CANADIAN WILDLIFE SERVICE

Use of Aerial Surveys

by the

Canadian Wildlife Service

by DENIS A. BENSON

OCCASIONAL PAPERS No. 3

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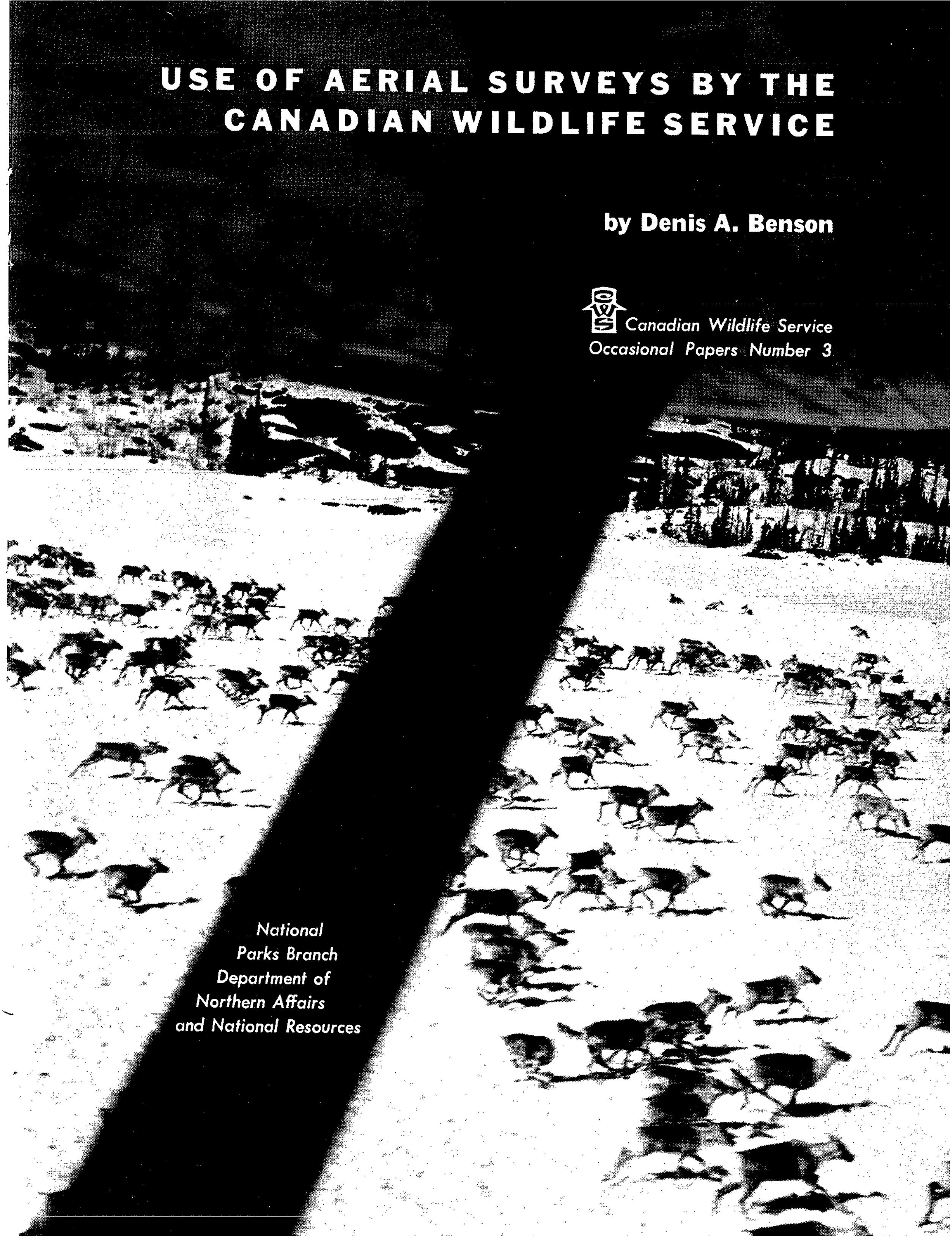

National
Parks Branch
Department of
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and National Resources

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INTRODUCTION

A federal agency, the Canadian Wildlife Service is part of the National Parks Branch of the Department of Northern Affairs and National Resources. In the Northwest Territories and all National Parks, the Service is responsible for wildlife research, and management recommendations. Co-operative studies with the provinces and the Territories have been a part of the history of the Service.

In Canada, legislative responsibility for game, fur-bearing animals, and birds is divided between the Provincial, Territorial, and Federal Governments. The overriding responsibility for migratory birds has rested with the Federal Government since 1916, when the Migratory Birds Treaty was signed between Mexico, the United States, Canada, and Newfoundland. Newfoundland, now a province of Canada, was at that time the oldest of the Crown colonies. Continental waterfowl management is a highly complex, co-operative business, handled by the Canadian Wildlife Service on behalf of the Federal Government (in consultation with the provinces), by the United States Fish and Wildlife Service (in consultation with the states), and by the game administration of Mexico.

The foregoing notes are offered to explain two apparent anomalies in this paper. 1) Wildlife surveys in the provinces for species other than waterfowl are not reported. 2) Waterfowl surveys carried out in the provinces, almost entirely by U.S. Fish and Wildlife Service personnel and equipment, are included because they are within the framework of the co-operative international waterfowl management program.

Methods of aerial survey used by the Canadian Wildlife Service are as numerous as the types of survey being carried out. Results are even more diverse. The two major factors that dictate methods and determine results are 1) geography and 2) the attributes of the species concerned.

The northern region of Canada will be defined for our purposes as consisting of the Yukon and Northwest Territories north of 60° latitude.

The islands in Hudson Bay (part of the N.W.T.) lie south of that line and Quebec Province extends north of it. The mainland caribou often spend the winter to the south of the line, and most of our geese spend the summer to the north of it. Bison live astride it. (Fig. 5)

Our northern surveys are mainly of large mammals, primarily caribou, but also muskoxen and bison. To obtain a picture of Northern Canada as the pilot sees it, the reader is referred to Dunbar and Greenaway (1956).

South of 60° the major concern of the Service is migratory waterfowl, and interest is centered in the prairie-pothole region of southern Alberta, Saskatchewan, and Manitoba. With the neighbouring states of Montana, North Dakota, and South Dakota, that area is known as "The Big Duck Factory" (Fig. 2). The Mackenzie River Valley is also important as a source of ducks, and the North contains most of the nesting grounds of the continental goose populations. Canada geese nest in a widely dispersed pattern south to the Hudson Bay lowlands of Ontario and Manitoba, but our colonial nesters breed further north. The pattern of their major colonies is mirrored by migratory bird sanctuaries (Fig. 5). Many of the northern sanctuaries were established only recently as part of the Service's effort to protect the source of a continental resource from the inroads that might otherwise be a product of the rapid development that is taking place in the Canadian Arctic.

Aerial surveys of waterfowl in Canada reached a peak in extent and coverage about 1956-57 (Fig. 1). Since then, they have become more restricted, being concentrated on the southern prairies.

Besides the two major groups of surveys (large mammals in the north and waterfowl in the south) there have been a number of different kinds that I will degrade beneath their true worth by giving them the label: "Other Surveys".

In a land where transport and aircraft are so nearly synonymous as they are in the Canadian North, it is not easy to define an aerial wildlife survey. If a flight is planned to make wildlife observations, it will be considered for the purposes of this paper to be a survey. We thereby exclude discussion of the organized reporting of wildlife observations by commercial, governmental, and Royal Canadian Mounted Police pilots, although they must be acknowledged as valuable adjuncts to ground studies and "surveys" as defined above.

CARIBOU SURVEYS IN THE NORTH

The first major aerial surveys of caribou in Canada have been described by Banfield (1949, 1950, 1954*a*, 1954*b*). To obtain a resumé of those aspects of the work of interest to us here, we can do no better than go to his relevant publication (Banfield, 1954*a*).

"The Barren-ground caribou is an important renewable resource of the Northwest Territories and the northern sections of the three Prairie Provinces of Canada. In an area of approximately 600,000 square miles it is one of the basic factors in the economy of approximately 20,000 Canadians. In large areas of the Northwest Territories human habitation would be impossible without the caribou." (p. 37)

There had been previous investigations of the caribou, but they

" . . . were handicapped by the geographical magnitude of the problem. The investigators were limited to single parties using the time-honoured means of northern travel, canoe in summer and dog-team in winter." (p. 1)

" . . . the investigation was undertaken by the Canadian Wildlife Service of the Department of Resources and Development *, with the full co-operation of the Game Departments of the provinces of Alberta, Manitoba and Saskatchewan." (p. 2)

"It was evident that, because of the immensity of the area to be investigated, aircraft must be used extensively as a means of transportation as well as for observation. The extensive field work was to be accomplished by aerial reconnaissance and photography. From this type of observation, data concerning distribution, migration routes, abundance, herd segregation, and effect of predators could be obtained." (p. 4)

"Air service was provided in some cases by the Royal Canadian Air Force and the Manitoba and Saskatchewan Government Air Services, and pilots of the Royal Canadian Air Force on northern duty turned in numerous valuable observations concerning the movements of caribou. The greater part of the flying, however, was done by private charter of local air services in northern Manitoba and the Northwest Territories.

"Besides extensive aerial observations, intensive research was undertaken at a series of ground stations throughout the caribou range at

* An earlier name of the Department of Northern Affairs and National Resources.

various seasons in order to supplement and verify aerial observations and obtain as complete as possible an understanding of the various seasonal aspects of the problem." (p. 4-5)

During the two years of this investigation (1948-49) a total of 87 survey flights were made. Linear miles flown amounted to 36,296. A transect area of 24,695 square miles was observed, and 358,881 caribou counted.

There was much information that resulted from the investigations that is not relevant here. Our concern is with aerial surveys and their results in terms of estimations of wildlife populations.

"It has been estimated that during the later part of the exploratory period in northern Canada, about the year 1900, the caribou population totalled about 1,750,000. On the basis of aerial surveys during the present investigation it is estimated that the present population consists of about 670,000 caribou, indicating an apparent reduction of 62 per cent." (p. 38)

Kelsall (1957) acknowledged the importance of Banfield's work (1954*a*) as a report of the history of the problem, and as a review of the literature on caribou.

The work carried out in 1950-53 by Kelsall, and reported by him in 1957, was less comprehensive biologically, but miles flown, including transportation and extensive survey flights, were 58,141. Almost 2,500 of those miles were devoted to a muskox survey in the Thelon Game Sanctuary.

Banfield's original estimate of population in the area studied by Kelsall was a quarter of a million caribou. Kelsall reported a 25 per cent increase. In view of the extensive nature of the survey, the possible population shifts of the caribou herds, and two years of generous reproduction, the results were interpreted as indicating some increase. As will be stressed throughout this paper, aerial wildlife surveys are yet in their infancy, and are far from being precise and sensitive tools for measuring wildlife populations.

During the 1950-52 period, Kelsall reported a diversified use of aircraft. Actual counts of caribou became a means to various ends, such as the location of herds, the determination of their migration routes, their winter range, calving grounds, and summer range (Fig. 3). The technique of "segregation counts" was developed further: counts of calves and of total animals in a herd were made at various seasons from the air and from the ground. Interpretation of the results provided a means of estimating herd increase. Kelsall reported segregation counts of 3,227 animals, of which 891 were calves.

An attempt was made to estimate wolf populations. Difficulties of observation, relatively small numbers of wolves, and the tendency of wolves to hide from aircraft reduced accuracy to the point where such estimates were useful only as a very general guide to relative densities at different times and/or in different places, when variations were extreme. Wolf observations are still recorded, but flying is not carried out primarily for that purpose.

The caribou herds were re-surveyed in 1955-56. Banfield (1956) told the story to a northern audience, and again to a far wider audience (Banfield, 1957). That last paper is quoted here to illustrate the value of aerial surveys for population estimation, and to emphasize that such surveys are enhanced greatly by a supporting program of ground studies.

"In 1947 the Eleventh Conference of Provincial and Dominion Wildlife Officials considered reports of the decrease both in numbers and range of the barren ground caribou and recommended that a thorough investigation should be made. The Canadian Wildlife Service accepted this task and put the author in charge of the field investigation. This started in 1948. It was to include: status, distribution and movements of caribou; the population trend and its causes; life history and ecological relations; human utilization and a program for future management . . . "

"Most of the counts were made by aerial transects; that is by flights across the herds at definite intervals, the observers counting the caribou up to a certain distance on each side of the line of flight. The information obtained from the transects was plotted on large-scale maps. The boundaries of migration corridors were drawn and the positions of the front and rear of each moving herd fixed. An estimate of the total population was then made using the transect density figures.

"With large herds a photograph was taken to check the transect results. Ground stations were also used throughout the caribou range to supplement aerial observations and to study the other aspects of the investigation.

"As a result of this first inquiry, which finished in 1950, nineteen caribou herds were named and recorded, together with their winter and summer ranges and their populations. The total number of barren ground caribou arrived at was about 670,000. If, as is mentioned earlier, the caribou population in 1900 was 1,750,000, there was a fall of 62 per cent in 50 years . . . "

"From 1950 onwards caribou investigations continued. Mr. J. P. Kelsall was stationed at Yellowknife to study particularly fawning habits and food requirements. In 1953 a survey of the Yukon herd was undertaken in co-operation with the U.S. Fish and Wildlife Service. In 1954-55 aerial surveys showed a Baffin Island population of 5,000 and another 5,000 in the Ungava peninsula, Quebec.

"1955 Spring Survey—During the spring of 1955 a complete aerial re-survey of the central area was undertaken. The results are alarming, for they indicate that the present barren ground population is about 277,000 animals—a decline of 393,000, or 60 per cent, during the last six years . . . Only in Keewatin District did the caribou population seem to be holding its own.

"1955-56 Winter Survey—During the winter of 1955-56 a caribou air survey was again carried out, except in Manitoba and Keewatin.

"The caribou were found to be much more widely scattered than they usually are in winter and were using some areas formerly considered summer range. The exceedingly light snow conditions may have partly accounted for this . . . "

"All the evidence in 1955-56 indicated a continued decline in caribou numbers. Man's use alone accounting for an annual decrease of 30 per cent." (p. 14-16)

The results of past surveys clearly indicated the need for closer study of the cause of decline of caribou. Kelsall (1960) reported on a study conducted in 1957-58.

"An intensive research program on barren ground caribou, *Rangifer arcticus arcticus* (Richardson) *, was officially commenced April 1, 1957 . . . "

"The program was conceived as a co-operative venture, involving federal, provincial and territorial government agencies. In practice this arrangement worked very well. The Canadian Wildlife Service, the Government of Manitoba, the Indian Affairs Branch of the Department of Citizenship and Immigration and the Northwest Territories Council jointly and successfully undertook the major financing of the project." (p. 1)

"The survey flying and movement of camps and supplies necessitated aircraft usage beyond that of any previous northern wildlife projects undertaken. This was particularly true at such periods as during the calving season in 1958 when 13 men, in four separate camps, were established at distances up to 500 miles from an operational base.

"This project was unique, in recent years at least, in that scientists and their assistants lived continuously on the northern taiga and tundra in tent camps throughout the study period. This period encompassed two springs, two summers and a winter. Air transport made it possible to remain always with the caribou, except for a few brief intervals. It was much to the credit of the men involved that they maintained high work standards, with no major accidents or illnesses, under circumstances which included, at times, the worst that the country could produce in the way of weather and ground conditions." (p. 5)

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* Now *Rangifer tarandus groenlandicus* (Linneaus). The common name "caribou" should now be replaced by "reindeer". (Banfield, 1961).

A total of 155,416 miles of flying was done; by Otter, 33,582; Beaver, 25,123; and Cessna (including a few thousand miles by Piper and Stinson aircraft), 96,711. The 1957-58 survey indicated that a further severe decline had occurred.

An impressive effort was made in 1961. Tener (1962) reported on a survey of 18 islands of the Queen Elizabeth Islands group at the extreme north of Canada. About 121,000 square miles of potential habitat were surveyed at intensities that varied from 1.8 per cent to 10.5 per cent, at a cost of about $0.40 per square mile.

The survey proper consisted of 17,500 linear miles of flying done at a height of 500 feet and a speed of 85 miles per hour. Piper Super Cub aircraft equipped with low-pressure large-diameter balloon tires were used for 175 hours of transect flying, and a Beaver aircraft was used for 25 hours. Including transport, supply, and trips to and from the transects, the survey required 500 hours of flying time by the Pipers, and 100 hours by the Beaver.

Transects one-quarter-mile wide on one side of the Pipers, and one-half-mile wide on both sides of the Beaver were used. Animals observed were recorded as being either on or off the transect.

Two pilots and three biologists made up the field party which was in the field during one Arctic summer.

The survey has produced information on the general distribution and numbers of caribou and muskoxen on the islands, and more limited information on many other mammals and birds.

Caribou studies are made possible by the availability of suitable aircraft in the North. Several caribou surveys have been carried out in other parts of Canada, but they were of lesser scope than those reported above. I have already quoted a reference to them (Banfield, 1957, p. 15). The Ungava survey was part of a more comprehensive study. It was a good example of a co-operative study arranged at the request of a province—in this case, Quebec (Banfield and Tener, 1958). Another co-operative venture of the same type was carried out in Newfoundland. The most recent statement of the problem of saving the caribou herds from extinction was made by Tener (1960).

WATERFOWL SURVEYS

Ducks are short-lived. The rapid turnover in population may result in annual population fluctuations of an extent important to the management of the continental flocks. Management procedures are aimed at setting seasons and bag limits that will adjust the annual kill to the available annual surplus.

Geese live longer than ducks, but the annual kill of geese normally contains a relatively large proportion of birds of the year. If production is poor, the older birds, the source of future production, suffer heavily unless the situation is recognized, and the hunter kill reduced by legislative means.

Annual aerial surveys of waterfowl, carried out throughout North America largely by the United States Fish and Wildlife Service, help to supply management information that is required annually on a continental scale.

"In January all but a minute proportion of North American waterfowl may be found south of the Canadian boundary; in July about 70 per cent of the population is north of that line. Generalities based on these facts have been frequently stated and are widely known. Partly through an appreciation of them the Migratory Birds Treaty was entered into in 1916 by the United States and Great Britain. Because of that international commitment the Federal Governments of Canada and the United States are presently engaged in waterfowl research and management.

"However, while ducks and geese are within any province or state they are the property of that province or state; and all those governments must assume a measure of responsibility for waterfowl welfare and must also, to satisfy the requirements of their citizens, make provisions for a sustained harvest of reasonable proportions, if at all possible." (Munro and Gollop, 1955)

Aerial surveys represent only one aspect of the co-ordinated international, national, provincial, territorial, and state programs. However, it is with the use of aerial surveys that we are concerned.

"In view of the need for information regarding changes in fall flights before the shooting season rather than after, experimental breeding ground surveys were conducted in 1947 to explore the possibility of measuring annual changes in production. It soon became apparent that extensive breeding ground surveys were practical, and they were expanded rapidly." (Crissey, 1957)

Figures 1 and 2 are from Crissey's paper. Figure 1 indicates the greatest extent reached by aerial waterfowl surveys in Canada. Annual arctic flights continue, although they are hampered by the logistics of arctic flying. In Eastern Canada the habitat is highly heterogeneous, and visibility is poor owing to forest cover. It is on the western prairies in the "Big Duck Factory" that waterfowl survey methods have been most highly developed.

"The breeding-ground survey is designed to obtain data to use in predicting annual variations in the size of the fall flight of ducks along the four administrative flyways. These data are considered in setting hunting regulations. They are gathered and analyzed using Canadian provinces as areas of reference so that the information obtained may be used also by the provinces in setting regulations. * The survey is designed to establish an index to the probable size of the fall flight of all ducks from each province. This index is then allocated to the four flyways on the basis of probable fall movements, as determined by banding data. The procedure for forecasting the flight to each flyway is described by Crissey (1957).

"The breeding-ground survey is designed so that the sampling error of the total duck index for each province would be less than 20 per cent at the 0.05 probability level. Whenever the sampling error has been estimated following a survey, it has been found to be considerably lower than this figure.

"To increase the efficiency of surveys, the waterfowl-production area was divided into smaller areas referred to as strata. Strata were established in each province on the basis of the expected waterfowl-population density, the variability of the population and, to some extent, the major habitat types, so that an optimum allocation of sampling could be determined.

"The survey is conducted from aircraft flying 100 to 200 feet above the ground along linear routes or 'transects'. The transects are further divided into segments, 18 miles in length, so that studies of variability may be made. A survey crew consists of one man acting as a pilot-navigator-observer, and another man as an observer. Each person records data from a strip ⅛ mile wide on his side of the aircraft. Whenever possible, waterfowl are recorded by species as 'pairs', 'lone drakes', or

* Canadian regulations are set by federal authority after consultation with the provinces.

'groups of mixed sexes'. When identification is not possible, the birds are recorded as a certain number 'unidentified'.

"In analyzing the data, it is assumed that each drake on a breeding area has a hen, either with him or on the nest and invisible to the observers. These unseen hens are included in the final index value. In groups composed of both sexes, a hen is not added for each drake; instead the total count is used. These mixed groups of birds make up only a small portion of the . . . population during the breeding season. The birds recorded as 'unidentified' are allocated as drakes or hens, according to the sex ratio of the 'identified' birds. The calculated number of drakes 'unidentified' is allocated to the various species in proportion to the occurrence of these species in the 'identified' group. A hen is added for each drake in order to arrive at a population index for the sample. These data are then expanded to a population index for the entire stratum.

"On the Canadian prairies, waterfowl are often so numerous that it is necessary to use dictaphones to record them. On northern surveys over forest and tundra, waterfowl are more widely scattered and observations are entered directly onto record forms. Surveys in the prairies and parklands are conducted with the Piper 'Super-cub', a tandem two-seater flying from 75 to 100 miles per hour. One Cessna '170', a four-seater with the crew sitting side by side, and flying about 100 miles per hour, is used in Alberta. Surveys beyond the prairies and parklands are conducted with Grumman 'Goose' and 'Widgeon' amphibians flying about 120 miles per hour, with the two crew members side by side." (Stewart *et al.*, 1958)

Those authors discuss the statistical design of the survey and analysis of the results. It is clear that the design of the surveys still leaves something to be desired. Diem and Lu (1960) have investigated various sources of bias by comparison of aerial and ground censuses on the same area:

"Today we are still confronted with the same three census problems recognized 20 years ago by Lack (1937). First, census efforts are too often unproductive because census takers have been unaware of associated ecological problems. Second, censuses made on artificial or small local areas have been used too frequently on large natural areas where they are not applicable. Third, little or no successful effort has been made to evaluate the widely varied habitat differences encountered in an extensive game census."

The results of the annual breeding ground survey have been reported in a series of reports prepared by the Fish and Wildlife Service of the

United States Department of the Interior. The reports that contain Canadian data are sponsored jointly by agencies of both countries.

The research biologist may (and frequently does) speak of the aerial survey as inexact, and as suffering from many variables and biases, known and unknown. Admitting those problems, the aerial survey remains the best, if not the only, available tool for the job. It has been used on a large scale for 15 years. It will continue to be used and, we hope, improved.

OTHER SURVEYS

Clarke (1940) carried out a biological investigation of the Thelon Game Sanctuary in 1937. He collated aerial observations of muskoxen made by various men of diverse governmental agencies, combining them with his own to produce one of the first aerial wildlife surveys in Canada.

In 1949, Fuller (1950) carried out a "strip census" of bison in Wood Buffalo National Park. He described an earlier attempt by the Royal Canadian Air Force to photograph the entire winter range in 1931: "The attempt was not altogether successful and less than 1,400 animals were photographed." In 1947 the Park Superintendent "adopted the strip census method and saw 2,494 bison. On the basis of one-third coverage, he estimated 7,482 animals."

Fuller describes his own work:

"For the present census two types of ski-equipped aircraft were used —a De Havilland 'Beaver' and a Fairchild '71C'. Both machines are capable of cruising at 120 miles per hour and afford excellent opportunities for observation. The 'Beaver', being a completely modern machine, equipped with an efficient heater, and especially designed for bush flying, was used for all but two flights. The heater assumes paramount importance when hands must be continually exposed either to make notes or to operate binoculars while the outside temperature is from —10 to —20°F.

"Each member of the party was provided with a mounted map on which flight lines were prominently ruled. In addition, the observers carried 6 × 30 binoculars and notebooks. An Abney level, K-20 type aerial camera, and a Zeiss plateback camera completed the list of equipment.

"The survey party included a pilot, the writer and a second observer. The flight engineer acted as second observer for approximately one-third of the flights, which were all made in the northern section of the park. The Chief Park Warden, I. F. Kirkby, was an observer on the remaining flights, which covered the areas of greatest concentration. It was found that holding accurately to our course required the full attention of the pilot, who was therefore excused from making any observations except to point out herds which were situated directly on the line of flight and which might otherwise have passed unseen beneath the aircraft." (p. 446)

"The total flying time involved, including the special search outside the park, was 29 hours and 40 minutes. Of this, one hour and 50 minutes could be charged directly to administration, which included transportation of personnel and a medical emergency call. The aircraft was chartered at $60.00 per hour, which made the total cost $1,766.00. Approximately 4,500 square miles were brought under direct observation, and an estimated 25 per cent coverage obtained for about 18,000 square miles. The cost was less than ten cents per square mile. There is no basis for comparison with the expense of a ground survey, since such a survey is impracticable in this wilderness area." (p. 447)

The method of deriving a total figure from the sample was empirical.

"In Wood Buffalo Park proper and the Little Buffalo-Slave Rivers lowlands 3,263 bison were counted. The greatest concentration was found on the wet meadows between Baril Lake and the northwest bay of Lake Claire. Here, 729 bison were counted in a large loosely connected herd. Aerial and ground reconnaissance in this area had established that there was only one such aggregation. Since the census was based on the theory of one-quarter coverage, it was the original intention to multiply the number observed by four to arrive at an estimate of the total population. Obviously, a considerable error would have been introduced if this policy had been followed with respect to the above herd. To arrive at an estimate, therefore, the factor of four was used on the 2,534 other animals, and the 729 then added to give a total for this area of 10,865." (p. 448)

The difficulty of arriving at an estimate of total population from a sample is illustrated clearly. In this case the analysis of results was based on the implicit assumption that the distribution of most of the animals was random, and that the sample should be multiplied by four, except for one herd which was counted in its entirety and its total added without multiplication.

Fuller faced the usual difficulty of estimating the magnitude of errors of observation.

"From the limited evidence available it now appears that estimates based on ground studies have exceeded the mark and aerial counts have been too low. Soper felt that an allowance of 25 per cent should be made for animals which were hidden in the timber and thus not counted. If he was correct, there may be as many as 15,000 bison on the northern ranges. Soper's allowance is considered generous by the present writer so that the 1949 population is thought to be between 12,000 and 15,000." (p. 450)

Aerial surveys of bison in Wood Buffalo Park continue to be a useful management technique. Experience and repetition, rather than major improvements in the basic technique, have probably improved the accuracy of the estimates obtained.

Colls (1952) reported on "Surveys of elk and other wildlife in Riding Mountain National Park, Manitoba, 1950-51 and 1952."

The more mountainous National Parks cannot be surveyed from the air. However, the technique is used in the prairie parks, where the topography permits it.

There have been only minor improvements in survey technique in the parks since the date of Coll's report. That report will serve to characterize further aerial surveys as still used in the parks. The tendency at present is toward making a total count.

"Through the courtesy of the Royal Canadian Air Force, an aircraft and crew were placed at the writer's disposal . . . Flight lines, or transects, two miles apart were flown, starting at the west side of the park and progressing eastward across it. The Dauphin Airport, situated approximately seven miles north of the north gate of the park, was used as an operating base.

"In addition to the above, an aerial survey of the east side of the park and adjacent farming country was made on February 16, 1950, in co-operation with the Manitoba Game and Fisheries Branch. The same area was again surveyed from the air three times in the following winter . . . " (p. 1)

"The primary purpose of the investigation was to ascertain as accurately as possible, for administrative purposes, the total number and distribution of elk in the park. It was also desired to obtain information about the other large mammals, especially moose, deer, wolves, and coyotes." (p. 1-2)

"After experimentation it was found that in the western end of the park it was possible, from an altitude of 75 to 100 feet, to observe one-quarter to one-half a mile from the line of flight. In the eastern end of the park, however, heavy forest limited observation to about one-fifth of a mile. For the sake of uniformity it was decided to restrict the observed strip to about one-fifth of a mile on all the transects, on each side of the aircraft.

"The seating arrangement of the aircraft made it impossible for pilot and observer to count on opposite sides. Because of this, all transects were flown in both north and south directions. The strip covered along each transect was, therefore, two-fifths of a mile (about 700 yards) wide. The total number of lineal miles flown was 538.0; and 215.6 square miles, or about 19 per cent of the total park area of 1,148 square miles, was sampled. This coverage was obtained in 25 hours of flying time, completed in five days averaging five hours flying time per day.

"The writer counted the animals by entering them in columns on sheets of paper fastened to a clip board. The pilot carried a tally counter and obtained a total count on each flight to check against the writer's totals. When groups were seen, they were circled over to obtain an accurate count. In this way both observers counted the same areas at the same times, and it was believed that very few animals were missed." (p. 3)

For elk the surveys appear to have been relatively precise (results were repeatable). Their accuracy (closeness to the true value) is less easily gauged. Colls used much auxiliary data to estimate accuracy, but the figures he gave were derived from the size of the area concerned (transects) extrapolated to the total area surveyed (the park). The implicit assumption is again that of a random distribution of animals.

For species smaller and less easily observed than elk, the surveys were of far less value. It should be recorded that, although we speak of "prairie" parks, the areas being surveyed were wooded in many parts, a situation different from that of the northern tundra or the prairie pothole region.

Colls' remarks are indicative of the limited use of aerial surveys for smaller species.

"Deer are considerably smaller than elk, and they generally prefer more cover. It is likely that many more were present than were visible from the air." (p. 18)

"Moose are primarily browsing * animals, inhabiting swamps and muskegs. It is likely that they cannot be censused accurately by methods used in censusing elk. This may account partially for the great difference between the aerial survey estimate of 1950 and the Chief Warden's estimate in the same year." (p. 18)

"Only 12 coyotes were seen along the transects in 1950. The estimate based on this figure was probably several times too low. The weather at that time was cloudy and cool and coyotes were not likely to be out in the open. In the woods they are hard to see from the air." (p. 19)

"During the transect flights only one wolf was seen in 1950, none was seen in 1951 or 1952. However, there was other evidence to show that there were quite a number of wolves in the country." (p. 20)

In order to estimate wildlife populations, it is not always necessary to count the animals themselves. Fuller (1953) describes a technique of aerial survey for beaver.

"The two major objectives of the surveys were: (1) To examine all parts of the Mackenzie District and evaluate the quality of beaver habitat; (2) to develop an index of abundance which can be used either to compare the beaver populations of different areas, or to follow the trends

* Browse—twigs, leaves, and buds of woody plants. In summer moose often feed extensively on aquatic plants.

in the beaver population of a given area over a period of time." (p. 329-330)

"Before describing methods in detail, it is necessary to point out certain difficulties which were encountered. First, because of the great size of the area, the coverage had to be extensive rather than intensive. Second, as many of our flights exceeded the normal range of the light aircraft used, it was necessary to carry gasoline and oil in the cabin of the airplane. Certain areas, e.g., the north shore of Great Bear Lake, could not be reached even then because gasoline caches are few and widely scattered in that area. Third, the standard map sheet is on a scale of eight miles to one inch. Although the general quality of these maps is good, it is impossible to portray the smaller features accurately on this scale. Finally, there is a scarcity of physiographic data for this entire area. Few elevations and no contours are shown on the standard maps, and the personal knowledge of the investigators is therefore important.

"The method of surveying consists in flying along a prearranged route with an observer on each side of the aircraft recording in a notebook all evidence of the presence of beaver * . . . Whenever large, easily identified landmarks are passed, the time is recorded and the nature of the reference point is entered in the Remarks column. Brief notes on topography, vegetation, recent fires, or other observations of possible significance are also made from time to time . . . "

"Flight lines are plotted to sample the greatest amount and variety of beaver habitat in the area to be covered. Where the beaver habitat consists mainly of streams, a number of these are followed, and the course is planned in such a way that unproductive travel between watersheds is kept to a minimum. The pilot is instructed to fly along one side of the stream so that one observer devotes his full attention to the stream while the other observer views some of the tributaries, and usually, a number of small lakes which lie along the course. Following the main stream requires the intense concentration of the observer which produces fatigue. When this occurs, the pilot shifts the aircraft to the other side of the stream, which reverses the tasks of the observers.

"A course such as this can be followed accurately and reflown in a similar manner in subsequent surveys.

"Where the beaver habitat consists mainly of lakes, the same method will often succeed. Sometimes, however, the lakes are so numerous that they cannot all be portrayed on the map, and as individual lakes cannot be identified it is impossible to follow a prearranged route. To avoid this

* The evidence consists of beaver dams, ponds, houses ("lodges"), submerged piles of food stored for winter use, recently felled trees, and freshly flooded areas.

difficulty a technique is being developed whereby an attempt is made to fly along a straight line between recognizable points. At the same time the proportion of lakes occupied by beaver is noted.

"The altitude at which the surveys are carried out varies with conditions. Stream courses are usually followed from an elevation of 500 to 800 feet above the ground. When flying over lake country, however, it has been found that beaver "sign" is easily seen from the elevation of 2,500 feet." (p. 330-331)

"The results obtained from aerial surveys in 1949, 1951, and 1952 have been used to map three grades of beaver habitat. An index of abundance (colonies per mile) has been used to identify saturated habitats, to study the rate of population gain, and to demonstrate the beneficial effects of a sanctuary." (p. 335)

Fuller was aware that he could not obtain absolute population estimates from his survey. He was attempting to establish an "index" of population from a fixed and repeatable sample, as defined by the flight track. As a management technique, the value of this type of survey lies in its repeatability and in correlations between periodic surveys, ground counts of parts of the track, trappers' catches, weather records, and other data.

As part of a more comprehensive study of the Atlantic walrus, Loughrey (1959) investigated the possibility of using aerial surveys as a management technique. During the study he worked out of Coral Harbour, Southampton Island.

"On the preliminary aerial survey flown in a Royal Canadian Air Force Lancaster bomber in August, 1952, several known hauling-out areas—Nottingham, Salisbury, Walrus, and White Islands—were surveyed at low altitude. No walruses were seen.

"On July 16, 1953, while on the flight with E. Wellein of the U.S. Fish and Wildlife Service, walruses were observed at Coats Island and Walrus Island. The only sizable herd seen was one of 30 on Walrus Island. They started to scramble towards the water when the aircraft was still more than a quarter of a mile away, and had all reached it by the time the aircraft passed over them. Their quick reaction to the sound of the aircraft made it doubtful whether aerial census would be successful.

"On August 20, 1954, two survey flights were flown out of Coral Harbour, Southampton Island. The aircraft used was a twin-engine, land-based Anson with a cruising range of 800 miles.

"Since a total count was desired, all known hauling-out areas had to be surveyed at the right time to catch most of the walruses hauled out. Ground observation and careful questioning of local Eskimos provided information not only on the islands and peninsulas, but also on the exact locations where walruses are known to haul out year after year. As previously, noted, such favoured locations may often be spotted at a considerable distance, by the darkening of the rocks by excrement and the accumulation of rubbed-off hair in the crevices. It was necessary also to know the location of the floating pack ice. If it comes close to the hauling-out areas the walruses leave the land for the ice and spread out over a wide area.

"The hauling-out areas were marked on the pilot's map, and a circuit was laid out to cover them all as economically as possible.

"Walruses usually lie so close together on land that it is difficult to count them individually. Considerable experience in observing, counting, and estimating them on land is needed for making accurate visual estimates of herds numbering as many as 1,000. On the survey flights, an Eskimo of tested reliability in the work accompanied the writer and made separate estimates.

"It was found that the noise of the aircraft disturbed the walruses more at low than at high altitudes. Moreover, at low altitude, it was difficult to make even a quick estimate because the time of observation was so short. The best results were obtained by making the initial run upwind at a height of 1,000 to 1,500 feet. It was then often possible to make a second run before all the animals took to the water. Large herds particularly were slow to leave the rocks.

"Seven known hauling-out areas were surveyed in that manner on two flights totalling 500 miles. A total of 2,900 walruses was estimated. This figure was obtained by taking the mean of the highest and lowest estimates and rounding it to the nearest 50. The total is believed to be within 15 per cent of accuracy.

"Judging from the preliminary survey flights, close estimates of herds hauled out on land are possible by the described survey procedure if weather and ice conditions are favourable. Visual estimates could be checked by aerial photography if the aircraft was equipped for it. Telephoto photographs might permit calf segregation, which is not possible visually from the air. With experience and proper photographic equipment, sex and age groups might be identifiable from aerial photographs." (p. 79-81)

In this review of large-mammal survey techniques, extensive quotations are offered. It is hoped that the words of the men actively involved in aerial survey will make more vivid the readers' visualization of the physical reality of the work. The list of published material will be concluded by reference to a paper on methods worked out by Canadian Wildlife Service biologists from their experience with surveys in Northern

Canada (Banfield *et al.,* 1954). That paper describes observational techniques and the use of a hand-held aerial camera—a Fairchild K20 using a 4″ × 5″ negative. The photographs were used for segregating the herds into age and sex classes, and to facilitate accurate counting of herds.

In their introduction the authors state:

"It was soon realized that aerial survey was the only practical means of obtaining big game population data in the vast regions of northern Canada. It was used extensively during the preliminary barren-ground caribou investigation in 1948 and 1949 (Banfield, 1954). Since that time mammalogists of the Canadian Wildlife Service have flown approximately 2,000 hours on aerial survey work in northern Canada." (p. 519-520)

No exact record of hours flown on aerial survey has been kept, but certainly the period 1954-1961 has seen far more flying time than did the period prior to 1954. The Arctic Islands survey of 1961, the most extensive recent survey, used 600 flying hours.

The extent of aerial survey carried out by the Canadian Wildlife Service to date should not be judged on the record of published papers. It seems that the first of each type of survey was reported in print. Subsequent surveys had management and administrative value, or had application to a specific research project but, in general, more recent reports have not appeared in print. Canadian Wildlife Service files contain about 200 typescript reports of projects that include the use of aircraft for purposes other than transportation. It may be anything from the locating of Arctic fox dens on the barrens of the Northwest Territories to attempts at "herding" sandhill cranes on the prairies. Little would be gained by reviewing those reports in detail.

Vegetation surveys in the North have been carried out by contract, as part of a study of the lichens that constitute the major winter food supply of caribou. Aerial photographs (or negatives) taken by the Royal Canadian Air Force were employed as a base for type mapping. The techniques of photogrammetry as applied in the field of forestry are utilized. The major problems arise from the need to adapt the techniques of photogrammetry as developed for forestry purposes to the measurement of lichen distribution and abundance.

Vegetation surveys differ in so many ways from wildlife surveys that they do not qualify for detailed discussion in the present context. A reference to them is made merely to complete the picture.

MECHANICAL AIDS

Tally Counters

Small counters that may be operated with one hand have been used, mainly for counting animals in photographs.

Cameras

References have been made to the use of cameras. Far greater use of this particular aid may be expected. A camera does not suffer from the imperfections that are characteristic of human observers. Particularly during periods of turbulent air currents, the observers would, no doubt, welcome being replaced by automation. The use of cameras in aerial wildlife investigations has been discussed by Leedy (1948, 1960).

Tape Recorders

When populations are too dense to allow the observer time to relax his scrutiny to record his observations by hand, tape recorders have proved most useful.

Aircraft

It may be considered disrespectful to speak of aircraft as "mechanical aids", but the terminology can be justified. Aircraft are mechanical and without them aerial surveys would, of course, be impossible. The length of this paper is partly owing to the inclusion of quotations that provide information on types of aircraft used, and methods of use, with particular reference to height, speed, range, and so on, as indicators of their suitability for the work under various conditions.

Helicopters have been used, as for example, to count muskoxen on Fosheim Peninsula, Ellesmere Island (Tener, 1954), and to assist in the management work on bison. They have the advantages of low speed, low cruising height, excellent visibility, and ease of landing. On the other hand, they have a limited range, cannot be economically ferried to the Arctic, and are about three times as expensive to charter as are fixed-wing aircraft.

The "Big Wheel"

Northern pilots are noted for their ability to land and take off from the most unlikely places. There has been a development recently that greatly assists that practice on soft ground or rough terrain.

Mr. W. W. Phipps *, (in a letter) has very kindly provided us with a description of his successful efforts to develop a wheel with a large low-pressure tire for use in the Arctic.

In 1953, while flying scientific parties in the Arctic Islands, Mr. Phipps noted that a high performance, light, fixed-wing aircraft could be of greater use if it were equipped with a special undercarriage which would offer good shock-absorbing qualities and high floatation on soft ground. A Piper Super Cub was selected as the most suitable light aircraft in 1954, and a series of experiments followed.

Caterpillar-type units utilizing a tandem set of 800 × 4-inch wheels** and a 12-inch canvas belt produced friction losses that seriously impaired take-off performance.

In 1958, a Super Cub was equipped with 25 × 11 × 4-inch wheels†, with a bearing capacity of 7 lbs. per square inch. The modification was effective, but still inadequate in some situations.

For the 1959 season, five Super Cubs were equipped with 35 × 15 × 6-inch wheels providing a bearing capacity of 4 lbs. per square inch. The 35-inch wheels proved to be adequate for practically all soft ground conditions likely to be encountered. Since then, Beaver and Otter aircraft have been equipped with 45 × 20 × 10-inch wheels. These aircraft have proved to be invaluable for heavier caching and camp-moving operations.

The Super Cub, Beaver, and Otter are designed to meet United States CAR-3 structural requirements, but I will not attempt to provide all engineering details in this paper. The original 35 × 15 × 6-inch air wheel, as originally used on the Lockheed 10, was manufactured by Goodyear on special order with a ply rating reduced from 6 to 4 to

* Vice-President, Bradley Air Services, Carp, Ontario, Canada.
** 20″ outside diameter of tire; 4″ hub diameter.
† 25″ outside diameter of tire; 11″ maximum width of tire; 4″ hub diameter.

reduce weight. The 45 × 20 × 10-inch tires used on the Beavers and Otters were used on early model DC3's. They are presently being used in their original 10-ply construction, but the manufacture of a reduced ply rating is under consideration.

The 35- and 45-inch tires incorporate a fluted-type bead to prevent tire slippage. The bead diameter of the fluted tire is slightly larger than the smooth bead type. In the case of the Super Cub and the Beaver, a thin aluminum flange was bonded to the wheel bead ledge to increase the ledge diameter and to adapt the wheel to the fluted bead. The aluminum flange was bonded in place with Shell Epon 8. In the case of the Otter, a complete wheel was designed and manufactured.

The terrain of the Canadian North varies from rugged mountains and permanent ice fields and glaciers through soft muskeg underlain by a viscous layer on top of permafrost to dry, sandy, or stony desert conditions. Mr. Phipps, an experienced northern pilot himself, offers some advice:

"When picking a landing area from the air, a pilot has several factors to take into consideration. He must judge whether the area is large enough, smooth enough, firm enough, and he must judge the amount of grade. With experience, and by following a few simple rules, this becomes fairly easy. Some of the rules to follow when picking landing areas are:

1) Land on high ground, particularly in the early part of the season.
2) Avoid areas fed by melt water from snow-drifts, etc.
3) Avoid river bottoms and outwashes unless they can be positively identified as gravel.
4) Land upgrade and into the wind.
5) Never land where a safe overshoot cannot be put into effect, such as landing toward a hill.
6) Do not land on obviously wet ground.

Landing on grades up to 30 degrees is common. It requires added skill on the part of the pilot."

The "big wheel" was used on the wildlife resource survey that was carried out by the Canadian Wildlife Service in the high Arctic Islands in 1961. Figure 4 is a photo taken during that survey, showing the wheel installation.

DISCUSSION

The published reports of aerial wildlife surveys carried out by the Canadian Wildlife Service have been reviewed, with particular reference to the role of the aircraft. Although that role is extraordinarily variable, a pattern emerges in the methods and techniques that are employed. At this point, we turn to an assessment of the strengths and weaknesses of the aerial survey as a method of obtaining a measure of wildlife populations.

Strengths

Aircraft can be used to obtain population estimates over large areas. It is not possible to obtain equally large-scale coverage by ground surveys for two reasons:

1) The ideal of an instantaneous count is approximated by an aerial survey, whereas ground parties can seldom move more rapidly than the animals they wish to count.
2) When thousands, or even hundreds of square miles are involved, the cost of a ground survey is prohibitive.

Aircraft are used because they provide the only means of obtaining a rapid count over large areas at a reasonable cost per unit area.

Weaknesses

The weaknesses of aerial surveys can be classified as sources of error in the final population estimate. The three major sources of error are:

1) Difficulty in spotting animals from the air,
2) human fallibility, and
3) statistical error.

1) *Difficulty in Spotting Animals from the Air*

This source of error cannot be removed. It is possible to see caribou and muskoxen on the barrens of the Northwest Territories. It is not possible to see ruffed grouse in forest cover. Between the two extremes there are such cases as elk on prairie "parklands", where, with careful choice of cloud cover, snow cover, time of day, and other factors, a substantial portion of the population can be observed.

There are two major methods of controlling error:

a) Methods can be standardized to minimize the variability of the error.

b) Ground counts on small areas, or other auxiliary data, may be used to measure the magnitude of the error.

Both activities must be directed toward a particular species in a particular area. The techniques that are developed may be useful in other situations, but the results are applicable only to the species and area from which they were obtained.

2) *Human Fallibility*

If animals are present and theoretically visible from the air, they may not be seen by the observer; or if seen, they may not be counted and recorded correctly. There may be uncertainty whether a particular animal is on or off the transect being censused.

Considerable effort is usually directed toward minimizing human error. Several observers may be used, and their results compared. Inexperienced observers start by flying with experienced men. Short flights are planned, where possible, to minimize fatigue. Transect widths are indicated by markers on wing struts, or by some other visual guide. However, in wildlife surveys human error is not expressed as a measurable ratio of animals observed to animals present, other than by simultaneous ground censuses in some cases (waterfowl "beat-outs").

In the field of aerial search and rescue, an attempt has been made to express the searching efficiency of the human observer. Stanley (1949) states:

"Broadly speaking, the things which affect searching efficiency, either increasing it or decreasing it, (at least within the limits of this study) are:

a) Height (the lower the better);

b) Speed (the slower the better);

c) Meteorological visibility (the clearer the better);

d) The calmness of the air (the calmer the better);

e) The initial health, mental and physical, of the observers (the better it is the better the search);

f) The incidence of airsickness (the less the better);

g) The size of the lost aircraft (the larger the better);

h) The condition of the crash (the less smashed the better);

i) The nature of the terrain (the flatter it is, the fewer the trees, the higher the contrast with the wreck and the fewer the fissures and ravines, the better the search);

j) The number of observers (the more the better);

k) The position of the observers (the blister is the best);

l) The duration of the search (the shorter each search flight, the better, as long uninterrupted flights mean higher scanning fatigue);

m) The time from take-off to start of search (the shorter the better and so on)."

Each of the factors listed was reduced by Stanley to a numerical formula, and tables supplied to allow each factor to be expressed numerically. Each of these "efficiency factors" for any particular search flight is chosen from the appropriate table and the sum of the factors represents the "search efficiency" of the flight.

Stanley points out that his contribution is a preliminary one, and that many of his tables are at least partially subjective. He suggests that continued use of the system should provide data for its improvement. We can accept the possibility of improvement in that way when the purpose of the search is to locate a single object, or a known number of objects. However, taking into account the urgency of a search and rescue operation, it is open to conjecture whether all the data required of any search flight would be recorded with the requisite scientific detail and thoroughness.

Since the purpose of the search in a wildlife survey is to locate and count an unknown number of objects, the same method of development of numerical measures of human fallibility holds little promise. It is more likely that the use of photogrammetric methods will help to reduce human error. Continuous-strip photography could be used to record all transects. A wide variety of films is available, and the use of colour film and infra-red film might be tested. Heat-sensitive films may yet prove useful, especially on the northern tundra in winter.

Human error may eventually be reduced to that of the pilot in his attempt to maintain a predetermined height on a predetermined course, and to the errors of photo-interpretation.

3) *Statistical Error*

If we refer to a manual of wildlife techniques (Mosby, 1960), we find no references to analysis of results of aerial surveys. There are references to methods of collecting data from an aircraft by direct observation (Petrides, 1953; Banfield *et al.*, 1954) and with the aid of a camera (Chattin, 1952). We find mention also of an assessment of aerial counts

(Gilbert and Grieb, 1957). A similar paper has been mentioned previously (Diem and Lu, 1960). The list is not exhaustive. Methods of making observations from aircraft have been described in the literature and a few studies have been carried out to assess various unknowns.

Perhaps a standardized technique for aerial sample surveys of wildlife that includes a means of measuring observational error, and a method for analysing the degree of reliability, is not a practical goal to work toward. I do not believe that such a combination of techniques exists today.

It is possible to support that statement by reference to Schultz (1961). He searched 31 journals for references to the use of statistics in ecology. He found no papers on statistics applied to aerial wildlife surveys that have not already been quoted in this paper.

There is, therefore, an obvious gap in the applied science of wildlife biology. Biologists have used aircraft, and know much of the logistics of an aerial survey. Mathematicians tarred with the biological brush have elaborated many means of estimating population numbers from samples. The journals "Biometrics", "Biometrika", and others, contain many examples of mathematics applied to the problems of estimating population size of a variety of living organisms in a variety of habitats. However, each tends to be a specific technique for a specific species in a specific environment. Generalization is needed for aerial surveys. This paper does not attempt to close the gap that exists, but we can at least inspect it.

Present practice tends to be crude. We tend to make several unjustifiable assumptions in order to permit the application of statistical procedures that are valid only if those assumptions hold. In practice, it is usually assumed that:

a) The habitat is homogeneous.

b) Animals are distributed at random within the habitat.

We then apply routine statistical procedures, and come up with a population estimate complete with fiducial limits and all the trimmings.

Let us look at those assumptions. No habitat is *absolutely* homogeneous. Stratification may represent an improvement, but how do we divide an area into homogeneous strata? Geological formations, soil types, forest or other vegetative cover, water areas, surface topography, and other physical features of the landscape may be used if suitable maps are available. It may be possible in some cases to approach the ideal of homogeneous strata.

If reasonably homogeneous strata are found and can be fitted into a survey design, we are then faced with a number of strata, and our assumption of randomness still applies to them all. Yet we know that almost never are individual animals of a species distributed at random.

They may occur in an approximation of the normal, Poisson, negative binomial, or some form of contagious distribution, to name a few of the better known types. They may conform closely to one or other of the more exotic species of distributions known only to the more exotic species of statisticians. Maybe a particularly perverse population could be arrayed in accordance with no known and mathematically described distribution.

It is also known that any given population will exhibit different distribution patterns that are determined by the seasons of the year. Food availability, colonial breeding habits, and family groupings are all examples of factors that affect the distribution of a population.

Less well known, but also important, are daily habits. Waterfowl may concentrate on lakes at night, disperse to feeding areas in the morning, and concentrate again in the afternoon at "loafing" areas. Moose frequent lakes and rivers at times to obtain relief from biting insects. Caribou may congregate on windy knolls for the same purpose.

A possible approach to analysis might be to test how closely the data of a stratum "fits" a number of distributions. The distribution displaying the best degree of fit would then determine the form of analysis to be applied.

The end result might be a number of different distributions in different strata, each with a different degree of fit, and a different level of efficiency obtaining for the appropriate method of analysis. The production of a final population estimate with fiducial limits and a measure of reliability in such a hypothetical situation would be a truly arduous task. It may be that, instead of looking for mathematical generalizations that may not be forthcoming, the laborious and involved analytical procedures might be made practical by the collection and development of computer programs to test the "fit" of observational data to a number of mathematical distributions, to measure the degree of fit achieved, and perhaps also to analyse the data by means suited to the appropriate distribution.

THE FUTURE

There can be no doubt that the use of aircraft for wildlife surveys will continue. However, as the wildlife populations of Canada become better known, and as the Arctic develops and becomes more accessible, aerial surveys may decrease in value as other, more exact methods of population estimation develop. If, on the other hand, aerial surveys are improved in accuracy, their innate advantages of speed and economical coverage of large areas will lead to continued, and probably greater, use.

I am emboldened to suggest that aerial wildlife surveys can be improved, but the cost is very likely going to include 1) the further development of observational techniques, based largely on photogrammetric methods, to reduce observational error; 2) the use of synchronous ground census on test areas, or other methods of measuring the amount of observational error; and 3) the use of electronic computers to permit the application of more rigorous statistical methods of analysis to data sufficiently accurate to justify such treatment.

SPECIES MENTIONED IN THE TEXT

Birds

Canada goose	*Branta canadensis*
Ruffed grouse	*Bonasa umbellus*
Sandhill crane	*Grus canadensis*

Mammals

Arctic fox	*Alopex lagopus*
Coyote	*Canis latrans*
Wolf	*Canis lupus*
Atlantic walrus	*Odobenus rosmarus*
Beaver	*Castor canadensis*
Elk	*Cervus canadensis*
Mule deer	*Odocoileus hemionus*
White-tailed deer	*Odocoileus virginianus*
Moose	*Alces americana*
Caribou	*Rangifer tarandus*
Bison (Plains bison and Wood buffalo)	*Bison bison*
Muskox	*Ovibos moschatus*

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FIG. 1


WATERFOWL
BREEDING GROUNDS
AERIAL TRANSECTS
1956
RE-DRAWN FROM CRISSEY (1957)

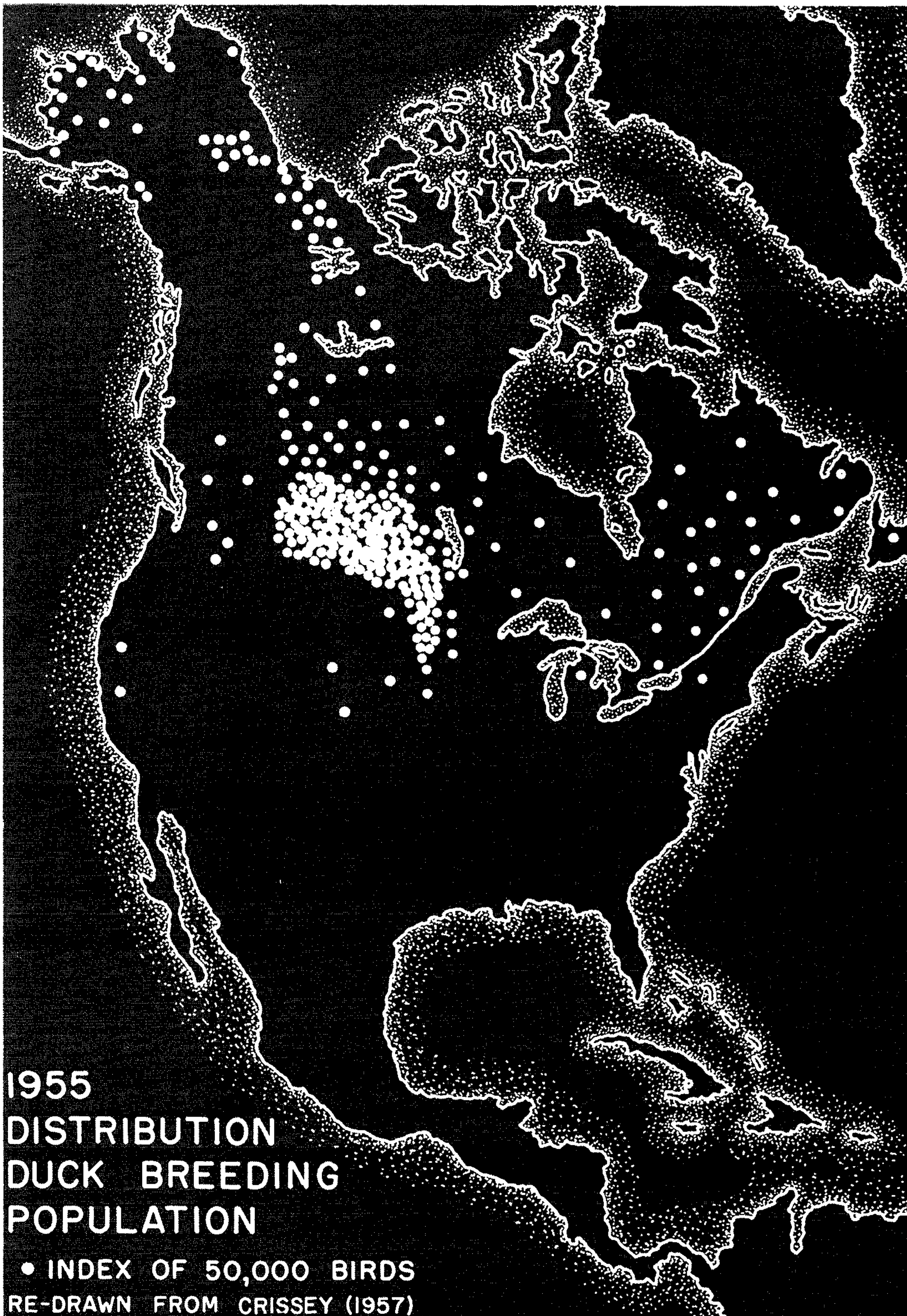

1955
DISTRIBUTION
DUCK BREEDING
POPULATION
• INDEX OF 50,000 BIRDS
RE-DRAWN FROM CRISSEY (1957)

FIG. 2

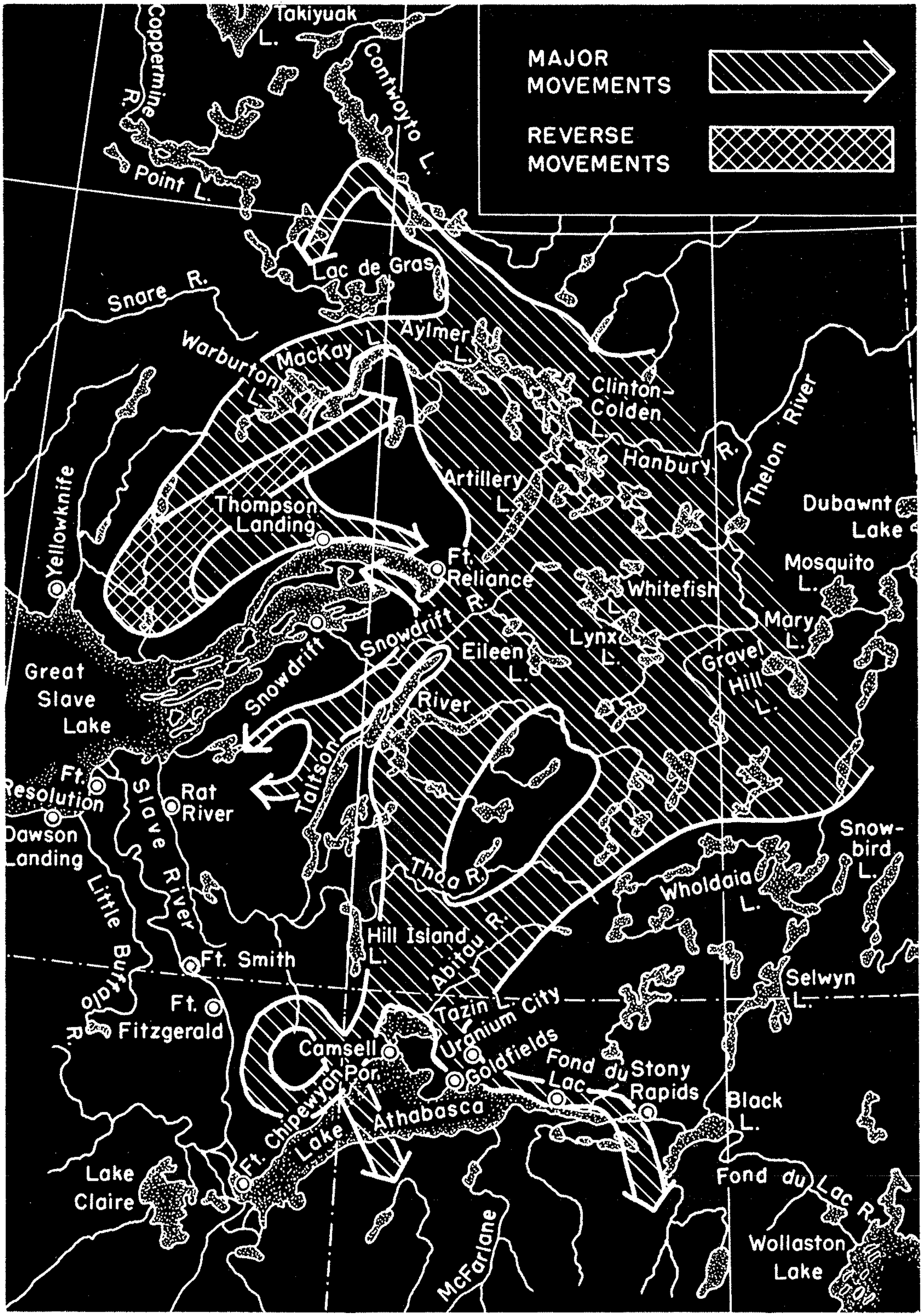
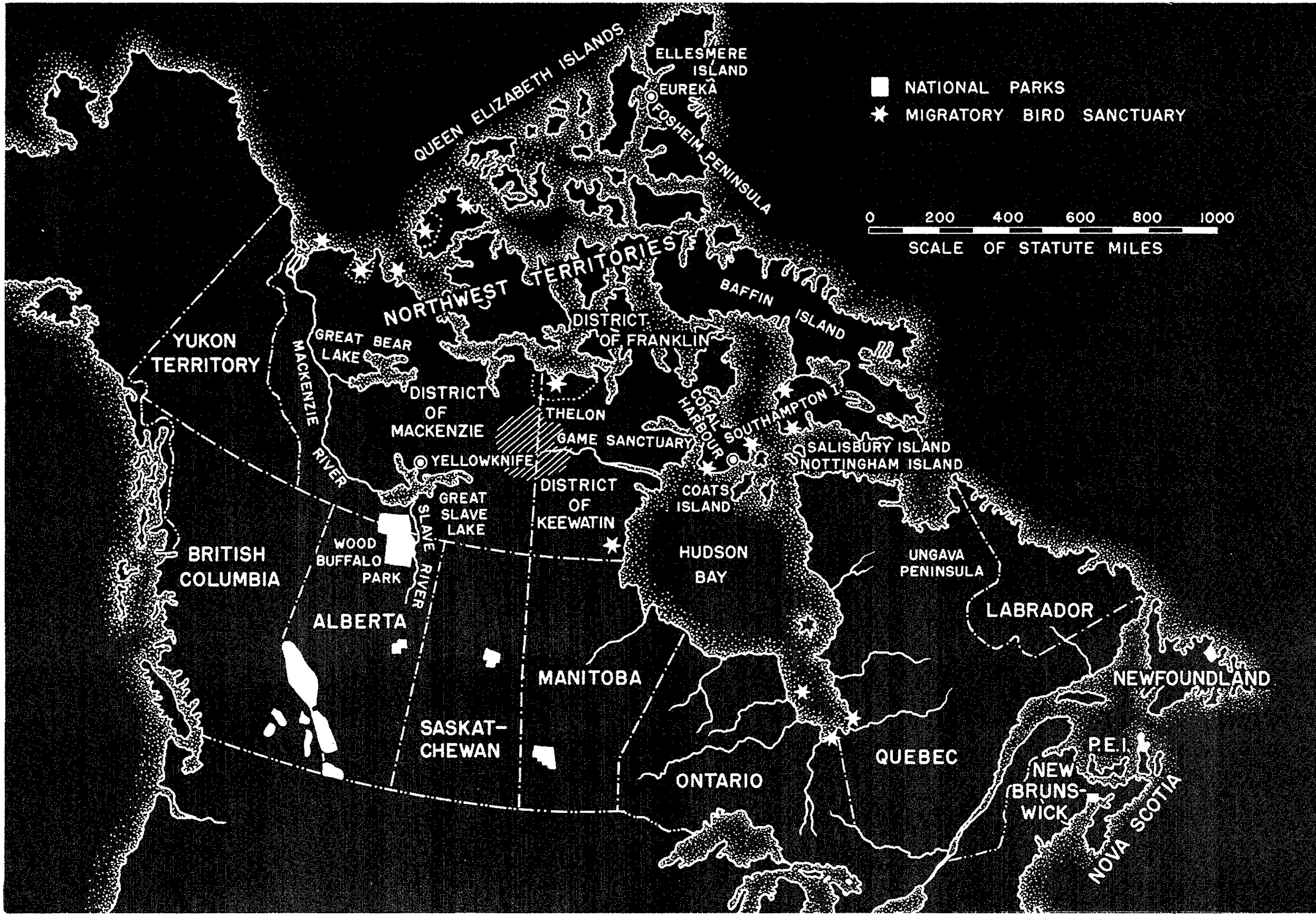

MAJOR MOVEMENTS
REVERSE MOVEMENTS
Takiyuak L.
Coppermine R.
Contwoyto L.
Point L.
Lac de Gras
Snare R.
Aylmer L.
Warburton L.
MacKay L.
Clinton-Colden L.
Hanbury R.
Thelon River
Yellowknife
Artillery L.
Thompson Landing
Ft. Reliance
Dubawnt Lake
Mosquito L.
Whitefish
Snowdrift R.
Lynx L.
Mary L.
Eileen L.
Gravel Hill L.
Great Slave Lake
Snowdrift
River
Taltson
Ft. Resolution
Rat River
Dawson Landing
Slave River
Snowbird L.
Thoa R.
Wholdaia L.
Little Buffalo R.
Hill Island L.
Abitau R.
Ft. Smith
Selwyn L.
Ft. Fitzgerald
Tazin L.
Uranium City
Camsell Por.
Goldfields
Fond du Lac
Stony Rapids
Black L.
Ft. Chipewyan
Lake Athabasca
Lake Claire
Fond du Lac R.
McFarlane
Wollaston Lake

FIG. 3

FIG. 4

A Piper Super Cub fitted with large, low-pressure tires. This photograph was taken by Dr. John S. Tener on the 1961 Arctic Islands Survey.

FIG. 5



NATIONAL PARKS
MIGRATORY BIRD SANCTUARY
0 200 400 600 800 1000
SCALE OF STATUTE MILES
QUEEN ELIZABETH ISLANDS
ELLESMERE ISLAND
EUREKA
FOSHEIM PENINSULA
NORTHWEST TERRITORIES
BAFFIN ISLAND
DISTRICT OF FRANKLIN
YUKON TERRITORY
GREAT BEAR LAKE
MACKENZIE RIVER
DISTRICT OF MACKENZIE
THELON GAME SANCTUARY
CORAL HARBOUR
SOUTHAMPTON I.
SALISBURY ISLAND
NOTTINGHAM ISLAND
YELLOWKNIFE
GREAT SLAVE LAKE
DISTRICT OF KEEWATIN
COATS ISLAND
SLAVE RIVER
WOOD BUFFALO PARK
BRITISH COLUMBIA
HUDSON BAY
UNGAVA PENINSULA
LABRADOR
ALBERTA
MANITOBA
NEWFOUNDLAND
SASKAT-CHEWAN
QUEBEC
ONTARIO
P.E.I.
NEW BRUNS-WICK
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