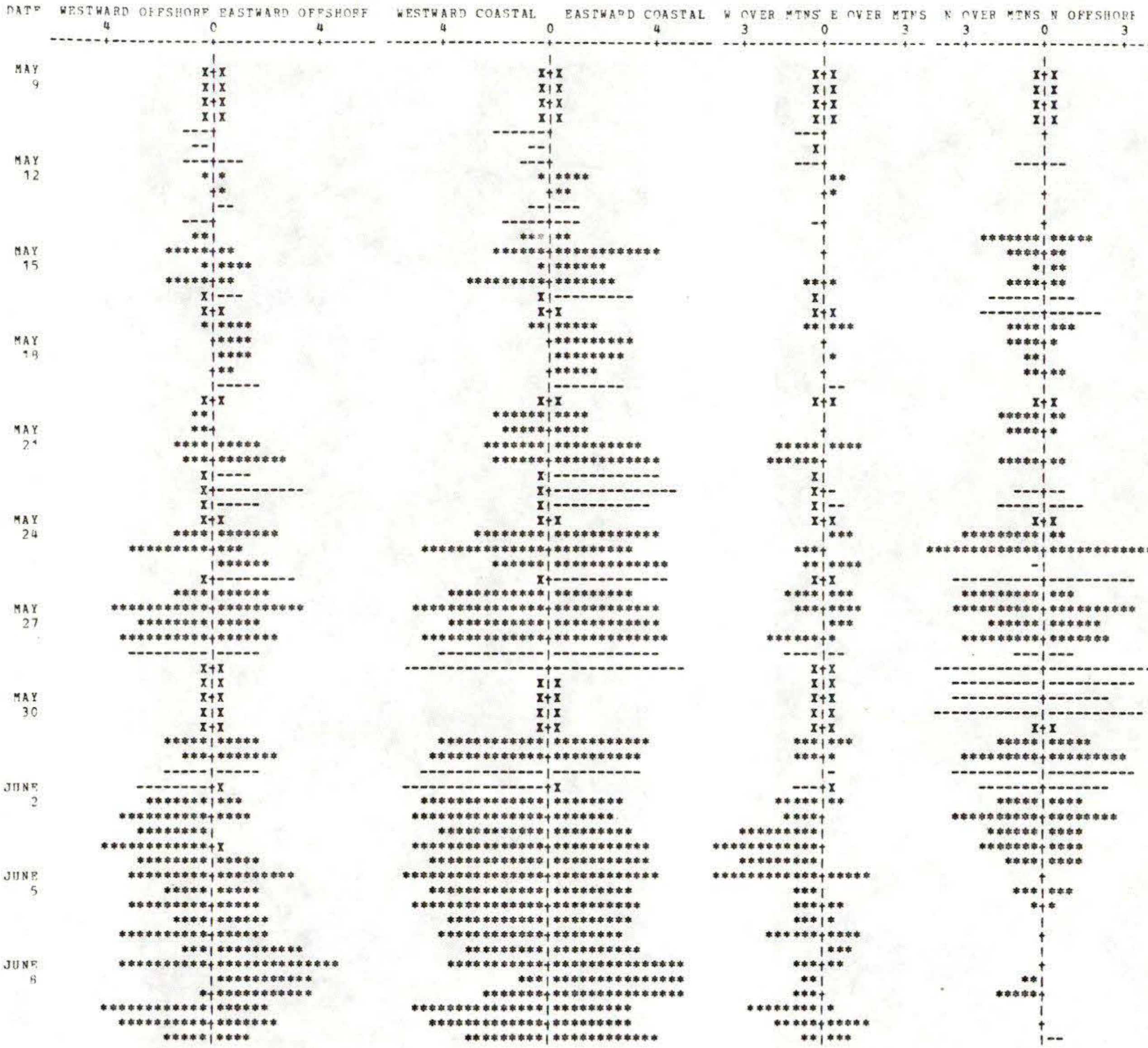

FIGURE 6. Amount of Migration Detected by the Komakuk Radar at 12-hr Intervals, 1975, Recorded on A Zero to Eight Ordinal Scale (0 = None; 8 = Intense).

*=BASED ON GOOD-QUALITY TIME LAPSE FILMS; -=BASED ON DATA OF SUBOPTIMAL RELIABILITY; X=NO RADAR DATA AVAILABLE

DENSITIES ARE GIVEN FOR 00:00, 03:00, 06:00, ... , 21:00 YST EACH DAY. THE 00:00 VALUES ARE OPPOSITE THE "----" MARKS

VALUES PLOTTED ARE MEDIANS OF DENSITIES AT 03:00, 06:00 AND 09:00 YST (OPPOSITE ROW TITLES) OR AT 15:00, 18:00 AND 21:00 YST (LINES BELOW ROW TITLES)

FIGURE 6. (Cont'd) Amount of Migration Detected by the Komakuk Radar at 12-hr Intervals, 1975, Recorded on A Zero to Eight Ordinal Scale (0 = None; 8 = Intense).

PLATE 3. Examples of Different Patterns of Distribution of Migrants. All photographs are eight-revolution time exposures.

A. Broad-front east-southeast and west-northwest movement over the sea and coast, but with little concentration along the coast. Along the coast there were almost as many flocks moving west-northwest as east-southeast; offshore most were moving east-southeast. A few flocks, all eastbound, were detectable over the mountains (7 July 1975; 05:13 YST; 74 km radius).

B. Broad-front eastward movement over the sea with concentration over the coast and almost no birds detectable over the mountains (28 June 1975; 04:52 YST; 74 km radius).

C. Eastward movement uniformly distributed across the North Slope with few birds offshore, no shoreline concentration, and no birds detectable over the mountains (22 May 1975; 15:30 YST; 37 km radius).

D. Eastward migration detectable to 28 n mi (52 km) inland over the British Mountains. Time-lapse film of the radar for this period revealed some flocks as far as 60 km inland (17 May 1975; 14:39 YST; 74 km radius).

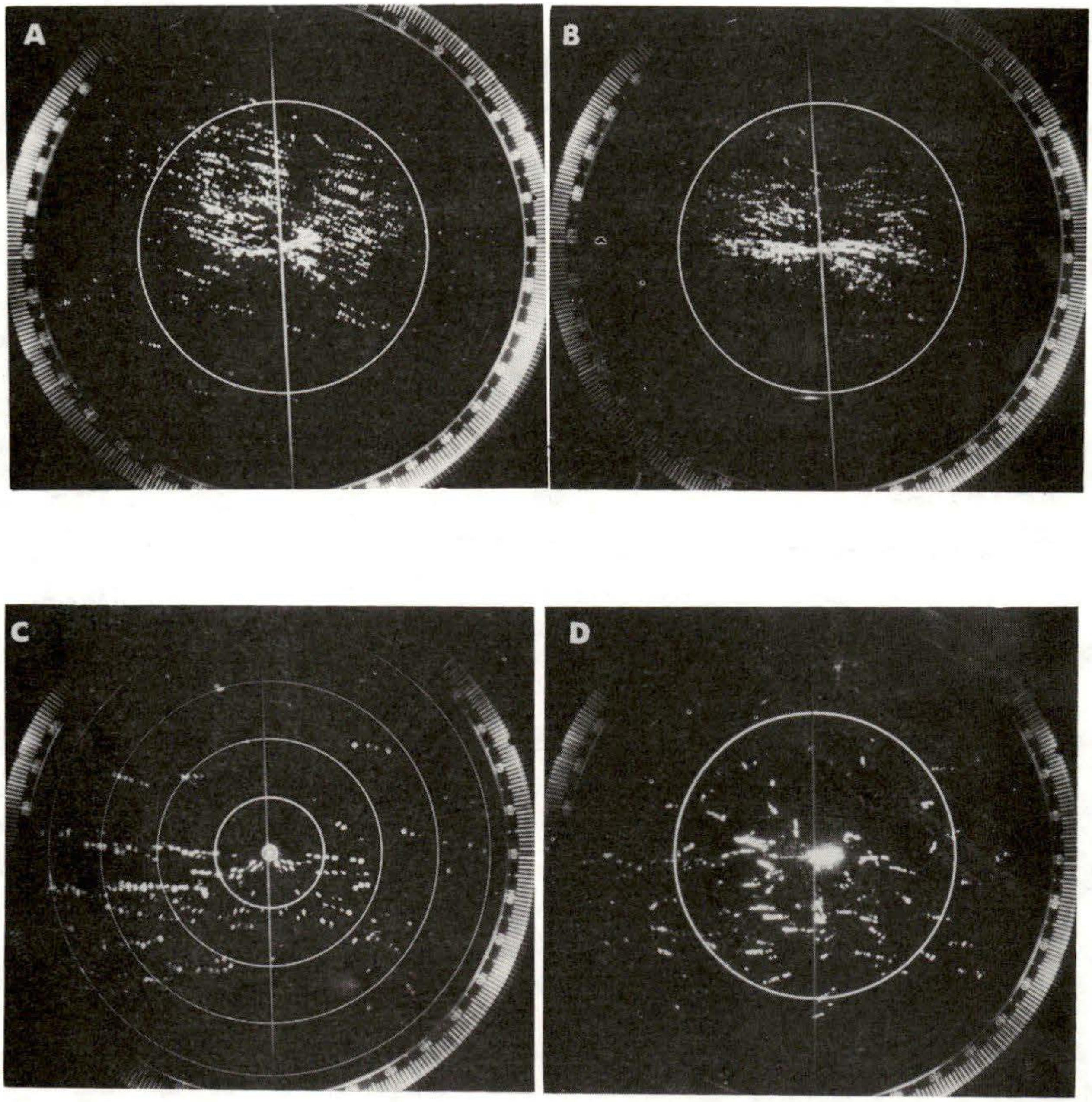

PLATE 3. Examples of Different Patterns of Distribution of Migrants.

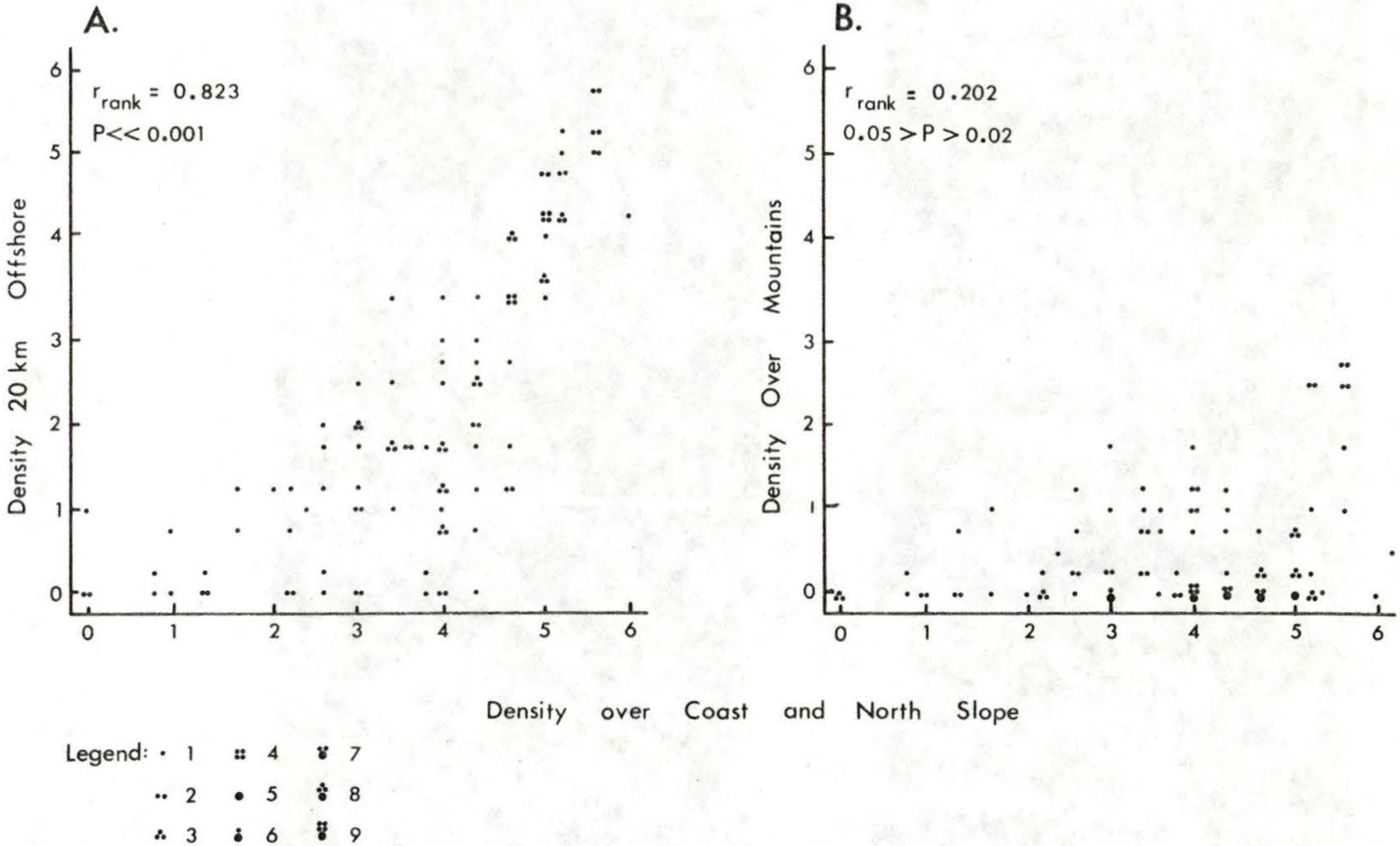

FIGURE 7. Amount of Eastward Migration Detected by Radar Offshore and Inland (over the British Mountains) Relative to That Over the Coast and North Slope. Migration Traffic Rates measured on the zero to eight ordinal scale (see 'Methods') are plotted for two periods each day--03:00-09:00 YST and 15:00-21:00 YST. (The median values for each period are plotted.)

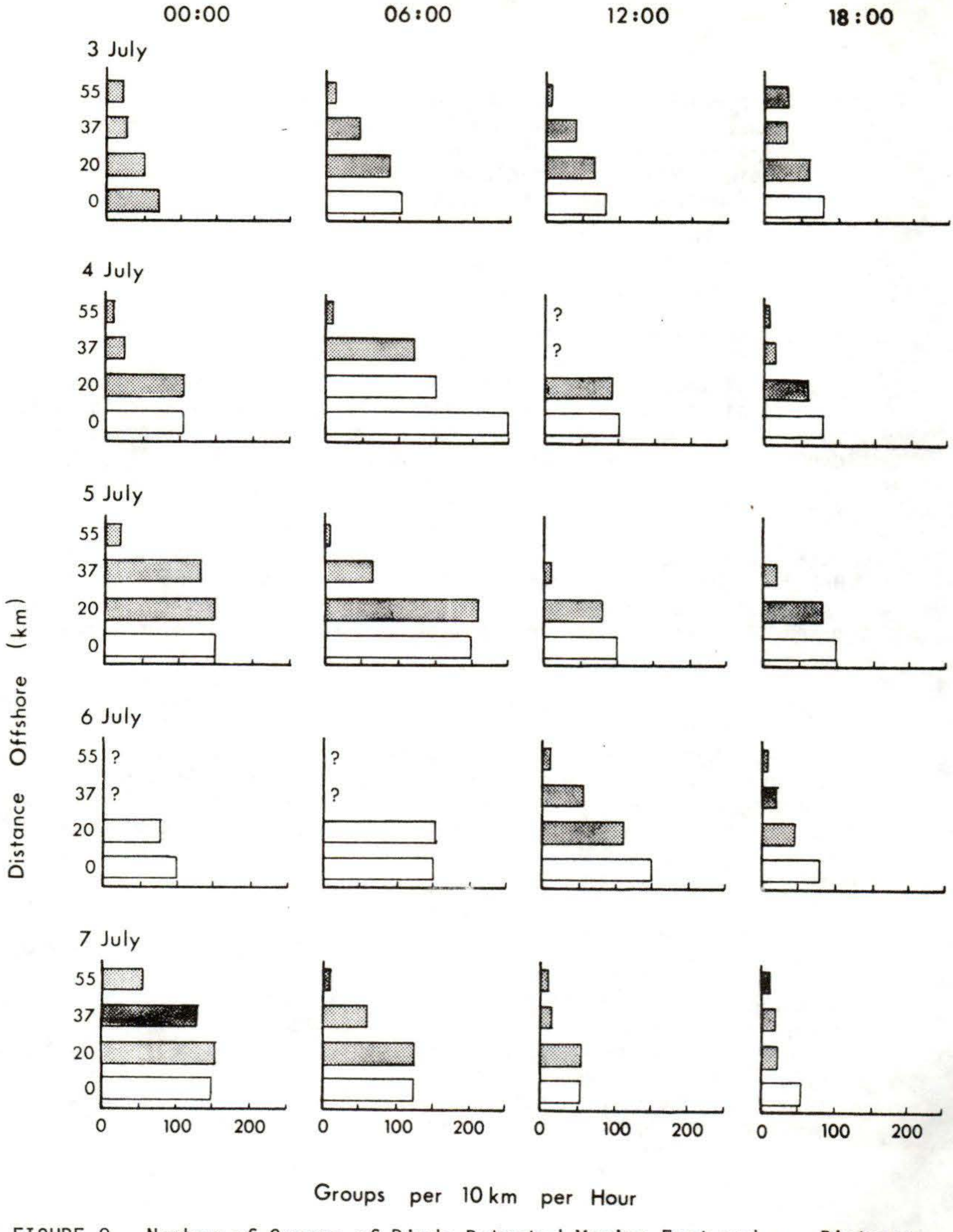

FIGURE 8. Number of Groups of Birds Detected Moving Eastward *vs.* Distance from Shore, 3 to 7 July 1975. Data are given for 00:00, 06:00, 12:00, and 18:00 YST each day in terms of echoes/10 km of front/hr. An echo represents a flock or, in the case of the '0 km offshore' category, either a flock or an individual. Stippled bars are derived from actual counts of echoes; open bars are derived from estimates of density on the zero to eight scale and Table 1.

3. The portion of the area surveyed by radar that was surveyed by visual observations was small. Hence, it is probable that a low-density movement that was readily detected by radar might remain undetected by field observers and that this movement could not, therefore, be identified.
4. It was rare for the total flow of migrants to be dominated by only one species; this complicated interpretation of the radar data.

Because of the above factors, the visual observations must be interpreted with caution; they do not permit an unambiguous identification of most of the movement detected by radar. In particular, it must be recognized that the visual observations provide little information about shorebirds or passerines (which are relatively inconspicuous during migration) or about species that rarely occurred along the coast (such as the King Eider, which apparently migrates eastward far offshore [W.L. Flock 1973, pers. comm.]).

Data gathered during the seven aerial surveys conducted over the Beaufort Sea are occasionally mentioned in the following section. These data, together with information on ice conditions at sea, are given in detail in a later subsection entitled 'Results of Aerial Surveys'.

Figure 9 shows the average numbers of each common species seen moving east (020°-160°; predominantly 060°-120°) during each of six 10-day periods. Species for which the eastbound or westbound migration rate averaged over a 10-day period never exceeded 0.062 birds/hr (the minimum value represented by one asterisk on Figure 9) are not listed. More detailed information about individual species is given in the 'Species Accounts' section of Richardson *et al.* (1975) and in Johnson *et al.* (In Press).

9 to 20 May--During the period 9 to 20 May, the only species detected moving east in significant numbers was the Glaucous Gull (an average of 0.37 birds seen/hr). Eiders (particularly King Eiders) would have been expected to have migrated eastward over the Beaufort Sea during this period; this expectation is based on the dates of passage at Point Barrow, Alaska (Gabrielson and Lincoln 1959; Johnson 1971; Flock 1973, pers. comm.) and on the fact that most of the eiders depart east-northeast across the Beaufort Sea from Point Barrow rather than east or east-southeast along the coast (Flock 1973, pers. comm.). However, during an aerial survey over the Beaufort Sea on 14 May to a point 280 km north of Herschel Island, no birds were observed in the small cracks between ice pans.

The eastward movements detected by radar during this period probably consisted largely of Glaucous Gulls. This species was recorded over land as well as over the coast and sea; 24% of the Glaucous Gulls detected visually at Komakuk were recorded as being more than 90 m inland, although most of these were seen later in the season.

21 to 31 May--From 21 to 31 May, the predominant species that moved east were Brant (average of 28.2 birds/hr), Oldsquaws (10.7), Glaucous Gulls (3.6), and Pomarine Jaegers (1.1). The first shorebirds were detected during this period (3.5/hr), but only the Pectoral Sandpiper was identified in significant numbers (0.7). Sixty-five unidentified scoters were seen during an aerial survey over the Beaufort Sea on 29 May, but they were probably not eastbound.

A large fraction of the birds seen between 21 and 31 May were seen during the last three days of this period.

Each of the four most commonly detected species that is mentioned above tended to fly close to the ground or ice (at least insofar as field observers could detect; Figures 10, 11). In contrast, most shorebirds are known to migrate at moderate and high altitudes (Lack 1960a; Nisbet 1963; Richardson 1972b). Radar detects high-flying birds more reliably than low-flying ones; field observations have the opposite bias (e.g., Evans 1966). Because some shorebirds were moving during this period, a larger fraction of the eastbound birds detected by radar than of those detected visually were probably shorebirds.

1 to 10 June--During the first 10 days of June, extensive eastward migration was recorded both visually and by radar. The most abundant species detected visually were again Brant (86.7/hr), Oldsquaws (22.3), Pomarine Jaegers (9.4), and Glaucous Gulls (4.7). An average of 1.8 loons (predominantly Arctic and Red-throated) per hour were seen moving eastward during this period. Common Eiders, Arctic Terns, and Red Phalaropes were seen moving eastward at average rates of approximately one bird/hr. Furthermore, other species of shorebirds occurred in significant numbers. In view of their relative inconspicuousness, shorebirds were probably proportionately more common than visual observation suggested.

During an aerial survey over the Beaufort Sea on 5 June, more birds were observed than during the other six surveys combined. Oldsquaws were by far the most common species (4274 seen); lesser numbers of Common (723) and King (115) Eiders, and of Brant (194) were seen. Each of these species was predominantly eastbound at this time of year.

11 to 20 June--From 11 to 20 June, the most commonly detected eastbound migrants were Oldsquaws (12.3/hr), Pomarine Jaegers (4.1/hr averaged over the 10-day period but almost all before 13 June), Glaucous Gulls (3.3), eiders (3.1, predominantly Common Eiders), Arctic Terns (1.5), Brant (1.5, which was drastically fewer than during the 1 to 10 June period), and loons (1.4).

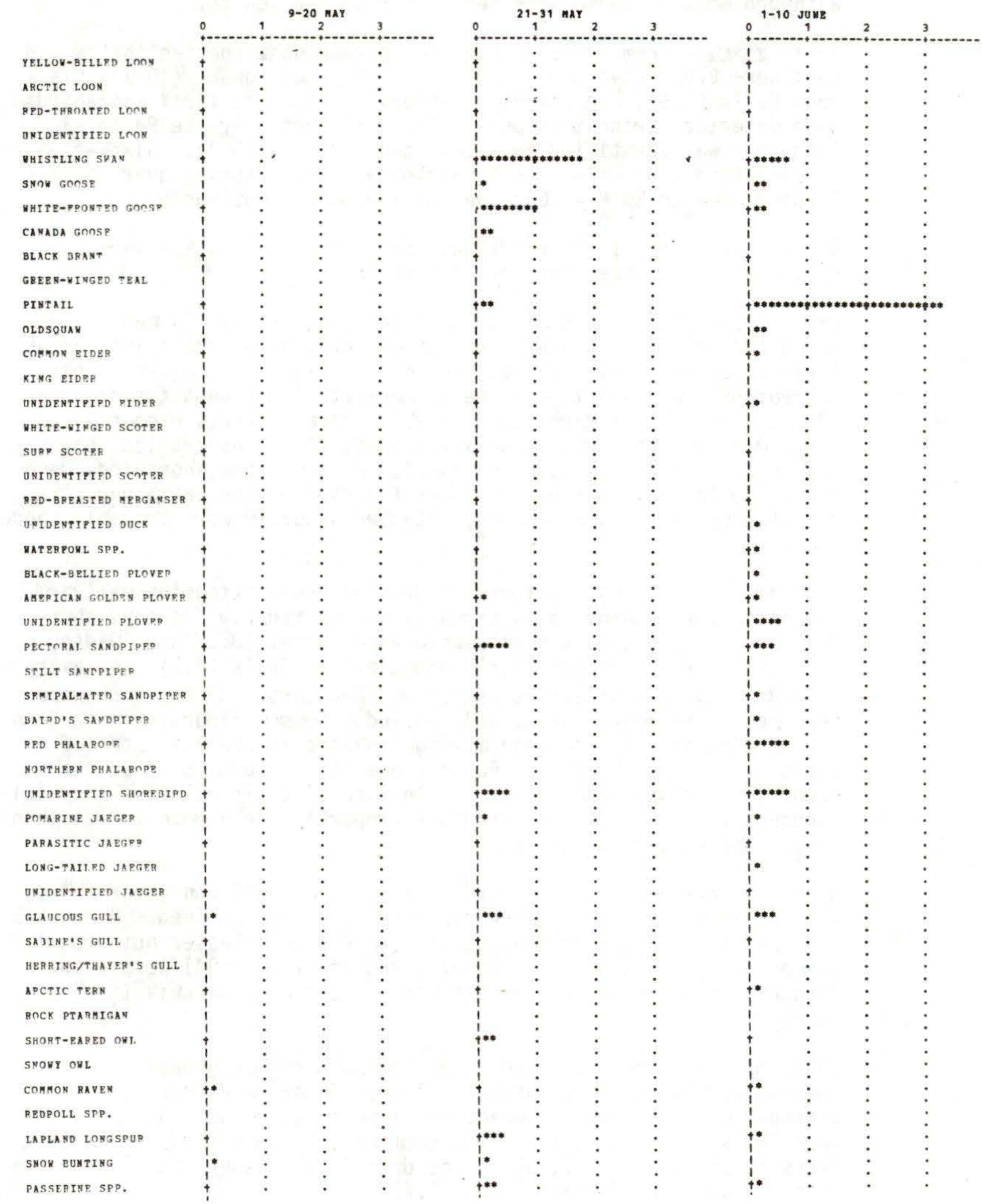

Figure 9. Average Number of Eastbound Birds of Each Species Seen per Hour at Clarence Lagoon and Komakuk by 10-day Periods.

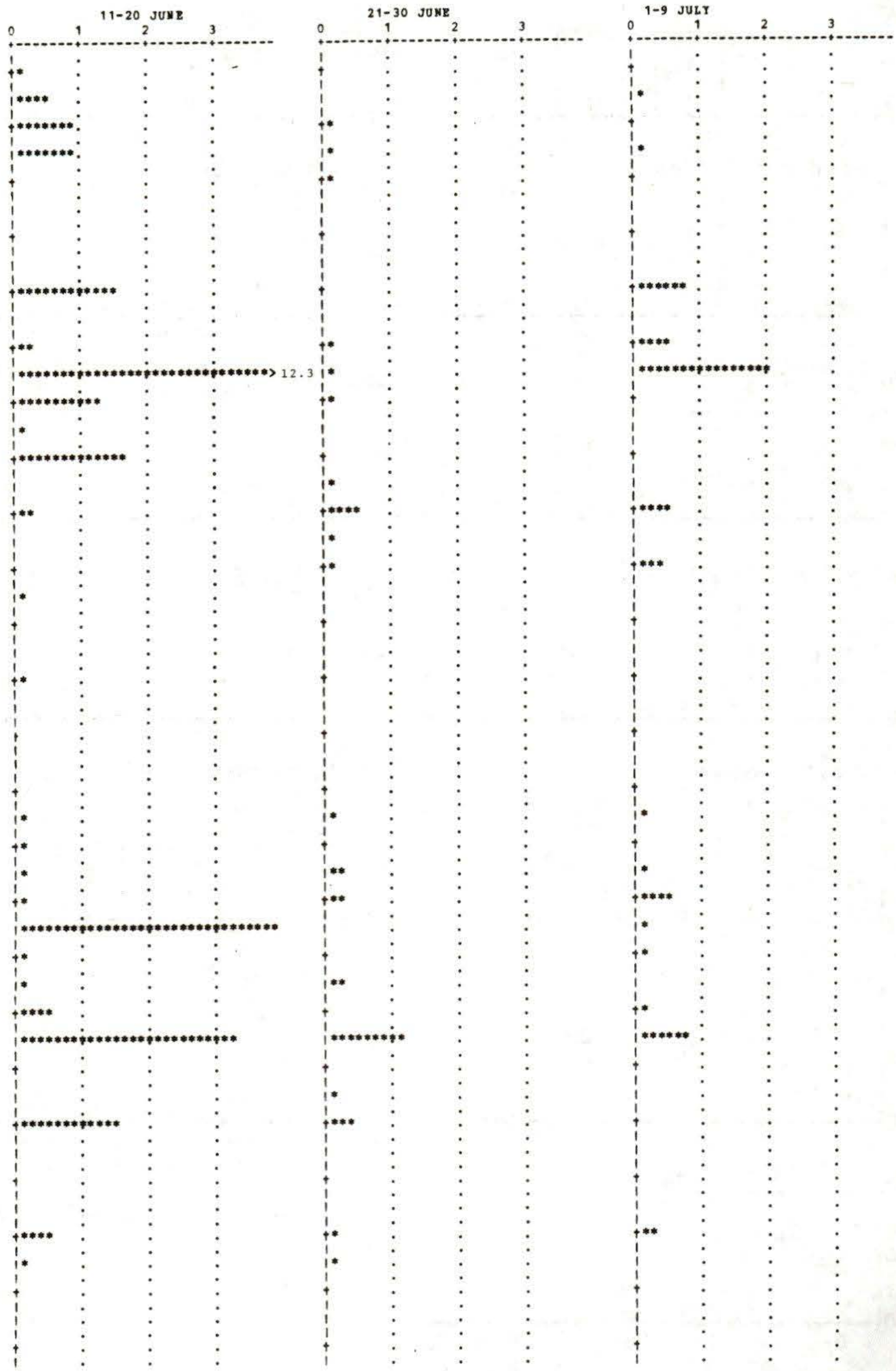

Figure 9. (Cont'd) Average Number of Eastbound Birds of Each Species per Hour at Clarence Lagoon and Komakuk by 10-day Periods.

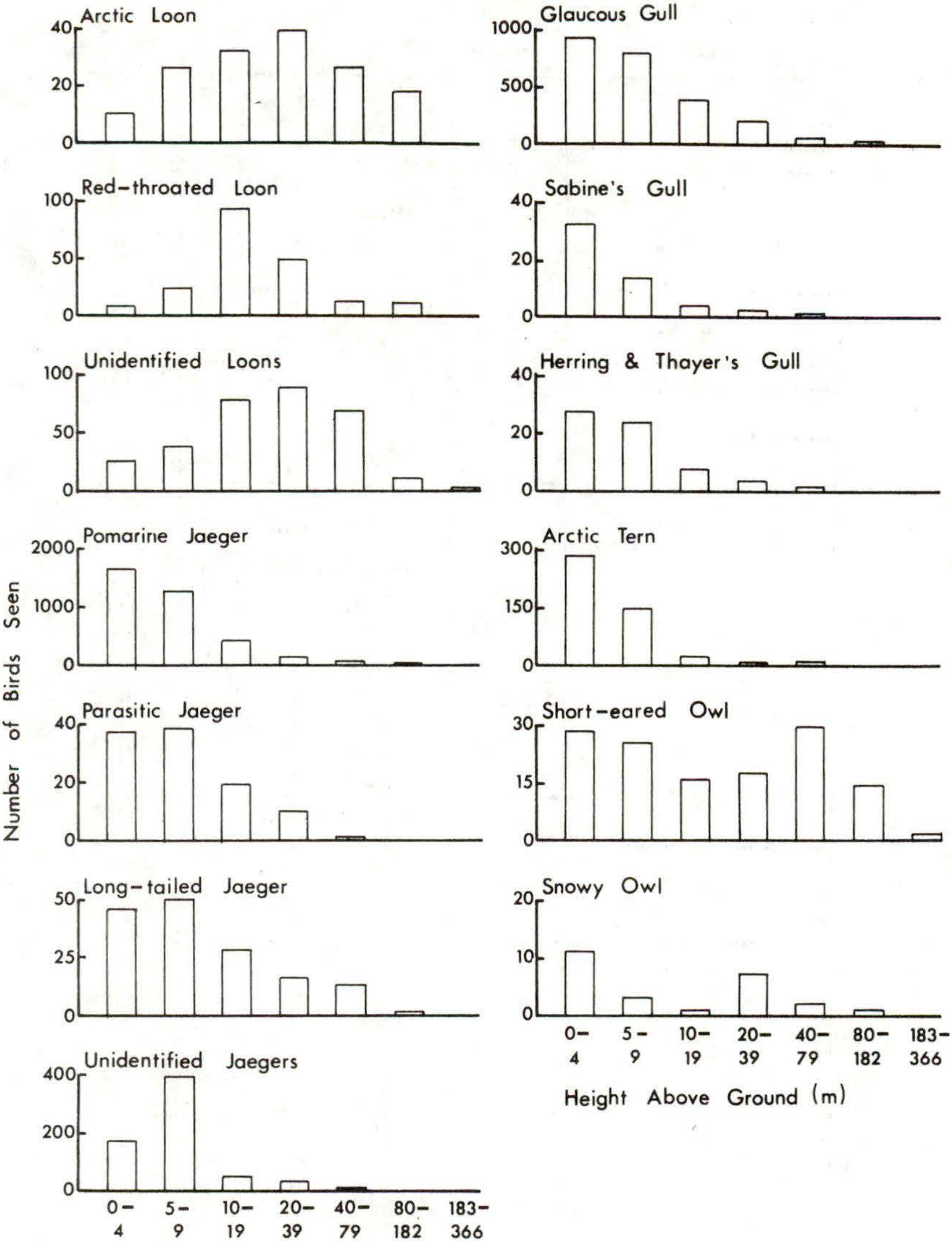

FIGURE 10. Height Distributions of Migrating Loons, Jaegers, Gulls, Terns, and Owls Seen During Watches at Komakuk and Clarence Lagoon, 9 May-9 July 1975.

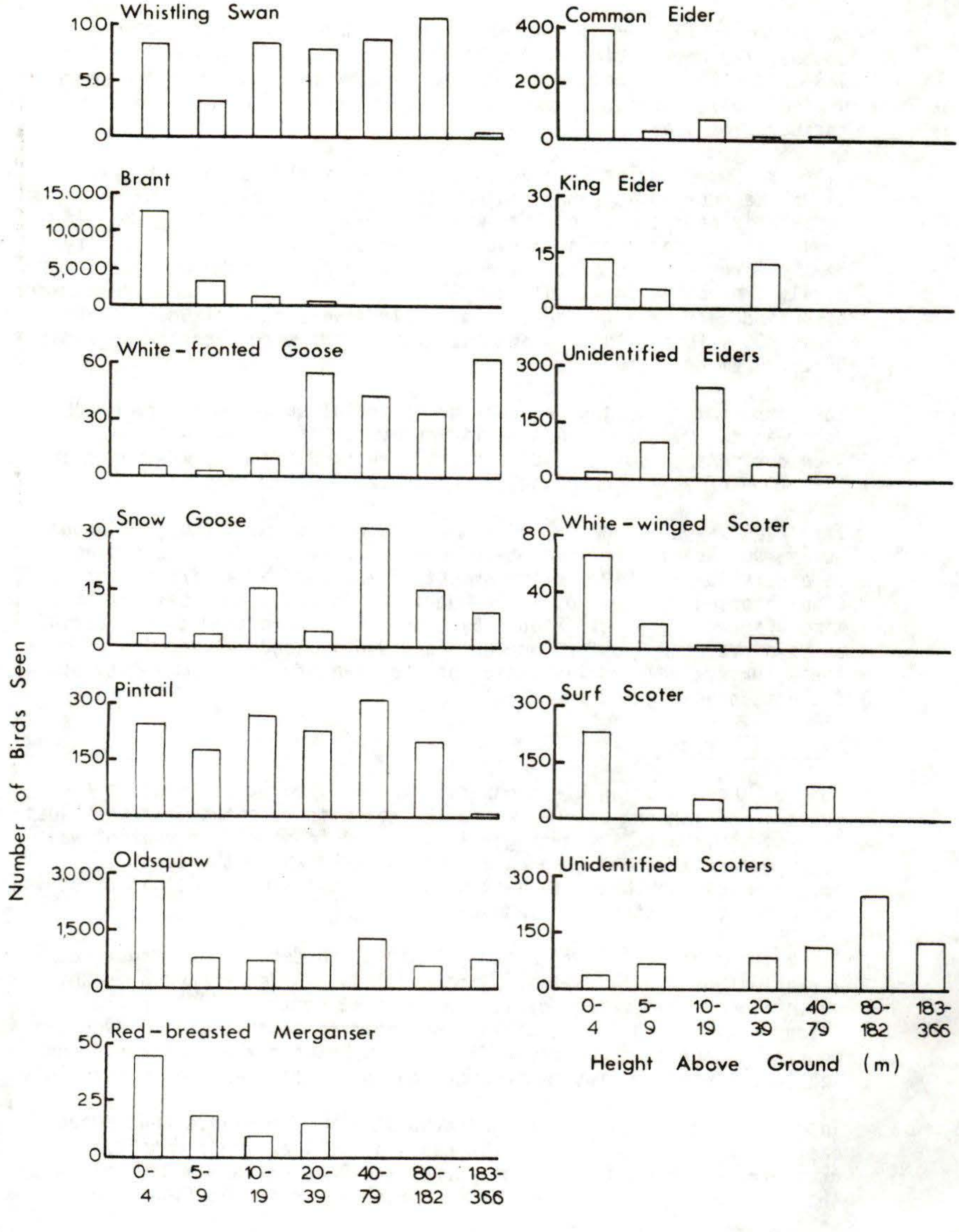

FIGURE 11. Height Distributions of Migrating Waterfowl Seen During Watches at Komakuk and Clarence Lagoon, 9 May-9 July 1975.

During an aerial survey over the Beaufort Sea on 15 June, 977 Oldsquaws, 120 Common Eiders, and 163 King Eiders, and an additional 143 unidentified eiders were seen on leads within 35 km of the shore; no individuals of these species and few of other species were seen farther offshore.

21 to 30 June--During late June, the field observers saw far fewer birds than during late May and during early and mid-June, but no comparable decrease in numbers was recorded by radar. Only the Glaucous Gull was detected at a rate of over one bird/hr. The identity of the large numbers of birds detected by radar is unknown, but it is highly improbable that most were Glaucous Gulls--given that speeds were often moderate or high and that many birds were at altitudes of at least 100 m (based on the fact that many birds were detected by radar 45 to 75 km offshore).

The most common species seen during an aerial survey offshore on 26 June was the Oldsquaw. A significant number of scoters was also seen during this survey, but scoters were predominantly westbound at this time of year (see below).

1 to 9 July--During early July, small numbers of Oldsquaws, Glaucous Gulls, and Brant were seen moving east. However, the numbers seen were very low relative to the amount of eastward broad-front migration detected by radar over the Beaufort Sea and Yukon coast at this time (Figures 4, 6; cf. Figure 5). Few birds were seen during aerial surveys over the Beaufort Sea on 3 and 9 July, and the results of these surveys gave no indication of the identity of the majority of the eastbound migrants.

Flight Directions

Most of the migrating birds observed visually moved parallel to the coast. At Clarence Lagoon, where the coast is oriented west-northwest to east-southeast, the average direction of 'eastward' migration was east-southeast rather than east. At Komakuk, where the coast is oriented west-southwest to east-northeast, the average flight direction was east-northeast rather than east.

The average direction of 'eastward' migration detected by radar was variable from day to day and place to place. Offshore and over the North Slope, the average direction was most commonly 100° or 110° (Figure 3A), which is the general orientation of the coast. Over the mountains, there was no clear distinction between the 'eastward' and the 'northeastward' movement described in a later section (Figure 3B).

The radar often showed a concentrated stream of migrants that moved eastward within 1 or 2 km of the coast as well as lower density broad-front eastward migration across the Beaufort Sea and/or along the North Slope. The birds in the concentrated stream along the coast usually changed course as necessary in order to follow the changes in orientation of the coast (i.e., the birds approached Komakuk from the west with flight direction ['track'] 110°, changed course to 070° as they passed Komakuk, and then returned to a track of 110°-120° approximately 10 km east of Komakuk at the base of Nunaluk Spit). Birds involved in broad-front movement offshore and inland had a greater tendency to maintain straight tracks than did those that moved along the coast.

On many occasions, some or all migrants that had been moving east along the coast did not change course from east to east-southeast near the base of Nunaluk Spit, where the orientation of the coast changes from west-east to west-northwest to east-southeast. Instead, these migrants maintained an easterly track and thus moved away from the coast towards the western side of Herschel Island. Figures 12 and 13 show the paths of a number of such echoes.

On one day, 8 July 1975, some flocks that had been moving east-southeast 25 to 40 km offshore from the Demarcation Bay-Clarence Lagoon area changed course, moved southeast or south-southeast toward shore, and then returned to an east-southeast track closer to shore (10 to 25 km offshore from the Komakuk area). At this time, a lead was oriented northwest to southeast in the area where the birds 'jogged' laterally toward shore; it is probable that these birds were responding to the sight of open water.

Hour-to-hour Variations in Numbers

Because continuous daylight prevailed throughout this study, the day *vs.* night differences in the density, nature, and species composition of migration that occur at temperate latitudes were not expected.

During the period 21 May to 20 June, which encompasses the dates of peak migration as detected by visual observations, the maximum extent of hour-to-hour variation in the median density of migration was two-thirds of a unit on the zero to eight scale (Figure 14). The range of this variation was small by temperate zone standards (e.g., Richardson 1970). The similarity in average densities at different times of day was found inland, offshore, and over the coast.

During the period 21 June to 8 July, when the radar revealed extensive eastward migration but when visual observations revealed little such migration, median densities were slightly more variable with time of day (Figure 15). Both offshore and along the coast, the density tended to be lower in the afternoon (12:00-18:00 YST) than at other times of day. Again, however, the range of variation was relatively small in comparison to the range that would occur at temperate latitudes.

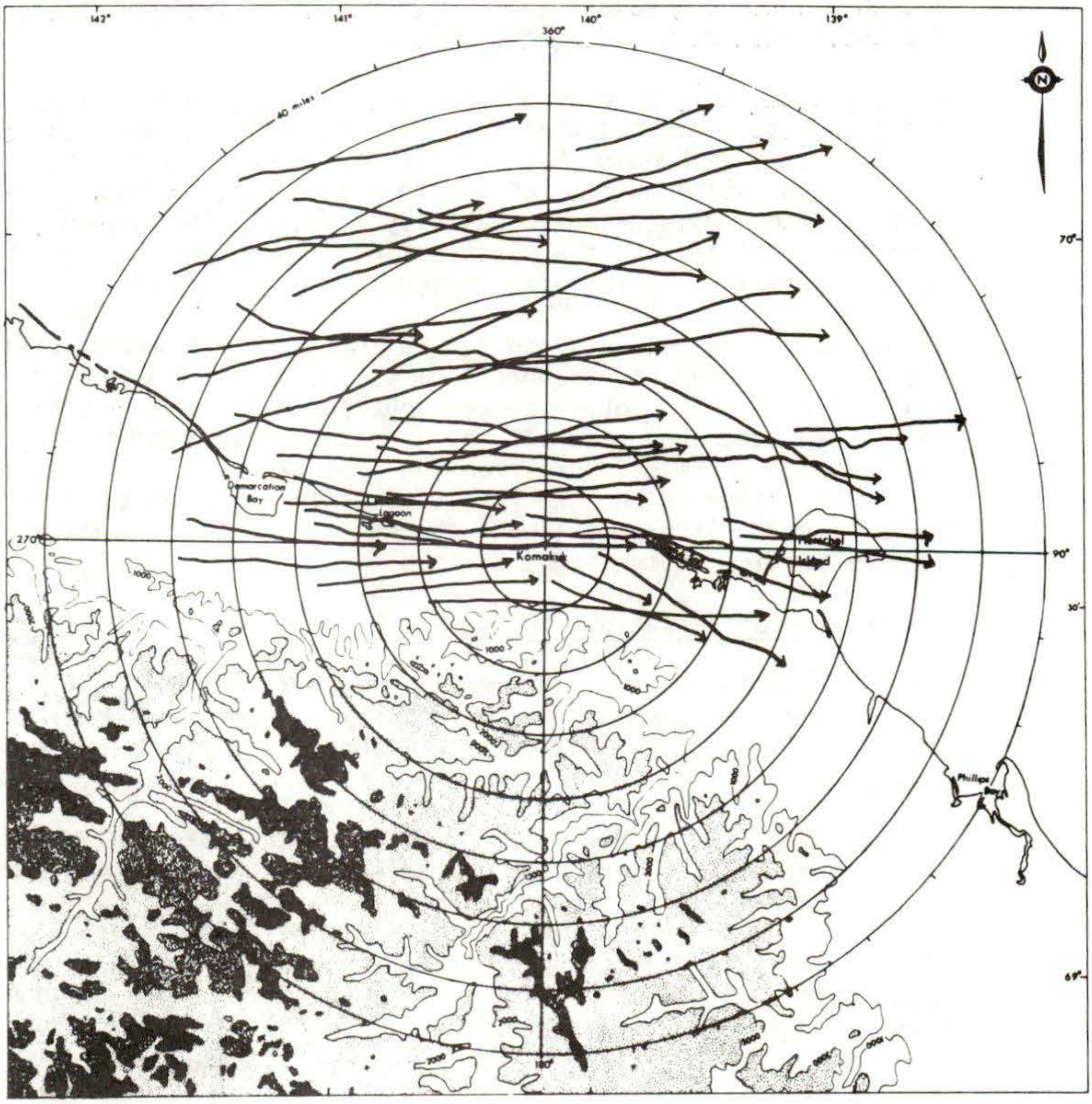

FIGURE 12. Tracing of Paths of Birds Moving East Over the North Slope and Beaufort Sea, 26-27 June 1975, 21:00-03:00 YST. Visual observations gave no clear indication of the identity of the birds.

FIGURE 13. Tracing of Paths of Birds Moving East Over the Beaufort Sea, North Slope and British Mountains, 7-8 July 1975, 21:00-01:00 YST. Visual observations gave no direct information about the identity of these birds.

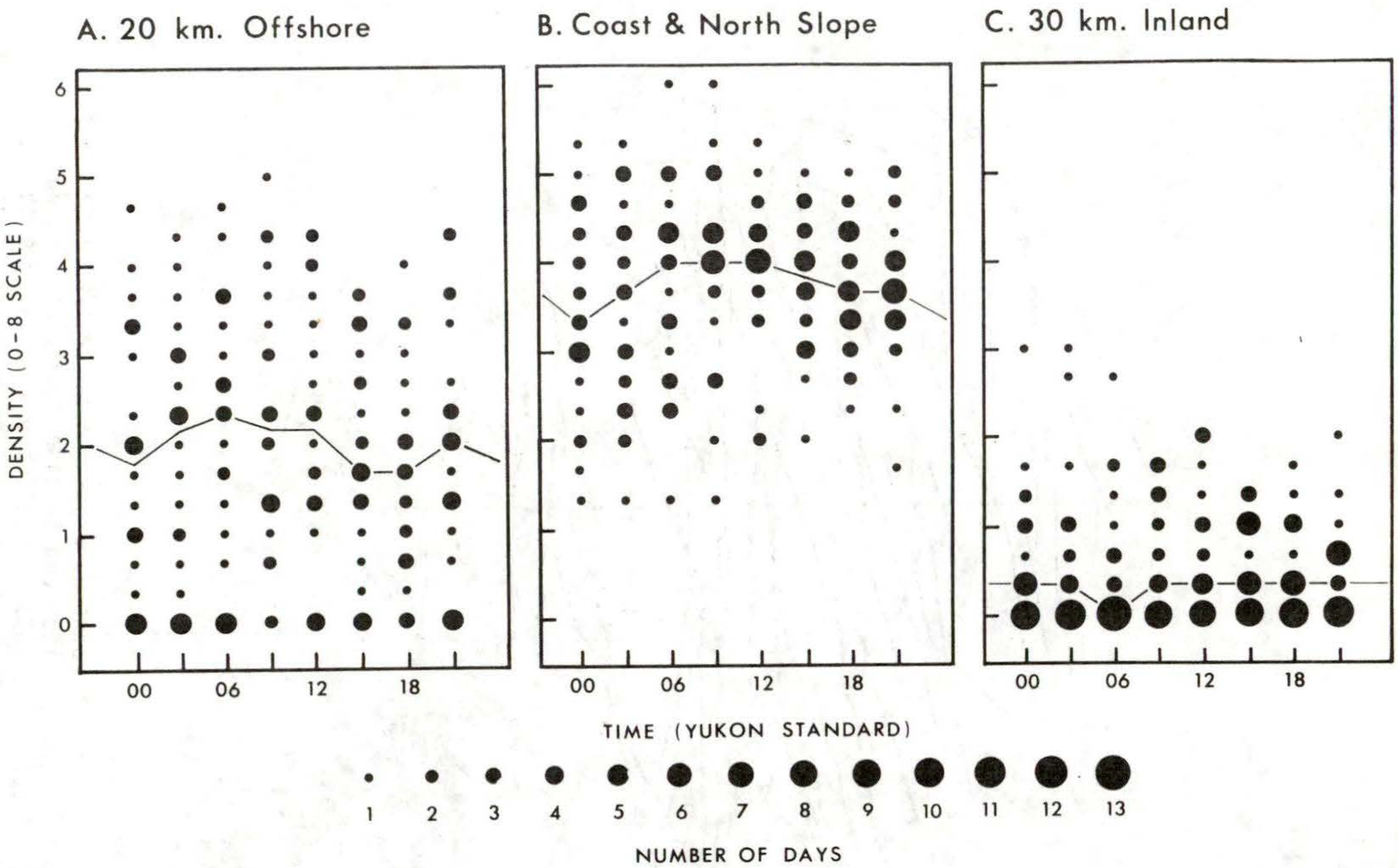

FIGURE 14. Density of Eastward Migration Near Komakuk, Y.T., at Various Times of Day in the Period 21 May to 20 June 1975. The line shows the median density at each time of day. Each column of data points gives the density distribution at one time of day. The area of a point is proportional to the number of days that had a given density at a given time of day. The scale of areas is given above.

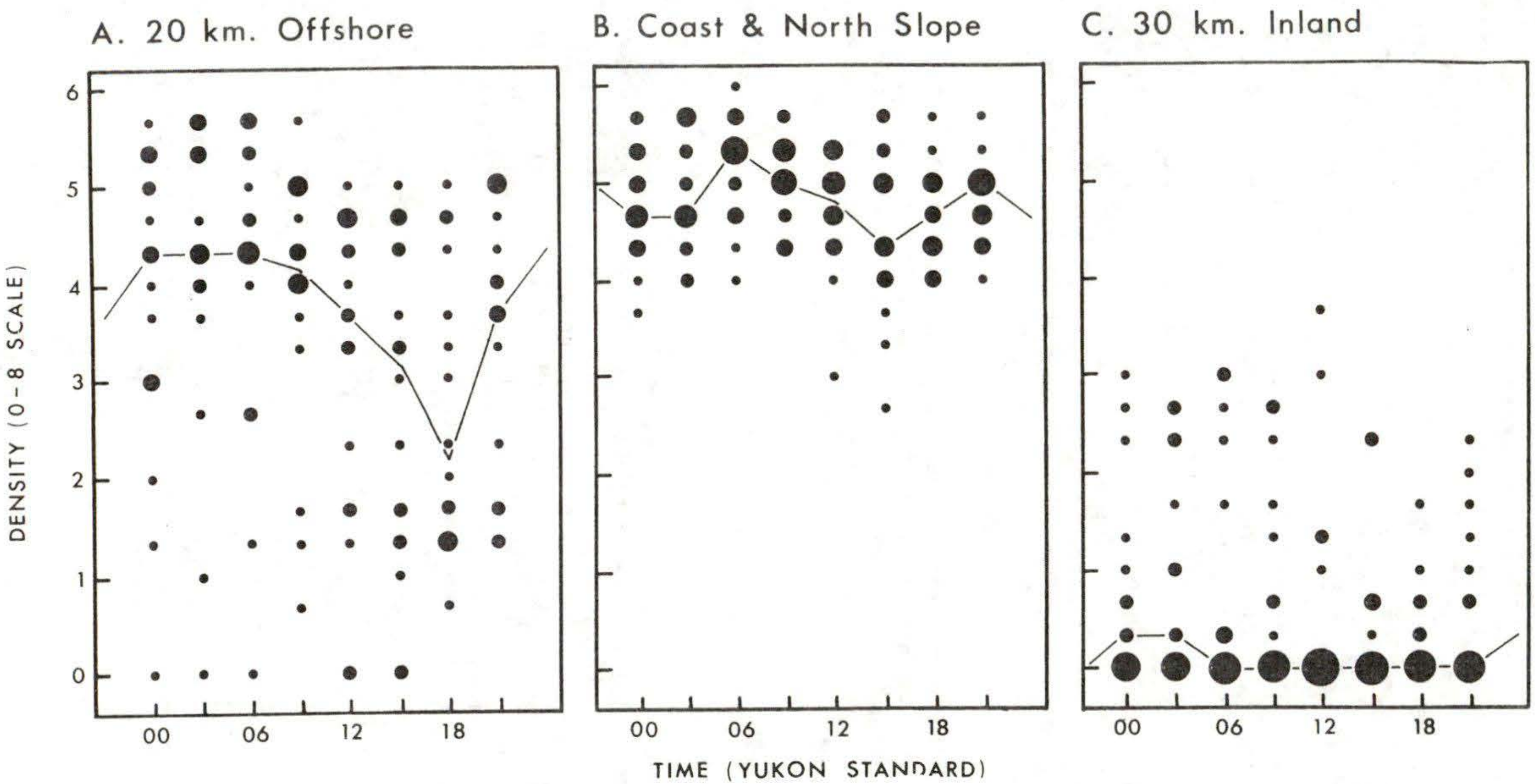

FIGURE 15. Density of Eastward Migration Near Komakuk, Y.T., at Various Times of Day in the Period 21 June to 8 July 1975. The line shows the median density at each time of day. Each column of data points gives the density distribution at one time of day. The area of a point is proportional to the number of days that had a given density at a given time of day. Scale as in Figure 14.

Visual observations of particular species relative to time of day are difficult to interpret because observations were infrequent at certain times of day and because most species were seen in significant numbers on only a few days, if at all. Brant, for example, were detected in much larger numbers between 06:00 and 18:00 YST than between 00:00 and 06:00 (Figure 16). However, almost all of the Brant were seen on only three days; hence, the generality of the tendency seen in 1975 is by no means certain.

The data given in Figure 16 are more reliable for species such as the Pomarine Jaeger, Oldsquaw, and particularly the Glaucous Gull, which were seen on numerous days in considerable numbers. Glaucous Gulls tended to occur in larger numbers at both Clarence Lagoon and Komakuk in the latter part of the morning and in the afternoon than in early morning. With the exception of a peak of unknown significance at 04:00-06:00 YST, Pomarine Jaegers showed little hour-to-hour variation in numbers at Clarence Lagoon. However, the numbers of Pomarine Jaegers seen at various times of day at Komakuk were less consistent. At both sites, Oldsquaws were recorded in largest numbers during the late morning and afternoon.

There was no obvious similarity between the times of day when the largest numbers of the most abundant species of eastbound migrants tended to be seen and the hourly pattern of densities detected by radar. This lack of similarity is further evidence that field observers and radar detect different components of the flow of migrants.

Westward Migration

Seasonal Variations in Numbers

Westward migration, like eastward migration, was detected by radar on almost every day during the study period (Figures 6, 17). However, relatively little westward movement was recorded until late May. Thereafter, the numbers that moved along the coast and North Slope were high on most days through to the end of the study period. Numbers that moved westward offshore were lower in early July than in June. Numbers over the British Mountains were much lower from mid-June to the end of the study than they had been in early June.

The seasonal pattern of variation in number of westbound birds detected visually did not parallel that detected by radar (Figure 18). Very few birds were seen moving west until the end of May, and large numbers were not detected until mid-June. The maximum rate of detection on any one day was 127/hr on 21 June; almost all of these birds were unidentified scoters.

In total, considerably fewer birds were seen moving west than east. However, the proportion seen moving west increased significantly over the course of the two-month study period; the most pronounced

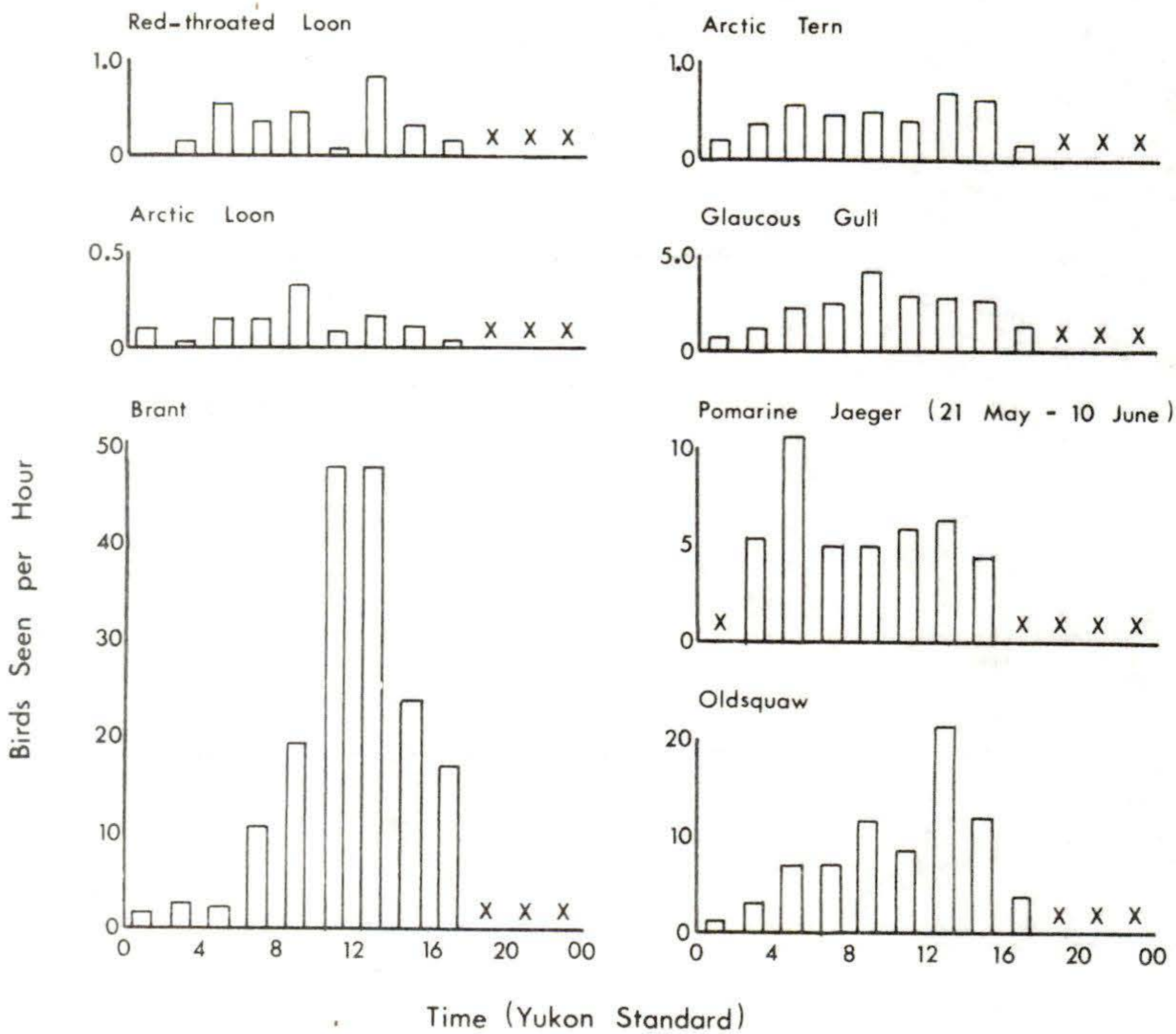

FIGURE 16. Average Number of Birds Seen per Hour at Clarence Lagoon at Various Times of Day. All of these species were predominantly eastbound (Pomarine Jaegers were moving east in the dates considered here). Data are not plotted for periods with less than 15 hr of observation (indicated by 'x').

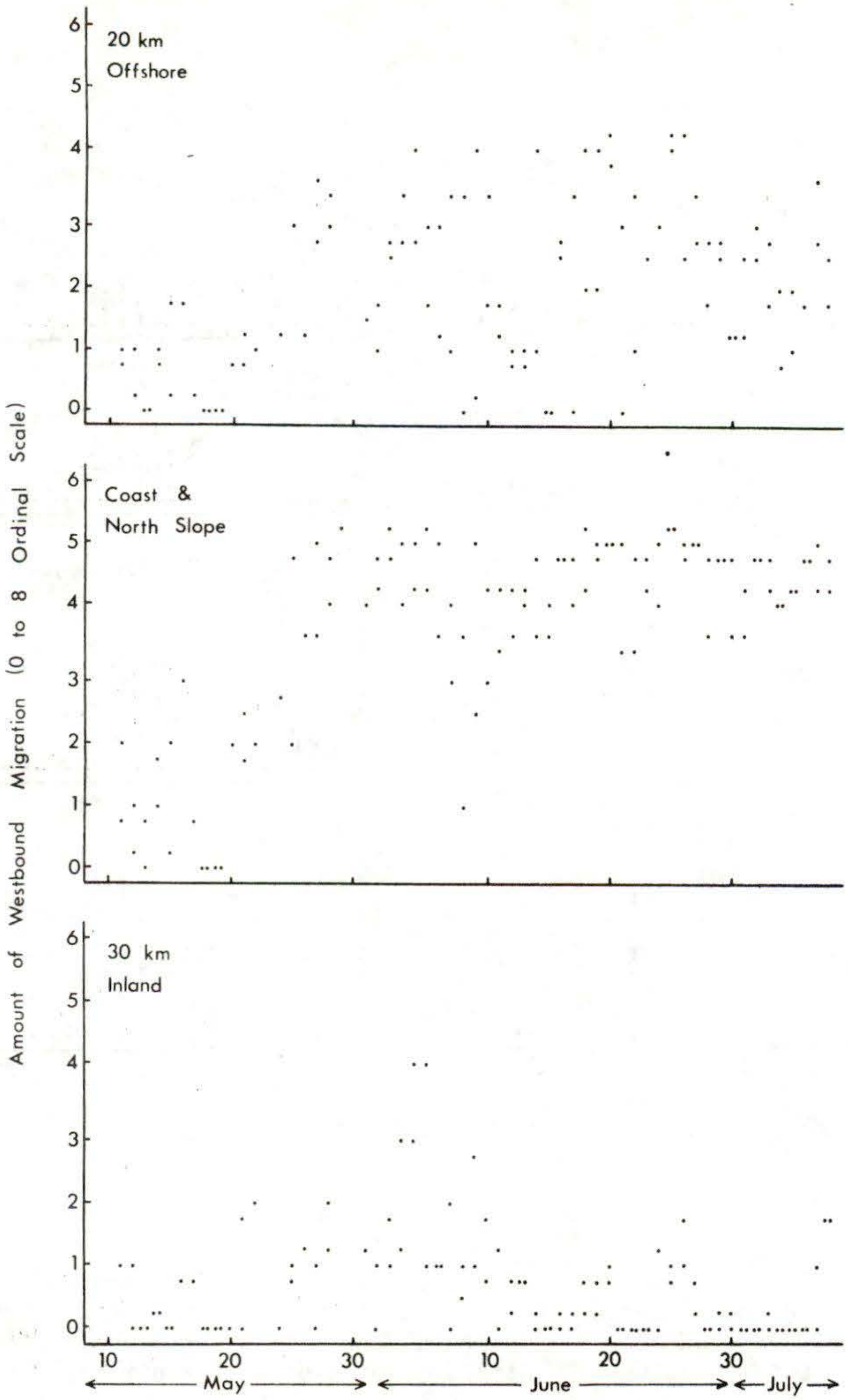

FIGURE 17. Amount of Westward Migration Detected by Radar *vs.* Date. Migration Traffic Rates measured on the zero to eight ordinal scale (see 'Methods') are plotted for two periods each day--03:00-09:00 and 15:00-21:00 YST. (The median value for each period is plotted.)

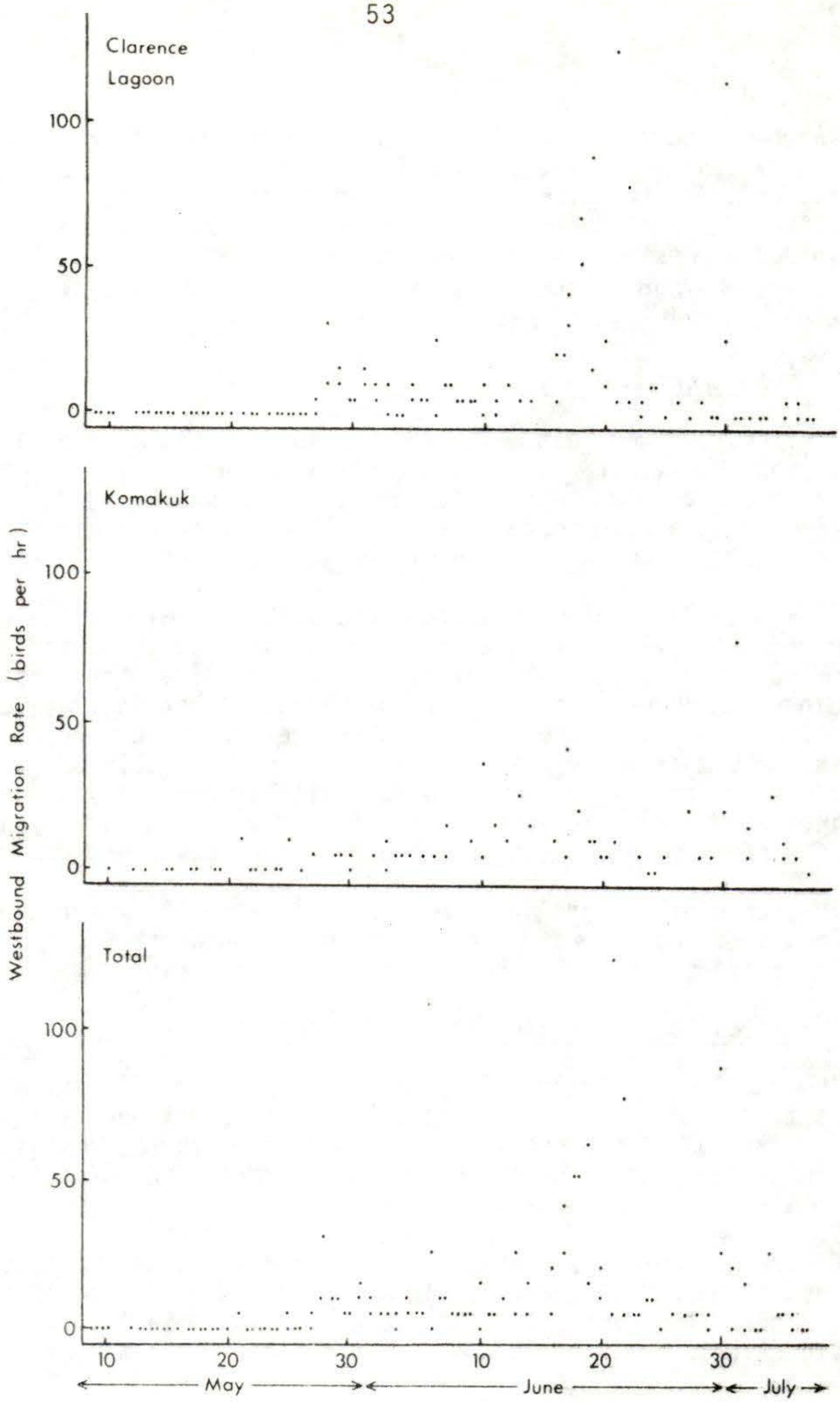

FIGURE 18. Amount of Westward Migration Seen by Ground Observers *vs*. Date. Migration Traffic Rates in birds per hour are plotted for two periods each day--02:00-10:00 and 14:00-22:00 YST. Periods with less than 1 hr of observation and those with poor visibility (<1.6 km) are not plotted. The 'Total' section weights the Clarence Lagoon data more heavily than the Komakuk data; weights are proportional to the number of hours of observation at the two sites.

increase occurred around mid-June (Figure 19). This tendency was significant ($P < 0.001$) at both Komakuk and Clarence Lagoon as well as for these two sites pooled. Radar data, in contrast to the results of visual observations, did not confirm this tendency--the volume of westward migration detected by radar was not on the increase toward the end of the study period; nor was the amount of eastward migration on the decrease.

Broad-front Migration

The radar showed that many migrants moved west, more or less parallel to the coast, not only over the coast but also over the entire North Slope and to the limit of detectability offshore. Much smaller numbers were frequently detected moving northwest over the northern part of the British Mountains south of Komakuk.

As was the case with eastward migration, the relative numbers that moved west over different parts of the study area varied considerably (Figure 6). The density of flocks detected over the coast and North Slope was never less than that offshore or over the mountains, and this density was often considerably greater (Figure 20). Nevertheless, the fact that the density offshore was occasionally as great as that along the coast--even on some days with high density along the coast--indicated that large numbers of birds moved west far beyond the range of vision of an observer stationed on the coast.

The ratio of the amount of westward migration 20 km offshore to the amount of such migration over the coast and North Slope did not vary significantly over the course of the study period.

Species Composition of Westward Migration

The section on 'Species Composition of Eastward Migration' (see above) mentions the limitations of the visual observations as a basis of determination of the species involved in specific movements. The same limitations apply to the following interpretation of the westward movements.

Figure 21 shows the average numbers of each common species seen moving west (200°-340°; predominantly 220°-310°) during each of six 10-day periods. In order to facilitate comparison with Figure 9 (eastbound migration), the same species are plotted and the same scale is used.

9 to 20 May--During the first 11 days of the study, almost no birds were seen moving west. The radar rarely showed more than a few westbound groups at any one time; because these groups were distributed over an area of several thousand km^2, it is not surprising that the observers saw few westbound birds.

21 to 31 May--During this period, the amount of westbound migration increased considerably, although the number of birds seen moving west was much less than the number seen moving east at the same time. The

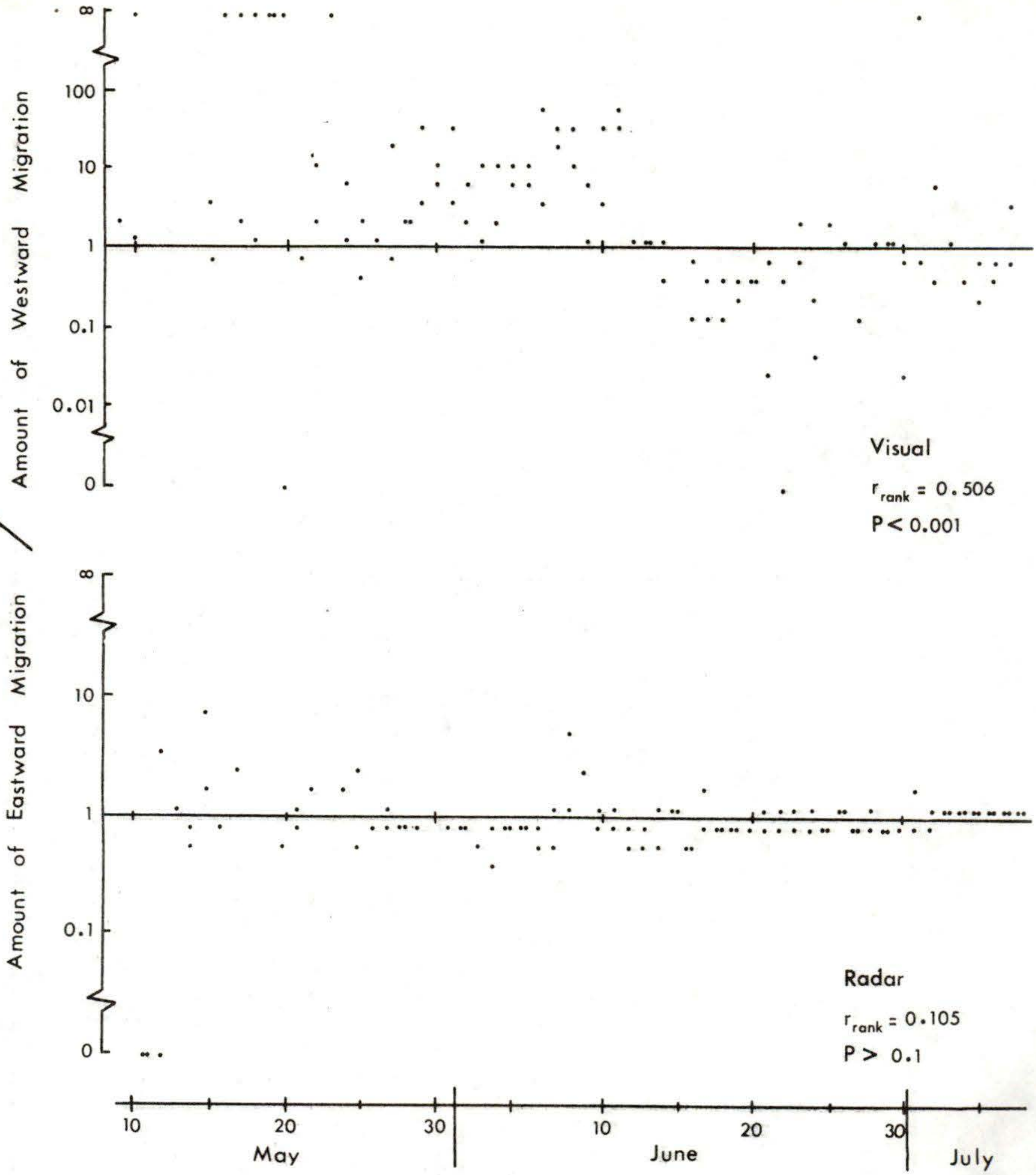

FIGURE 19. Ratio of Amount of Eastward to Amount of Westward Migration, as Detected Visually and by Radar, *vs.* Date. The ratios are plotted on a logarithmic scale. Migration Traffic Rates were recorded in birds/hr (visual observations) or on the zero to eight ordinal scale (radar observations). Data for two periods each day are plotted separately (02:00-10:00 and 14:00-22:00 YST).

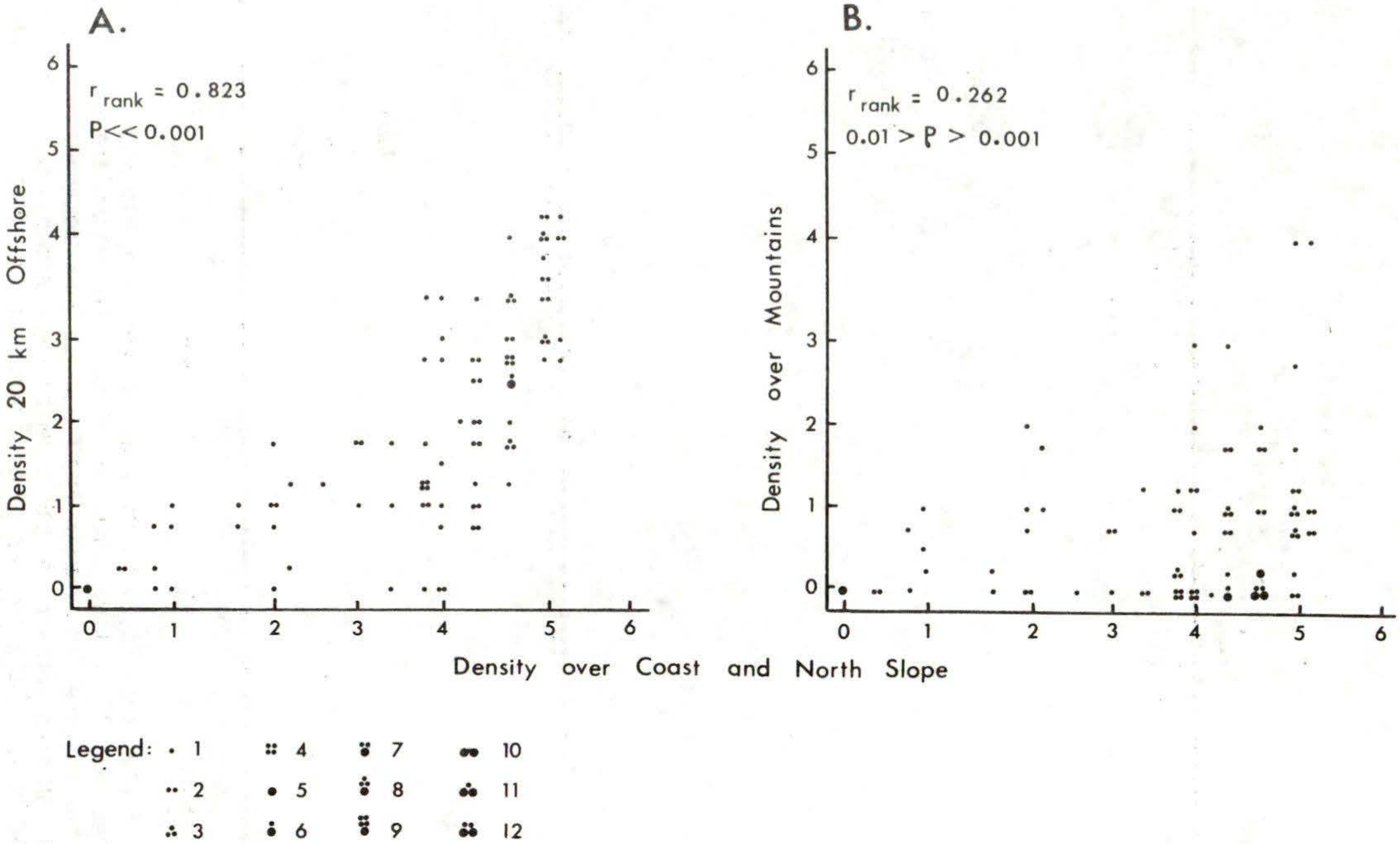

FIGURE 20. Amount of Westward Migration Detected by Radar Offshore and Inland Relative to That Over the Coast and North Slope. Migration Traffic Rates measured on the zero to eight ordinal scale (see 'Methods') are plotted for two periods each day--03:00-09:00 YST and 15:00-21:00 YST. (The median values for each period are plotted.)

predominant species were Whistling Swans (an average of 1.7 birds/hr) and White-fronted Geese (1.0/hr). In addition, there was some westward movement of shorebirds at this time. Because shorebirds tend to fly high and on a broad front--at least in other areas where their altitudes and tracks during migration have been studied--they probably contributed more substantially to the westward movement detected by radar than to such movement detected by field observers.

1 to 10 June--During the first 10 days of June, westward movement of swans continued (0.7 birds/hr), but Pintails became the dominant component of this movement (3.2/hr). More shorebirds of a wide variety of species were seen moving west in this period than earlier.

11 to 20 June--From 11 to 20 June, westward migration of Pintails continued at an average rate of 2.8 birds seen/hr. Few Whistling Swans moved west after 17 June. Scoters began to move west in significant numbers during this period (1.0/hr). Fewer shorebirds were seen moving west than had been seen in early June.

However, the most conspicuous westward movement during mid-June consisted of Pomarine Jaegers and unidentified jaegers (the latter group presumably consisted primarily of Pomarine Jaegers). Until 12 June, almost all observed Pomarine Jaegers were moving east; after 12 June, almost all were moving west. The average rate of detection of westbound Pomarine Jaegers and unidentified jaegers was 14.6/hr from 13 to 20 June (11.7/hr from 11 to 20 June). Previous studies have shown that when the food supply (lemmings) on the breeding grounds is inadequate, Pomarine Jaegers do not remain to nest (Parmelee *et al.* 1967; Maher 1974).

Only one jaeger was seen during the aerial survey over the Beaufort Sea on 15 June. This result and the fact that almost as many jaegers were seen inland as offshore during field observations at Komakuk and that few jaegers were seen during any of the other aerial surveys suggest that jaegers may not occur in large numbers far offshore. Nevertheless, on the afternoon of 16 June, when 75% of the birds seen at Komakuk and Clarence Lagoon were Pomarine Jaegers and unidentified jaegers, there was some westward migration out to at least 30 km offshore as well as concentrated movement along the coast (Plate 4; Figure 22).

21 to 30 June--During late June, the dominant components of the westward migration that were detected by field observers were scoters (5.4/hr; most unidentified), unidentified ducks (3.6/hr), and Pintails (1.5/hr). Although jaeger movement was again predominantly westward, few jaegers were seen in comparison to the numbers seen in mid-June.

1 to 9 July--During early July, only scoters (predominantly Surf Scoters; an average of 2.5/hr) and Oldsquaws (1.9) were seen moving west in significant numbers. Westward Pintail movement had virtually ceased.

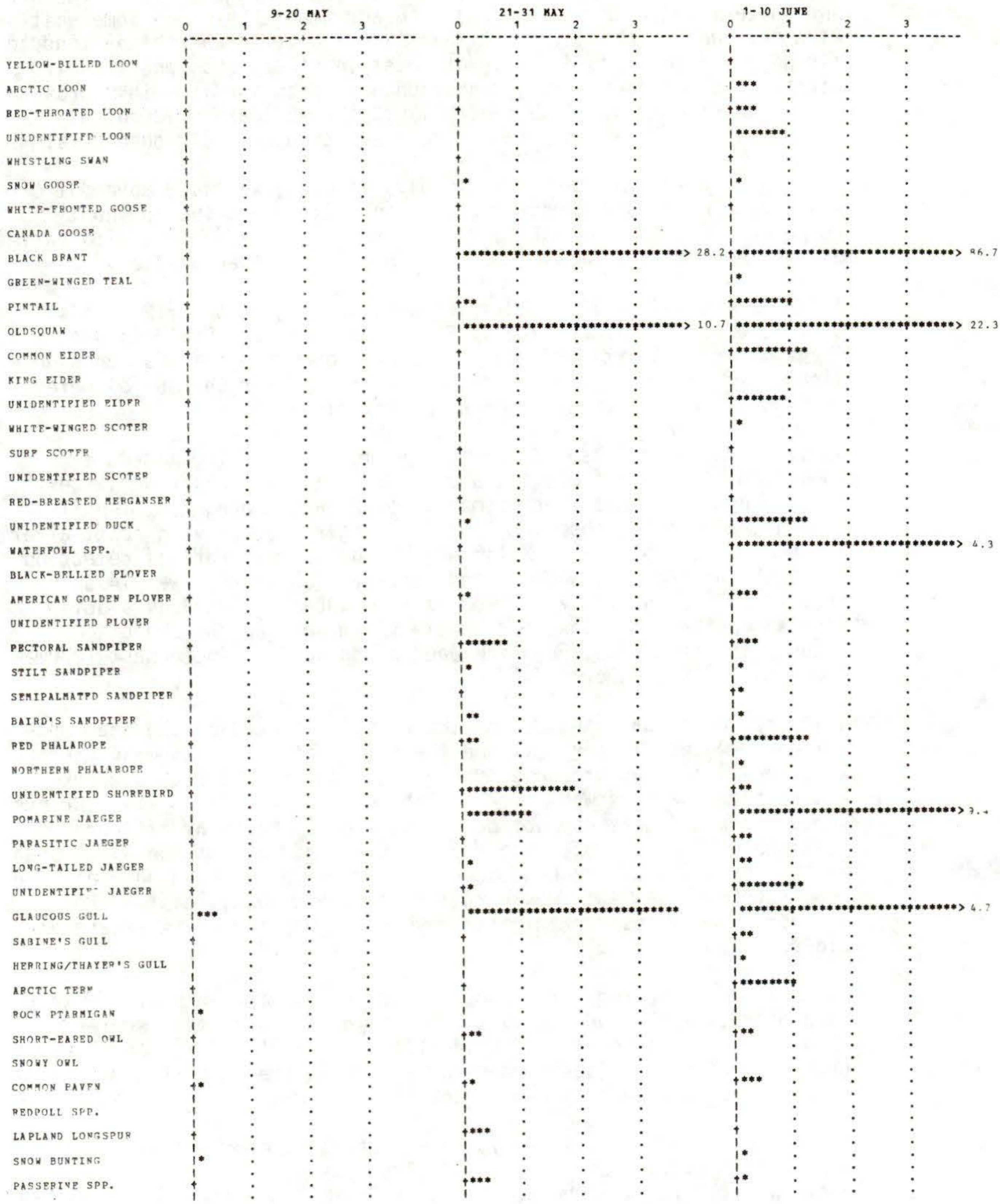

Figure 21. Average Number of Westbound Birds of Each Species Seen per Hour at Clarence Lagoon and Komakuk by 10-day Periods.

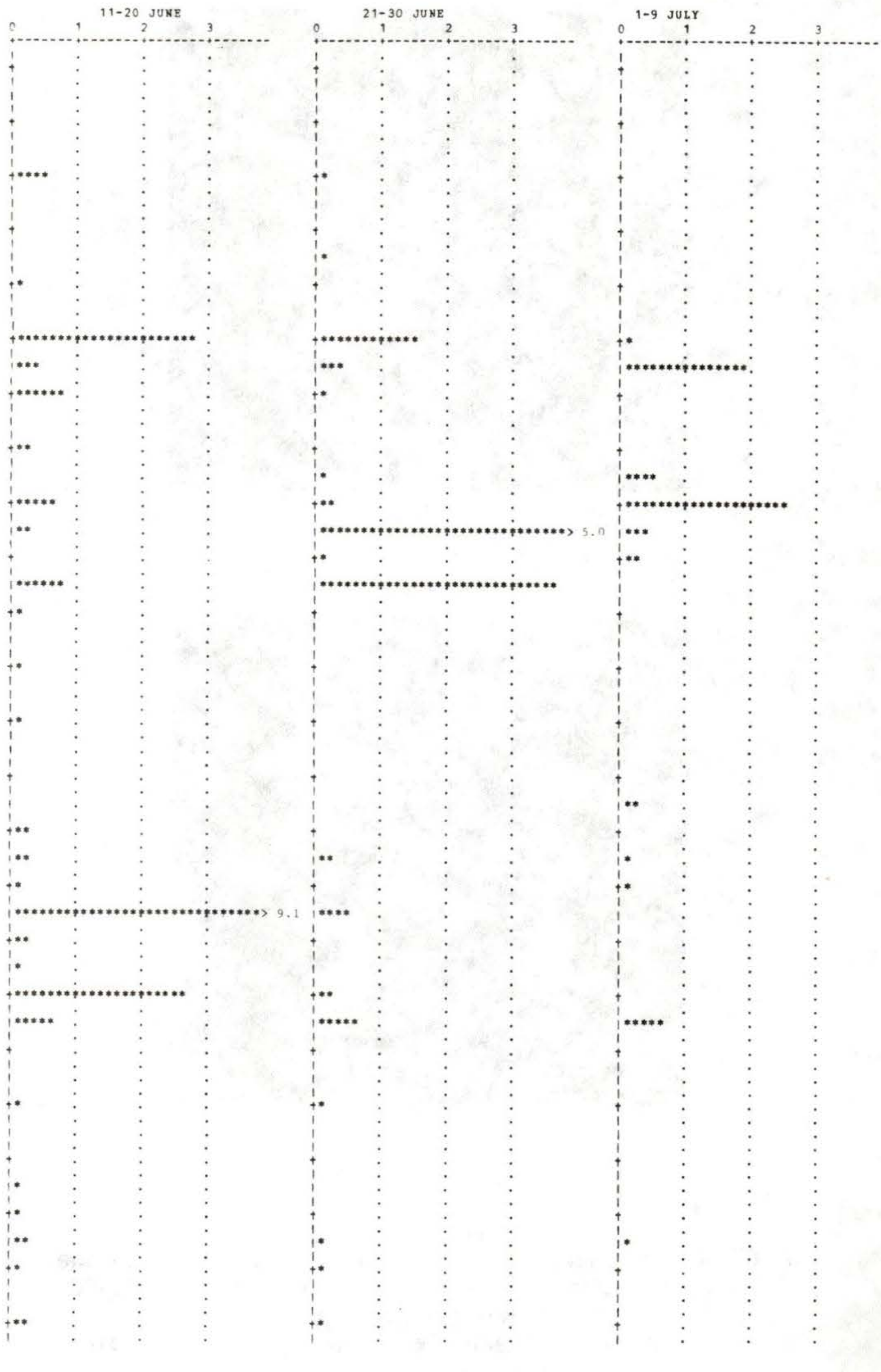

Figure 21. (Cont'd) Average Number of Westbound Birds of Each Species Seen per Hour at Clarence Lagoon and Komakuk by 10-day Periods.

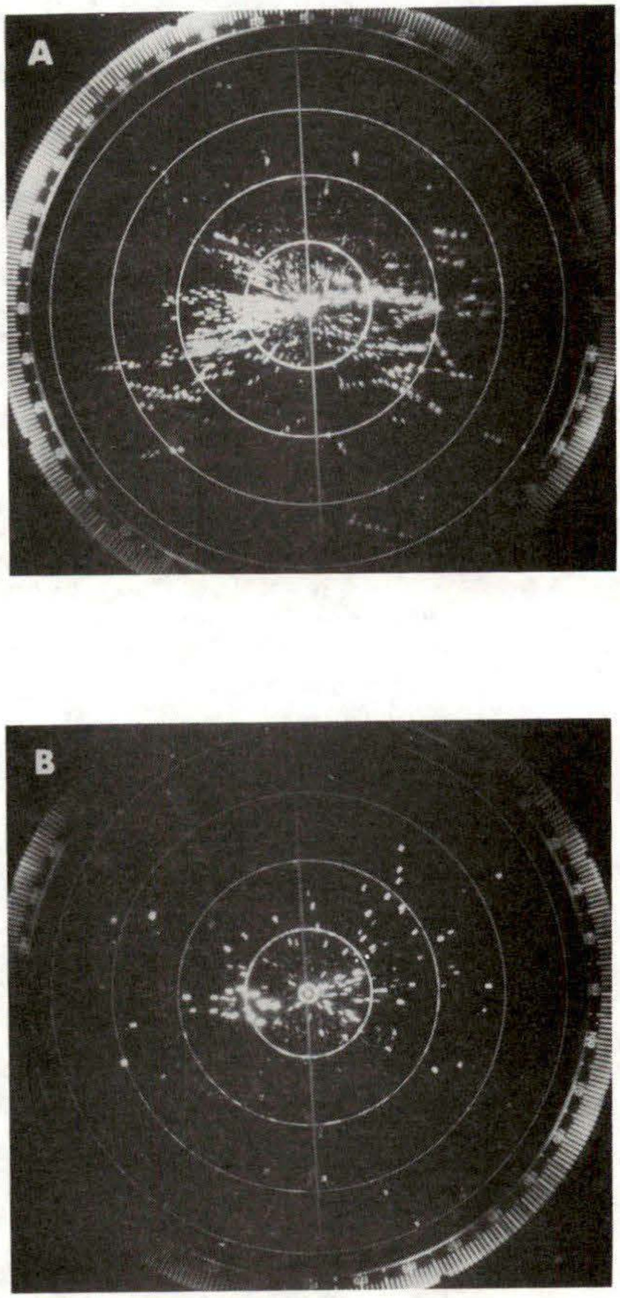

PLATE 4. Westward Movement, Probably Largely Pomarine Jaegers, as Recorded on 16 June 1975, 15:20 YST. Display radius 20 n mi (34 km). A: eight-sweep time exposure B: single-sweep. See Figure 22.

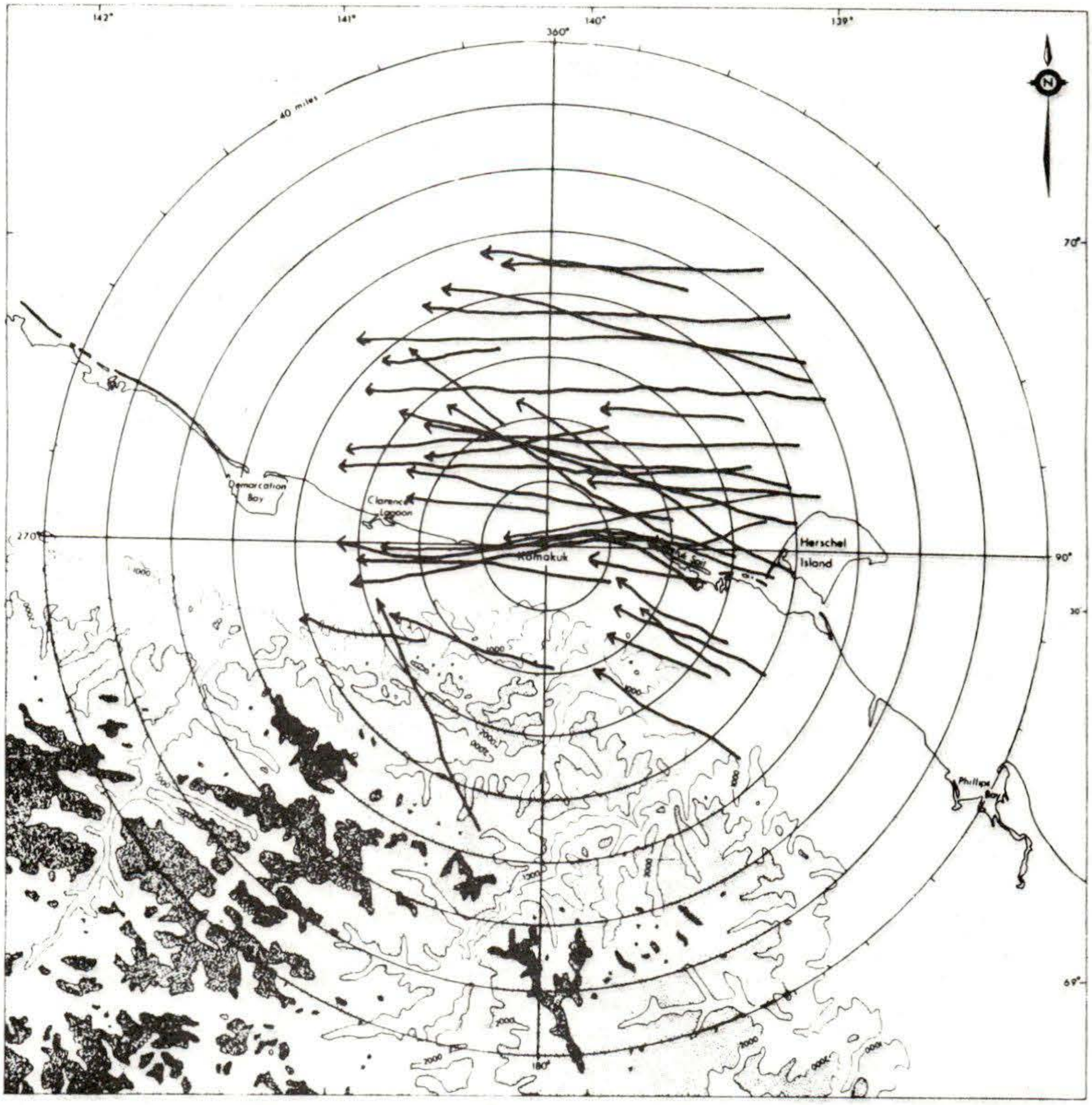

FIGURE 22. Tracing of Paths of Birds Moving West Over the North Slope and Beaufort Sea, 16 June 1972, 16:00-20:00 YST. Most westbound birds seen at this time were jaegers, predominantly Pomarine Jaegers. Note that some birds that approached from the direction of Herschel Island joined the concentration over or near the coast (the coastal concentration is under-represented in the sample--see Plate 4). The mean ground speed of these birds was 66 km/hr; their mean air speed was about 47 km/hr, assuming that the wind speed and direction at their altitude of flight was the same as that recorded near ground level.

The aerial survey over the Beaufort Sea on 3 July was the first survey during which significant numbers of scoters were seen (137 White-winged Scoters; 82 Surf Scoters; 289 unidentified scoters).

Flight Directions

As was the case with eastward migration, most of the visually observed westbound birds moved parallel to the coast. Because of the difference between orientation of the coast at Clarence Lagoon and at Komakuk, the mean directions of westward migrants observed at the two sites were slightly different.

The average direction of 'westward' migration detected by radar was different in different parts of the study area.

Over the British Mountains and the Buckland Hills (south and south-east of Komakuk), the mean direction was northwest (Figure 3A); individual flocks moved west-northwest, northwest, and even north-northwest (e.g., Figure 23). Although the mean direction (northwest) is close to the orientation of the section of the North Slope between the upper Mackenzie Delta and Komakuk, birds that moved north-northwest may have taken off from or flown over the Old Crow Flats or the Mackenzie Valley south of the Delta. Unfortunately, the radar could not detect birds farther south than the northern or, less frequently, the central part of the British Mountains.

Twenty kilometres offshore, the mean direction was west-northwest; most individual flocks moved west, west-northwest, or northwest. On some days, particularly late in the season, flocks were detected moving west-southwest over the Beaufort Sea; birds that flew west-southwest probably took off from the outer Mackenzie Delta or from locations to the east and/or north.

Figure 23 shows a situation in which the mean flight directions in different parts of the study area differed; many birds gradually curved to the left as they crossed the study area.

Radar often revealed a concentrated stream of migrants moving westward along the coast, which is oriented almost east to west near Komakuk. The broad-front movements tended to be directed west-northwest, parallel to the west-northwest to east-northeast orientation of the coastline as evident on a larger scale. Hence, the birds that moved along the shore usually moved in a slightly different direction than those elsewhere. Flocks whose paths intersected the coast after a flight along part of the North Slope often changed course slightly and joined the stream of birds moving along the coast. Furthermore, westbound flocks often approached the base of Nunaluk Spit from the direction of Herschel Island and joined the shoreline concentration when they reached the coast. Figure 23 shows the paths of a number of such flocks.

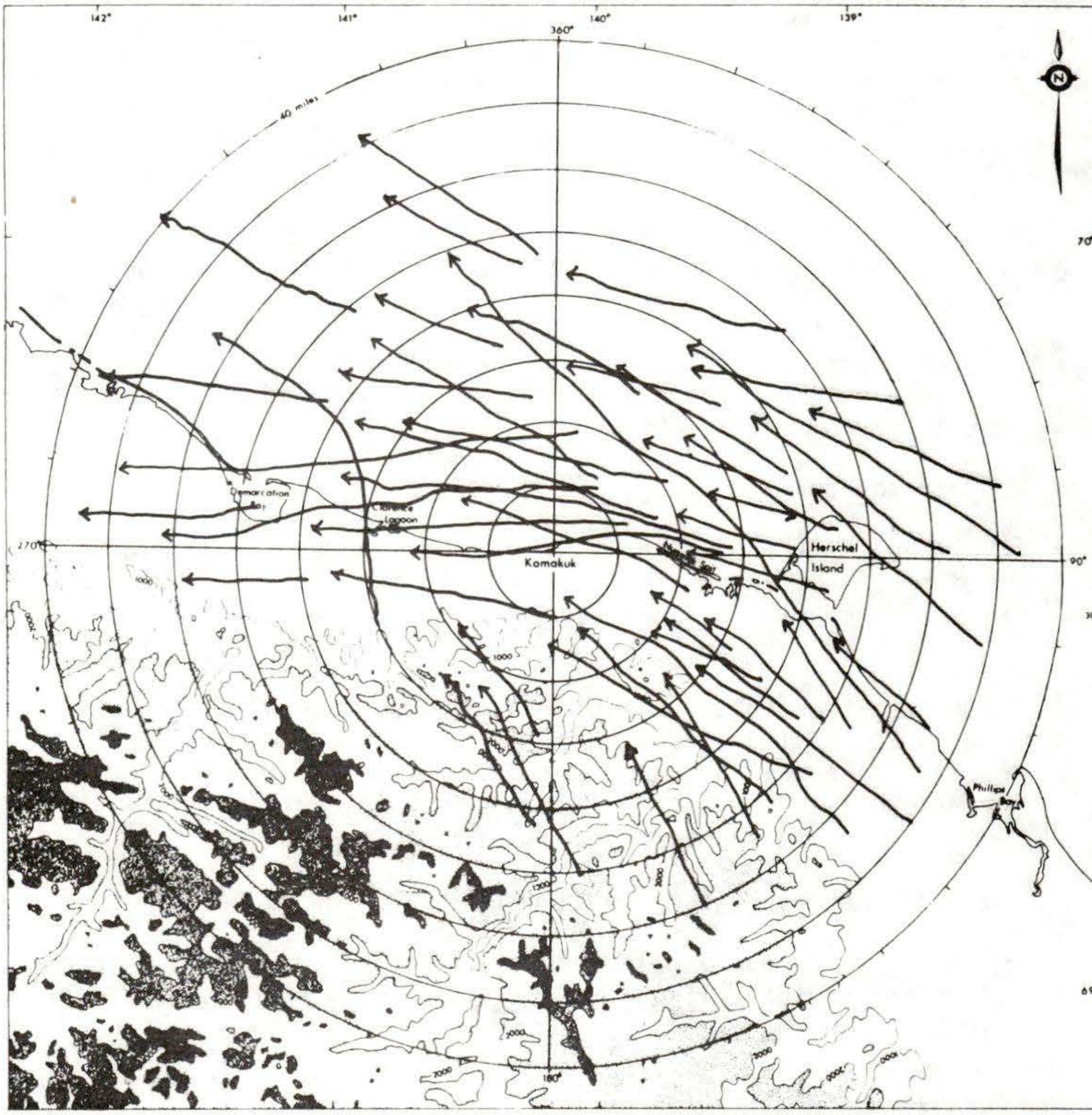

FIGURE 23. Tracings of Paths of Birds Moving West and Northwest Over the Northern Yukon Territory and the Beaufort Sea, 24-25 June 1975, 21:00-03:00 YST. Average ground speed 58 km/hr; air speed similar (surface wind speed zero). Almost no westbound birds were detected visually at or near this time; Pintails and scoters were the predominant westbound species during late June.

On one occasion, 7 to 8 July, a few very intense echoes (i.e., large flocks) that were moving at a ground speed of 77 km/hr and in a west-northwest direction along the North Slope changed direction over the Buckland Hills southeast of Komakuk and flew west-southwest (Figure 24). These flocks disappeared from the radar display over the Brooks Range southwest of Komakuk, presumably having moved out of range rather than having landed.

The identity of these birds is unknown; they appeared, subjectively, to be flocks of waterfowl. They could have been scaup or scoters, or White-fronted or Canada Geese undertaking a moult migration, possibly to the Old Crow Flats and Yukon Flats. Whistling Swans and Sandhill Cranes occur along the Yukon North Slope as well; any one of these species travelling with favourable winds could have reached the observed flight speeds.

Hour-to-hour Variation in Numbers

Over the coast and North Slope, the median density of migration was similar at different times of day. This was true both during the period 21 May to 20 June (Figure 25B) and during the period 21 June to 9 July (Figure 26B).

Offshore, the median density was more variable with time of day. The number of flocks detected by radar tended to be highest very early in the day and tended to decline to a minimum in the early afternoon. This pattern was observed both near the middle (Figure 25A) and toward the end (Figure 26A) of the study period.

Over the mountains the median density was low at all times of day.

None of the predominantly westbound species was seen sufficiently often to provide reliable information on hour-to-hour patterns of variation in numbers.

Northeastward Migration

Numbers

Northeastward movements were detected by radar intermittently throughout the study period (Figures 6, 27). Significant northeastward movement (density of 0.7 on the zero to eight scale) was recorded as early as 12 May; northeastward movement was still occurring in early July.

The distinction between east and northeast movements was at times unclear (Figure 28). Also, because certain movements could have been classed as either east or northeast, the record of the daily amount of northeastward movement is occasionally imprecise. In contrast, however, to the eastward and westward categories, there were many

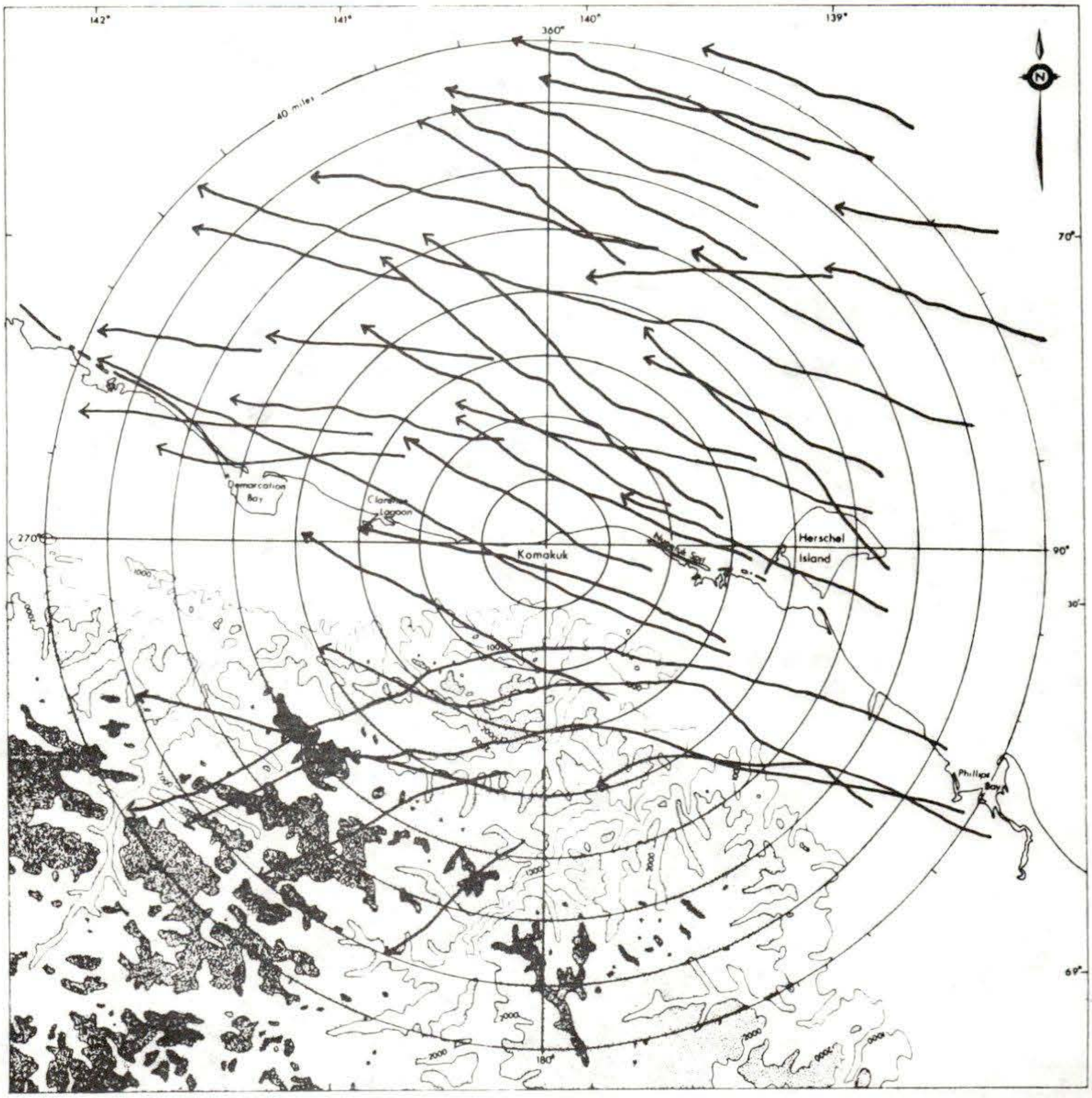

FIGURE 24. Tracing of Paths of Birds Moving Westward on 7-8 July 1975, 21:00-01:00 YST. Oldsquaw and scoters were the predominant westbound migrants detected visually during early July. Several very intense echoes are shown curving from west-northwest to west-southwest inland; their ground speed was 77 km/hr.

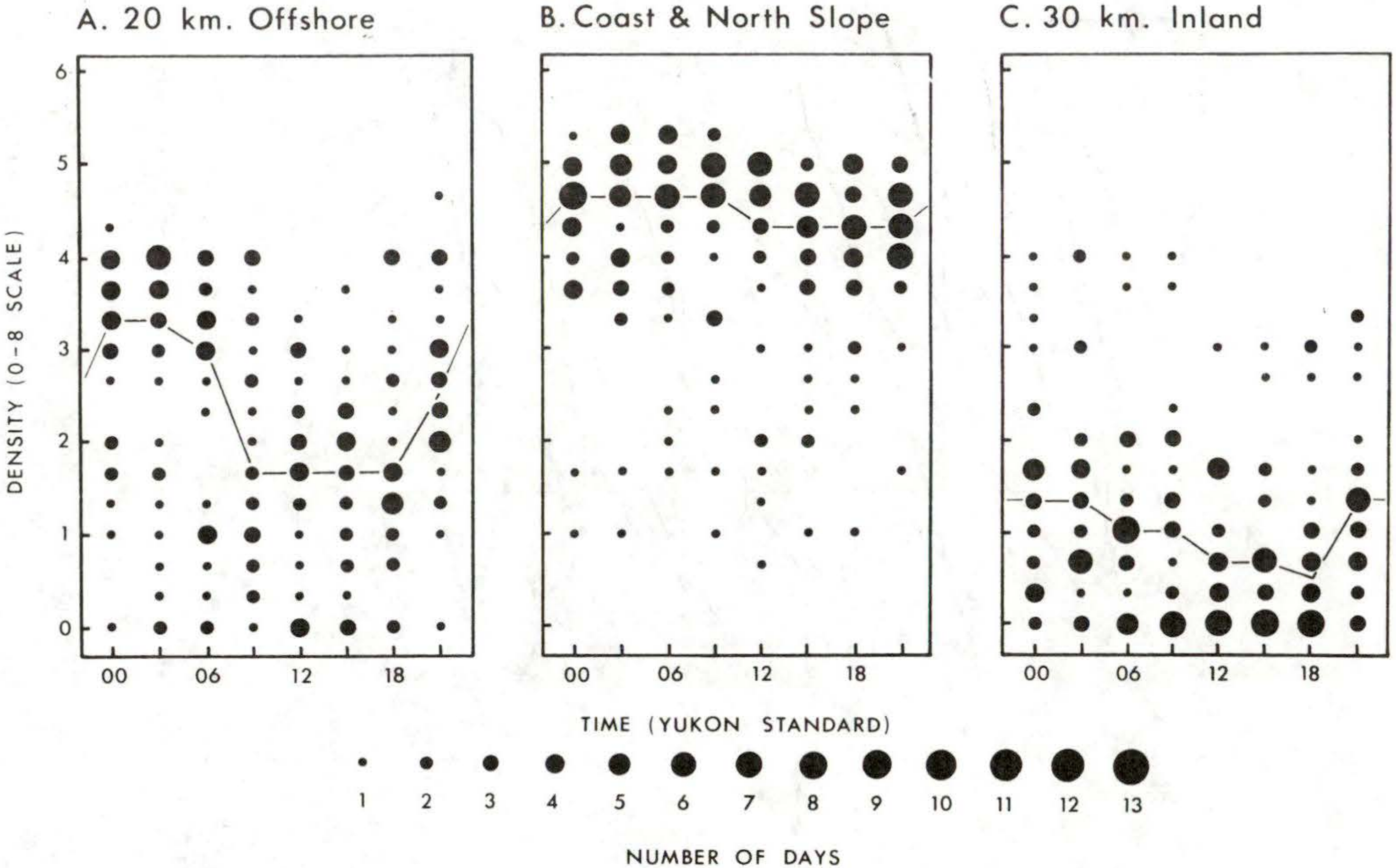

FIGURE 25. Density of Westward Migration Near Komakuk, Y.T., at Various Times of Day in the Period 21 May to 20 June 1975. The line shows the median density at each time of day. Each column of data points gives the density distribution at one time of day. The area of a point is proportional to the number of days that had a given density at a given time of day. The scale of areas is given above.

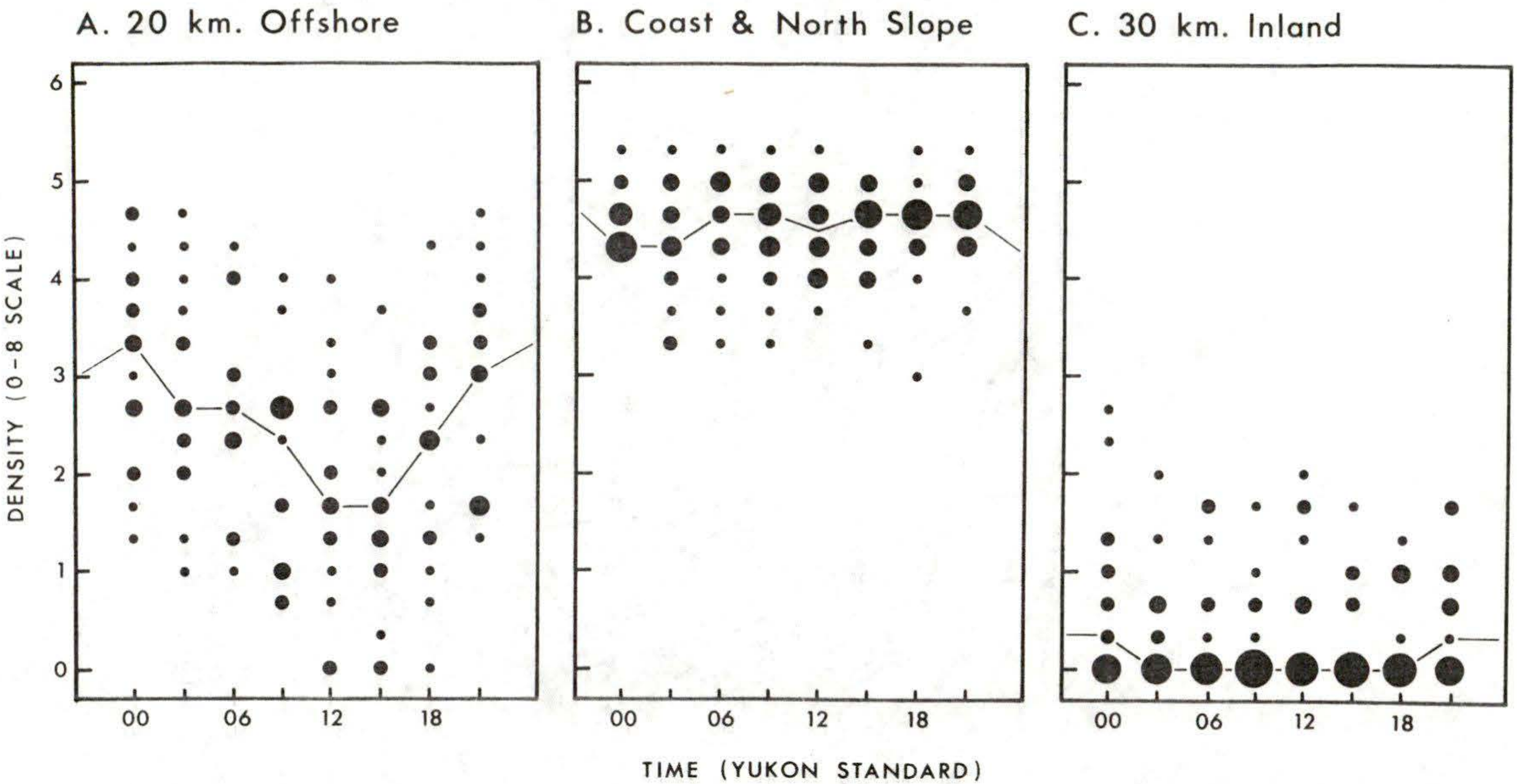

FIGURE 26. Density of Westward Migration Near Komakuk, Y.T., at Various Times of Day in the Period 21 June to 8 July 1975. The line shows the median density at each time of day. Each column of data points gives the density distribution at one time of day. The area of a point is proportional to the number of days that had a given density at a given time of day. Scale as in Figure 25.

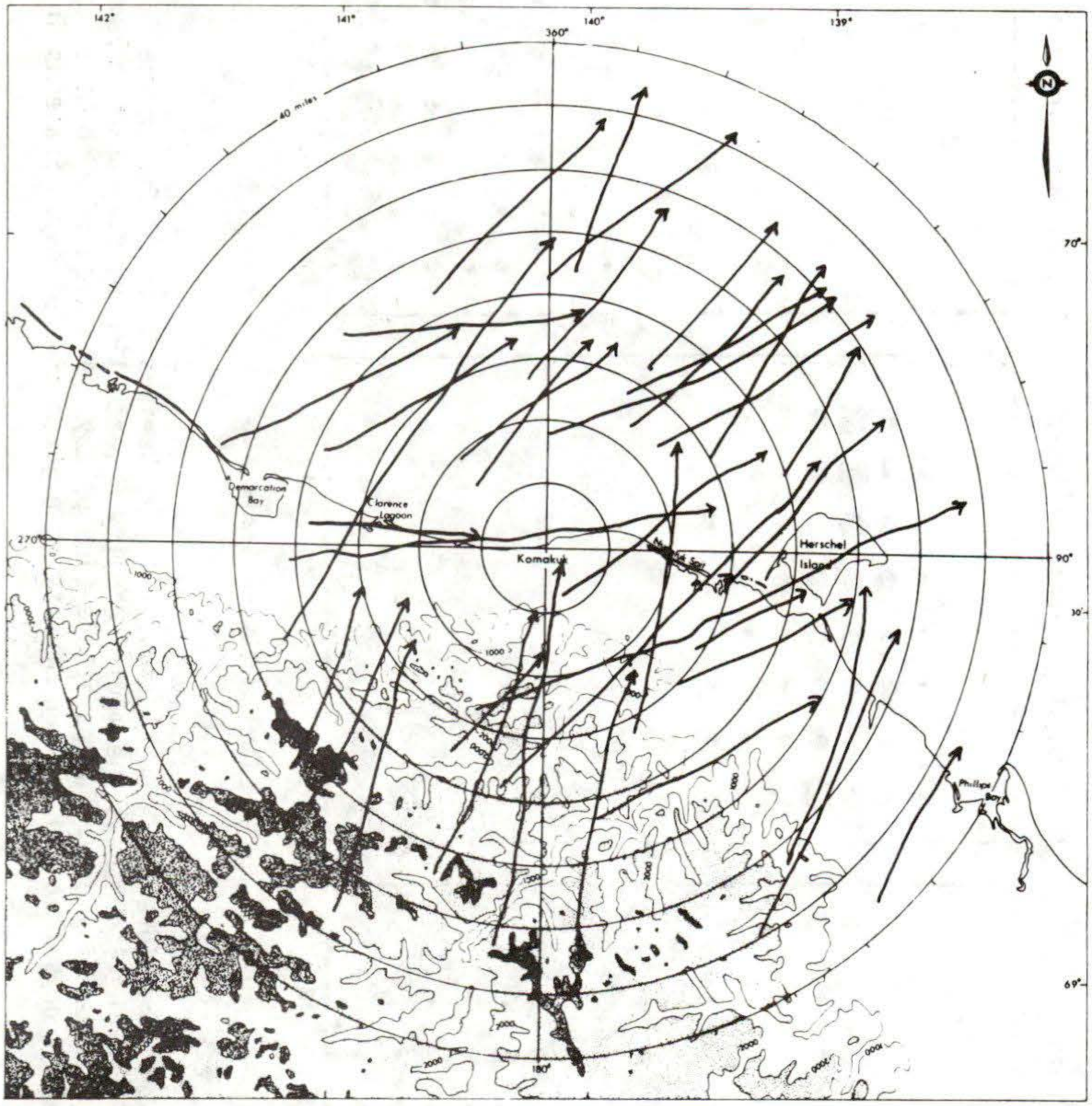

FIGURE 27. Tracing of Paths of Flocks Moving Northeast on a Broad Front on 22-23 June 1975, 20:00-01:00 YST. Simultaneous east-southeast and west-northwest movements are not shown.

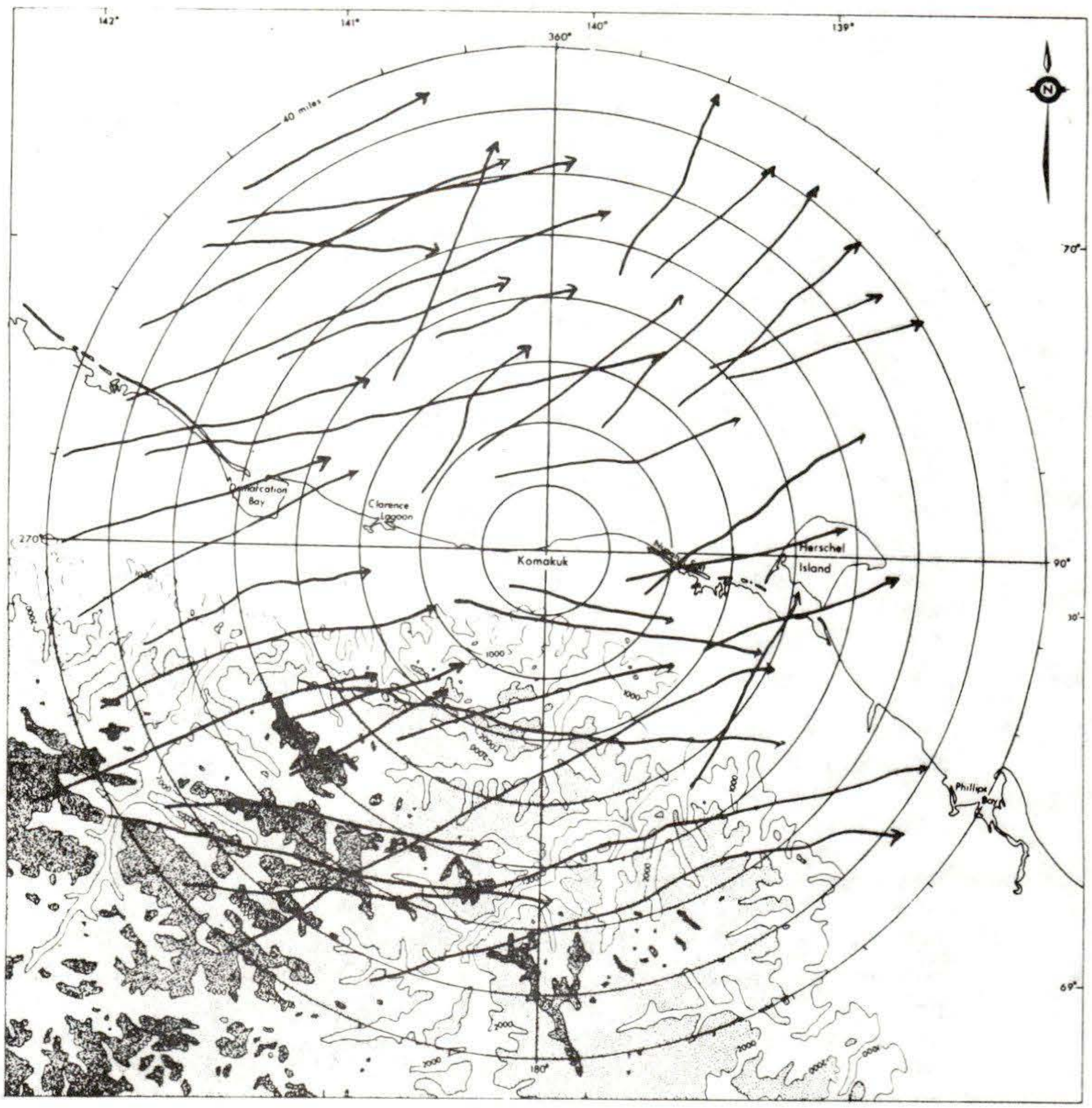

FIGURE 28. Tracing of Paths of Flocks Moving North-northeast to East on 27 May 1975, 04:00-09:00 YST. The distinction between northeast and east movement is unclear on this date. Shorebirds and Glaucous Gulls were the species most commonly detected moving east along the coast at this time, but Brant were noted later in the day. The mean ground speed of flocks shown here was 77 km/hr; their air speeds would be higher, since the wind was easterly.

occasions when no northeastward-moving birds were detectable. Although the northeast movements were often conspicuous on the radar display, at any one time these movements usually involved only a few flocks over the several thousand km^2 being surveyed (Plate 5). During some days in late May and early June, however, as many as 25 to 30 flocks/10 km of front/hr moved northeast.

The northeastward movements were not clearly recognizable in the field, probably because of their low density relative to that of eastward and westward migrations and because of their altitude. (High altitude is implied by the facts that the northeast movements arrived from over the British Mountains and that they were usually detectable to at least 55 and often to 75 km offshore.)

Extent and Directions of Northeastward Migration

The northeastward movements were always on a broad front over land and over the sea. The birds approached from over the British Mountains and Brooks Range; they were often detectable 55 km or more to the south and southwest of Komakuk (Figure 27). They usually continued across the North Slope and coast with no change in direction. Once offshore, most flocks continued to the northeast until they moved out of radar range (or below the radar horizon) 45 to 75 km offshore.

On most of the occasions depicted in Plate 5, the northeastward movement was detectable on the time-lapse films as having occurred farther inland and farther offshore than was apparent on the still photographs. Also, because the movements of all echoes were much more readily apparent on the films than on still photographs, the classes of migrants could be distinguished more readily.

On some days, some of the flocks changed direction from northeast to east after they had moved out over the sea. Usually, the result of this manoeuvre was that the birds joined an eastbound movement in progress offshore. On one day, 29 June, some birds involved in a density two north-northeast movement turned to the west-northwest to north-northwest after having crossed the coast and joined a density 3.3 (offshore) west-northwest movement that was in progress. Birds that did change direction after having moved offshore did so at a wide variety of distances from shore. Some turned within a few kilometres of the coast; others maintained their original track until they were as much as 45 km offshore and then turned. It is possible that birds that were not observed to turn might have done so after having moved out of radar range.

The directions of 'northeastward' migration were quite variable. Mean directions at different times ranged from north to east-northeast (Figure 3). Directions of individual flocks ranged from north-northwest to east-northeast. Figure 29 shows an example of a northbound movement.

Birds that moved northeast across the study area probably took off from interior Alaska. The Yukon Flats are in the direction from which the majority of the birds were coming. Birds that moved north over the study area (e.g., Figure 29) were coming from the direction of the Old Crow Flats, Y.T., and may have taken off from there.

The landfall locations of the birds observed departing over the Beaufort Sea are unknown. Such birds might be *en route* to any of a wide variety of locations depending upon whether these birds followed great-circle routes, rhumb-line routes (i.e., maintained a constant bearing), or some less readily definable routes (Figure 30). Rhumb-line courses would probably be the simplest courses to maintain if a sun-compass mechanism of orientation were used*. However, great-circle routes are often shorter, especially in the Arctic (Figure 30). Regardless of whether the birds were maintaining great-circle or rhumb-line routes, the small number of birds that departed north-northwest, north, and north-northeast would not have encountered land until they reached the north coast of the U.S.S.R. or Greenland unless they changed course. It is possible that many of these birds were disoriented and did not survive. Cases of maladaptive departures over oceans have been discovered elsewhere (e.g., Ralph 1975). It should be emphasized that the number of flocks that departed offshore to the north-northwest, north, and north-northeast was extremely small relative to the numbers that moved east, west, or even northeast.

Species Composition of Northeastward Movements

Little direct evidence concerning the species composition of the northeastward flights is available. Results of observations along the coast during this study provided little relevant information.

Some Brant are known to move from the Yukon River Basin in Alaska north and northeast over the mountains to the Beaufort Sea (Cade 1955; Irving 1960), and one flock has been reported flying northeast 480 km offshore (Barry 1967:75). During the aerial survey on 28 May 1975, flocks of 10 and 30 Brant were seen 135 and 100 km north of Herschel Island, and on 5 June five flocks of 17 to 80 Brant were recorded 25 to 30 km from land. Oldsquaws are the most common ducks that move down the tributaries of the Colville River, in the foothills of the Brooks Range, in spring (Kessel and Cade 1958); because this species migrates east along the coast in large numbers, it is possible that there is also a broad-front northeastward movement over the

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*However, maintenance of a rhumb-line route through use of a sun-compass mechanism would have been considerably complicated by the rapid changes in longitude (and hence in local time relative to chronometer time) that are possible in the Arctic.

PLATE 5. Examples of Northeastward Movement.

A. 17 May 1975, 05:14 YST, display radius 40 n mi (74 km) with 25 n mi (46 km) radius range mark. Northeastward movement visible to 70 km offshore. Note the parallelism of the paths of different flocks.

B. 25 May 1975, 08:20 YST. Same scale as A. Northeastward movement with simultaneous east-southeast (density four) and west-northwest (density 2.7) movements.

C. 29 May 1975, 10:02 YST. Same scale as A. Northeastward movement with simultaneous higher density east-southeast and west-northwest movements, particularly near the coast.

D. 1 June 1975, 09:06 YST. Display radius 22 n mi (40 km) with range marks at 5 n mi (9.25 km) intervals. Low density north-northeast movement with higher density east-northeast and west-southwest movement.

E. 3 June 1975, 15:39 YST. Same scale as A. Low dentisy north-northeast to northeast movement with simultaneous higher density east and west-northwest movement.

F. 11 June 1975, 03:56 YST. Same scale as A. Low density northeast movement with simultaneous higher density east and west-northwest movement.

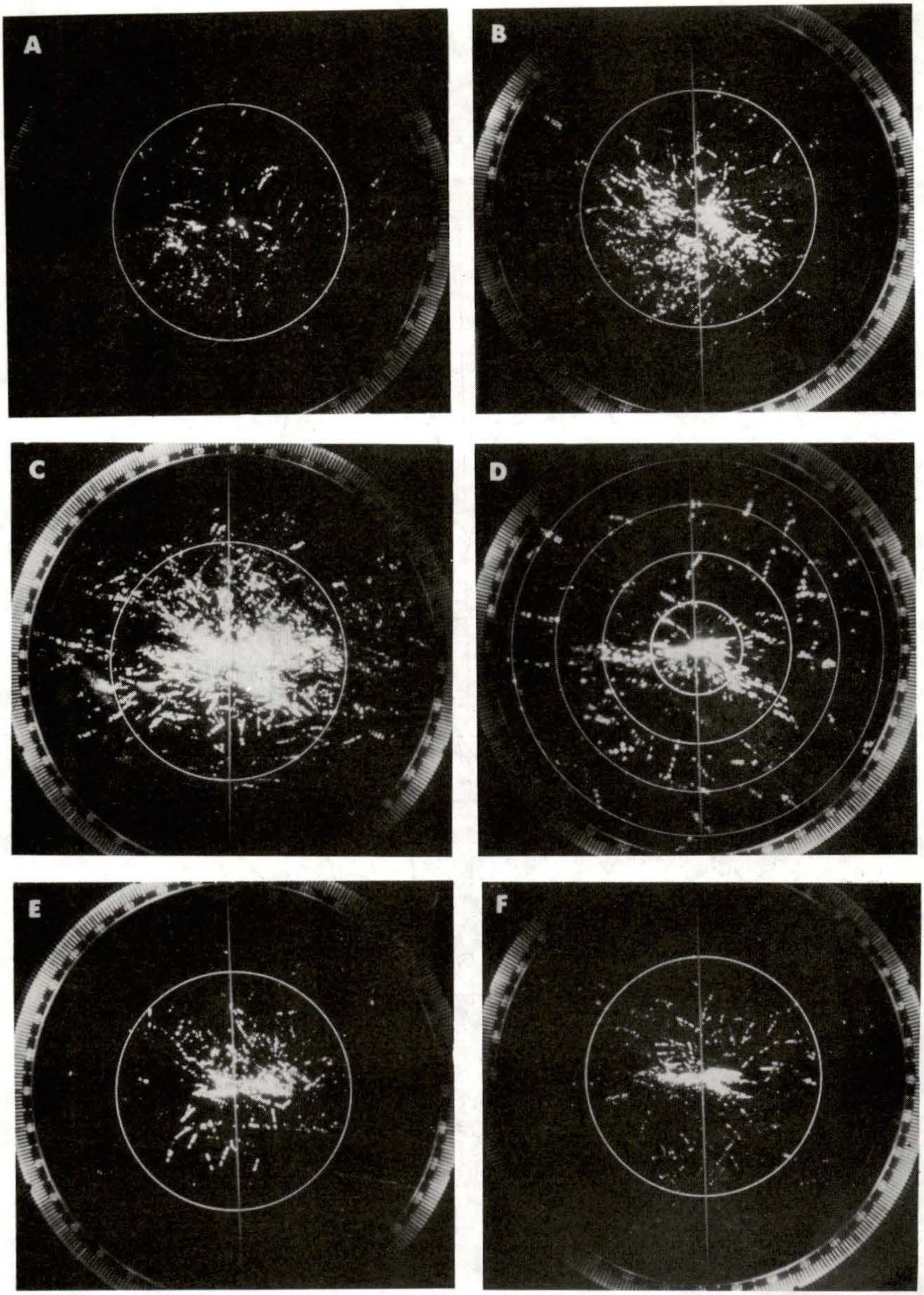

PLATE 5. Examples of Northeastward Movement.

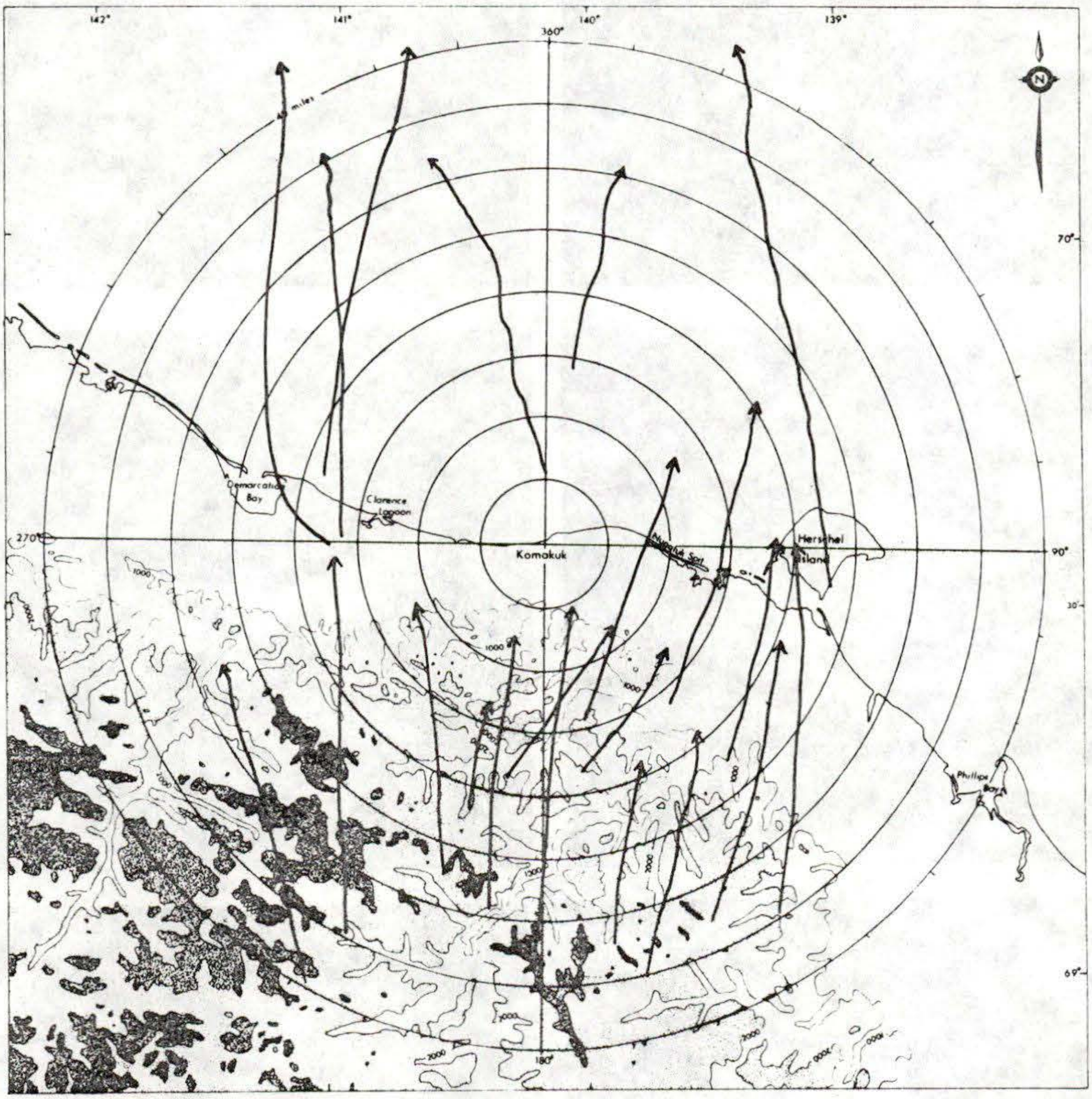

FIGURE 29. Tracing of Paths of Northbound Flocks on 24-25 June 1975, 21:00-02:00 YST. The mean ground speed of these birds was 83 km/hr. There were simultaneous east and west-northwest movements of considerably higher density along the coast and offshore.

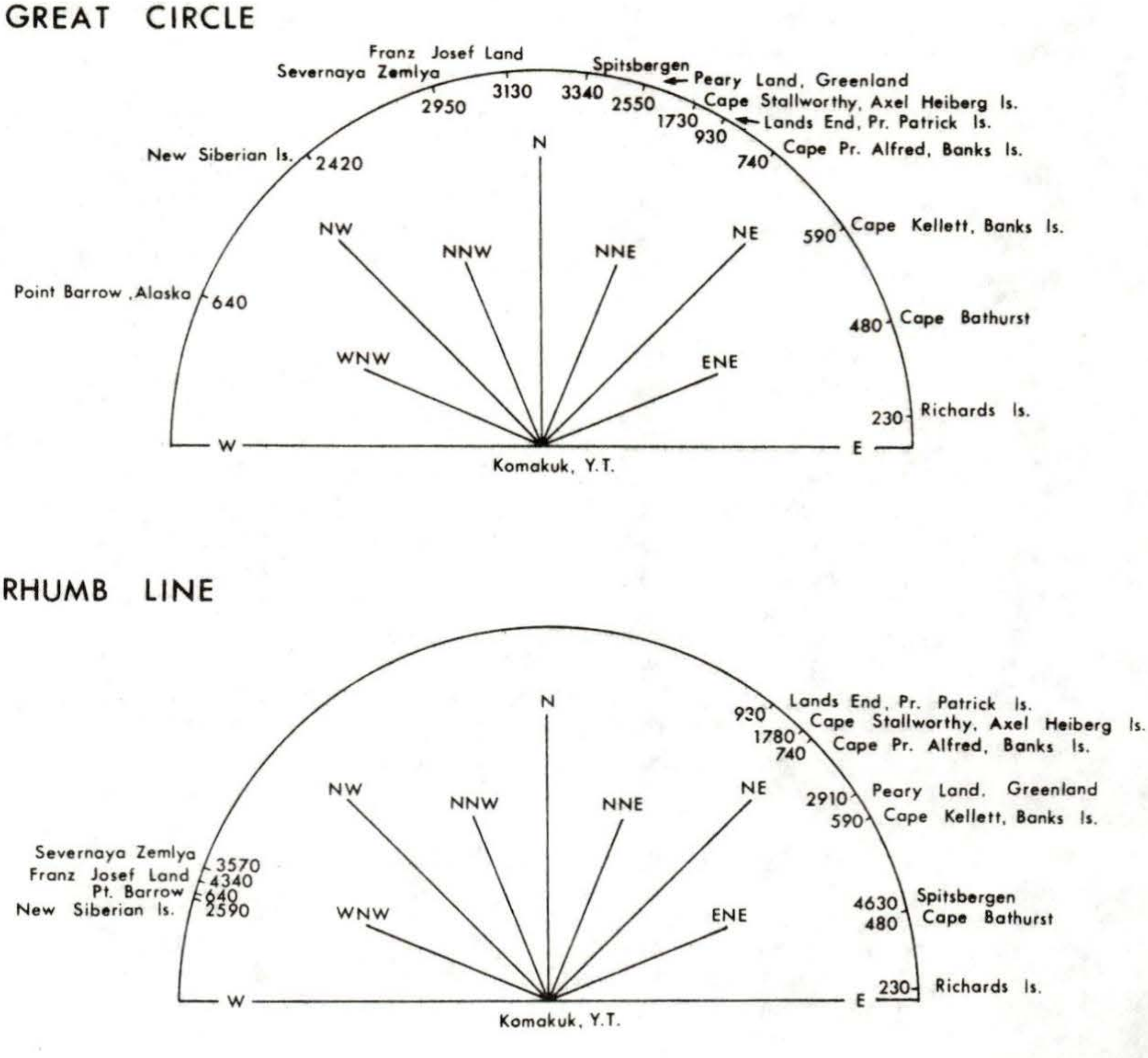

FIGURE 30. Great-circle and Rhumb-line Bearings and Distances (in km) From Komakuk to Various Arctic Locations. Imboden and Imboden (1972) give the methods of calculation.

mountains and Beaufort Sea towards Banks Island, where Oldsquaws are common in summer (Manning *et al.* 1956). Other species of waterfowl that have been seen migrating in significant numbers through the foothills of the Brooks Range in spring (White-fronted Geese, Pintails, White-winged and Surf Scoters [Kessel and Cade 1958; Kessel and Schaller 1960]) are predominantly westbound when observed along the coast and are unlikely to be involved in broad-front movements to the northeast.

Shorebirds of various species are also possible northeastward migrants. Shorebirds routinely migrate very long distances non-stop on a broad front, often at high altitudes (Elliot 1895; Cooke 1910; Henshaw 1910; Stickney 1943; Nisbet 1959, 1963; McNeil and Burton 1973; Richardson in prep.). However, there is no direct evidence that some of the flocks that were moving northeast when detected by radar were shorebirds.

The identity of the birds that moved northeast in mid-May before either shorebirds or waterfowl were seen in significant numbers is especially puzzling (e.g., Plate 5A; Figure 31). The air speed of the birds whose tracks are shown in Figure 31 was approximately 70 km/hr (38 n mi/hr), which seems high for Glaucous Gulls. The only other birds expected to be migrating eastward in large numbers in mid-May would be eiders. Small numbers of eiders have been seen moving northeast and north across northern Alaska in spring (Myres 1958; Johnson 1971). Furthermore, Common Eiders are known to migrate across southern Sweden at moderate and high altitudes (Alerstam *et al.* 1974) and are suspected to undertake similar flights across Finland (Bergman 1974) and New England (Reed 1975). However, available evidence does not indicate that significant numbers of eiders migrate northeast across the interior of northeastern Alaska (Bailey 1948; Gabrielson and Lincoln 1959; Irving 1960).

Hour-to-hour Variations in Numbers

There was no evidence of major systematic differences in the average amount of northeastward migration at different times of day. The median density was slightly lower both inland and offshore around mid-day than early and late in the day (Figure 32).

Visible and Actual Migration

Previous sections have shown that the numbers of migrants observed visually and by radar were not always closely related. The radar showed that extensive eastward migration continued to the end of the study period; however, field observers saw little eastward migration after mid-June (Figures 4, 5). The radar also showed that extensive westward migration occurred over a longer period than was indicated by results of visual observations (Figures 17, 18).

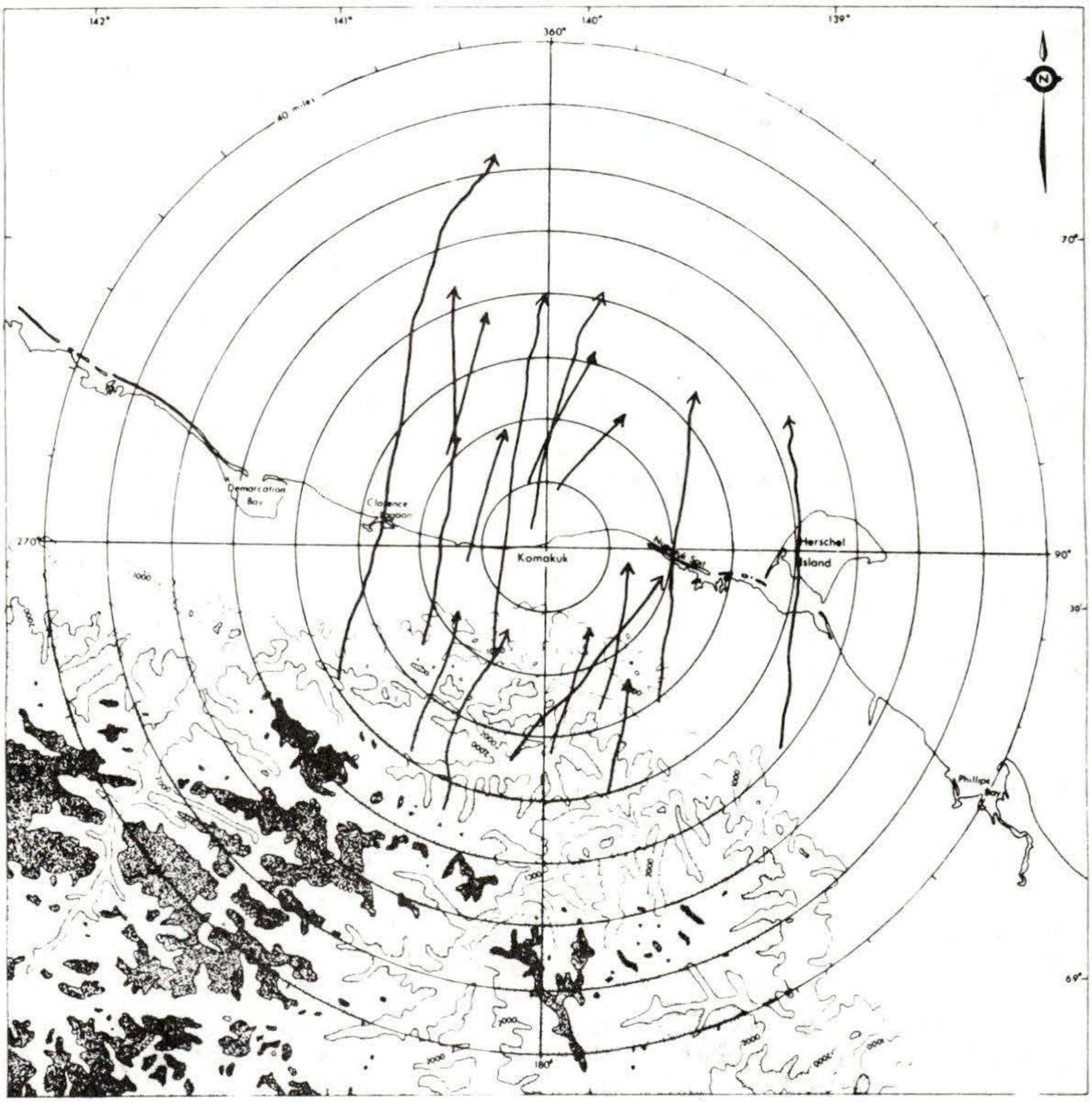

FIGURE 31. Tracing of Paths of Birds Moving North and North-northeast on 14 May 1975, 21:00-00:00 YST. The mean ground speed was 59 km/hr (32 n mi/hr) under strong cross-wind conditions (surface wind 100° at about 40 km/hr). If the wind at the height of the migrants was similar to that at the surface, their headings and airspeeds averaged northeast and 70 km/hr respectively.

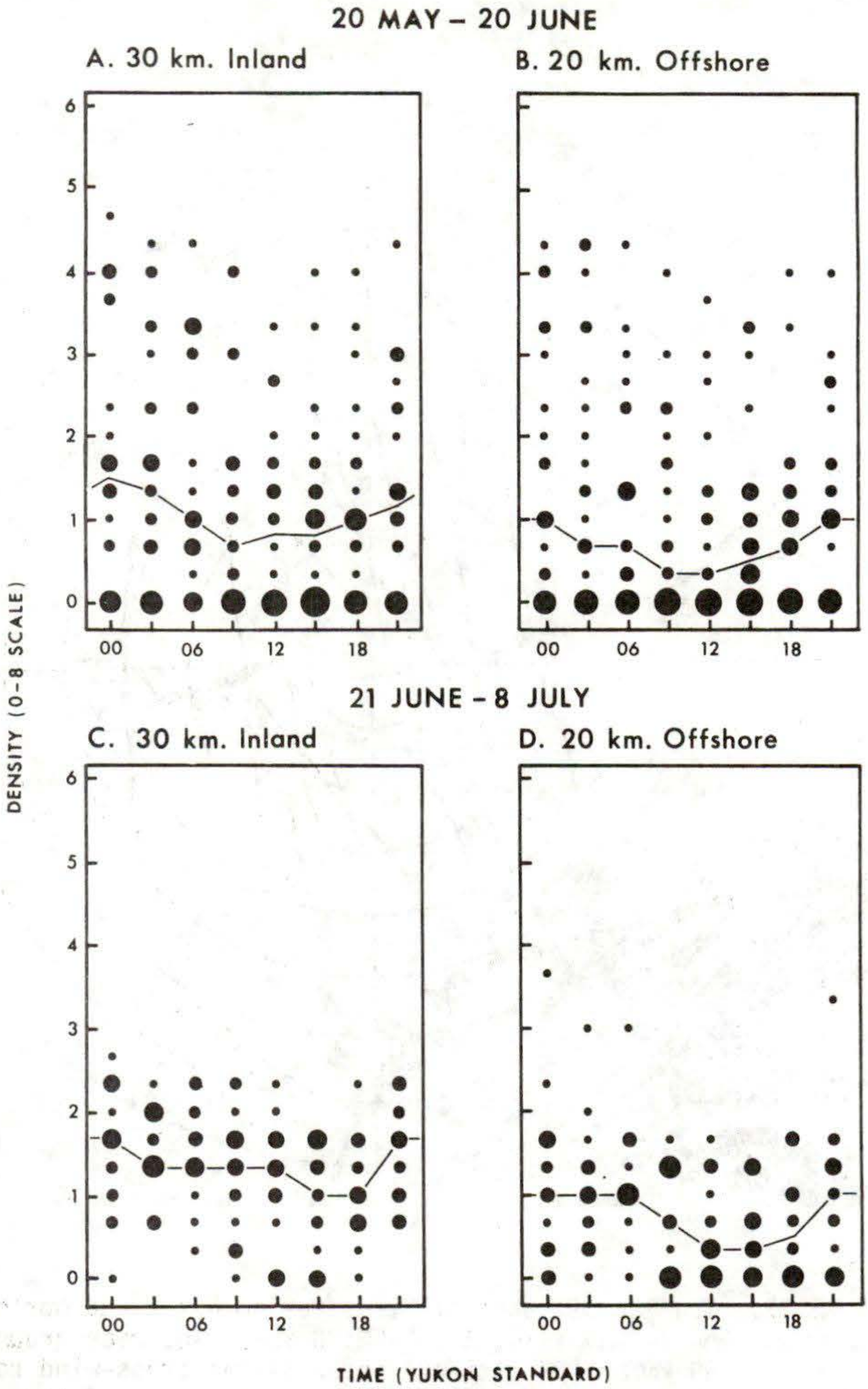

FIGURE 32. Density of Northward and Northeastward Migration Near Komakuk, Y.T., at Various Times of Day. The lines show the median density at each time of day. Each column of data points gives the density distribution at one time of day. The area of a point is proportional to the number of days that had a given density at a given time of day. Scale as in Figure 25.

Over the whole season, the amounts of eastward migration detected each half-day by radar monitoring and visual observation were not significantly correlated (Figure 33). Over the whole season, the amounts of westward migration detected by the two techniques were correlated (Figure 34), but the relationship disappeared when dates before 27 May were excluded. (Before this date few birds were detected by either technique.)

Previous sections have also demonstrated that a substantial fraction of the birds that moved east and west near the Yukon coast were too far inland or offshore to be seen by an observer on the coast. The numbers that moved offshore and to a lesser degree over the mountains were correlated with the numbers that moved along the coast (Figures 7, 20). However, the correlations between numbers aloft over the coast and offshore or over the coast and inland were not sufficiently close to permit estimation of numbers offshore or inland from coastal observations. Moreover, had the correlations been closer than they were, results of visual observations along the coast nevertheless appeared to be biased, and hence unsuitable as the basis for such estimates.

There have been a number of previous studies of the biases inherent in radar and visual techniques of surveying diurnal migration. The following summarizes these biases:

1. Unless a systematic program of 'vertical' watches is conducted (Deelder 1949; Gauthreaux 1971), visual observers fail to detect most high-altitude migrants, particularly small birds such as passerines and shorebirds (Mascher *et al.* 1962; Axell *et al.* 1963; Wilcock 1964; Alerstam and Ulfstrand 1972).
2. Radars detect a larger fraction of the medium- and high-altitude migrants that are present than of the low-altitude migrants (Mascher *et al.* 1962; Axell *et al.* 1963; Wilcock 1964; Alerstam and Ulfstrand 1972). This bias is severe at long range, where the low-altitude migrants are below the radar horizon, but minimal at short range unless there are hills or other obstructions between the birds and the radar (Nathanson 1969; Richardson 1972a).
3. Low-flying birds are more likely to be deflected by topographic 'leading lines' (coasts, rivers, ridges, passes) than are high-flying birds (Deelder 1949; Van Dobben 1953; Axell *et al.* 1963; Evans 1966). Concentrated streams of migrants along leading lines are, therefore, usually at low altitudes. Consequently, visual observers tend to overestimate the fraction of birds that follow leading lines, and radar may underestimate this fraction.
4. Because low-flying birds often move upwind and high-flying birds are less likely to do so, visual observers tend to overestimate the amount of 'upwind' migration, and radar tends to underestimate this amount (Deelder and Tinbergen 1947; Mascher *et al.* 1962; Axell *et al.* 1963; Wilcock 1964; Rabøl and Hindsbo 1972).

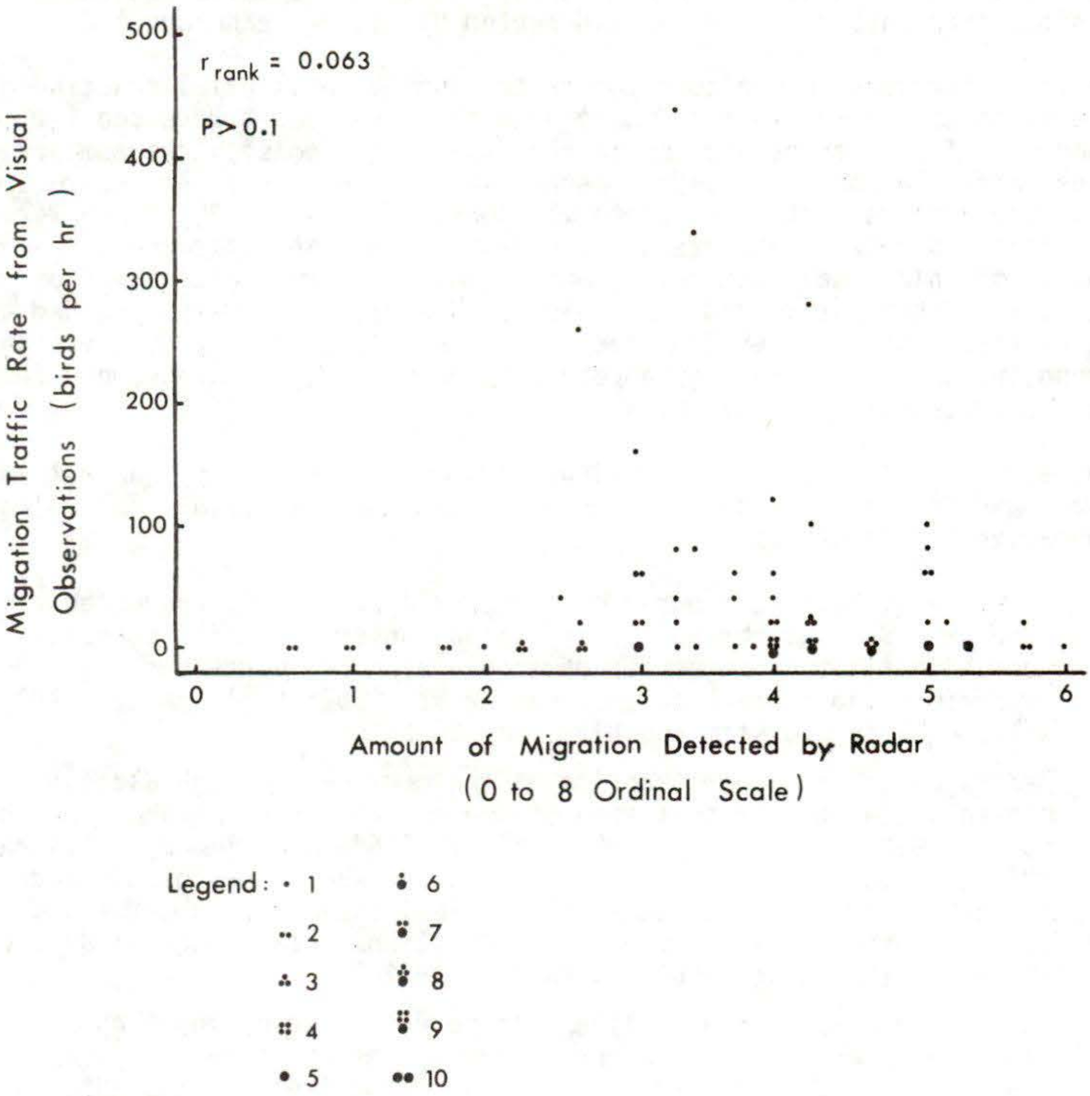

FIGURE 33. Amount of Eastward Migration Detected by Visual Observations at Clarence Lagoon and Komakuk (pooled) *vs.* That Detected by Radar Along the Coast and North Slope. One data point is plotted for each of two periods each day (02:00-10:00 and 14:00-22:00 YST).

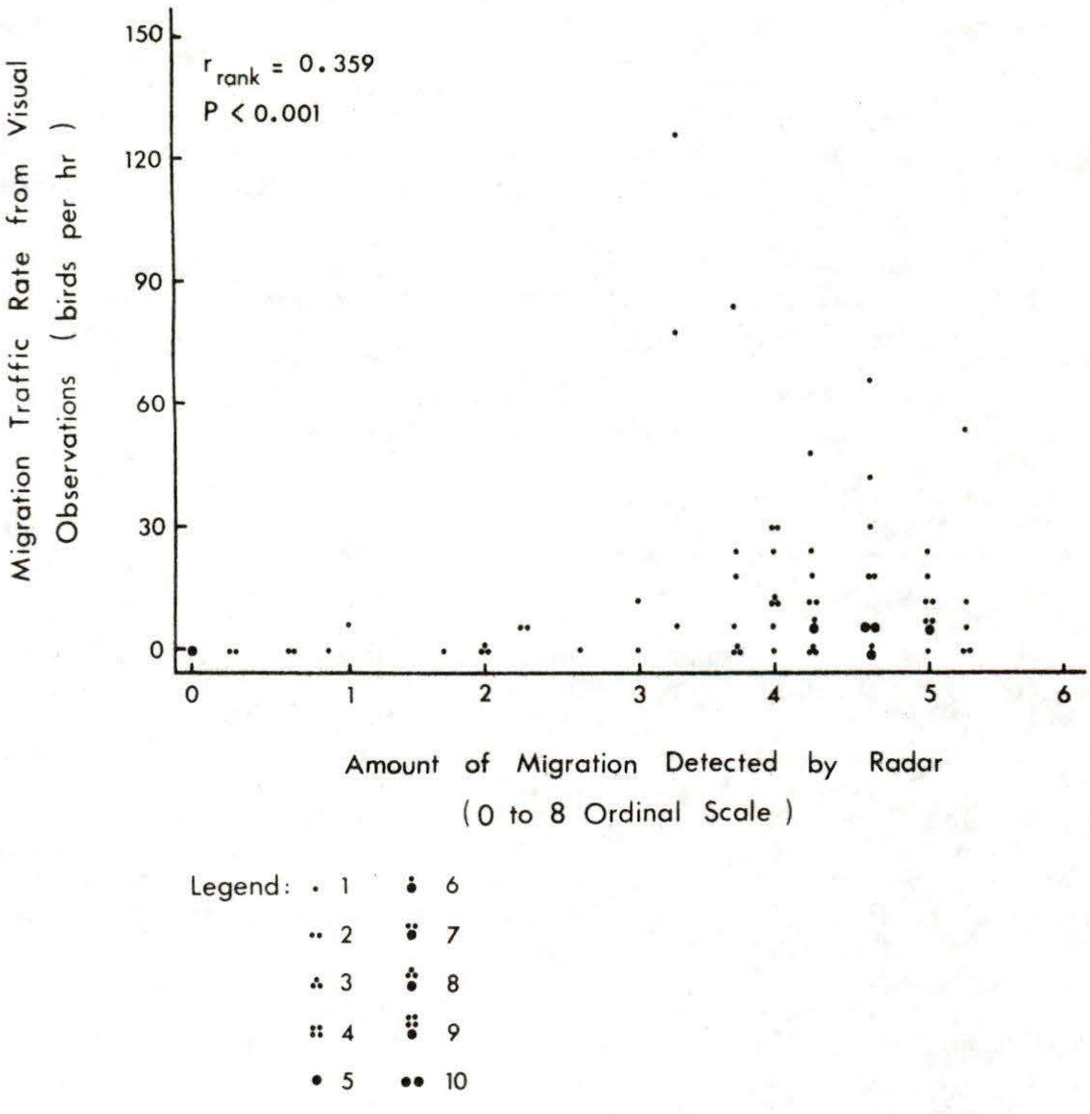

FIGURE 34. Amount of Westward Migration Detected by Visual Observations at Clarence Lagoon and Komakuk (pooled) *vs.* That Detected by Radar Along the Coast and North Slope. One data point is plotted for each of two periods each day (02:00-10:00 and 14:00-22:00 YST).

5. Visual observers can count or estimate the number of individual birds that they see whereas radar records only the number of resolvable groups that pass by. Surveillance radars such as the DEW radars can rarely resolve two birds or flocks that are within 1/2 km or less of each other (Eastwood 1967). Although the echo diameter is to some degree correlated with the size of the flock, no precise or objective estimate of flock size is obtainable from a surveillance radar. Thus, the appearance of x flocks of average size 10 birds on a radar display is very similar to that of x flocks of average size 1000 birds. Although there is some quantitative evidence that flock sizes tend to be positively correlated with the number of individuals aloft (Johnson 1971; Rabøl and Noer 1973), the relationship is not adequately documented and is unlikely to be very precise.

6. Because medium- and high-powered radars can detect birds over an area of several thousand km^2, movements of extremely low density are readily observed with radar. Even if such a movement continued all day, it would be unlikely that visual observers would see a single flock; even if they did, they would be unable to recognize its significance as a part of a broad-front movement.

These differences in the capabilities and biases of the radar and visual techniques probably account for a considerable proportion of the apparent differences in migration patterns indicated by the results of the two methods during the present study.

It is probable that the visual observers were unable to record passerine and shorebird migration to any significant extent. Very few individuals of these groups were seen migrating relative to the numbers known to occur on the Yukon North Slope (Richardson and Gollop 1974; Salter and Davis 1974; Tull *et al.* 1974; Koski 1975). Radar doubtless recorded at least the shorebird migration to a greater extent than did visual observers. Unfortunately, it was rarely possible to distinguish shorebirds from other migrants on the basis of radar data alone, and little complementary visual information on shorebirds, which would have provided the basis for identification, was available.

The northeastward and northward movements were not recorded or identified by the visual observers. This was probably in part the result of the paucity of flocks involved in these movements and in part the result of their broad-front nature and probable high altitude.

The differences in the apparent seasonal patterns of numbers were partially the result of the fact that large flocks of waterfowl were aloft during late May and early June. These flocks were recorded by visual observers in terms of the impressive numbers of individual birds aloft and by radar in terms of the considerably less impressive numbers of flocks aloft. Another factor that contributed to the apparent differences in seasonal patterns of numbers was the fact that the degree of concentration along the coast was greater during the early and middle parts than during the later part of the field season. Radar, which surveyed the broad area, did not record reduced numbers late in the season; however, visual observers located in areas of coastal bird concentrations did record a reduction in numbers within their smaller areas of observation.

Weather *vs.* Migration

At temperate latitudes the timing of migration has been shown to be closely related to weather (e.g., Lack 1960b, 1963; Nisbet and Drury 1968; Richardson 1975); most birds tend to migrate in largest numbers when the wind is following relative to their 'preferred' direction of travel.

In the Arctic, breeding success and the phenology of the annual cycle are strongly related to weather (see Barry 1962, 1967; Immelmann 1973), but there has been little systematic study of the effects of daily weather on day-to-day variations in the amount of migration. However, larger numbers of eiders have been reported to fly past Point Barrow with following than with opposing winds (Thompson and Person 1963; Johnson 1971). Figures 2, 35, 36 show the relationships between snow and ice melt in 1975 and the timing of migration on the Yukon north coast.

We have used the radar data collected at Komakuk in 1975 as the basis for an examination of the relationships of migration volume near the Yukon coast to weather. Visual observations were not analyzed relative to weather, partly because of time constraints and partly because the periods of significant migration of most species were too brief to provide an adequate sample size (one day, or at best one half-day, constitutes one unit of observation in such an analysis).

Methods of Analysis

Four different measurements of migration were examined relative to 13 weather parameters. Because weather conditions are interrelated and because migration is commonly related to many weather variables, it was necessary to apply multivariate techniques. Stepwise Multiple Regression Analysis (henceforth abbreviated SMRA) was used to summarize the simultaneous relationships of these weather variables to migration.

The four measurements of migration volume that were considered were as follows:

1. density of westward movement 20 km offshore (zero to eight scale);
2. density of eastward movement 20 km offshore (zero to eight scale);
3. density of westward movement along the shore and over the North Slope (zero to eight scale);

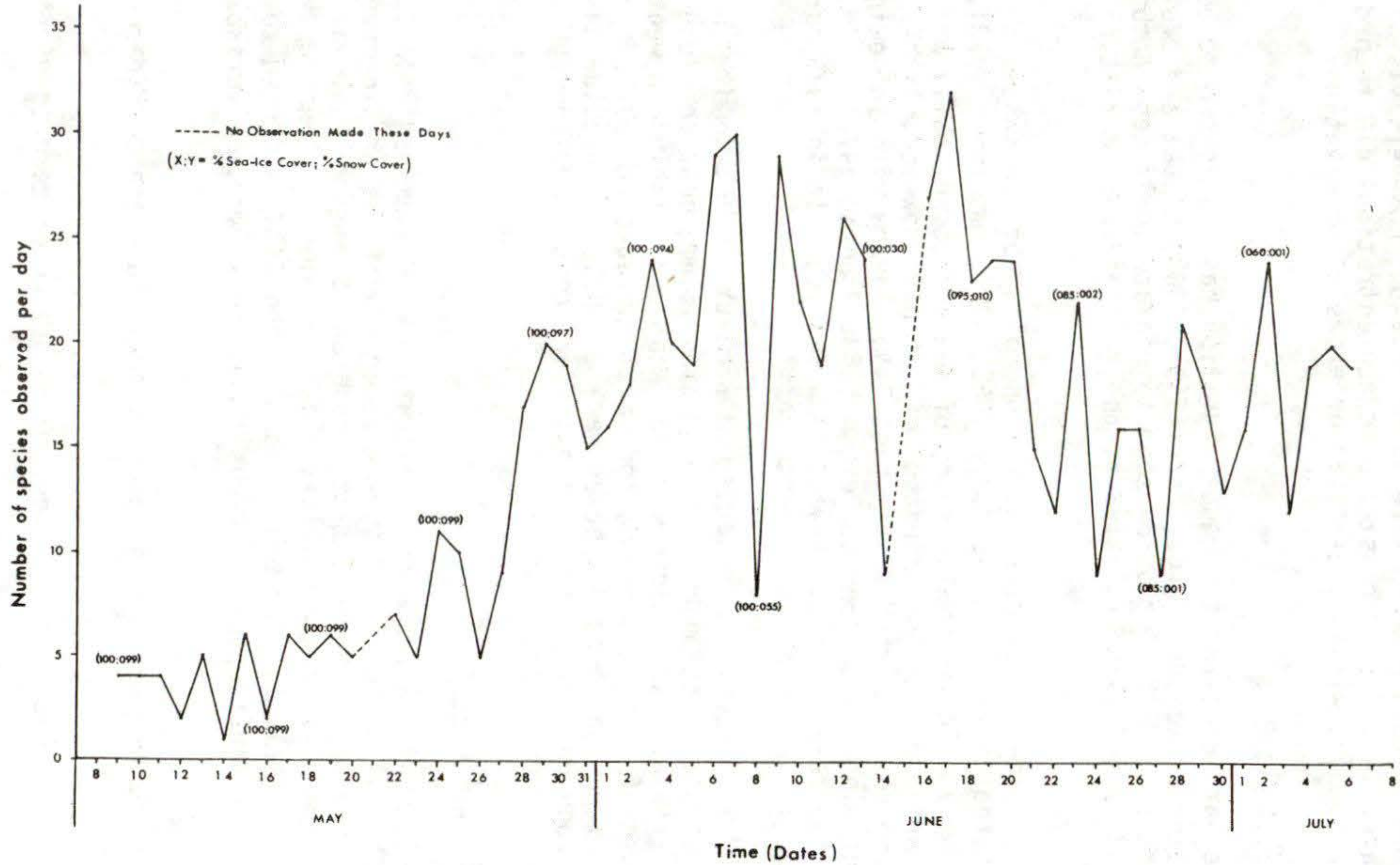

FIGURE 35. Number of Species Seen Each Day at Komakuk. The percent of the sea covered by ice (first value) and of the ground covered by snow (second value) is given every five days.

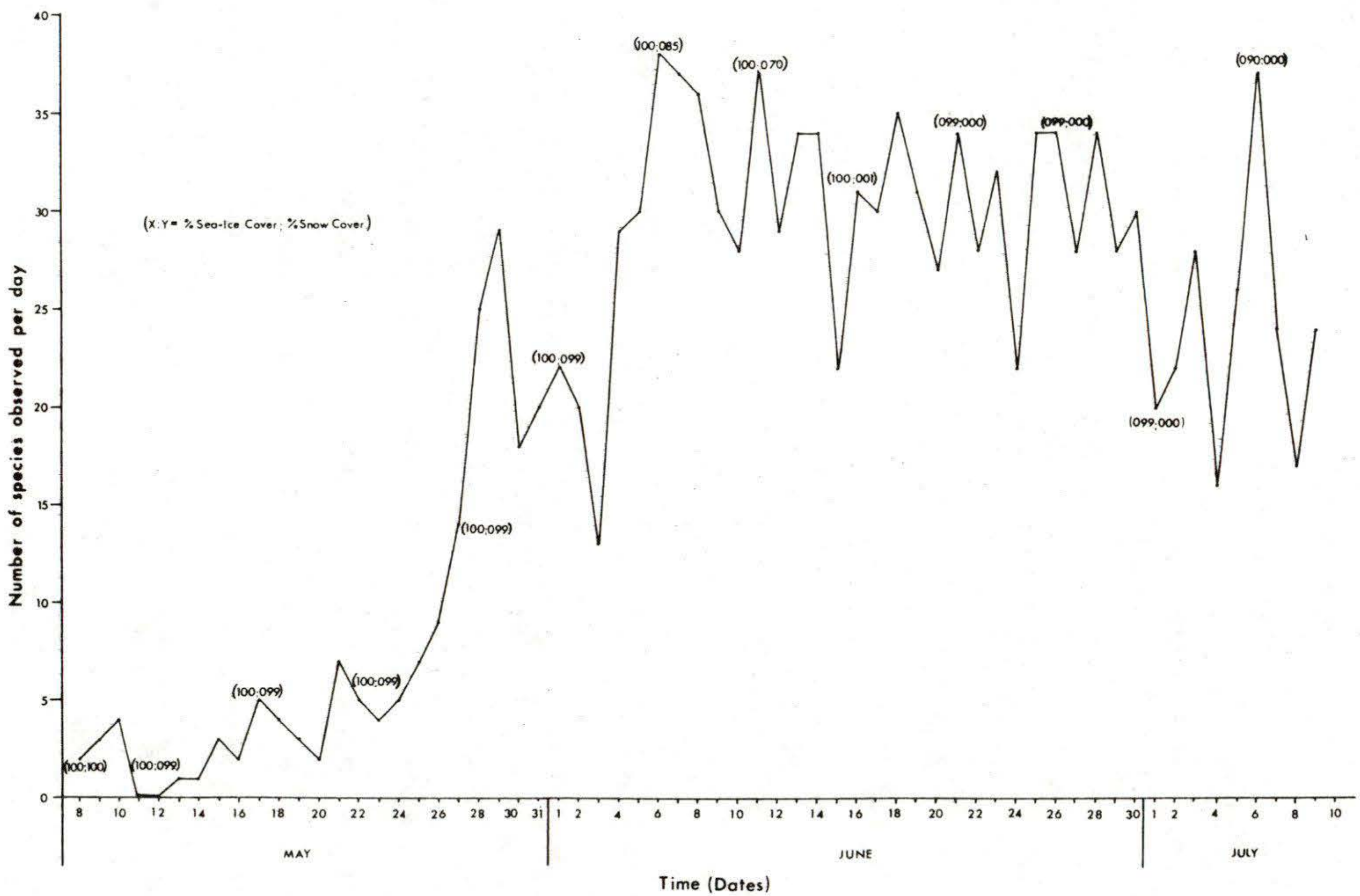

FIGURE 36. Number of Species Seen Each Day at Clarence Lagoon. The percent of the sea covered by ice (first value) and of the ground covered by snow (second value) is given every five days.

4. density of eastward movement along the shore and over the North Slope (zero to eight scale).

The 13 weather variables used in each of the four analyses were as follows:

1. ceiling (measured on the one to six scale described by Richardson [1974a]);
2. visibility (square root of recorded visibility, in mi);
3. precipitation (0 to 11 scale, in ascending order of assumed severity*);
4. clear/haze/fog (0 = none; 1 = haze; 2 = fog);
5. barometric pressure (in millibars minus 1000);
6. 6-hr pressure trend (in millibars, + or -);
7. 24-hr temperature trend (in °F, + or -);
8. temperature relative to normal (in °F)**;
9. east-west component of the surface wind (in knots, east winds + and west winds -)***;
10. north-south component of the surface wind (in knots, north winds + and south winds -)***;
11. relative humidity (in %);
12. 24-hr relative humidity trend (in % + or -);
13. opacity (proportion of sky covered by opaque cloud, in tenths).

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* 0 = No Precipitation
1 = Drizzle
2 = Rain Shower
3 = Snow Shower
4 = Rain
5 = Snow
6 = Snow Pellets or Grains
7 = Thunderstorm
8 = Freezing Drizzle
9 = Freezing Rain
10 = Ice Pellets
11 = Hail

** Normal value for each date and time determined from fitted trend line on date.

*** Obtained by trigonometrically resolving the recorded wind direction (Θ) and speed (s) i.e., east-west component = $s \sin \Theta$
north-south component = $s \cos \Theta$

The variables listed above were considered because they have often been found to be related to the amount of migration (e.g., Lack 1960b). The specific scales mentioned above were chosen because experience has shown that they meet the SMRA assumptions of linearity, normality, and homogeneity of variance (Richardson 1974a, 1975). The appropriateness of these scales to the present study and the accuracy of these assumptions were confirmed by examination of the residuals of the SMRA analyses (Anscombe and Tukey 1963; Draper and Smith 1966). Analysis of residuals also confirmed that use of the zero to eight ordinal scale of densities was an acceptable scaling procedure.

For purposes of analysis, the two-month study period was divided into half-day intervals that were considered in the compilation of Figures 4, 17 and others were used--03:00-09:00 YST and 15:00-21:00 YST each day. The median densities of eastward and westward movement in each interval were the basic measurements used.

The weather data were extracted from the records of the Komakuk DEW station. The averages of weather observations at 03:00 and 09:00 YST were used in association with the 'morning' radar observations; the averages of weather observations at 15:00 and 21:00 YST were used in association with the 'afternoon' radar observations.

The subdivision of each day into two units could have two undesirable consequences:

1. One or more of the dependent variables might be systematically different at one time of the day than at the other.

2. The densities in adjacent 12-hr intervals might not be independent.

The first potential problem was eliminated by consideration of a 14th predictor variable--whether the 12-hr period was a morning (1) or an afternoon (2). The second potential problem is less readily avoided. In previous studies, autocorrelation analysis has been applied to the residuals in order to confirm that temporally-adjacent cases were statistically independent (Nisbet and Drury 1968; Richardson 1974a, 1975). This technique was not attempted here because of time limitations. In practice, the result of any lack of independence between adjacent cases would be a slight reduction in the degrees of freedom associated with the statistical tests reported below. However, even if the degrees of freedom were reduced to 50% of their assumed values, none of the results or interpretations would change appreciably (i.e., none of the relationships that are listed in Table 3 as significant at the $P \leq 0.05$ level would become non-significant at that level, and none of the relationships would drop in significance by more than one of the levels listed in the footnote to Table 3.

The volume of most classes of migration recorded in 1975 was obviously correlated with date--there was less movement in May than in June or July (Figures 4, 17). In order to minimize the confounding effect of date, the day of the year (1 = 1 January; 129 = 9 May; 190 = 9 July; 365 = 31 December) was considered as the 15th predictor. Furthermore, because the relationship of migration volume to date is likely to be non-linear, the square of the date was considered as a potential 16th predictor variable. Simultaneous inclusion of date and date^2 as terms in a multiple regression equation permits one to identify tendencies for the values of the dependent variables to 'level out' or to first increase and then decrease when plotted against date.

SMRA was performed using the BMD02R computer program (Dixon 1973) with a $P \leq 0.1$ criterion for inclusion of predictor variables*.

Results

Table 3 summarizes the results of the SMRA of four measurements of migration volume.

Westward Migration

Both near the coast and 20 km offshore, the volume of migration was positively correlated with date but negatively correlated with the square of the date. These correlations reflect the fact that the average volume of migration increased sharply from early May to early June, but leveled off (or, in the case of offshore migration, declined) thereafter; Figure 17 shows these relationships.

Both coastally and offshore, the amount of westward migration was significantly greater ($P < 0.01$) in the morning than in the afternoon after the effects of other factors had been accounted for. This difference was clearly evident offshore even before other factors had been considered (Figures 25A and 26A; Table 3, line 14, column A), but it was not evident near the coast prior to consideration of the east-west wind component (Figures 25B and 26B; Table 3, line 14, column C).

Both coastally and offshore the amount of westward migration was very strongly correlated with the east-west component of the wind ($P << 0.001$). The consistent positive sign on this relationship (Table 3), together with the fact that winds from the east were assigned a positive east-west component whereas those from the west were assigned a negative component, shows that many more birds moved west when the winds

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* i.e., Predictor variables were added to the regression equation in descending order of partial correlation to the dependent variable until none of the remaining excluded variables would, if included, increase the predictability of the dependent variable by an amount significant at the $P \leq 0.1$ level. A $P < 0.2$ criterion for deletion of previously-included variables was also used, but no variable--once included--was deleted during any of the four SMRA runs, since the significance of the partial correlation of included variables never decreased to the $P < 0.2$ level.

TABLE 3. Summary of Stepwise Multiple Regression Analyses of the Density of Migration Relative to Sixteen Potential Predictor Variables†.

PREDICTOR VARIABLE	WESTWARD MOVEMENT				EASTWARD MOVEMENT			
	20 km OFFSHORE		COASTAL		20 km OFFSHORE		COASTAL	
	A. PRELIMINARY	B. FINAL	C. PRELIMINARY	D. FINAL	E. PRELIMINARY	F. FINAL	G. PRELIMINARY	H. FINAL
1. Ceiling	ns	ns	ns	ns	-*	ns	ns	ns
2. Visibility	ns	ns	ns	ns	ns	+**	+*	+**
3. Precipitation	ns	ns	ns	ns	ns	ns	-(*)	ns
4. Clear/Haze/Fog	ns	ns	ns	ns	ns	ns	ns	ns
5. Barometric Pressure	ns	ns	ns	ns	ns	ns	ns	ns
6. Six-hour Pressure Trend	-**	ns	-**	ns	+****	+**	+***	+*
7. Twenty-four-hour Temperature Trend	ns	ns	+*	+(*)	-(*)	ns	ns	ns
8. Temperature Relative to Normal	+(*)	ns	+*	ns	ns	ns	-**	-(*)
9. East-West Wind Component	+****	+****	+****	+****	-***	-(*)	-****	-**
10. North-South Wind Component	ns	ns	-(*)	ns	ns	ns	ns	ns
11. Relative Humidity	ns	ns	ns	ns	ns	ns	ns	ns
12. Twenty-four-hour Relative Humidity Trend	ns	ns	ns	ns	ns	ns	ns	ns
13. Opacity	-(*)	ns	ns	ns	+**	+*	+(*)	ns
14. AM or PM	-(*)	-**	ns	-**	-*	-*	ns	ns
15. Date	+**	+**	+****	+****	ns	ns	+**	+***
16. (Date)^2	-**	-*	-****	-****	ns	+(*)	-*	-***
17. Multiple Correlation Coefficient (R)	0.474	0.674	0.812	0.889	0.540	0.750	0.762	0.847
18. Percent Variance Explained	22.5	45.4	66.0	79.0	29.2	56.2	58.1	71.7
19. Standard Error of Estimate	1.149	0.976	0.910	0.726	1.342	1.084	0.897	0.753
20. Mean Density	---------1.873---------		---------3.644---------		---------2.042---------		---------3.669---------	
21. Standard Deviation of Density	---------1.292---------		---------1.544---------		---------1.579---------		---------1.371---------	

† the sign and significance level of the partial correlations between predictor variables and migration volume are given. For each of the four categories of movement analyzed (eastward and westward along the coast and 20 km offshore), two sets of significance levels are given:

1. The columns headed 'Preliminary' show the partial correlation of predictors 1 through 14 to migration volume after the two date terms (predictors 15 and 16) have been considered. Examination of these columns shows the 'simple' correlation of migration volume and the designated predictor (1 through 14) after the confounding effects of the systematic seasonal variation in numbers had been accounted for.

2. The columns headed 'Final' show the partial correlation of all predictors to migration volume when all are considered simultaneously. Significance levels are given as:

   ns if $P > 0.1$
   (*) if $0.1 > P > 0.05$
   * if $0.05 \geq P > 0.01$
   ** if $0.01 \geq P > 0.001$
   *** if $P \leq 0.001$
   **** if $P \ll 0.001$ (F-ratio at least twice that for $P = 0.001$)

were easterly (following) than when they were westerly (opposing).

Both coastally and offshore, there was a negative correlation between the 6-hr pressure trend and the amount of westward migration after the confounding effects of date were accounted for (Table 3, line 6, columns A and C). There was significantly less movement with increasing than with decreasing barometric pressure ($P < 0.01$). However, this correlation (along with weaker correlations of migration and temperature) disappeared after the east-west wind component was considered (columns B and D). Examination of the matrix of simple correlations among weather variables (Table 4) provides the explanation. Easterly winds tended to occur at times with decreasing pressure ($r = -0.497$; $P < 0.001$) and, to a lesser degree, at times with high temperature ($r = 0.261$; $P < 0.01$). Before the wind was considered as a predictor, consideration of pressure trend or temperature permitted some degree of prediction of migration volume. However, once the strong relationship of wind direction to the amount of westward migration had been included in the prediction equation, consideration of parameters correlated with wind direction--pressure trend and temperature--did not improve the predictability of migration volume.

This result is a consequence of the interrelationships among the weather variables. It demonstrates the fact that multivariate analysis cannot reveal the precise weather variables to which birds respond--it can only provide a description of the interrelationships of dependent and predictor variables (see Richardson 1974a for further discussion).

None of the other weather variables was significantly related to the amount of westward migration either before or after other weather variables had been considered (Table 3).

Eastward Migration

Near the coast, the amount of eastward migration, like the amount of westward migration, increased rapidly early in the study period but then tended to level off (Figure 4). This is reflected in the positive correlation with date ($P < 0.001$) and negative correlation with the square of the date ($P < 0.001$).

Offshore, however, a general tendency for a gradually increasing amount of eastward migration with date was complicated by the frequent absence of eastward movement in mid-June (Figure 4). The multivariate analysis showed little correlation between date and the amount of eastward migration offshore.

Offshore, there was a slight tendency ($P < 0.05$) for there to be less migration in the afternoon than in the morning (Table 3;

TABLE 4. Means, Standard Deviations and Matrix of Simple Correlation Coefficients for Variables Considered as Potential Predictors of Migration Volume and Characteristics*.

VARIABLE	AM (1) OR PM (2)	CEILING	VISIBILITY	PRECIPITATION	CLEAR (0)/ HAZE (1)/FOG (2)	BAROMETRIC PRESSURE	SIX-HOUR PRESSURE TREND	TWENTY-FOUR-HOUR TEMPERATURE TREND
Date	-0.030	0.054	0.076	-0.315	0.047	-0.415	0.097	-0.006
AM or PM	1.000	0.221	0.332	-0.144	-0.318	0.014	-0.113	0.004
Ceiling		1.000	0.414	0.093	-0.393	-0.176	-0.289	0.218
Visibility			1.000	-0.441	-0.717	0.029	-0.069	0.113
Precipitation				1.000	0.186	0.090	-0.026	-0.021
Clear/Haze/Fog					1.000	-0.074	0.112	-0.159
Barometric Pressure						1.000	0.071	-0.202
Six-hour Pressure Trend							1.000	-0.345
Twenty-four-hour Temperature Trend								1.000

VARIABLE	EAST-WEST WIND COMPONENT	NORTH-SOUTH WIND COMPONENT	RELATIVE HUMIDITY	TWENTY-FOUR-HOUR RELATIVE HUMIDITY TREND	CLOUD OPACITY	TEMPERATURE RELATIVE TO NORMAL	$(DATE)^2$	MEAN	STANDARD DEVIATION
Date	-0.283	0.157	-0.179	0.029	0.083	0.102	0.999	159.3	16.6
AM or PM	0.156	0.120	-0.310	-0.066	-0.192	-0.049	-0.030	1.5	0.5
Ceiling	0.104	-0.254	-0.593	-0.254	-0.834	-0.020	0.059	3.8	1.5
Visibility	-0.108	0.004	-0.417	-0.143	-0.309	0.037	0.074	3.4	0.9
Precipitation	0.244	-0.377	-0.018	0.049	-0.050	-0.025	-0.306	0.6	2.1
Clear/Haze/Fog	-0.029	0.102	0.335	0.150	0.308	-0.050	0.049	0.3	0.5
Barometric Pressure	0.168	0.104	0.195	-0.120	0.125	-0.151	-0.413	14.7	7.6
Six-hour Pressure Trend	-0.497	0.249	0.278	0.227	0.440	-0.102	0.099	0.0	1.8
Twenty-four-hour Temperature Trend	0.126	-0.377	-0.410	-0.425	-0.317	0.540	-0.014	0.2	4.4
East-West Wind Component	1.00	-0.222	0.014	-0.101	-0.238	0.261	-0.288	4.9	10.9
North-South Wind Component		1.00	0.154	0.134	0.316	-0.152	0.154	0.1	2.4
Relative Humidity			1.000	0.490	0.487	-0.154	-0.181	90.5	5.0
Twenty-four-hour Relative Humidity Trend				1.000	0.272	-0.080	0.030	-0.2	5.3
Cloud Opacity					1.000	0.010	0.080	7.5	2.7
Temperature Relative to Normal						1.000	0.096	-0.2	4.4
$(Date)^2$							1.000	25636.9	5280.6

* scaling procedures are outlined in the text. Correlations are significant at the $P < 0.05$ level (two-sided) if their absolute values exceed 0.195, at the $P \leq 0.01$ level if they exceed 0.254, and at the $P \leq 0.001$ level if they exceed 0.321.

see also Figure 15A). Near the coast, however, the tendency was not significant ($P > 0.1$: Figure 15B).

Both coastally and offshore, there were strong tendencies for there to be more eastward movement with westerly than with easterly winds and with rising than with falling pressure (Table 3; columns E,G). However, once one of these interrelated parameters was included as a predictor, the residual value of the second as a predictor decreased considerably. The apparent significance of the partial correlation of migration volume to pressure trend and wind was further reduced by the addition to the regression equation of other weather variables (opacity, temperature) that were weakly correlated to pressure trend and wind (Table 4). The effects of these interrelated weather variables on the volume of eastward migration could not be separated. In summary, the amount of eastward migration tended to be greatest with rising pressure, westerly winds, and good visibility. Less consistent relationships of high migration volume to low temperature and cloudy skies were also evident.

Discussion

The weather conditions that appeared to be most favourable to eastward and westward migration were very different; birds moved east in largest numbers with westerly winds and rising pressure, whereas they moved west in largest numbers with easterly winds and falling pressure. Thus, during spring migration in the Beaufort Sea area, as at temperate latitudes, birds apparently tend to migrate on days when the wind is following relative to their flight direction.

The multiple regression models accounted for moderate to high proportions of the day-to-day variance in amount of migration (45.4 to 79.0%--Table 3; line 18, columns B, D, F, and H). These values are comparable to results obtained using similar methods in New England (Nisbet and Drury 1968), the southeastern United States (Able 1973), Puerto Rico, and the Maritime provinces (Richardson 1974a, b, 1975). However, a large fraction of the variance in the present study was accounted for by the regression of migration volume on date (Table 3; line 18, columns A, C, E, and G), whereas in the studies cited above little of the variance was accounted for by factors other than weather. Hence, the relationships of the amount of spring migration to weather appear to be less precise in the Beaufort Sea area than at temperate latitudes. This result, if confirmed by future work, would be in accordance with the view that Arctic birds must, because of the brevity of Arctic summer, move towards their breeding grounds as soon as climatic conditions (e.g., snow and ice cover) permit, even if the weather is not ideal for migration.

It should be noted that conclusions based on data collected in only

1 yr are of unproven generality. Furthermore, the inability to separate species when dealing with radar data and the necessity of treating the entire two-month period as a unit further limit the results. If radar data were available for more than one spring season--i.e., if the sample size were larger--, it would be possible to analyze shorter segments of the season as units. If visual data were available for more than one spring season, there would be sufficient data to permit analysis of the timing of migration relative to weather on a species-by-species basis. Nonetheless, the present study has demonstrated quantitatively that in spring, the amount of migration each day in the Beaufort Sea area is related to weather, and has documented for the first time in that area various basic interrelationships among weather and migration variables.

Results of Aerial Surveys

14 May Aerial Survey

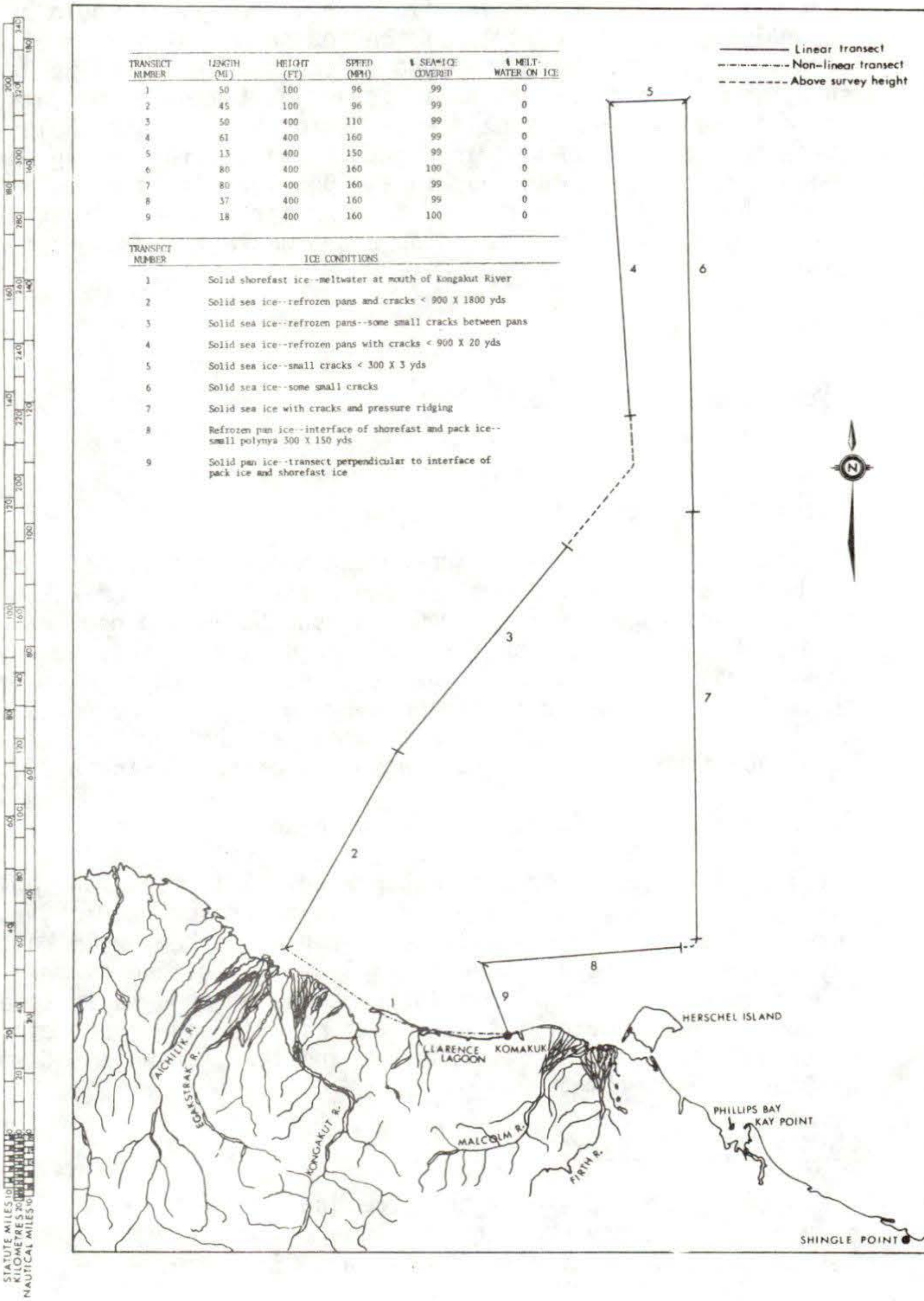
The first aerial survey was conducted before either meltwater or leads appeared on the shorefast ice offshore from Komakuk Beach and Clarence Lagoon. Birds (40 Glaucous Gulls and one Snowy Owl) were seen only during the first of the nine transects surveyed; these birds were seen off transect (i.e., more than 200 m from the path of the aircraft) on the overflow ice at the mouth of the Kongakut River, Alaska. Some areas at the mouth of this river were snow-free and some river water was present (Figure 37; Table 5).

During the survey of Transect 4, the plane was flown as far as 280 km north from Herschel Island, Y.T.; during this survey, almost total ($\geq$ 99%) ice cover was encountered. All cracks and holes seen during this survey were either very short or very narrow, and all were isolated. A NOAA satellite photograph taken on 15 May, the day after the survey, showed small leads far offshore (more than 300 km north of Komakuk) and larger areas of open water somewhat closer to shore north of Alaska, but no extensive areas of open water between Point Barrow, Alaska, and the area west and southwest of Banks Island (Plate 6A).

28 May Aerial Survey

Small amounts of meltwater and some leads were seen during this survey, but ice cover along the transects and over the Beaufort Sea was still extensive ($\geq$ 95%; Figure 38; Plate 6B).

A total of seven species was seen during this survey. Most birds seen during the survey of Transect 1 were on transect and were



TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT-WATER ON ICE
1	50	100	96	99	0
2	45	100	96	99	0
3	50	400	110	99	0
4	61	400	160	99	0
5	13	400	150	99	0
6	80	400	160	100	0
7	80	400	160	99	0
8	37	400	160	99	0
9	18	400	160	100	0

TRANSECT NUMBER	ICE CONDITIONS
1	Solid shorefast ice--meltwater at mouth of Kongakut River
2	Solid sea ice--refrozen pans and cracks < 900 X 1800 yds
3	Solid sea ice--refrozen pans--some small cracks between pans
4	Solid sea ice--refrozen pans with cracks < 900 X 20 yds
5	Solid sea ice--small cracks < 300 X 3 yds
6	Solid sea ice--some small cracks
7	Solid sea ice with cracks and pressure ridging
8	Refrozen pan ice--interface of shorefast and pack ice--small polynya 300 X 150 yds
9	Solid pan ice--transect perpendicular to interface of pack ice and shorefast ice

FIGURE 37. Aerial Survey Conducted on 14 May 1975.

TABLE 5. Results of the 14 May 1975 Aerial Survey.

TRANSECT NUMBER		SPECIES		TOTAL BIRDS
		GLAUCOUS GULL	SNOWY OWL	
1	On	-	-	-
	Off	40	1	41
	Density	-	-	-
2	On	-	-	-
	Off	-	-	-
	Density	-	-	-
3	On	-	-	-
	Off	-	-	-
	Density	-	-	-
4	On	-	-	-
	Off	-	-	-
	Density	-	-	-
5	On	-	-	-
	Off	-	-	-
	Density	-	-	-
6	On	-	-	-
	Off	-	-	-
	Density	-	-	-
7	On	-	-	-
	Off	-	-	-
	Density	-	-	-
8	On	-	-	-
	Off	-	-	-
	Density	-	-	-
9	On	-	-	-
	Off	-	-	-
	Density	-	-	-

[1] On--count of birds on central 1/4 mi wide strip of transect
Off--birds outside central 1/4 mi wide strip
Density--density of birds on transect (birds/mi^2)

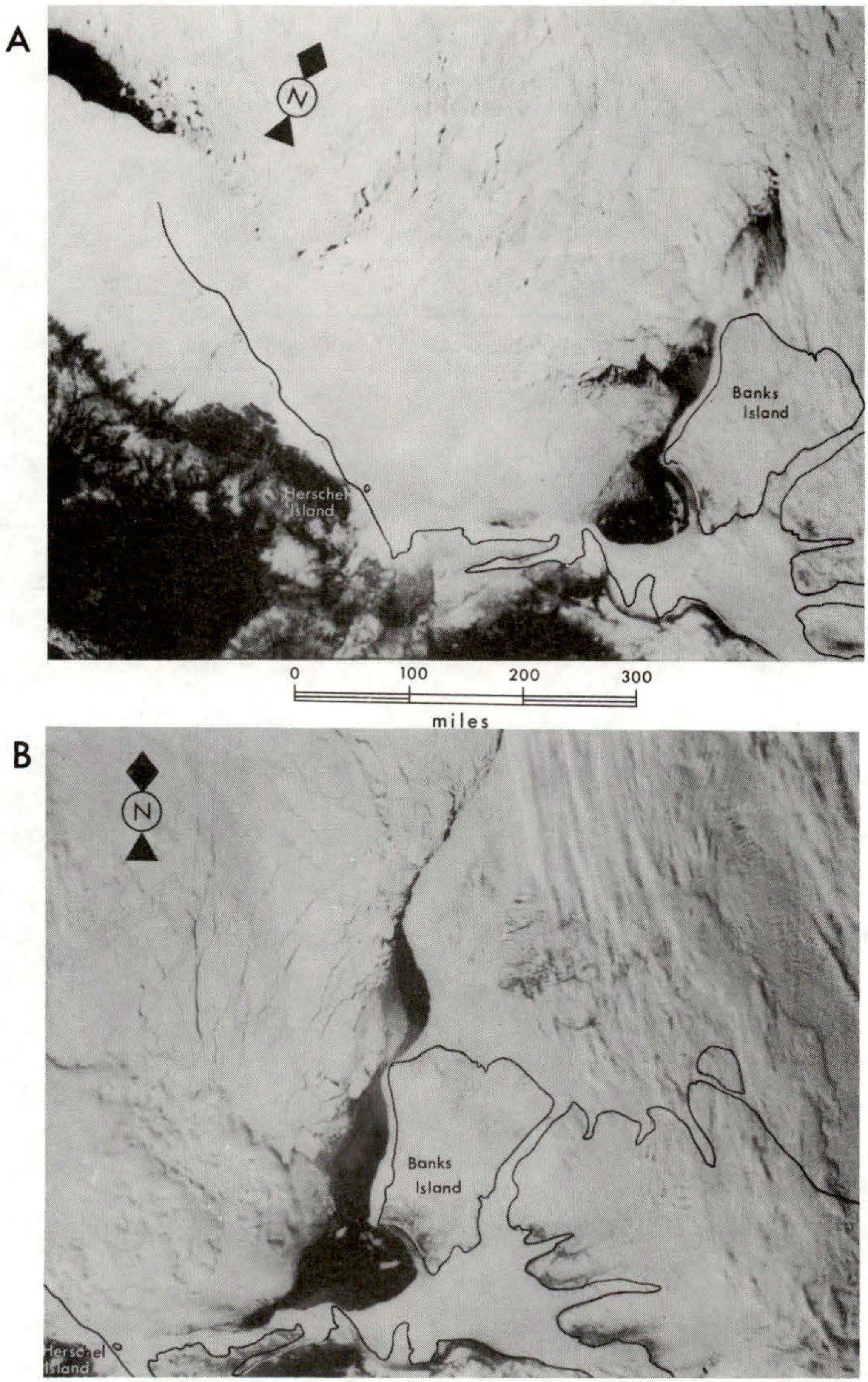


PLATE 6. Ice Conditions in the Beaufort Sea.
A: 15 May 1975.
B: 27 May 1975.

sighted along the interface between pack ice and shorefast ice, where small cracks, holes, and surface meltwater provided open water for Glaucous Gulls and unidentified scoters (Table 6). Densities of waterbirds were highest during the surveys of Transects 1 and 2 (14.5 and 15.5 birds seen/mi^2 [5.6 and 6.0 birds/km^2] respectively). The survey of Transect 2 was flown adjacent to a long, narrow crack, where Oldsquaws and scoters were observed. Surveys of Transects 3 and 4 were flown over solid sea ice, where no meltwater was present.

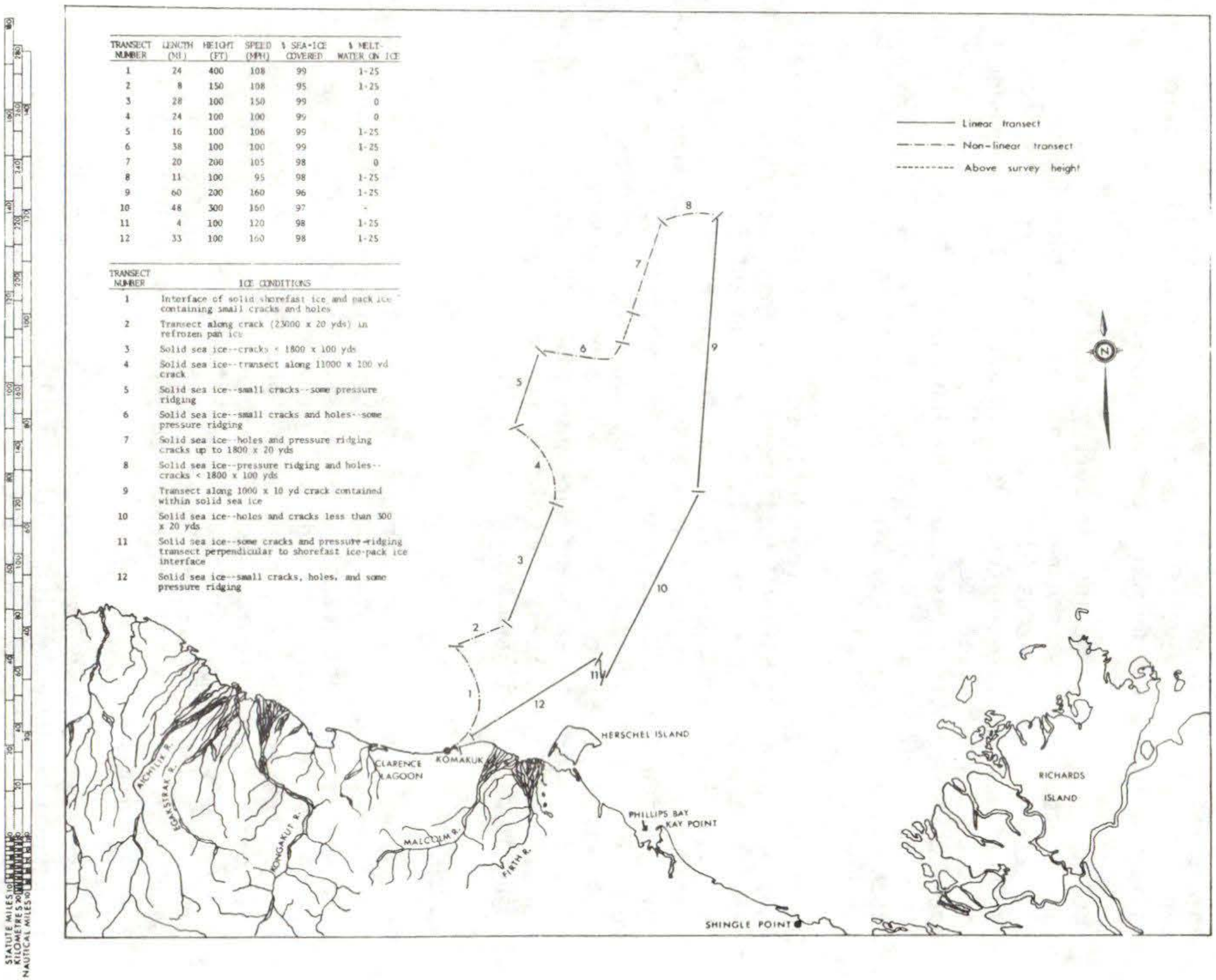
The only birds seen during the surveys of Transects 3 and 4 were three Glaucous Gulls seen near a long, narrow crack in the ice on Transect 4. The Glaucous Gull was also the only species seen during Transect 5; 20 individuals were seen flying west along a small crack in the sea ice. During the survey of Transect 6, 30 Brant were seen off transect and flying southeast over solid ice. The Glaucous Gull was the only species seen during Transect 7; a flock of 10 and one single bird were seen flying south and west-southwest (respectively).

Yellow-billed Loons were frequently seen offshore during aerial surveys; the first bird of this species was observed near a small crack in the sea ice on Transect 8. On Transect 9, 10 Brant were observed flying east over solid sea ice; these were the only birds seen during the survey of this transect. Thirty Oldsquaws and two unidentified diving ducks were seen on Transect 10; the Oldsquaws were flying over ice; and the diving ducks were swimming along a small crack in the ice. No birds were seen on Transect 11 although meltwater and open sea water were present. Separate flocks of Surf Scoters and four unidentified shorebirds were seen flying east and adjacent to a small crack on Transect 12.

5 June Aerial Survey

The largest number of sea birds (approximately 5580) was seen during this survey. Approximately 4274 of these birds were Oldsquaws that were seen on and off transect (of these, 2677 were on transect and 1597 were off transect during the survey of Transect 7). The highest densities of sea birds, 152.9 and 122.0 birds/mi^2 (58.8 and 47.0 birds/km^2), were recorded during the surveys of Transects 4 and 7, respectively. Transect 4 was situated along the south side of a large lead (Figure 39; Plate 7; Table 7), and Transect 7 was over an area that consisted completely of open water (only 3% floating ice).

Nine separate species were recorded during this survey, and this was the only survey during which relatively large numbers of King and Common Eiders were recorded. The eiders were primarily in the open water along Transect 7. A large number of Yellow-billed Loons was seen during this survey; most of these loons were seen on transect during the surveys of Transects 2, 5, and 7. Few scoters were observed during this survey; a total of seven



TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT-WATER ON ICE
1	24	400	108	99	1-25
2	8	150	108	95	1-25
3	28	100	150	99	0
4	24	100	100	99	0
5	16	100	106	99	1-25
6	38	100	100	99	1-25
7	20	200	105	98	0
8	11	100	95	98	1-25
9	60	200	160	96	1-25
10	48	300	160	97	-
11	4	100	120	98	1-25
12	33	100	160	98	1-25

TRANSECT NUMBER	ICE CONDITIONS
1	Interface of solid shorefast ice and pack ice containing small cracks and holes
2	Transect along crack (23000 x 20 yds) in refrozen pan ice
3	Solid sea ice--cracks < 1800 x 100 yds
4	Solid sea ice--transect along 11000 x 100 yd crack
5	Solid sea ice--small cracks--some pressure ridging
6	Solid sea ice--small cracks and holes--some pressure ridging
7	Solid sea ice--holes and pressure ridging cracks up to 1800 x 20 yds
8	Solid sea ice--pressure ridging and holes--cracks < 1800 x 100 yds
9	Transect along 1000 x 10 yd crack contained within solid sea ice
10	Solid sea ice--holes and cracks less than 300 x 20 yds
11	Solid sea ice--some cracks and pressure ridging transect perpendicular to shorefast ice-pack ice interface
12	Solid sea ice--small cracks, holes, and some pressure ridging

FIGURE 38. Aerial Survey Conducted On 28 May 1975.

TABLE 6. Results of the 28 May 1975 Aerial Survey.

TRANSECT NUMBER		SPECIES										TOTAL BIRDS
		YELLOW-BILLED LOON	BLACK BRANT	KING EIDER	OLDSQUAW	SURF SCOTER	SCOTER SPP.	DIVING DUCK SPP.	SANDPIPER SPP.	GLAUCOUS GULL	SNOWY OWL	
1	On	-	-	5	-	-	40	-	-	41	1	87
	Off	-	-	0	-	-	0	-	-	0	0	0
	Density	-	-	0.8	-	-	6.7	-	-	6.8	0.2	14.5
2	On	-	-	-	6	-	25	-	-	-	-	31
	Off	-	-	-	0	-	0	-	-	-	-	0
	Density	-	-	-	3.0	-	12.5	-	-	-	-	15.5
3	On	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-
4	On	-	-	-	-	-	-	-	-	3	-	3
	Off	-	-	-	-	-	-	-	-	0	-	0
	Density	-	-	-	-	-	-	-	-	0.5	-	0.5
5	On	-	-	-	-	-	-	-	-	20	-	20
	Off	-	-	-	-	-	-	-	-	0	-	0
	Density	-	-	-	-	-	-	-	-	5.0	-	5.0
6	On	-	-	-	-	-	-	-	-	-	-	-
	Off	-	30	-	-	-	-	-	-	-	-	30
	Density	-	-	-	-	-	-	-	-	-	-	-
7	On	-	-	-	-	-	-	-	-	11	-	11
	Off	-	-	-	-	-	-	-	-	0	-	0
	Density	-	-	-	-	-	-	-	-	2.2	-	2.2
8	On	1	-	-	-	-	-	-	-	-	-	1
	Off	0	-	-	-	-	-	-	-	-	-	0
	Density	0.4	-	-	-	-	-	-	-	-	-	0.4
9	On	-	10	-	-	-	-	-	-	-	-	10
	Off	-	0	-	-	-	-	-	-	-	-	0
	Density	-	0.7	-	-	-	-	-	-	-	-	0.7
10	On	-	-	-	30	-	-	2	-	-	-	32
	Off	-	-	-	0	-	-	0	-	-	-	0
	Density	-	-	-	2.5	-	-	0.2	-	-	-	2.7
11	On	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-
12	On	-	-	-	-	7	-	-	4	-	-	11
	Off	-	-	-	-	0	-	-	0	-	-	0
	Density	-	-	-	-	0.9	-	-	0.5	-	-	1.4

[1] On--count of birds on central 1/4 mi wide strip of transect

Off--birds outside central 1/4 mi wide strip

Density--density of birds on transect (birds/mi^2)

unidentified scoters were seen on transect during the surveys of Transects 2, 4, and 6. Large numbers of Brant were seen both on and off Transects 3, 4, and 6; and a peak density of 6.5 birds/ mi^2 (2.5 birds/km^2) was recorded along Transect 6.

Large numbers of flying birds were observed during this survey; the general trend in flight direction was between azimuths 45° and 135° regardless of the direction from which the birds were approached by the aircraft.

15 June Aerial Survey

By 15 June, many of the larger leads that had been present offshore during the 5 June survey had closed; most birds seen during the 15 June survey were closer to shore, between Komakuk Beach and Clarence Lagoon. The area of open water in the southeastern Beaufort Sea had, however, extended westward from its position in late May (Plate 8A; cf. Plate 6B).

The results of this survey clearly depict the relationship between the presence of open water along shore and the abundance of sea birds. An ice cover of $\geq$ 90% was recorded during the surveys of all transects except Transects 1 and 9; of the 1451 birds seen during this survey, all but three were seen during the surveys of Transects 1 and 9, which were near shore and had 5% and 3% ice cover, respectively (Table 8; Figure 40).

During this survey, nine species were observed. Three Black Guillemots were observed during the survey of Transect 9, near Herschel Island, Y.T.; these Black Guillemots were the first seen during the study. They are known to nest on Herschel Island (Vermeer and Anweiler 1975).

Most birds were observed during the survey of Transect 1; the most frequently observed species were Oldsquaws (791), King Eiders (136), Common Eiders (100), and Brant (30 birds). The highest density of birds for the 15 June survey was recorded on this transect--81.5 birds/mi^2 (31.4 birds/km^2).

Seven species were seen during the survey of Transect 9. Oldsquaws were the most common birds (186 of the total of 249 birds observed), and King and Common Eiders were second and third in numbers (27 and 20 birds, respectively). Five Yellow-billed Loons were seen during this survey; one during the survey of Transect 6 and four during the survey of Transect 9.

26 June Aerial Survey

By 26 June the area of open water in the southeastern Beaufort Sea had extended west to the Komakuk area (Plates 8B, 9A; Figure 41). Markedly fewer individual birds but a greater number of sea-bird species were observed during this survey than during the 15 June survey (Table 9; Figure 41). All three species of scoters (a total of 71 birds), Common and King Eiders (33 birds and 20 bird, respectively), Yellow-billed and Red-throated Loons (one bird and two birds, respectively), Oldsquaws (104 birds), one Pomarine Jaeger, Glaucous Gulls (16 birds), and one Arctic Tern were observed.

The highest number of individuals and the highest number of species were observed during the survey of Transect 1 (101 birds of five species; 27.5 birds/mi^2) and during the survey of Transect 5 (116 birds of 10 species; 13.2 birds/mi^2). Oldsquaws were observed on a greater number of transects than were any other species; these birds were seen during the surveys of seven of the 10 transects, and they accounted for 36% of the birds observed. Scoters were second (30% of total) and eiders third (19% of total) in numbers observed.

During this survey, there appeared to be no clear relationship between the number of birds observed and particular locations or the amount of ice cover; it should be noted, however, that most birds were observed during the survey of Transect 5, which had only 5% ice cover (within 200 m of the flight path).

3 July Aerial Survey

The amount of floating ice on transect during the 3 July aerial surveys had decreased to 30% or less, and meltwater covered at least 25% to 50% of the ice that was present. The total numbers of birds and of species observed increased to 881 and 13 (respectively) during the 3 July survey--compared to 290 and 11 (respectively) during the 26 June survey. This increase was due to the large number of scoters (509 birds; 58% of total) that were observed offshore during this survey (Table 10; Figure 42). Oldsquaws were observed much less frequently during this survey (220 birds; 25% of total), and Red-breasted Mergansers were observed for the first time during aerial surveys. Most birds (94%) were seen on the first two transects; both the transects were near shore and over leads or cracks in the ice.

The highest bird density (40 birds/mi^2) was recorded during the survey of Transect 2; the second highest density (23.2 birds/mi^2) was recorded during the survey of Transect 1.

Three species of loons, Common and King Eiders, White-winged and Surf Scoters, Glaucous Gulls, and Arctic Terns were observed during this survey.

9 July Aerial Survey

On 9 July, the large area of open water formed by the combination of water from the Mackenzie River and the large lead off the west coast of Banks Island extended about as far west as it had in late

TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT-WATER ON ICE
1	13	140	120	100	1-25
2	20	200	120	99	0
3	30	150	160	10	-
4	30	150	160	5	-
5	30	120	100	11	·
6	29	110	90	90	·
7	45	110	120	3	-
8	58	80	150	99	-

TRANSECT NUMBER	ICE CONDITIONS
1	Shorefast ice--no open water
2	Small cracks and holes--transect perpendicular to shorefast ice-pack ice interface
3	Transect along north side of 53000 x 4000 yd lead
4	Transect along south side of same lead
5	Transect along centre of same lead
6	Pack ice with many holes and large leads--leads [illegible] 1000 x 200 yds
7	Open water with many large floating pans
8	Open water--slush ice at shorefast ice-pack ice interface--transect along 20 yd wide crack parallel to north shore of Herschel Island extending to the mainland.*

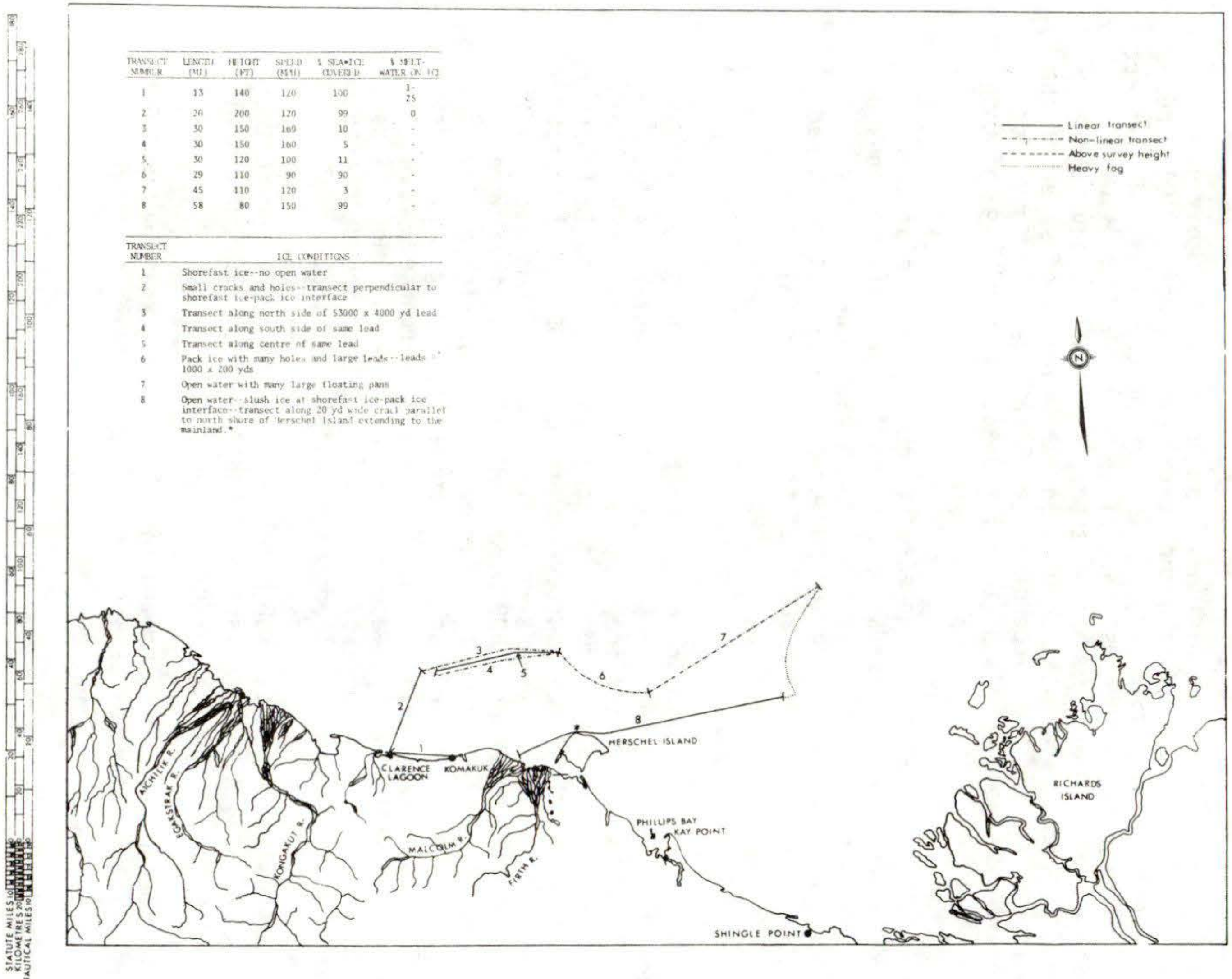


FIGURE 39. Aerial Survey Conducted on 5 June 1975.

TABLE 7. Results of the 5 June 1975 Aerial Survey.

TRANSECT NUMBER		SPECIES: YELLOW-BILLED LOON	LOON SPP.	WHISTLING SWAN	BLACK BRANT	PINTAIL	DABBLING DUCK SPP.	OLDSQUAW	COMMON EIDER	KING EIDER	EIDER SPP.	SCOTER SPP.	DIVING DUCK SPP.	PARASITIC JAEGER	GLAUCOUS GULL	TOTAL BIRDS
1	On	-	-	-	-	50	-	-	-	-	-	-	-	-	5	55
	Off	-	-	-	-	0	-	-	-	-	-	-	-	-	0	0
	Density	-	-	-	-	15.4	-	-	-	-	-	-	-	-	1.5	16.9
2	On	10	-	-	-	-	-	39	1	2	-	2	-	-	-	54
	Off	0	-	1	-	-	-	10	2	0	-	0	150	-	1	164
	Density	2.0	-	-	-	-	-	7.8	0.2	0.4	-	0.4	-	-	-	10.8
3	On	-	-	-	-	-	-	8	2	-	-	-	-	-	-	10
	Off	-	-	-	80	-	-	0	0	-	-	-	-	-	-	80
	Density	-	-	-	-	-	-	1.1	0.3	-	-	-	-	-	-	1.4
4	On	2	-	-	17	-	-	1117	5	2	-	3	-	-	-	1146
	Off	0	-	-	0	-	-	7	0	0	-	0	1	-	-	8
	Density	0.3	-	-	2.3	-	-	148.9	0.7	0.3	-	0.4	-	-	-	152.9
5	On	8	-	-	-	-	3	219	250	-	-	-	-	-	-	480
	Off	0	-	-	-	-	0	10	0	-	-	-	-	-	-	10
	Density	1.1	-	-	-	-	0.4	29.2	33.3	-	-	-	-	-	-	64.0
6	On	-	-	-	47	-	-	242	182	8	25	2	-	-	-	506
	Off	-	-	-	50	-	-	50	0	0	0	0	-	-	-	100
	Density	-	-	-	6.5	-	-	33.4	25.1	1.1	3.4	0.3	-	-	-	69.8
7	On	10	-	-	-	-	-	976	281	103	-	-	-	1	-	1371
	Off	0	-	-	-	-	-	1520	0	0	-	-	-	0	-	1520
	Density	0.9	-	-	-	-	-	86.8	25.0	9.2	-	-	-	0.1	-	122.0
8	On	-	1	-	-	-	-	76	-	-	-	-	-	-	-	77
	Off	-	0	-	-	-	-	0	-	-	-	-	-	-	-	0
	Density	-	0.1	-	-	-	-	5.2	-	-	-	-	-	-	-	5.3

[1] On--count of birds on central 1/4 mi wide strip of transect

Off--birds outside central 1/4 mi wide strip

Density--density of birds on transect (birds/mi^2)

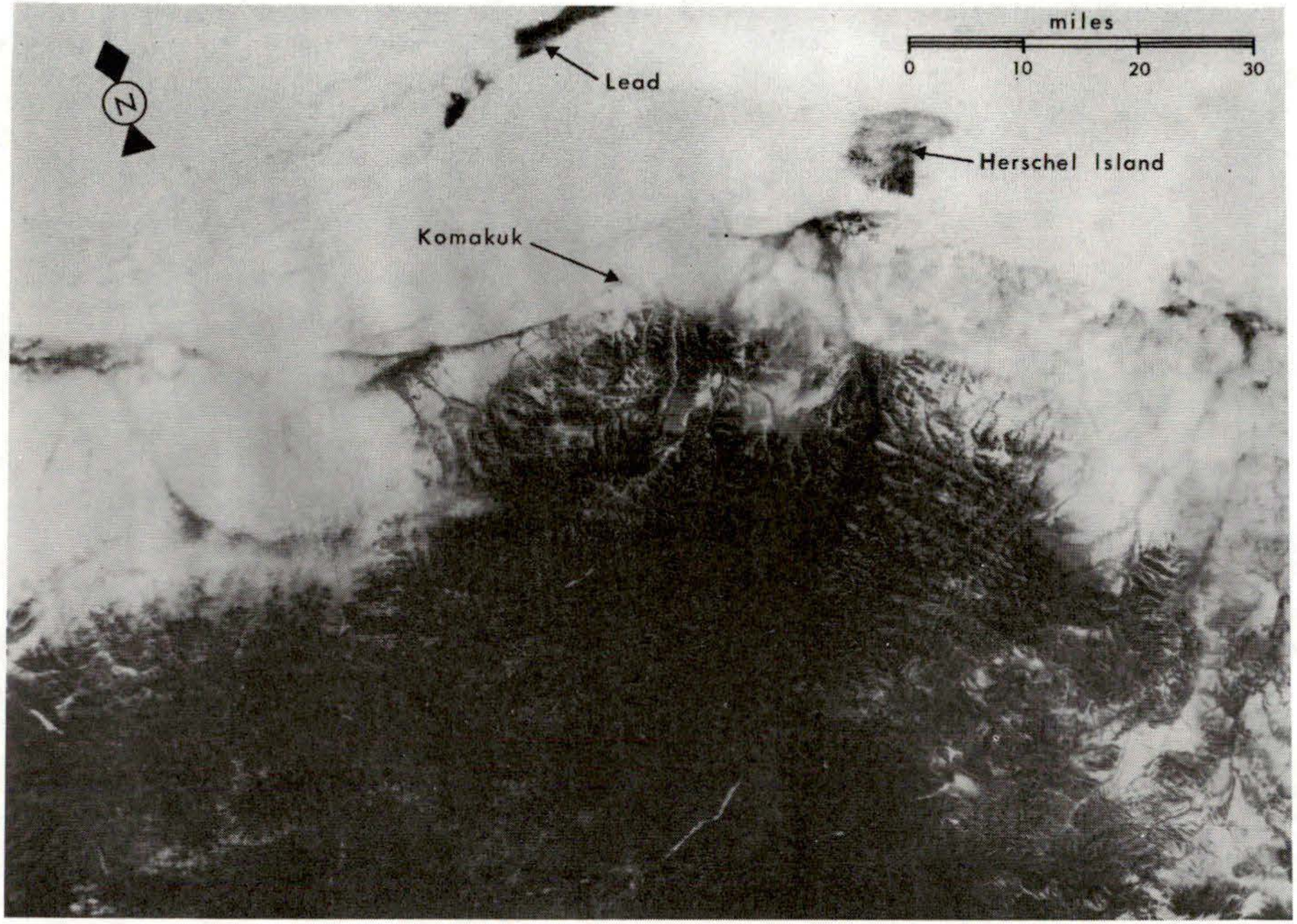


PLATE 7. Ice Conditions Along the Beaufort Sea Coast Near Herschel Island; 5 June 1975. From ERTS imagery.

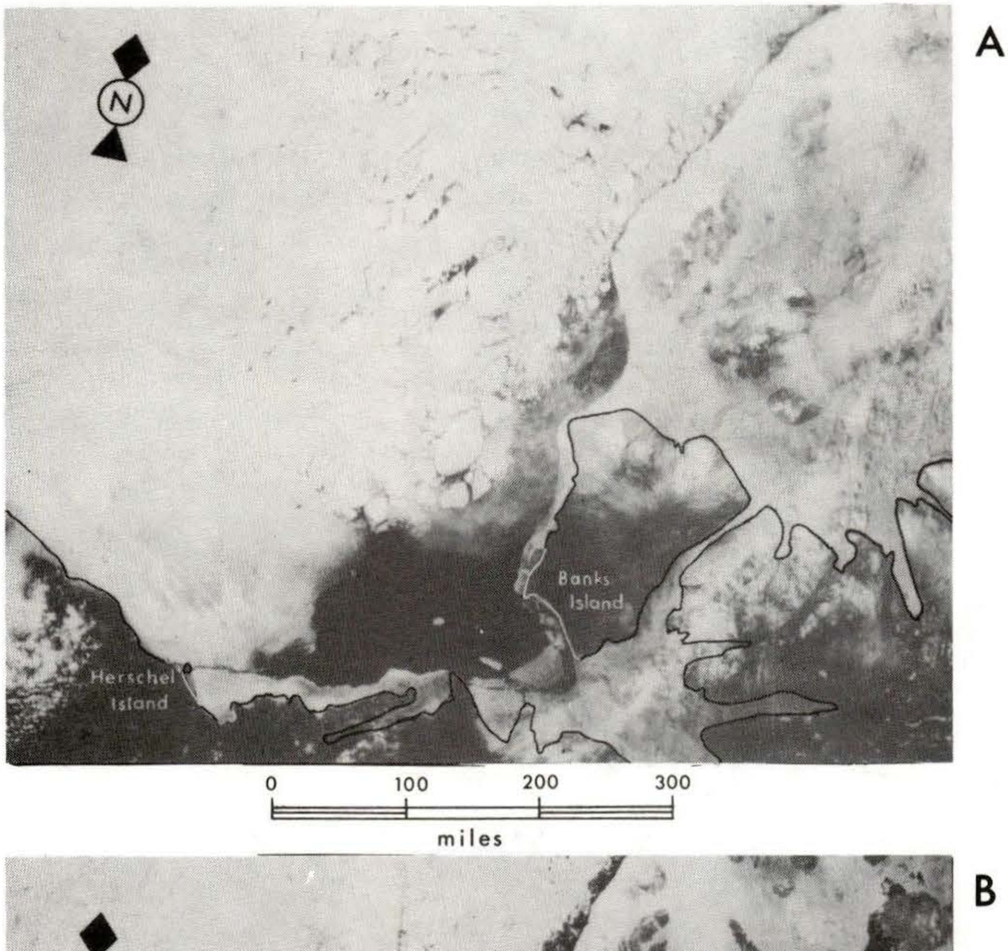
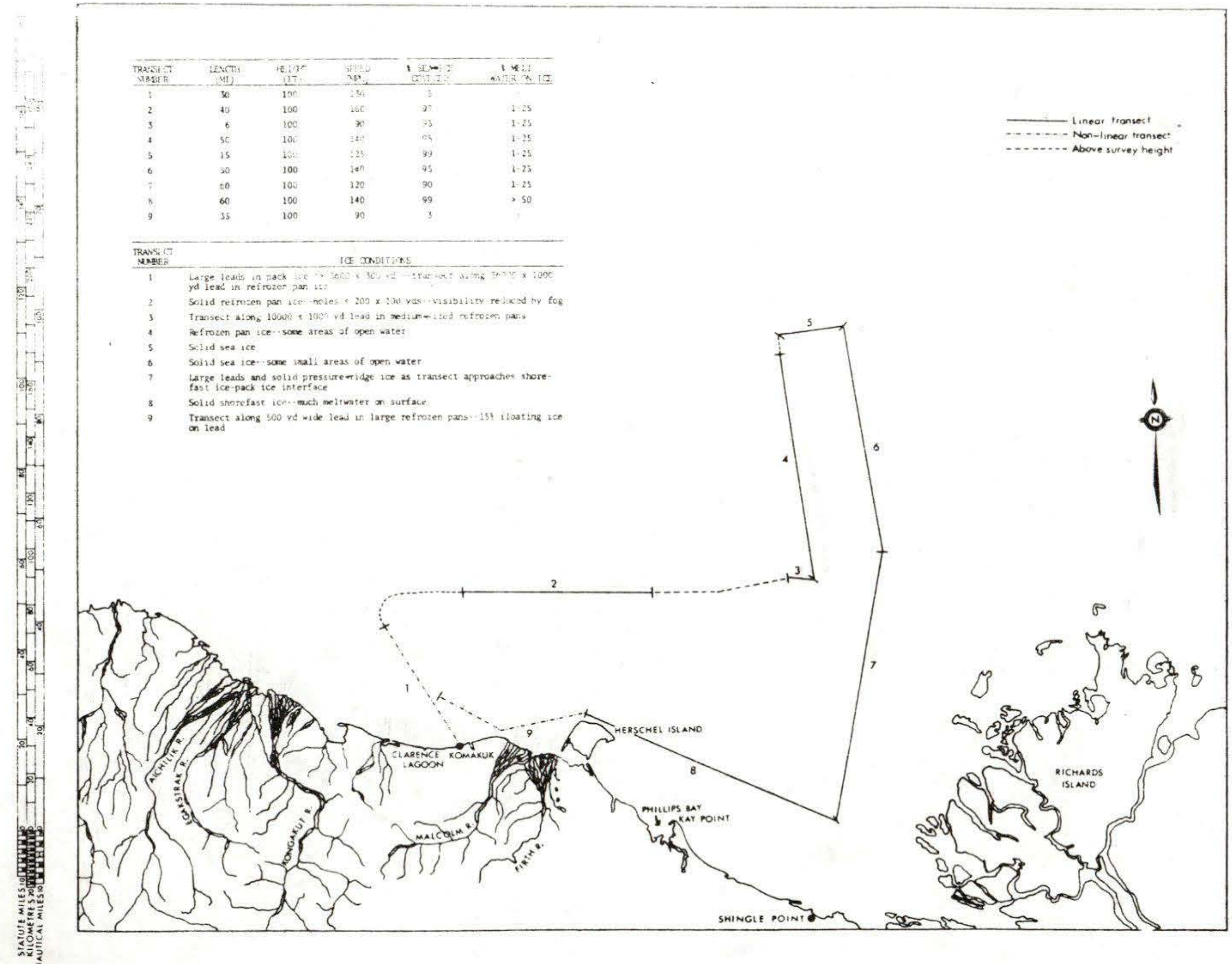


PLATE 8. Ice Conditions in the Beaufort Sea.
A: 16 June 1975.
B: 25 June 1975.

TABLE 8. Results of the 15 June 1975 Aerial Survey.

TRANSECT NUMBER		SPECIES: YELLOW-BILLED LOON	ARCTIC LOON	RED-THROATED LOON	LOON SPP.	BLACK BRANT	OLDSQUAW	COMMON EIDER	KING EIDER	EIDER SPP.	SANDPIPER SPP.	BLACK GUILLEMOT	JAEGER SPP.	GLAUCOUS GULL	TOTAL BIRDS
	On	-	-	-	3	-	462	84	59	-	1	-	-	2	611
1	Off	-	-	-	3	30	329	16	77	133	0	-	-	0	588
	Density	-	-	-	0.4	-	61.6	11.2	7.9	-	0.1	-	-	0.3	81.5
	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	On	1	-	-	-	-	-	-	-	-	-	-	-	-	1
6	Off	0	-	-	-	-	-	-	-	-	-	-	-	-	0
	Density	0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.1
	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	On	-	-	-	-	-	-	-	-	-	-	-	1	1	2
8	Off	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	Density	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	0.2
	On	4	5	1	2	-	167	9	27	-	-	3	-	-	218
9	Off	0	1	0	0	-	19	11	0	-	-	0	-	-	31
	Density	0.5	0.6	0.1	0.2	-	19.1	1.0	3.1	-	-	0.3	-	-	24.9

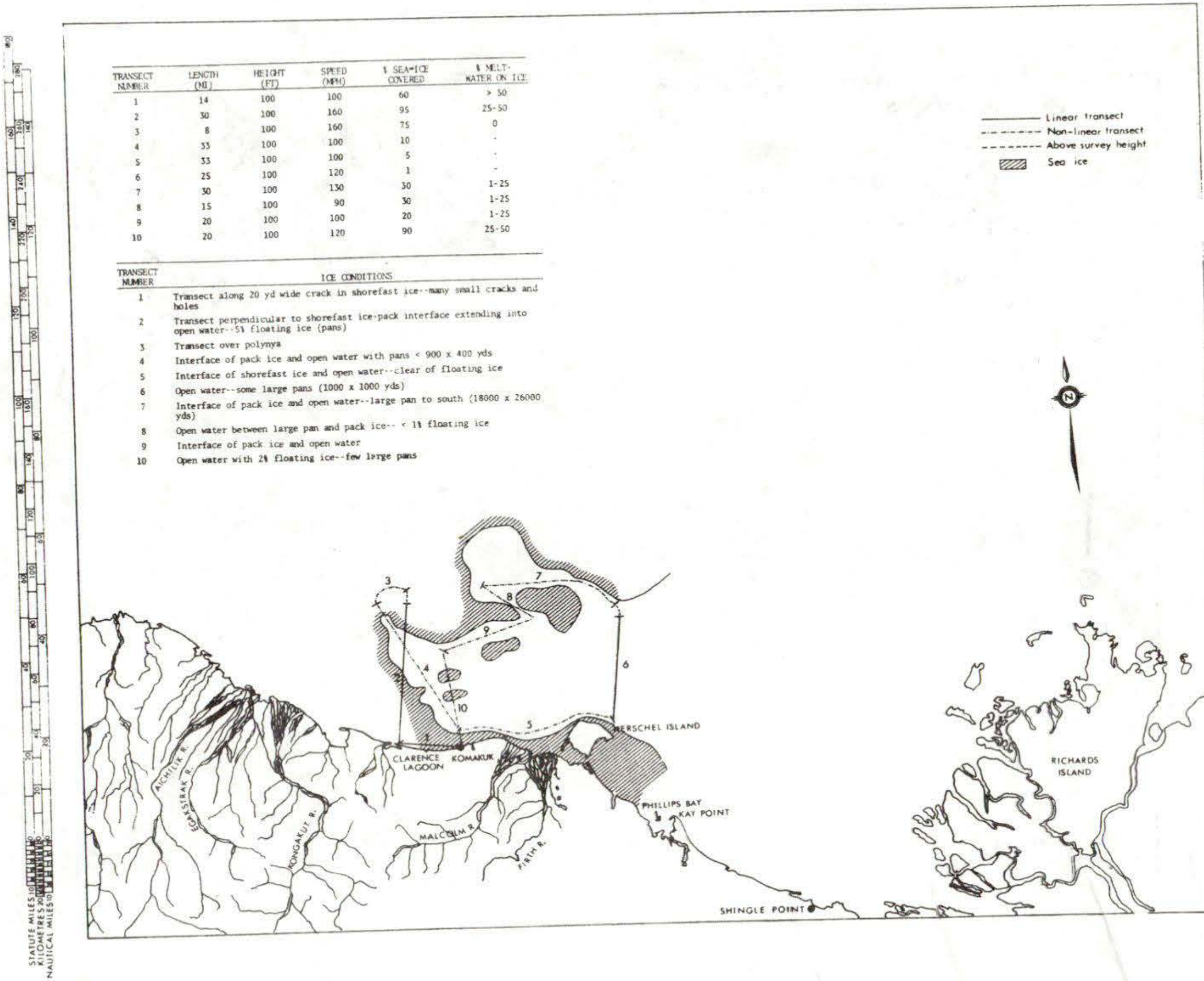
[1] On--count of birds on 1/4 mi wide strip of transect
Off--birds outside central 1/4 mi wide strip
Density--density of birds on transect (birds/mi^2)



TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA ICE COVER	% MELT WATER ON ICE
1	30	100	130	5	[illegible]
2	40	100	160	97	1-25
3	6	100	90	95	1-25
4	50	100	140	95	1-25
5	15	100	125	99	1-25
6	50	100	140	95	1-25
7	60	100	120	90	1-25
8	60	100	140	99	> 50
9	35	100	90	3	[illegible]

TRANSECT NUMBER	ICE CONDITIONS
1	Large leads in pack ice >5000 x 300 yd--transect along [illegible] x 1000 yd lead in refrozen pan ice
2	Solid refrozen pan ice--holes < 200 x 200 yds--visibility reduced by fog
3	Transect along 10000 x 1000 yd lead in medium-sized refrozen pans
4	Refrozen pan ice--some areas of open water
5	Solid sea ice
6	Solid sea ice--some small areas of open water
7	Large leads and solid pressure-ridge ice as transect approaches shore-fast ice-pack ice interface
8	Solid shorefast ice--much meltwater on surface
9	Transect along 500 yd wide lead in large refrozen pans--15% floating ice on lead

FIGURE 40. Aerial Survey Conducted on 15 June 1975.



TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT-WATER ON ICE
1	14	100	100	60	> 50
2	30	100	160	95	25-50
3	8	100	160	75	0
4	33	100	100	10	-
5	33	100	100	5	-
6	25	100	120	1	-
7	30	100	130	30	1-25
8	15	100	90	30	1-25
9	20	100	100	20	1-25
10	20	100	120	90	25-50

TRANSECT NUMBER	ICE CONDITIONS
1	Transect along 20 yd wide crack in shorefast ice--many small cracks and holes
2	Transect perpendicular to shorefast ice-pack interface extending into open water--5% floating ice (pans)
3	Transect over polynya
4	Interface of pack ice and open water with pans < 900 x 400 yds
5	Interface of shorefast ice and open water--clear of floating ice
6	Open water--some large pans (1000 x 1000 yds)
7	Interface of pack ice and open water--large pan to south (18000 x 26000 yds)
8	Open water between large pan and pack ice-- < 1% floating ice
9	Interface of pack ice and open water
10	Open water with 2% floating ice--few large pans

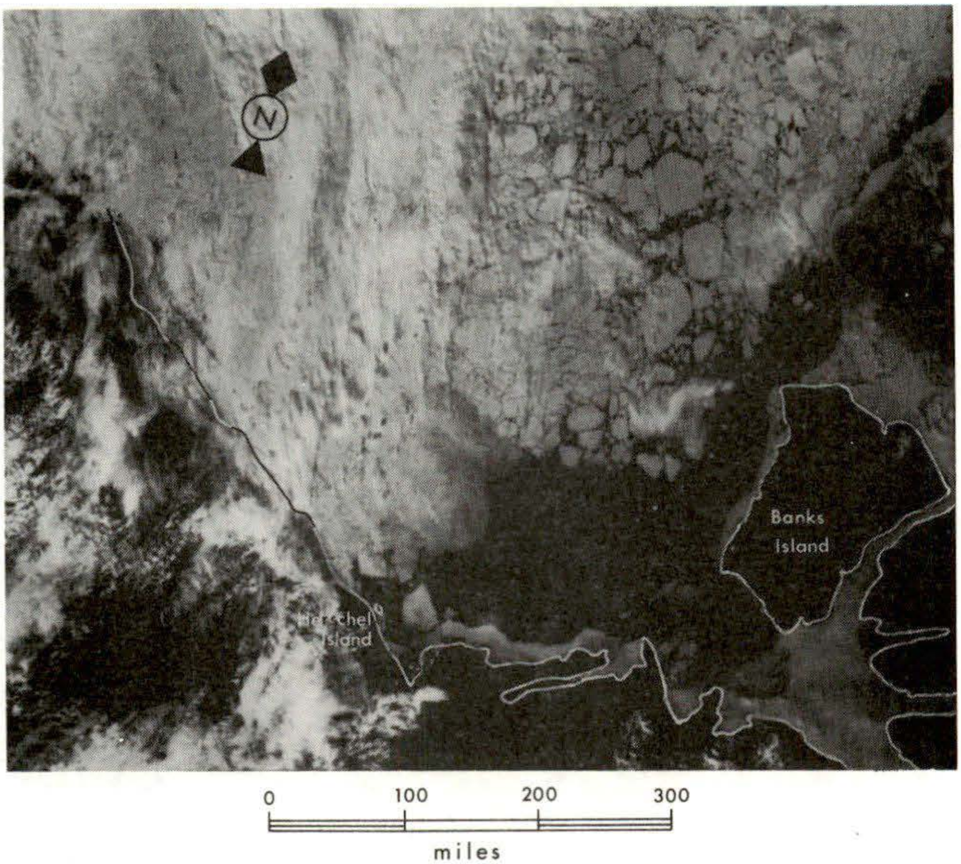
FIGURE 41. Aerial Survey Conducted on 26 June 1975.

TABLE 9. Results of the 26 June 1975 Aerial Survey.

TRANSECT NO.	[1]	YELLOW-BILLED LOON	RED-THROATED LOON	LOON SPP.	OLD-SQUAW	COMMON EIDER	KING EIDER	EIDER SPP.	SURF SCOTER	COMMON SCOTER	WHITE-WINGED SCOTER	SCOTER SPP.	DIVING DUCK SPP.	DUCK SPP.	SHORE-BIRD SPP.	POMARINE JAEGER	JAEGER SPP.	GLAUCOUS GULL	ARCTIC TERN	TOTAL BIRDS
		SPECIES																		
1	On	-	-	-	35	21	10	-	-	-	15	-	-	-	-	-	-	15	-	96
	Off	-	-	-	0	0	0	-	-	-	0	-	-	5	-	-	-	0	-	5
	Density	-	-	-	10.0	6.0	2.9	-	-	-	4.3	-	-	-	-	-	-	4.3	-	27.5
2	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	2
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	0
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	-	1.0
4	On	-	1	1	2	-	-	-	-	-	-	-	-	-	5	-	-	-	-	9
	Off	-	0	0	0	-	-	-	-	-	-	-	8	-	0	-	-	-	-	8
	Density	-	0.1	0.1	0.2	-	-	-	-	-	-	-	-	-	0.6	-	-	-	-	1.0
5	On	-	-	-	15	10	10	1	14	30	12	15	-	-	-	1	-	-	1	109
	Off	1	1	-	3	2	0	0	0	0	0	0	-	-	-	0	-	-	0	7
	Density	-	-	-	1.8	1.2	1.2	0.1	1.7	3.6	1.5	1.8	-	-	-	0.1	-	-	0.1	13.1
6	On	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	Off	-	-	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	Density	-	-	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
7	On	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
	Off	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	Density	-	-	-	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7
8	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	On	-	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25
	Off	-	-	-	0	-	-	-	-	-	-	4	-	-	-	-	-	-	-	4
	Density	-	-	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.0
10	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] On--count of birds on 1/4 mi wide strip of transect
Off--birds outside central 1/4 mi wide strip
Density--density of birds on transect (birds/mi^2)

A



B

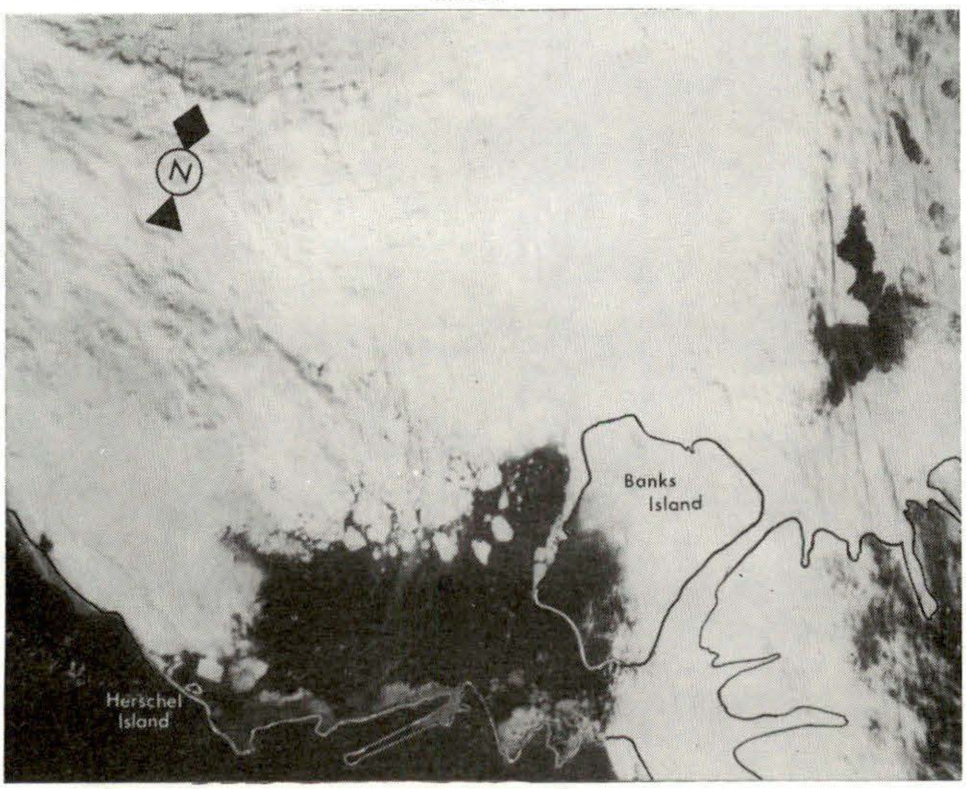


PLATE 9. Ice Conditions in the Beaufort Sea.
A: 26 June 1975.
B: 7 July 1975.

June; the western margin of this open-water area lay between Komakuk Beach and Herschel Island (Plate 9B). North of Clarence Lagoon, almost continuous ice cover persisted; this cover was not solid, however, and much of it consisted of small to very large free-floating pans that were separated at their perimeters by cracks of varying width.

Although the number of species observed during this survey increased to 13, the total number of birds observed declined markedly (from 881 on 3 July survey to 206 on this survey [Tables 10-12]). A major portion of the birds were seen along Transects 2 to 4, and 73% of all birds were observed along Transects 1 to 4. Owing to the presence of a large number of Oldsquaws (Table 11), the highest bird density (3.7 birds/mi^2 [1.43 birds/km^2]) was calculated for Transect 3.

Two notable birds were observed during this survey: an immature Ivory Gull on Transect 5 and an adult kittiwake on Transect 6 (probably Black-legged Kittiwake). These were the only records of these species during the study period. Oldsquaws comprised 33% of the total number of birds recorded during this survey; scoters decreased from 58% of the total number of birds observed on the previous survey to 20% of the total recorded on this survey.

On the 9 July survey, birds appeared to be associated more with leads and open-water areas within the Beaufort Sea pack ice than with the open water farther east near the Mackenzie River Delta (Figure 43).

ACKNOWLEDGEMENTS

William Adams and Gavin Johnston made major contributions to this study during the field program, during the analysis of data, and during the writing of this report.

Dr. Thomas Barry, Canadian Wildlife Service, helped to make this study possible, and we have appreciated his advice and patience.

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TABLE 10. Results of the 3 July 1975 Aerial Survey.

TRAN-SECT NO.		YELLOW-BILLED LOON	ARCTIC LOON	RED-THROATED LOON	LOON SPP.	BLACK BRANT	OLDSQUAW	COMMON EIDER	KING EIDER	EIDER SPP.	WHITE-WINGED SCOTER	SURF SCOTER	SCOTER SPP.	RED-BREASTED MERGANSER	DIVING DUCK SPP.	MEDIUM SHOREBIRD SPP.	PARASITIC JAEGER	JAEGER SPP.	GLAUCOUS GULL	ARCTIC TERN	TOTAL BIRDS
		S P E C I E S																			
1	On	1	-	-	8	6	42	8	-	-	9	52	44	7	-	-	-	-	42	3	222
	Off	0	-	-	2	0	75	0	-	-	80	20	201	0	5	-	-	-	15	0	398
	Density	0.1	-	-	0.8	0.6	4.4	0.8	-	-	1.0	5.5	4.6	0.7	-	-	-	-	4.4	0.3	23.2
2	On	-	1	1	-	-	96	-	-	-	46	8	43	-	-	-	-	-	4	1	200
	Off	-	0	0	-	-	0	-	-	-	2	2	1	-	2	-	-	-	0	0	7
	Density	-	0.2	0.2	-	-	19.2	-	-	-	9.2	1.6	8.6	-	-	-	-	-	0.8	0.2	40.0
3	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	On	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	2
	Off	-	-	-	-	-	-	-	-	0	-	-	0	-	-	-	-	-	-	-	0
	Density	-	-	-	-	-	-	-	-	1.0	-	-	1.0	-	-	-	-	-	-	-	2.0
5	On	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	7	-	-	10
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	3	0	2	-	5
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	0.1	0.9	-	-	1.2
6	On	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	3
	Off	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	Density	-	-	-	-	-	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	0.8
7	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	On	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
	Off	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	0
	Density	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	0.4
9	On	-	3	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	7
	Off	-	0	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	Density	-	0.9	-	-	-	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0
10	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Off	-	-	-	-	-	-	-	-	-	-	-	-	-	25	-	-	-	-	-	25
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] On--count of birds on 1/4 mi wide strip of transect

Off-birds outside central 1/4 mi wide strip

Density--density of birds on transect (birds/mi^2)

TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT WATER ON ICE
1	38	100	100	5	> 50
2	20	100	110	10	> 50
3	28	100	100	1	-
4	4	100	100	1	25-50
5	30	100	120	5	25-50
6	15	100	110	5	25-50
7	10	100	120	5	25-50
8	10	100	120	1	25-50
9	14	100	100	5	25-50
10	35	100	100	30	25-50

TRANSECT NUMBER	ICE CONDITIONS
1	Interface of shore lead (300 yd wide) and shorefast ice--10% floating ice on lead
2	Lead between shorefast ice and Herschel Island--5% floating ice on lead
3	From shore lead, across shorefast ice and out across open water--5% floating ice on open water
4	Interface of pack ice and open water
5	Interface of pack ice and open water--15% floating ice pans on open water
6	Interface of pack ice and open water free of ice cover
7	Interface of pack ice and open water free of ice cover
8	Interface of pack ice and open water free of ice cover
9	Interface of pack ice and open water with 5% floating ice
10	Open water (with large free floating pans) to shorefast ice-open water interface

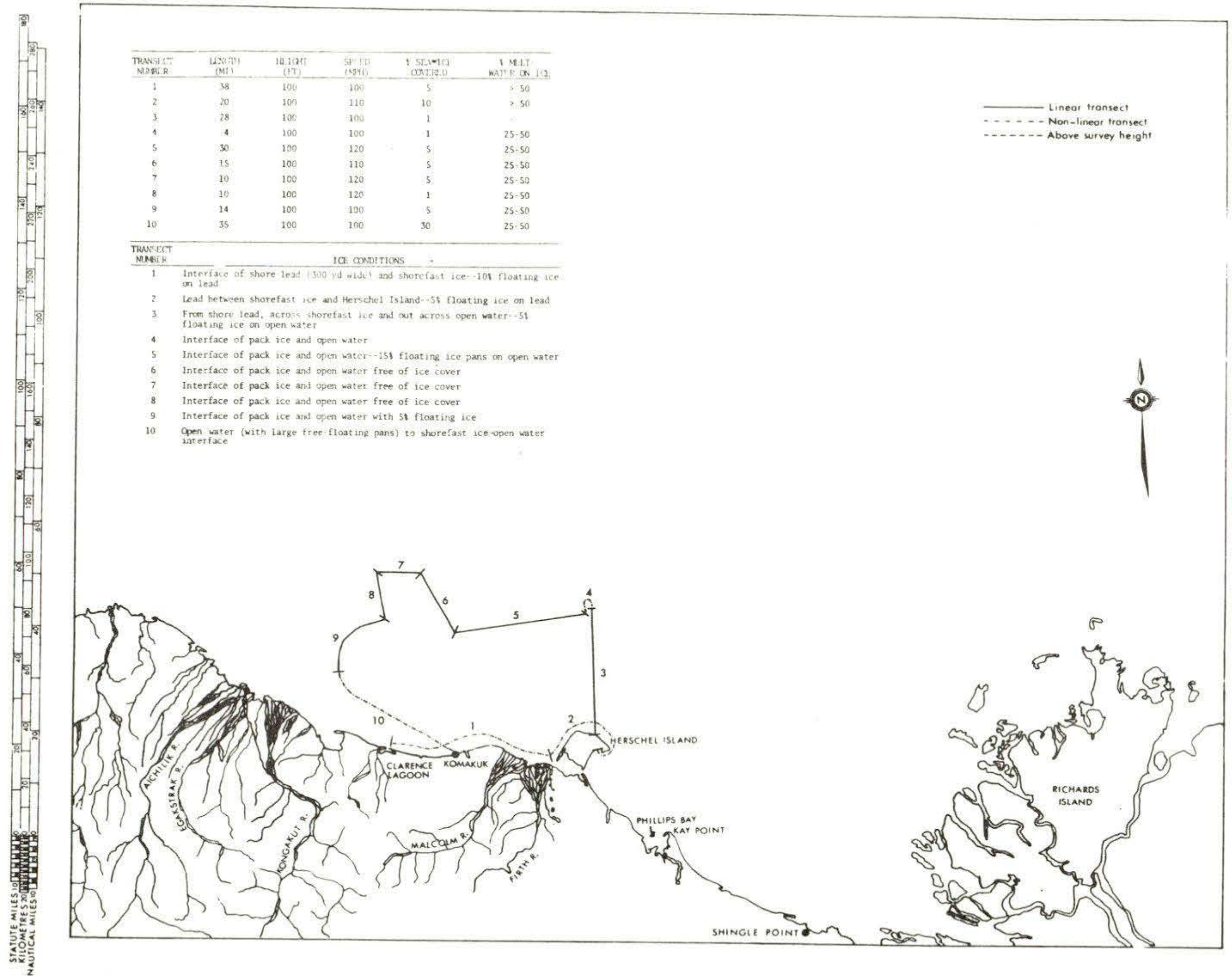


FIGURE 42. Aerial Survey Conducted on 3 July 1975.

TABLE 11. Results of the 9 July 1975 Aerial Survey.

TRAN-SECT NO.		YELLOW-BILLED LOON	ARCTIC LOON	LOON SPP.	WHISTLING SWAN	OLDSQUAW	COMMON EIDER	KING EIDER	EIDER SPP.	WHITE-WINGED SCOTER	SURF SCOTER	SCOTER SPP.	DIVING DUCK SPP.	POMARINE JAEGER	PARASITIC JAEGER	JAEGER SPP.	GLAUCOUS GULL	IVORY GULL	KITTIWAKE SPP.	BLACK GUILLEMOT	TOTAL BIRDS
		SPECIES																			
1	On	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	Off	1	0	-	-	8	-	-	-	-	-	-	4	-	1	-	1	-	-	1	16
	Density	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
2	On	-	-	-	-	2	21	-	-	-	-	2	1	-	-	-	-	-	-	-	26
	Off	-	-	-	-	4	0	-	-	-	4	0	0	-	-	1	-	-	-	-	9
	Density	-	-	-	-	0.1	1.5	-	-	-	-	0.1	0.1	-	-	-	-	-	-	-	1.8
3	On	-	-	1	-	49	-	-	1	-	-	-	-	-	-	-	-	-	-	-	51
	Off	-	-	1	-	0	-	-	6	-	-	-	-	-	-	-	-	-	-	-	7
	Density	-	-	0.1	-	3.5	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	3.7
4	On	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
	Off	-	-	-	-	0	-	-	-	35	-	-	-	-	-	-	-	-	-	-	35
	Density	-	-	-	-	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9
5	On	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
	Off	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	0	-	-	1
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	0.1
6	On	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	1	-	4
	Off	-	-	-	-	-	-	5	-	-	-	-	-	-	0	4	-	-	0	-	9
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	-	-	0.1	-	0.3
7	On	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	2
	Off	-	-	-	-	-	-	-	-	-	-	-	30	-	0	0	-	-	-	-	30
	Density	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	-	-	-	-	0.2
8	On	-	1	-	4	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	7
	Off	-	0	1	0	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	1
	Density	-	0.2	-	0.7	-	-	-	-	-	-	-	-	-	-	-	0.4	-	-	-	1.3

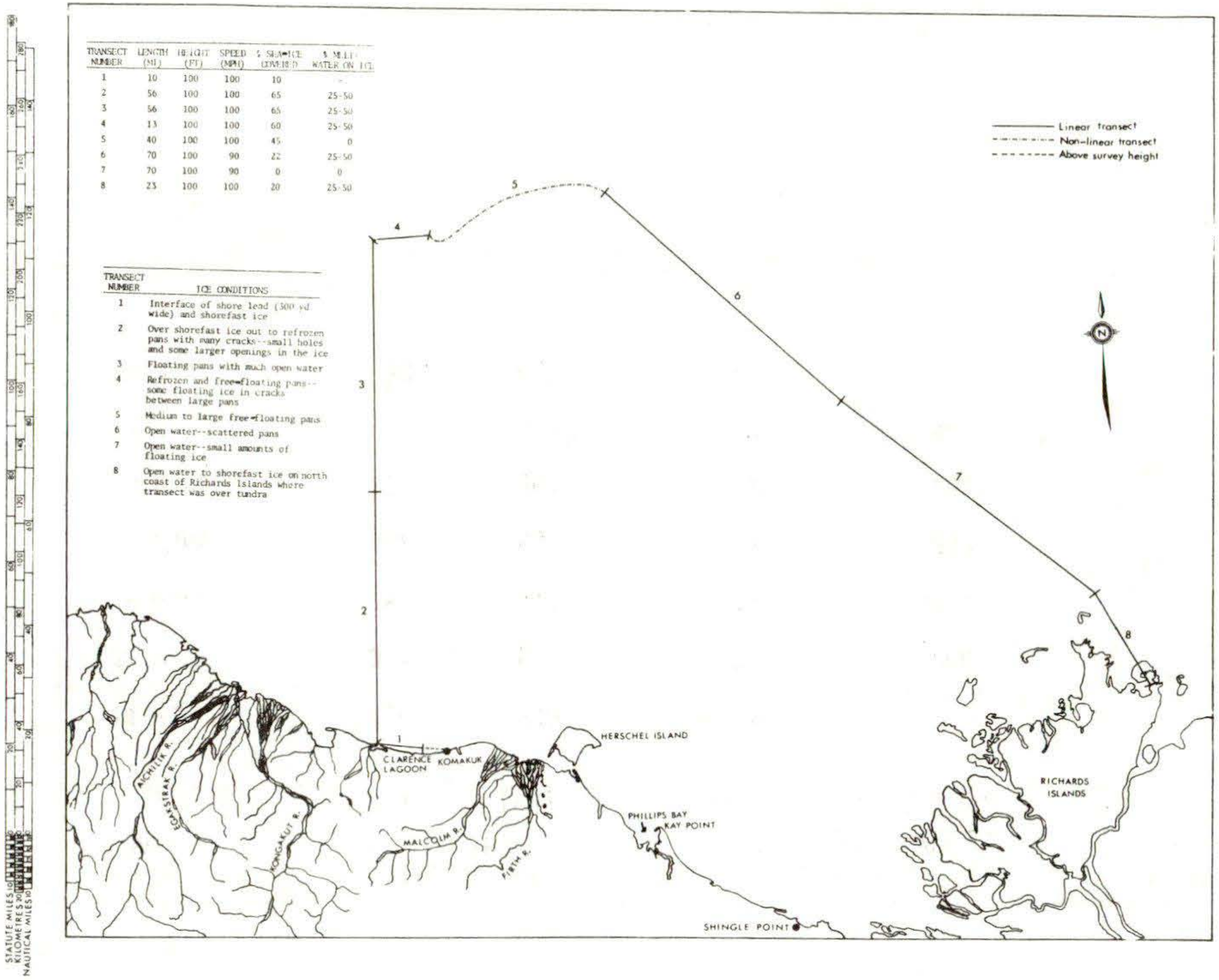
[1] On--counts of birds on 1/4 mi wide strip of transect

Off--birds outside of 1/4 mi wide strip

Density--density of birds on transect (birds/mi^2)

TABLE 12. Change in Total Numbers and Increase in Species of Waterbirds During Aerial Surveys Off Komakuk Beach, Yukon Territory, 1975.

SURVEY NUMBER	DATE	TOTAL SURVEY LENGTH		NUMBER OF BIRDS OBSERVED		TOTAL NUMBER OF SPECIES OBSERVED
		(MI)	(KM)	TOTAL	ON TRANSECT	
1	14 May	434	700	41	0	2
2	28 May	314	506	236	206	7
3	5 June	255	411	5565	3674	9
4	15 June	346	558	1430	832	9
5	26 June	228	367	290	263	11
6	3 July	204	329	881	445	13
7	9 July	338	545	206	98	13



TRANSECT NUMBER	LENGTH (MI)	HEIGHT (FT)	SPEED (MPH)	% SEA-ICE COVERED	% MELT WATER ON ICE
1	10	100	100	10	-
2	56	100	100	65	25-50
3	56	100	100	65	25-50
4	13	100	100	60	25-50
5	40	100	100	45	0
6	70	100	90	22	25-50
7	70	100	90	0	0
8	23	100	100	20	25-50

TRANSECT NUMBER	ICE CONDITIONS
1	Interface of shore lead (300 yd wide) and shorefast ice
2	Over shorefast ice out to refrozen pans with many cracks--small holes and some larger openings in the ice
3	Floating pans with much open water
4	Refrozen and free-floating pans--some floating ice in cracks between large pans
5	Medium to large free-floating pans
6	Open water--scattered pans
7	Open water--small amounts of floating ice
8	Open water to shorefast ice on north coast of Richards Islands where transect was over tundra

FIGURE 43. Aerial Survey Conducted on 9 July 1975.

Dr. Warren L. Flock of the University of Colorado kindly provided us with unpublished information about migration north of Alaska as revealed by Alaskan DEW radars.

George Calef's advice that we locate our field camp at Clarence Lagoon proved to be valuable.

Kenn Borek Air and Corridor Flights of Inuvik, N.W.T., supplied prompt and reliable air service throughout this study. We would especially like to thank pilots Gary Richards and Larry Buckmaster as well as pilots Al Hovi (Bow Helicopters Ltd.) and Joe Kreke (Kenting Helicopter Ltd.). Reindeer Air Services of Inuvik, N.W.T., kindly assisted in resupplying our field camp.

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British Airways pilots provided invaluable information on ice and weather conditions in the Beaufort Sea area. On several occasions during our aerial surveys, pilot Dave Cameron (Aklavik Air Services Ltd.) and biologist Mark Fraker gave us information about ice conditions on the Beaufort Sea area.

Many people in our Edmonton office provided help during this study; we wish to acknowledge Tom Wright's editorial assistance and to thank Myrna Bergot, Alan Birdsall, Pat Cary, Joanne Chabaylo, Bill Fricker, Diane Hollingdale, Donna Langner, Gary Searing, and Lynn Sharp, who also provided assistance.

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APPENDIX 1. Relationship Between Zero to Eight Ordinal Scale of Migration Densities and Number of Groups per Hour Crossing a Line 10 km Long Oriented Perpendicular to the Mean Flight Direction.

Figure 44 shows the relationship between the two estimates of migration volume. The correlation is high (Spearman rank correlation coefficient = 0.978), but the relationship is decidedly non-linear in the range 3.3 to 4.7 on the zero to eight scale. Below and perhaps above this range, the relationship between the two estimates is more or less linear.

Although wide ranges of counts were obtained in situations recorded as having the same zero to eight scale value, the standard deviations of the zero to eight scale values for most narrow ranges of counts were 0.2 to 0.5. Thus, well over 95% of the cases were apparently assigned to scale values within one scale unit of the 'correct' value (since 95% of the cases were expected to be within ± 2 s.d.). Furthermore, although the range of scale values for a single count results in part from imprecise assignment of scale values, this range also reflects sampling errors and counting errors in the determination of the counts. Thus, the assignment of zero to eight scale values is probably more precise than indicated above. In summary, it is concluded that the method involving the zero to eight scale is a useful way of recording the volume of migration.

Table 1 ('Methods' section) summarizes the average count for each integer scale value on the zero to eight scale.

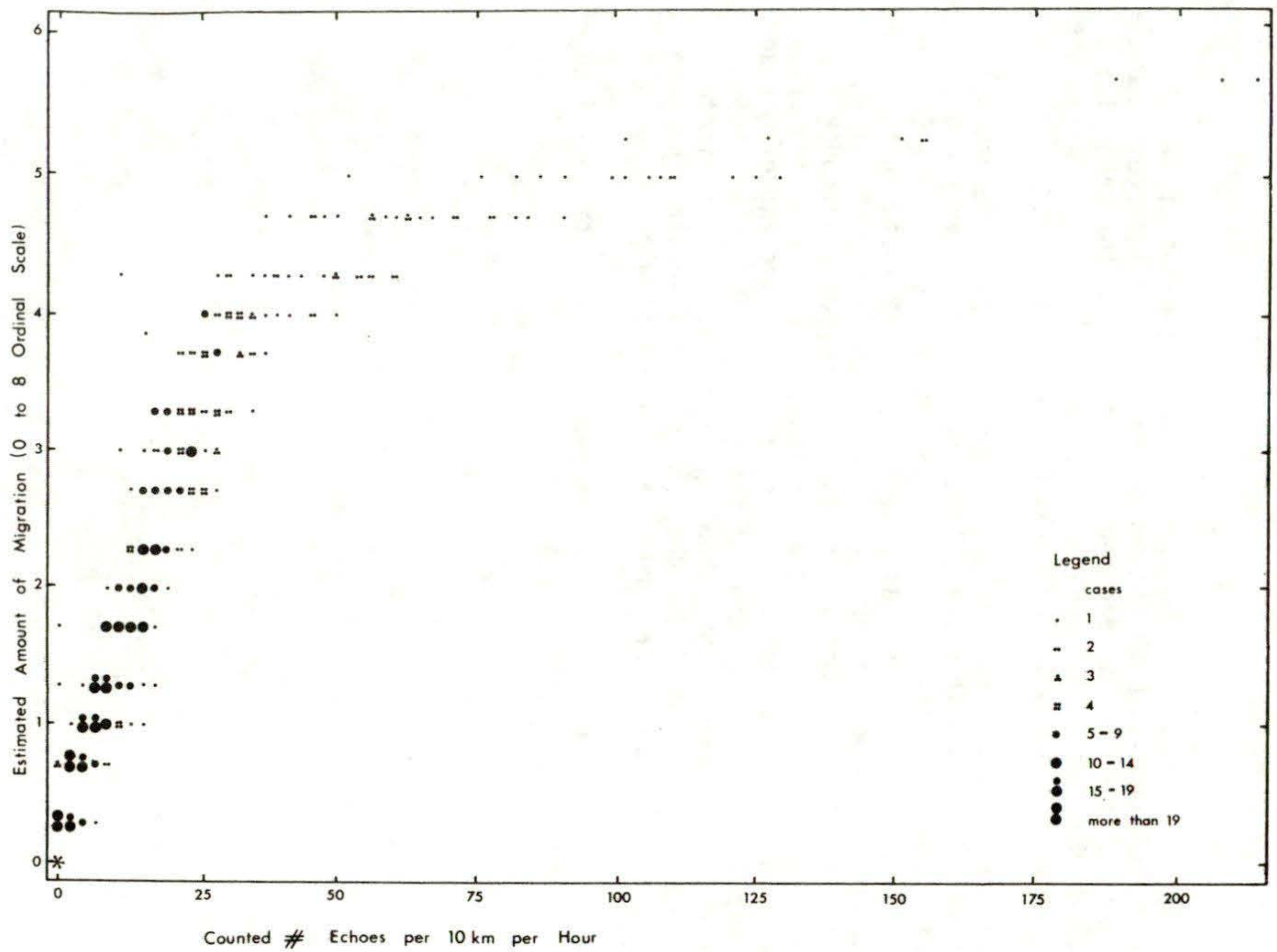

FIGURE 44. Relationship Between Zero to Eight Ordinal Scale of Migration Densities and Number of Groups per Hour Crossing a Line 10 km Long Oriented Perpendicular to the Mean Flight Direction.

APPENDIX 2. List of All Avian Species Recorded During Migration Watches, Aerial Surveys, and Casual Observations; Dates of First Observations and of Principal Migratory Movements; Predominant Directions of Movement.

An asterisk following a date of first observation indicates that the species in question was probably present in the study area before the date indicated. Dates enclosed in parentheses are of sightings made by reliable observers other than LGL personnel. The total number seen during migration watches (excluding casual observations) at Komakuk and Clarence Lagoon is presented, as is the number seen during the seven aerial surveys.

When less than 90% of the total number of migrating individuals seen during migration watches moved in other than the predominant direction, the two predominant directions are listed with the primary direction listed first. Directions are listed only if the directions were very consistent or if the samples were large.

See Richardson *et al.* (1975) and Johnson *et al.* (In Press) for details.

APPENDIX 2. List of All Avian Species Recorded During Migration Watches, Aerial Surveys, and Casual Observations; Dates of First Observations and of Principal Migratory Movements; Predominant Directions of Movement.

SPECIES	FIRST OBSERVED	NUMBER SEEN MIGRATION WATCH	NUMBER SEEN AERIAL	PREDOMINANT MIGRATION DIRECTION	PEAK MIGRATION DATES
Common Loon	31 May	9	0	East	4-13 June
Yellow-billed Loon	28 May	33	39	East	5-13 June
Arctic Loon	31 May	205	11	East	1-14 June
Red-throated Loon	2 June	221	4	East	5-14 June
Unidentified Loons	30 May	319	24	East	31 May-14 June
Red-necked Grebe	1 June	2	0	-	-
Whistling Swan	19 May	516	5	West	21 May-2 June
Canada Goose	28 May	50	0	West	29 May-3 June
Brant	27 May	17,530	270	East	28 May-8 June (stragglers until 14 June)
White-fronted Goose	15 May	212	0	West	28 May-1 June
Snow Goose	13 May	84	0	West and East	26 May-1 June (eastbound) 31 May-9 June (westbound)
Mallard	6 June	3	0	-	-
Pintail	25 May	1705	50	West and East	30 May-12 June (east and west-bound) 13-28 June (westbound)

APPENDIX 2 (cont'd)

SPECIES	FIRST OBSERVED	NUMBER SEEN		PREDOMINANT MIGRATION DIRECTION	PEAK MIGRATION DATES
		MIGRATION WATCH	AERIAL		
Green-winged Teal	29 May	48	0	-	-
American Wigeon	2 June	32	0	-	-
Northern Shoveler	30 May	4	0	-	-
Greater Scaup	1 June	14	0	-	-
Lesser Scaup	31 May	6	0	-	-
Unidentified Scaup	1 June	141	0	-	-
Common Goldeneye	26 June	1	0	-	-
Oldsquaw	28 May	8193	5650	East	29 May-13 June
Harlequin Duck	27 June	2	0	-	-
Common Eider	3 June*	641	905	East	5-15 June
King Eider	13 May	44	304	East	-
Unidentified Eider	7 June	406	176	East	7-14 June
White-winged Scoter	6 June	194	190	West	17 June-end of study
Surf Scoter	28 May	1247	107	West	17 June-end of study
Black Scoter	8 June	5	30	-	-
Unidentified Scoter	28 May	1051	379	West	17 June-end of study
Red-breasted Merganser	29 May	176	7	East and West	17 June-end of study
Rough-legged Hawk	28 May*	13	0	-	-

APPENDIX 2 (cont'd)

SPECIES	FIRST OBSERVED	NUMBER SEEN		PREDOMINANT MIGRATION DIRECTION	PEAK MIGRATION DATES
		MIGRATION WATCH	AERIAL		
Golden Eagle	26 May*	12	0	-	-
Marsh Hawk	30 May	10	0	-	-
Gyrfalcon	16 June*	3	0	-	-
Peregrine Falcon	17 June*	3	0	-	-
Willow Ptarmigan	12 May*	5	0	-	-
Rock Ptarmigan	12 May*	164	0	-	-
Sandhill Crane	20 May (14 May)	43	0	-	-
Semipalmated Plover	27 May	43	0	-	-
Killdeer	21 June	3	0	-	-
American Golden Plover	17 May	224	0	East and West	27 May-9 June
Black-bellied Plover	2 June	26	0	-	2-14 June
Ruddy Turnstone	18 May	56	0	-	-
Common Snipe	29 May	59	0	-	-
Whimbrel	30 May	3	0	-	-
Red Knot	19 June	1	0	-	-
Pectoral Sandpiper	24 May	439	0	East and West	28 May-12 June
White-rumped Sandpiper	9 June	4	0	-	-
Baird's Sandpiper	28 May	248	0	East and West	28 May-mid-June
Least Sandpiper	28 May	3	0	-	-
Semipalmated Sandpiper	28 May (26 May)	347	0	West and East	29 May-11 June
Dunlin	28 May	41	0	-	-

APPENDIX 2 (cont'd)

SPECIES	FIRST OBSERVED	NUMBER SEEN MIGRATION WATCH	 AERIAL	PREDOMINANT MIGRATION DIRECTION	PEAK MIGRATION DATES
Sanderling	27 May	17	0	-	-
Long-billed Dowitcher	27 May	12	0	-	-
Stilt Sandpiper	28 May	141	0	East	29 May-7 June
Buff-breasted Sandpiper	6 June	4	0	-	-
Hudsonian Godwit	3 June	2	0	-	(also 6 unidentified Godwits
Red Phalarope	31 May	446	0	East and West	31 May-10 June
Northern Phalarope	25 May	212	0	East and West	31 May-?
Unidentified Shorebirds	22 May	692	5	East and West	22 May-9 June
Pomarine Jaeger	29 May	3537	2	East West	28 May-12 June (eastbound) 11-21 June (westbound)
Parasitic Jaeger	22 May	124	9	East	3-12 June (eastbound) 17-22 June (westbound)
Long-tailed Jaeger	27 May	160	0	East and West	27 May-12 June
Unidentified Jaeger	-	651	16	East West	30 May-12 June (eastbound) 16-21 June (westbound)

APPENDIX 2 (cont'd)

SPECIES	FIRST OBSERVED	NUMBER SEEN		PREDOMINANT MIGRATION DIRECTION	PEAK MIGRATION DATES
		MIGRATION WATCH	AERIAL		
Glaucous Gull	11 May	4049	203	East	28 May-21 June
Herring and/or Thayer's Gull	21 May	94	0	East	24 May-7 June
Thayer's Gull	4 June	5	0	-	-
Mew Gull	12 June	12	0	-	-
Little Gull	16 June	2	0	-	-
Ivory Gull	9 July	0	1	-	-
Kittiwake spp.	9 July	0	1	-	-
Sabine's Gull	4 June	58	0	East	4-13 June
Arctic Tern	29 May	681	5	East	3-14 June
Black Guillemot	17 May*	2	4	-	-
Snowy Owl	14 May*	46	1	East West	7-14 June (eastbound) 18-22 June (westbound)
Short-eared Owl	15 May	199	0	East and West	28 May-12 June
Common Flicker	8 June	1	0	-	-
Horned Lark	14 May	23	0	-	-
Bank Swallow	7 June	4	0	-	-
Barn Swallow	29 June	1	0	-	-
Cliff Swallow	14 June	1	0	-	-
Common Raven	9 May*	624	0	-	-

APPENDIX 2 (cont'd)

SPECIES	FIRST OBSERVED	NUMBER SEEN		PREDOMINANT	PEAK
		MIGRATION WATCH	AERIAL	MIGRATION DIRECTION	MIGRATION DATES
Yellow Wagtail	3 June	35	0	-	-
Water Pipit	10 May*	4	0	-	-
Redpoll spp.	9 June	154	0	-	-
Hoary Redpoll	8 June	25	0	-	-
Savannah Sparrow	7 June	14	0	-	-
Dark-eyed Junco	21 May	1	0	-	-
Tree Sparrow	12 June	3	0	-	-
White-crowned Sparrow	28 June	1	0	-	-
Lincoln's Sparrow	12 June	1	0	-	-
Lapland Longspur	9 May*	1002	0	-	26 May-early June
Snow Bunting	8 May (10 April)	274	0	West and East	-