Pink-footed Geese of Iceland and Greenland: a population review based on an aerial survey of þjórsárver in June, 1970

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Introduction

The Pink-footed Geese *Anser brachyrhynchus* breeding in Greenland and Iceland winter solely within Britain; they numbered about 70,000 in November in 1968-1970 (Ogilvie 1969, 1970a). Those breeding in Svalbard winter in the Low Countries and Denmark and numbered 12-15,000 in the corresponding years (Morzer Bruyns *et al.* 1969).

The principal breeding ground of the British-wintering population is þjórsárver (64° 35′ N., 18° 40′ W.), an oasis of vegetation in the volcanic desert south of the Hofsjökull icecap in the central highlands of Iceland (Scott *et al.* 1953).

Detailed engineering proposals to make a reservoir on the upper þjórsá River as part of a hydro-electric power scheme have recently been made known. The reservoir would flood almost the entire oasis. The threat this poses to the Pink-footed Goose makes it imperative to obtain precise information on the importance of þjórsárver to the geese and to discover whether suitable alternative breeding sites are available or could be provided. The first step was to obtain an accurate and up-to-date estimate of the numbers of geese breeding in þjórsárver. This was done by means of a survey of nests in June 1970. Preliminary reports have already appeared (Ogilvie 1970b, 1971a). The first section of this paper provides a fuller account, with a description of the technique and a discussion of the statistical reliability. The second section compares the results with earlier estimates of the goose populations of the oasis. A brief review of numbers in other parts of Iceland and in Greenland follows. The present rôle of þjórsárver and of what might happen to the displaced geese if the oasis was to be destroyed are then discussed, with emphasis on the additional knowledge urgently required.

PART I. SURVEY OF þJORSARVER BY HELICOPTER, JUNE 1970.

The primary aim of the survey was to determine the number of Pink-footed Geese breeding in þjórsárver and to describe the distribution of the nests. Most of the survey was done during a period of clear, warm, calm weather from 10th to 12th June 1970. It was completed on 16th June under overcast skies with cool moderate winds.

Methods

The survey was conducted from a Bell Ranger helicopter with a crew consisting of a pilot (Björn Jónsen on 10th-12th and Pall Halldórsson on 16th June), a navigator (Kerbes) and a nest observer (Ogilvie).

The survey began with a qualitative reconnaissance to determine the extent of the nesting area. The area with nests was delimited and then sampled quantitatively by counting the nests within transects of fixed width. The transects were taken with the helicopter flying a straight line course 60 m. above ground at approximately 100 km.p.h. ground speed. Transect positions were selected to cover the nesting area uniformly.

The navigator chose and plotted the transect course and marked position fixes on a map of scale 1:40,000 (Sheet 231, þjórsárver, Vegetation Map of Iceland, Icelandic Survey Department). The observer, by limiting his scan to a sector marked with tape on the plexiglass 'bubble', recorded the number of nests passing beneath him on the transect within a fixed angle of view. The width of the transect on the ground was 50 yd. (45.72 m.). This was carefully checked against a line of markers spaced at 10 yd. intervals on the ground. The observer recorded his nest counts by length of transect to coincide with the position fixes taken by the navigator.

The accuracy of the transect counts was then tested by comparing the densities of nests found in ground searches with the density estimates obtained by aerial transects, on three separate areas. Each area for intensive search was chosen subjectively to provide a reasonable density of nests within limits readily defined both from the ground and from the air. Maps of scale 1:20,000 were used in conducting ground searches and in measuring the areas.

The sizes of the comparison areas were determined by transferring their outlines from maps on to millimetre-squared graph paper. As a check, a photocopy of the map was cut up and the pieces weighed to the nearest 0.001 gm. There

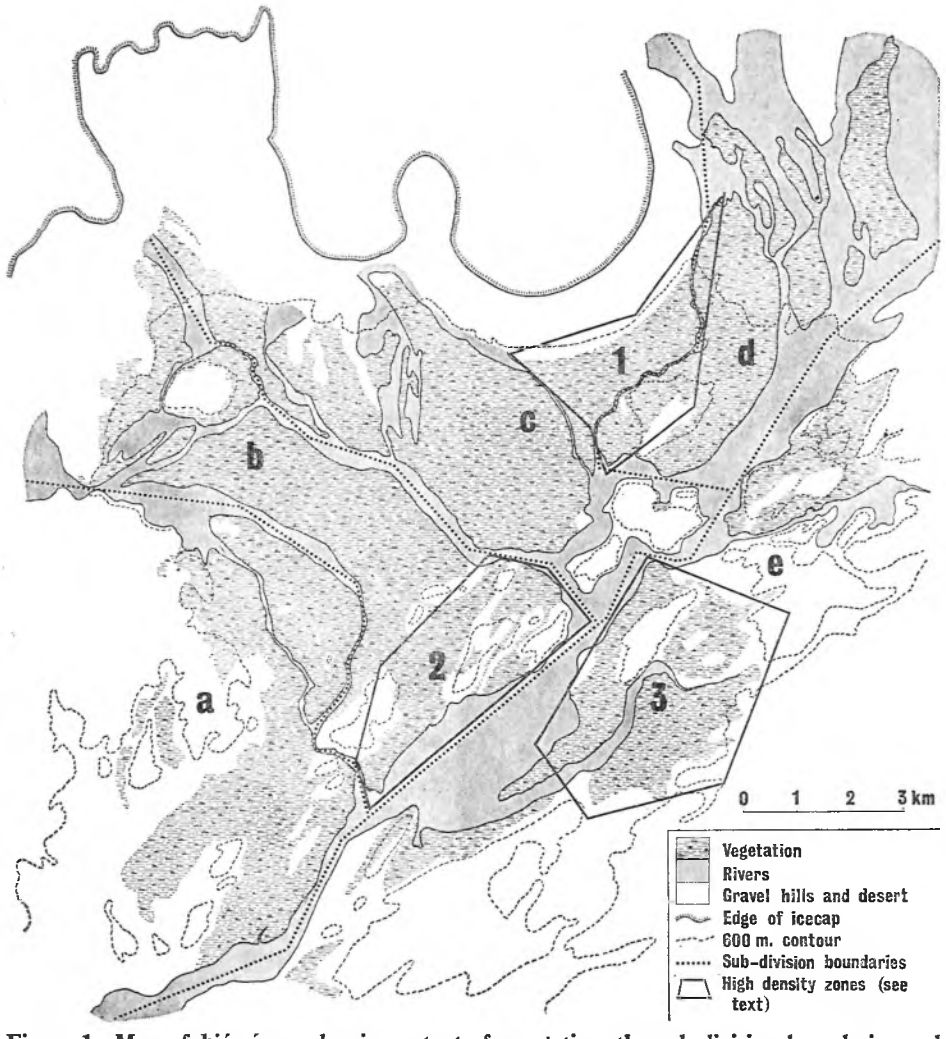

Figure 1. Map of Þjórsárver showing extent of vegetation, the sub-division boundaries and the three high-density zones (see text).

was extremely close agreement between the two methods. The total number of nests was estimated by multiplying the mean nest density of the transect counts by the total area of nesting habitat.

Results

There were approximately 81.6 sq. km. of nesting habitat within Þjórsárver (Figure 1) containing a total of about 10,700 nests (Table I).

The area occupied by nests coincided almost exactly with the vegetated area as depicted on the 1 : 40,000 map. Since nests were not found on gravel hills, sand banks and river channels within Þjórsárver, such areas were excluded from the calculations. The nests were typically situated on dry well-drained sites such as the banks of pools and streams, and on low heathy mounds and ridges. Most of the oasis, however, is flat, boggy ground interspersed with innumerable small pools and streams. Large expanses were under shallow water, following the spring thaw. Through the summer these dry out to become marshy, with lush vegetation on which the geese and their goslings feed (see Plates I and II).

The nests were found over the entire area of vegetated ground within Þjórsárver. Areas of high nest density merged gradually, sometimes suddenly, into areas of low density. Densities encountered during the survey ranged between 36 and 544 nests per sq. km. There were five major subdivisions of the oasis, arbitrarily delimited by watercourses, as shown in

Table I. Summary of results from the survey of Pink-footed Geese nesting in þjórsárver, Iceland, June 1970.

Total length of transects over nesting area	191.69 km.
Transect width (50 yards)	45.72 m.
Total nesting area covered by transects	8.76 sq. km.
Total nests recorded within transects	1,149
Mean nest density within transects	131.11 nests/sq. km.
Total area of nesting habitat within þjórsárver	81.59 sq. km.
Estimated total nests in þjórsárver	10,697
95% Confidence Interval of estimated total nests	9,059 to 12,335

Figure 1. The mean nest densities in each subdivision were rather similar: a — 95, b — 124, c — 146, d — 111, and e — 143 nests per sq. km.

All 88 transect counts were scaled by density, and then ranged into four equal groups. Each of the transects on the map was then categorized by density group. Three zones of high nest density were thereby defined (Figure 1, Table II). Chi-square tests ($P < 0.01$) showed that each of those zones had significantly more nests than would be expected from random or uniform distribution.

Table II. Zones of high nest density compared to nesting area outside those zones, þjórsárver, Iceland, June 1970.

	Nest Density (nests/sq. km.)	*Per cent of total size*	*Per cent of total nests*
Zone 1	251	7	13
Zone 2	170	6	8
Zone 3	186	9	13
non-Zone	102	78	66
Total	131	100	100

The proposed dam below þjórsárver would probably flood the oasis to the 600 metre contour at top water level (Jakob Björnsson, National Energy Authority, pers com.). As Figure 1 shows, the limit of vegetation follows this contour round much of the oasis. Only about 15 sq. km. of the vegetated area was above 600 metres, as calculated from the 1:40,000 vegetation map. The density of nests within the area to be flooded was about 137 nests per sq. km. Therefore, approximately 9,100 nests, or 85% of their total, would have been at risk in 1970.

Non-breeding geese (i.e. those in flocks) were remarkable by their absence. One flock of about 200 was seen during the survey, together with other smaller groups totalling a further 200 birds. Clearly the not inconsiderable non-breeding segment of the population, comprising the immature geese (survivors of the previous two seasons' production) together with any failed or non-breeding adults, had already left on their moult migration to East Greenland (see below, Part III). However, it is not known how many immature non-breeders actually visit þjórsárver at the end of their spring migration though it can be assumed that some one-year-olds do as they apparently leave Britain still in family parties, still being led by their parents.

Discussion of nest survey

The helicopter transect method used for surveying þjórsárver was devised and used by Kerbes to count the nests of Lesser Snow Geese *Anser c. caerulescens* on Baffin Island, Canada. A description, with a discussion of the geometrical principles and problems involved, has been given by Kerbes (1969).

The method used at þjórsárver was subject to four basic sources of error:

1. observer error,
2. calculation error of transect length,
3. variation in transect width,
4. unrepresentative sampling.

Failure of the observer to see and record all nests within the transect is believed to have been insignificant. There was no chance of misidentifying Pink-footed Goose nests because no other bird with a goose-sized nest breeds there. Pairs usually remained at their nests, easily seen from the helicopter as it flew over

them, and if they took flight, the light coloured eggs and down were still conspicuous.

Error due to inaccurate measurement of the transect lengths was also considered to be insignificant. The transects were flown in continuous reference to ground features shown on the map. The beginning and end of each transect was plotted with variation of less than 1% of its total length.

Potentially the most serious technical error was variation in transect width. Kerbes (1969) showed that such error was due to inadvertent movement of the observer's head in relation to the fixed observation sector of the helicopter 'bubble', and to variation in the altitude, pitch, roll and yaw of the machine. Theoretical calculations indicated that head movement and helicopter pitch can have the most effect in changing the width of transect, and that the total possible variation ranged from widening the transect by 42% to narrowing it by 30%. Therefore the sources of error might not cancel each other out, even if a large number of transect counts were taken in varied conditions. Rather, there would be a tendency to widen the transect by up to 12% with consequent over-estimation of nests.

The similar estimates of nest density made from the ground searches and from the aerial transects supported the accuracy of the transect counts. In conducting those comparisons it was reasonable to assume that the systematic ground search resulted in a total count of all nests present. However, some terrain was less easy to search. Area B was rather sodden, with sinuous hummocks in pools of stagnant water. Area C was relatively dry on a high peninsula surrounded by channels of the river. The transect coverage gave nest density estimates higher than the ground coverage in Area A, but lower in Areas B (of intermediate dryness) and C. The overall difference was only a 1.0% over-estimation by the transect count (Table III). Since the three comparison areas covered the whole range of nest densities and habitats, and were about 18% of the total area covered by transects, they provided valid evidence of the accuracy of the transect counts. We may conclude that the survey, conducted in a carefully controlled method under almost ideal weather conditions, had negligible observational or technical errors.

The theory of ratio estimates (Cochran 1953) was used to obtain estimates and confidence limits for the density and total number of nests. It was necessary to assume that the transects, both in length and position, were effectively random over the area. In fact, the transects were selected both randomly and systematically. This was a consequence of the technical limitations imposed by having to fly straight line transects over large areas of homogeneous terrain. In general, transect courses were selected from one recognizable landmark to another, count breaks occurring when intermediate landmarks, such as streams, crossed the transect. The terminal landmarks and direction of flight, however, were selected largely at random. A systematic effort was made to cover the entire nesting area with an approximately uniform density of transects. This was done by a subjective appraisal of the emerging pattern of coverage as the survey progressed. Eventually the transect sample covered more than 10% of the nesting area, a substantial fraction.

The statistical procedure indicated with 95% confidence that the mean nest density lay between approximately 110 and 150 nests per sq. km. With the same degree of confidence the estimates of total nests in Þjórsárver therefore lay between approximately 9,100 and 12,300 nests (Table I). It is stressed that this provides only a rough guide to the statistical accuracy of the method. Nesting density varied so greatly over such short distances that any estimate of mean density would

Table III. Air-ground comparison of Pink-footed Goose nest counts in Þjórsárver, Iceland, June 1970.

	Ground area searched (sq. km.)	*Air transect coverage (sq. km.)*	*Density/Ground (nests/sq. km.)*	*Density/Air (nests/sq. km.)*	*% difference Air vs. Ground*
A	0.545	0.537	115.6	141.9	+ 22.8
B	0.656	0.759	237.7	228.3	— 4.0
C	0.403	0.515	151.3	134.4	— 11.2
Total	1.604	1.811	174.5	176.2	+ 1.0

have had a high variance, regardless of the sampling scheme used.

Prior to the survey some apprehension had been expressed that the helicopter would cause undue disturbance to the geese. Pink-footed Geese in winter in Britain are extremely shy of aircraft, particularly helicopters. In fact, the machine caused only minimal disturbance on the nesting grounds. Most pairs remained at their nests as the helicopter flew over them, and many even made defensive threat postures at the machine. During the ground searches the geese were also very defensive of their territories, usually remaining at their nests until the investigators were to within 20 metres. Kerbes noted that the Pinkfeet were remarkably reluctant to leave their nests in comparison to nesting Lesser Snow Geese, which tend to flee at the distant approach of a helicopter or a man on the ground. Furthermore, there appeared to be very few predators in þjórsárver. Only four Great Black-backed Gulls *Larus marinus* and five Arctic Skuas *Skua parasiticus* were seen during the ground searches. There was, therefore, little chance for predation to occur during any short period in which the survey activities caused geese to be away from their nests.

Expeditions visiting the oasis in July and August in earlier years (summarised by Hardy 1967) saw more predators. In 1966 there were about 20 each of Great Black-backed Gull and Arctic Skua, together with at least one pair of Iceland Falcons *Falco rusticolus*. The gulls have not been recorded as breeding in the area, and so their effect is greatly reduced. Previous expeditions have only found one active earth of the Arctic Fox *Alopex lagopus*. The remoteness of þjórsárver, and lack of a year-round food source, may combine to make it less attractive to predators than might be expected, although the numbers of predatory birds recorded have increased since 1951.

Clutch size and hatching date

In the course of the ground searches, and during other temporary landings in the oasis, 312 nests were closely examined and the clutch sizes recorded. The mean clutch size was 3.9 (range 1-7).

On 16th June the first goslings were seen, a single brood no more than one day out of the nest, and a hatching clutch of eggs was found. Of some two hundred eggs candled, most would be hatching in the period 20th to 27th June. In 1951 the peak hatching date was estimated to have been 22nd June (Scott *et al.* 1953). This date was worked out by extrapolating back from the age of goslings seen soon after the hatch. A similar computation in August 1966 suggested a later peak hatching date that year, in the first week of July (Hardy 1967).

PART II. EARLIER ESTIMATES OF NUMBERS OF NESTS AND GEESE IN þJORSARVER.

þjórsárver had previously been visited by ornithologists interested in geese in 1951, 1953, 1956, 1964, 1966 and 1969. These inspections included a brief visit in May 1956 by Dr. Finnur Guðmundsson in an American Army helicopter. A stay from 17th to 25th August 1966 by a British party (Hardy 1967), though obtaining valuable evidence on several aspects of breeding biology, was not concerned with population measurement.

Numbers of nests in 1951

The only previous attempt to estimate the number of goose nests in the oasis was by Scott *et al.* (1953). They walked transects 102 km. in length and of a mean strip width of about 20 m., a searched area of 2.04 sq. km. They found 67 nests with a density of 32.9 nests per sq. km. They then estimated the total area used by the geese to be 114 sq. km., of which they explored 82 sq. km. Multiplying the number of nests found by (total area)/(area searched), i.e. $67 \times (114/2.04)$ they arrived at an estimate of 3,700 nests for the oasis in 1951. This was "almost certainly too high since much of the area was bog and tundra pools which could not be transected (or colonized)." They noted that the nests were grouped, rather than distributed uniformly or randomly and suggested that the mean density of nests might be as low as 15 nests per sq. km. which would have reduced the estimated number of nests in the colony to 1,700. A factor working in the opposite direction is the difficulty of finding every empty nest in such terrain.

There is no reason to think that the vegetated area used by the geese has altered greatly in its dimensions since 1951. The mapping of the region has been improved and for comparative purposes it seems proper to consider the area of nesting habitat in 1951 equal to that arrived at for 1970. i.e. 81.6 sq. km. rather than 114 sq. km. That would reduce the alternative estimates of the total number of nests in 1951 to 2,700 and 1,200.

Number of geese in May 1964

In May 1964 an aerial survey of Greylag Geese *Anser anser* was carried out in

Iceland and the opportunity was taken to visit Þjórsárver to look at the Pinkfeet (Boyd 1970). A fixed-wing light aircraft was used for the survey with a pilot (Sveinn Bjornsson) and two observers (Boyd and L. R. Schiess). On 8th May no search of the oasis was possible because of a snowstorm, but many groups of geese could be seen, despite the landscape being almost entirely covered in snow and ice.

On 21st May the oasis was surveyed rather more thoroughly. Much of the vegetation was still obscured by snow or ice, making habitat zones hard to identify and map-reading awkward, but a series of transects was flown at about 150 m. above ground. A total of 1,195 geese were seen, many of them in ones or twos, others in small groups. The effective strip width along the transects was believed to be no more than about 0.1 km. on each side of the aircraft. Unfamiliarity of the pilot with the technique of transect-flying and some difficulty in communication with the observers led to the pattern of search being less precise, and much less complete, than would have been desirable. Because of the high speed (160 km./hr.) it was not possible to make detailed records for the short sectors of the flight line where the geese were at all plentiful. The sampling was not proportional to the size of the sectors nor to the relative abundance of geese in each. The proportion of groups differed greatly from place to place.

Assuming the effective searching width to have been 0.2 km., a very rough estimate of 6,600 for the total population can be obtained from the number of birds seen (1,195) divided by 0.2 × distance flown (73.6 km.) and multiplied by the approximate vegetated area of the oasis (81.6 sq. km.). The mean number of geese recorded was 81.1 per sq. km. The density in different sectors varied from 18.2 to 122.0 birds per sq. km. If the geese in flocks are excluded the observed densities fall to 9-21 pairs per sq. km. No confidence limits can be put on these 1964 estimates. Because of the clumping of the geese and the crude sampling technique the limits would undoubtedly be wide. The most serious weakness lies in the unchecked assumption of effective transect width.

In both 1951 and 1969 the estimated peak date for completion of clutches in Þjórsárver was 25th May (Scott *et al.* 1953; Bulstrode and Hardy 1970). Assuming therefore that nesting was well advanced on 21st May in 1964, the geese still in flocks of over 20 birds (695 or 58%) may have been non-breeders. From winter population data (Boyd and Ogilvie 1969), a rough calculation suggests that in May 1964 the proportion of non-breeders was probably of the order of 53% in the Iceland/Greenland population as a whole. Thus the estimated total of 6,600 geese in Þjórsárver on 21st May 1964 did not correspond to 3,300 breeding pairs but to a substantially lower number, perhaps as few as 1,600, much the same as estimated for 1951. Yet the total wintering population had nearly doubled.

Numbers of geese in Þjórsárver in July and August

Estimates of the numbers of adults and goslings in the oasis in 1951, 1953 and 1969 have been published. They are summarized in Table IV. The capture-recapture methods so far used cannot provide reliable estimates in Þjórsárver, where the geese move extensively when disturbed by people and probably also range widely, but not randomly, when undisturbed. No idea of the number of moulters and goslings in any part of the oasis could be made until the birds were rounded up. It was virtually impossible to define the catching-effort with respect to area. The sampling was biased, due to difficulties of access and of visibility (of men to geese and vice versa). Thus confidence limits for numbers based on the assumptions of thorough mixing and random sampling are too narrow, if not wholly inappropriate. The published estimates for 1969 (Bulstrode and Hardy 1970) used the further hazardous assumption that the geese were evenly distributed over the vegetated area (which they were clearly not in 1953).

Nevertheless, it is reasonable to claim that the numbers present in late July were higher in 1953 than in 1951 and much higher in 1969 (and, presumably, in 1970). There is no necessary relationship between the distribution of nests in June and the location of families in late July and August. The latter are dependent upon the distribution of food supplies which are most plentiful in the low-lying, wetter areas—which would be flooded whatever the final upper datum line of the proposed reservoir.

PART III. NUMBERS IN OTHER PART OF ICELAND AND IN GREENLAND.

Iceland: north-east and east of Þjórsárver

All the known breeding places of the Pinkfoot in Iceland are shown in Figure

Table IV. Estimates of the numbers of Pink-footed Geese in þjórsárver in July and August in 1951, 1953 and 1969, from published sources.

(*a*) Published results

Year	*No. of adults*	*No. of goslings*	*Method of estimation*	*Source*
1951	6700	7000	mark-recapture	Scott *et al.* 1953
1953	8200	10200	mark-recapture	Scott *et al.* 1955
1969	13600	17100	sample catch and area ratio	Bulstrode and Hardy 1970

(*b*) Derived results

	No. of successful breeding pairs in þjórsárver in July	*Mean brood size*		*Total no. of successful breeding pairs in Britain in November*	*þjórsárver, July / Britain, Nov.*
		þjórsárver late July	*Britain November*		%
1951	3300	4.2	2.50	2900	114
1953	4700	4.3	2.75	3700	127
1969	8000	(4.25)	2.2	8200	98

November data for 1951 and 1953 from Boyd and Ogilvie (1969), for 1969 from unpublished data (M. A. Ogilvie).

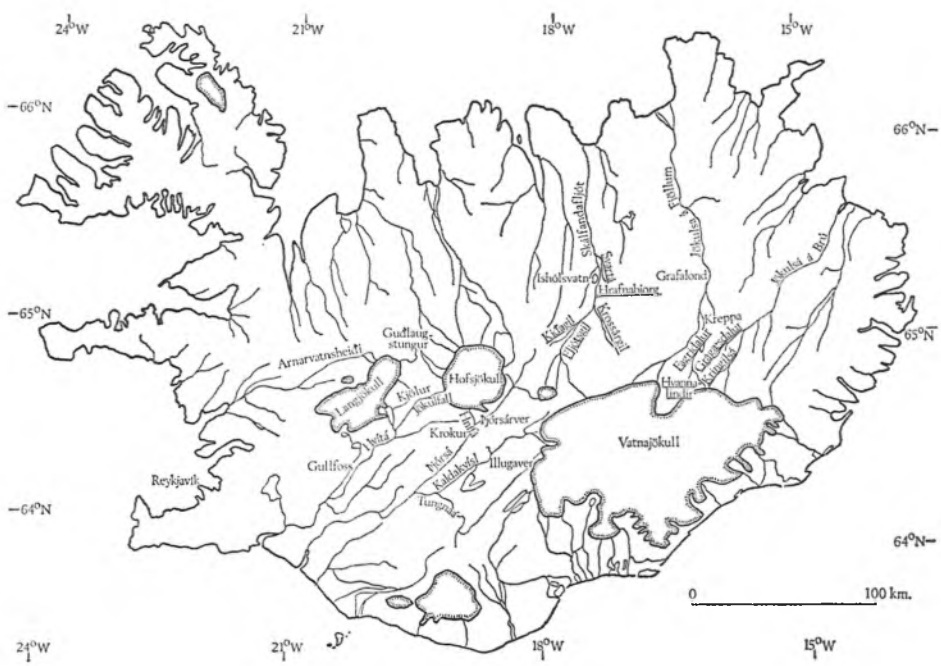

Figure 2. Map of Iceland showing the main localities mentioned in the text. Those underlined are the breeding localities for Pinkfeet recorded prior to 1951.

2. Those localities with the names underlined were known prior to 1951 (Scott *et al.* 1953). They all lie in the north-east quadrant of Iceland and nearly all in the upper reaches and head-waters of three large rivers: Skálfandafljót, Jökulsá á Fjöllum and Jökulsá á Brú.

Pink-footed Geese were first reported to be nesting in Iceland by Congreve and Freme (1930) who found at least seven nests of Pinkfeet at Krossárgil along the gorges of the Skálfandafljót in June 1929. In 1945 Finnur Guðmundsson surveyed the whole river system for geese and estimated that there were up to 200 Pinkfoot nests in all (Scott *et al.* 1953). Guðmundsson found four main breeding groups and nine minor ones (each with less than ten occupied nests) over about 45 km. of gorges.

On 9th May 1964 the Skálfandafljót was flown over from the sea to the vicinity of Isholsvatn (Boyd 1970). Ten pairs of Pinkfeet were found, over the 38 km. between Jarlstadir and Hrafnarbjörg, and one pair on Isholsvatn. The 1964 sighting at Jarlstadir, 25 km. downstream from Aldeyjarfoss, the previous known limit, indicated that some northward extensions of range may have occurred.

Magnus Bjornsson in 1933 found small numbers of Pinkfeet breeding in several scattered localities along both the Jökulsá á Fjöllum and the Jökulsá á Brú. Nowhere were there concentrations sufficient to be termed colonies and breeding in several localities was probably sporadic rather than annual (Scott *et al.* 1953).

On 8th May 1964 three Pinkfeet were seen (Boyd 1970) along the Kreppa, a tributary of Jökulsá á Fjöllum, south-southwest of Fajradalsfjall, near where some had been reported breeding thirty years earlier. The general area requires thorough exploration.

Iceland: west and north-west of Þjórsárver

Blurton Jones and Gillmor (1955), who visited the Arskard area, west of the Hofsjökull glacier, in August 1954, saw several family parties and found one dead gosling, killed before it was able to fly.

On 21st May 1964 low-level flights were made over several of the vegetated areas to the west and south-west (Boyd 1970). In Miklumyrar 23 Pinkfeet, representing 18 pairs, were seen, well scattered. Hrafnstóftaver had a pair and a single bird. There was a group of 13 on Hvítárnes. A further six pairs and a single bird were seen along the course of the river Hvítá itself, over the 40 km. from near Lambafell to just below Gullfoss. On Kjálkaver 22 Pinkfeet, representing 12 pairs, were found near the Þjórsá itself and there were 81 along the gorge near Gljufurleitarfoss (12 in flocks, and ones or twos representing 40 pairs) with another 38, representing 22 pairs, from near the junction of the Þjórsá and Tungnaá southwest to west to Þjofafoss. Closer to Þjórsárver, Eyvafen had only one pair but Hnífárver held 156 geese, 42 dispersed pairs and 72 birds in flocks. On Harnmyrar, above Þjórsárver, there were a group of ten, six pairs, and a single.

On 8th May 1964 Boyd (1970) left the Þjórsá at Langalda (64° 17′ N., 19° 20′ W.) and flew west-southwest across country to Braedratunga (64° 09′ N., 20° 23′ W.). Two small flocks, of 13 and 11 geese, were seen near Langalda itself; four pairs in Kistuver (64° 15′ N., 19° 32′ W.); and 39 geese, including three detached pairs, in Fossolduver (64° 15′ N., 19° 43′ W.). There are other scattered vegetated sites between Fossolduver and the Hvítá that should be searched for geese.

Pinkfeet have not been proved to breed in the central highlands further to the north-west than Guðlaugstungur but some incidental observations during positioning flights in May 1964 suggest that Tvidaegra and Arnavatnsheiði, north of the Langjökull and Eiriksjökull glaciers, should be examined carefully. Arnavatnsheiði is dotted with large numbers of lakes and tarns. Kinlen (1963) saw no families of Pinkfeet there in August 1962 but that does not exclude the possibility that some geese could be breeding in this extensive tract of vegetated upland. In the west, 15 Pinkfeet (a group of eight, three pairs and a single) were seen on 10th May 1964 by the Brennakvísl (at 65° 03′ N., 20° 55′ W.). On 9th May Pinkfeet were seen at three sites north-west of the Stori-Sandur: five pairs,, one single on Adalbolsheiði (at 65° 03′ N., 20° 23′ W.); a group of 14, 11 pairs, one single near the headwaters of the Vidadelsa (at 65° 06′ N., 20° 22′ W.) and two pairs at Skutatjorn (65° 12′ N., 20° 12′ W.). The strips searched during these flights amounted to about 7 sq. km., leading to an estimated density of 3.4 pairs of Pinkfeet per sq. km. That is low, but the area of similar-seeming country is relatively large.

On 11th May 1964, in an inspection of the river Tungnaá from its southern watershed near Kirkjufell (63° 58′ N., 18° 55′ W.), no geese were seen above Tungnaákrokur but from there to the confluence with the Þjórsá (64° 11′ N., 19° 30′ W.) there were flocks of about 60 and 16 and at least 150 in ones or twos,

representing some 70 pairs. This search included Þoristungur and the lower parts of the Kaldakvísl. Following the Þjórsá downstream from the Tungnaá confluence, three pairs of Pinkfeet were seen on Sultartangi, three pairs and a single at Holuskogur, three pairs south-east of Burfell and two pairs at Bringa (64°07′N., 20° 00′ W.).

In 1966 and 1969 British expeditions spent some time in the area known as the Kjölur between the Hofsjökull and Langjökull glaciers (Hardy 1967; Bulstrode and Hardy 1970). This included those parts visited by Blurton Jones and Gillmor in 1954 and also some of the meadow and marsh areas further to the north. An important new breeding site for Pinkfeet was found in 1966 along the gorge of the Jökulfall river (Figure 2), at least 70 nests being counted, though only about half were used that year. In 1969 nests were found in three more localities in the Kjölur, including two river gorges, and adults and goslings seen in five different meadows. Numbers were small, totalling some 40 breeding pairs.

In June 1970 Kerbes and Ogilvie also surveyed certain areas outside Þjórsárver by helicopter (Table V). The Þjórsá river was followed to its junction with the Tungnaá and parts of the latter and the Kaldakvísl were flown over on 12th June. Most of the small patches of vegetation between Kaldakvísl and Þjórsárver were checked. On 18th June the area between Hofsjökull and Langjökull was surveyed, including almost all the vegetated areas within that region. The weather that day was overcast, cool and moderately windy. Table V gives the approximate areas, or, for the rivers, the lengths searched. Even on the small meadows most nearly adjacent to Þjórsárver the nest density was less than one tenth that on the main breeding ground. It should be emphasised, however, that not all the areas of meadow surveyed were necessarily suitable Pinkfoot habitat. For example the large Guðlaugstungur appeared to have rather little lush marsh, most of the vegetation being of a dry heathy nature. The 100 pairs recorded for this area in 1970 contrast with the complete absence of geese in 1969 reported by Bulstrode and Hardy (1970), and the single old nest site found in 1966 (Hardy 1967).

Greenland

Though the range of the Pink-footed Goose in East Greenland in late summer has long been fairly well known (Salomonsen 1967) there is still no good estimate of the number breeding there. By 1950 the species had been found breeding from Mikkisfjord, south of Scoresby Sound, to Dove Bay, over 500 miles to the north. Only some parts of this long stretch of coast, much elongated by the dissecting fjords and islands, provide suitable breeding habitat for Pinkfeet and only in a few places had more than a handful of nests been found. The evidence of nesting summarized by Scott and Fisher (1953) did not account for more than about 500 breeding pairs.

Table V. Number of nesting Pink-footed Geese recorded outside Þjórsárver, Iceland, June 1970.

Locality	*Approx. area or length*	*Approx. no. of pairs or nests*	*Density nests/sq. km.*
Small meadows to south and south-east of Þjórsárver	18.0 sq. km.	190	10.6
Illugaver	2.5 sq. km.	25	10.0
Hnífárver	3.0 sq. km.	25	8.3
Krókur	5.5 sq. km.	25	4.5
Guðlaugstungur	100.0 sq. km.	100	1.0
All other meadows between Langjökull and Hofsjökull	115.0 sq. km.	0	0
Þjórsá—islands and gorge	60 km.	150	
Tungnaá and Kaldakvísl	55 km.	20	
Hvítá gorge	20 km.	50	
Total meadows	244.0 sq. km.	365	1.5 nests/sq. km.
Total river gorges	135 km.	220	1.6 nests/km.

Several ornithological expeditions have visited East Greenland subsequently (Goodhart and Wright 1958; Hall 1963; Marris and Ogilvie 1962), but they did not add much to our knowledge of the number of Pinkfeet breeding in the country. The particular reason for this is the large scale moult migration of non-breeding Pinkfeet from Iceland to east Greenland. This was first suggested by Taylor (1953) who observed skeins of geese apparently migrating north-west from central Iceland in late June. Christensen (1967) reviewed all available information, including his own observations of Pinkfeet moving north in East Greenland in late June and early July 1964, and concluded that as many as 15,000 Pinkfeet might be moult-migrating from Iceland to Greenland. Thus where the expeditions mentioned above reported only a handful of family parties of Pinkfeet among many hundreds of non-breeders, this did not (necessarily) mean that it was a poor breeding season but rather that most of the non-breeders were unrelated to the local breeding stock.

Christensen (1967) suggested that the total number of pairs breeding in Greenland was not more than 1,000, a figure also used by Salomonsen. It is not clear why the earlier estimate was doubled. There is no evidence that the numbers attempting to breed in Greenland have changed in the last forty years. As Christensen pointed out 'Investigations on these subjects should preferably be carried out in May and June, before the immigrants arrive from Iceland and complicate the situation'. This has yet to be done.

The total Iceland/Greenland breeding population in 1970

The survey of 1970 located approximately 11,300 nests of Pinkfeet. A best estimate for the number of pairs in the areas of Iceland not searched is a maximum of 1,500. The maximum figure for East Greenland has been suggested as 1,000 pairs. Thus the total number of breeding pairs in June 1970 probably lay around 14,000. Of this total, therefore, about 75% were in þjórsárver.

Age ratio and brood size counts in Britain each November have shown that the number of successful pairs with young at that date has varied over the years from a low of 2,800 to a maximum of 8,200 (Boyd and Ogilvie 1969; Ogilvie 1970, 1971). This variation reflects the rise in total numbers but also relates to the differing breeding success of each summer. 1970 was the first year in which a comparison could be made between a fairly reliable estimate of the number of pairs nesting in Iceland and Greenland in June (14,000) and the number of pairs with young in Britain in November (7,500). This suggests that almost half the nesting pairs had lost all their eggs or young in the five-month interval. The principal causes will have been weather and predation losses of eggs and young on the breeding grounds; losses on migration to Britain; and shooting on the wintering grounds prior to the census.

It is not possible to say for certain whether such a proportionate loss is normal, as there are no comparable sets of records. In November 1970 there were 23.1% young birds present in the wintering flocks, near the average for 1950 to 1969 of 26.2% (range 10.8 to 48.8).

Another question of considerable importance is whether the geese breeding in þjórsárver are more successful in rearing young than those breeding elsewhere. Such evidence as there is suggests that they should be, having the great advantage of safety in isolation and apparently excellent habitat. The breeding geese in East Greenland will almost certainly have a lower success, being subject to greater vagaries of weather and a shorter summer.

PART IV. THE PRESENT ROLE OF ÞJORSARVER AND OTHER BREEDING AREAS.

There are large numbers of mature Icelandic Pinkfeet (three or more years old) that fail to breed successfully in any given summer (Boyd and Ogilvie 1969). Whether these failures include sub-populations that consistently fail to attempt breeding or to breed successfully, or whether there is great variation in the success of particular pairs from place to place and from year to year, is not known. The sketchy evidence presented in Part III of fluctuations in the use of small nesting areas west of þjórsárver, together with hints of similar changes in the north-eastern colonies in the 1930's (see Scott and Fisher 1953) suggests that it may be inappropriate to regard any breeding area, even þjórsárver, as a stable environment for the annual production of geese. The 'carrying capacity' of other smaller areas may be even harder to assess.

How Pinkfeet choose their breeding places to provide both suitable nesting sites and adequate food supplies for later in the summer is not known. The preference shown for inaccessible nest-sites in river gorges suggests that safety from ground predators is a primary require-

ment. In oasis colonies their choice of nest site seems to be much less important, despite the recorded cases of 'traditional' sites, used year after year. (The same dichotomy between rigorous site-selection in gorges and the unimportance of site in large colonies is also very striking among Snow Geese in Arctic Canada.)

In considering what Pinkfeet displaced from Þjórsárver might do, or what might be done for them, it may be more important to pay attention to food supplies in late summer than to nest-sites. One facet of the problem is that in Þjórsárver few other grazing animals are now competing with the geese.

Some of the other areas inhabited by Pinkfeet are much more likely than Þjórsárver to be subjected to persistent grazing by sheep. A very recent assessment of the range resources of Iceland by Thorsteinsson *et al.* (1971) makes several points of great relevance to an understanding of the present and potential use of the central highlands by geese. Iceland has been subject to intensive soil erosion in the course of nearly 1,100 years of human settlement. Some 30-40% of the originally vegetated area of the country has become wind-eroded following the destruction of tree cover and over-grazing. Over-grazing has also resulted in the palatable herbs and grasses, formerly abundant, becoming relatively scarce. The floristic changes have been greatest in the lowlands. There is in any case a rapid decrease in numbers of plant species with increasing altitude. In the highlands much of the vegetation is moss heath *Rhacomitrium*. Its productivity is very low, the average annual yield being only 260 kg. per ha., dry matter as compared with 1,110 for the grassland and 1,120 for the bogs.

All the western parts of the Icelandic range of the Pinkfoot are classified by Thorsteinsson *et al.* as over-grazed. Only the little-known colonies north and east of the Vatnajökull are in an under-grazed region. The Pinkfeet are concentrated on poorly-drained land where productivity is relatively high but the vegetation is of little value to sheep because of unpalatability and the wet substrate.

It is at least possible that the changes in grazing practices in Iceland in recent years have improved conditions for breeding Greylags and for those Pinkfeet that may visit the lowlands in autumn and spring (Kear 1967; C. J. Sellick, pers. com.). The use of vegetation by geese, even in the seemingly remote interior of the country, should not be considered in isolation from stock distribution and management.

Þjórsárver is at present of paramount importance to the Pinkfeet of Iceland and Greenland, supporting at least 75% of the effective breeding population, with a mean density of nests, of about 130 per sq. km. over the whole oasis, much greater than elsewhere. The 15 sq. km. which may remain unflooded is unlikely to accommodate many of the 6,560 displaced pairs. It does not appear to be suited to intensive use, having a nest density (107 per sq. km.) below the average for the oasis. It is quite certain that it could not provide food for over 18,000 adults and 30,000 goslings in July and August.

What is the likelihood that the displaced geese can breed successfully in other places? In view of the low nest densities found in other areas and the large number of 'non-breeders' already in the population, it seems most improbable that they can be successful elsewhere without deliberate attempts to improve large areas for them. What improvements would be necessary and would be recognised as such by the geese can only be discovered by further research.

PART V. ECONOMICS AND RESEARCH.

In recent years the Icelandic Government has been trying to diversify the economy and to reduce its reliance on the fishing industry, a widely fluctuating source of income. The country has large untapped resources of relatively cheap hydro-electric power, which is being offered to foreign industrial firms to persuade them to operate in Iceland. One new power station on the middle reaches of the Þjórsá already supplies an aluminium smelter. According to the National Energy Authority this station and other power developments on the river would benefit from the proposed reservoir that would inundate Þjórsárver.

The Icelandic authorities have initiated an intensive research programme in the Þjórsárver oasis. This has been started by a team organised by the National History Museum of Iceland, under the direction of Dr. Agnar Ingolfsson of the Division of Biology of the University of Iceland. The programme is being funded by the Icelandic Government, through the National Energy Authority. Its purpose is to examine the ecological significance of the area. In 1971 the Icelandic investigators are making a detailed vegetation map of the area and

studying the feeding habits of the geese more fully. These studies will need to be supplemented by other research, both in Þjórsárver and outside it, which will require additional manpower and funds.

In Þjórsárver itself more needs to be learned about the dispersion of the geese after hatching; about possible differences in nesting and rearing success in different areas; and about the primary productivity of the oasis and the effects of goose grazing and droppings on the ecosystem.

Similar studies need to be conducted in other parts of the breeding range, in Greenland as well as Iceland. A nest survey should cover all potential breeding areas, by means of direct observations from a helicopter or, more practically, by aerial photograph from a fixed wing aircraft. Suitable photographic techniques are now being perfected in work on goose colonies in the Canadian High Arctic. Photography in early August may also be the best means of assessing both goose breeding success and productivity of the vegetation on a broad scale.

The financial backing for the research programme by the Icelandic Government is substantial. If external support of an equivalent amount could be obtained most of the necessary research could be completed within a few years.

If Þjórsárver is eventually flooded and there are no alternative breeding areas capable of sustaining a population of over 60,000 Pinkfeet, including 10-14,000 breeding pairs, what would happen? Presumably nothing immediately dramatic, unless large numbers of the displaced geese chose a moulting site with inadequate food supplies. Because of the cushioning presence of the non-breeders already in the population, it would probably be several years before any substantial decline in the wintering population became unmistakably apparent. The eventual loss would certainly be felt more in Britain than in Iceland and it therefore does not seem unreasonable to suggest that British finance should be forthcoming to help underpin the research.

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Summary

The proposal to flood the main breeding ground of the Pink-footed Goose *Anser brachyrhynchus* at Þjórsárver in Iceland required an up-to-date assessment of its importance. A helicopter survey in June 1970 resulted in an estimate of 10,700 nests widely dispersed throughout the 81.6 sq. km. of vegetated ground. The technique is described and its reliability tested. Comparison is made with earlier estimates of the numbers of geese breeding in Þjórsárver, indicating a considerable increase since 1951. Scattered information on Pinkfeet breeding sites elsewhere in Iceland and in east Greenland is assembled. It would appear that Þjórsárver holds approximately 75% of the breeding pairs in the Greenland/Iceland population which winters in Britain. If Þjórsárver is flooded to the designed level, 85% of the nest sites used in 1970 would be lost and the vegetated area remaining could not provide sufficient food to raise more than a small proportion of the goslings now produced annually in the oasis.

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Plate I. Aerial survey of the breeding grounds of the Pink-footed Goose *Anser brachyrhynchus* at Þjórsárver, central Iceland, in June 1970 (see pp. 5-17). (a) The north-east corner of the oasis with the Arnarfell mountains beyond the terminal moraine of the Hofsjökull icecap. (b) A view from the helicopter about 60 metres up over a favoured nest area. The drier ridges, on which the geese nest, are only a few metres apart.

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Plate II. (a) Female Pinkfoot on its nest beside some dwarf willow. The raised rim of the nest indicates that the site has been used again and again over the years. (b) Helicopter view of a low-lying marsh in Þjórsárver which will dry out by August to become an important feeding area for the geese and their goslings. In the foreground is one of the areas searched on the ground to check the counts of nests made from the air. The field of view is about 500 metres in mid-picture.

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