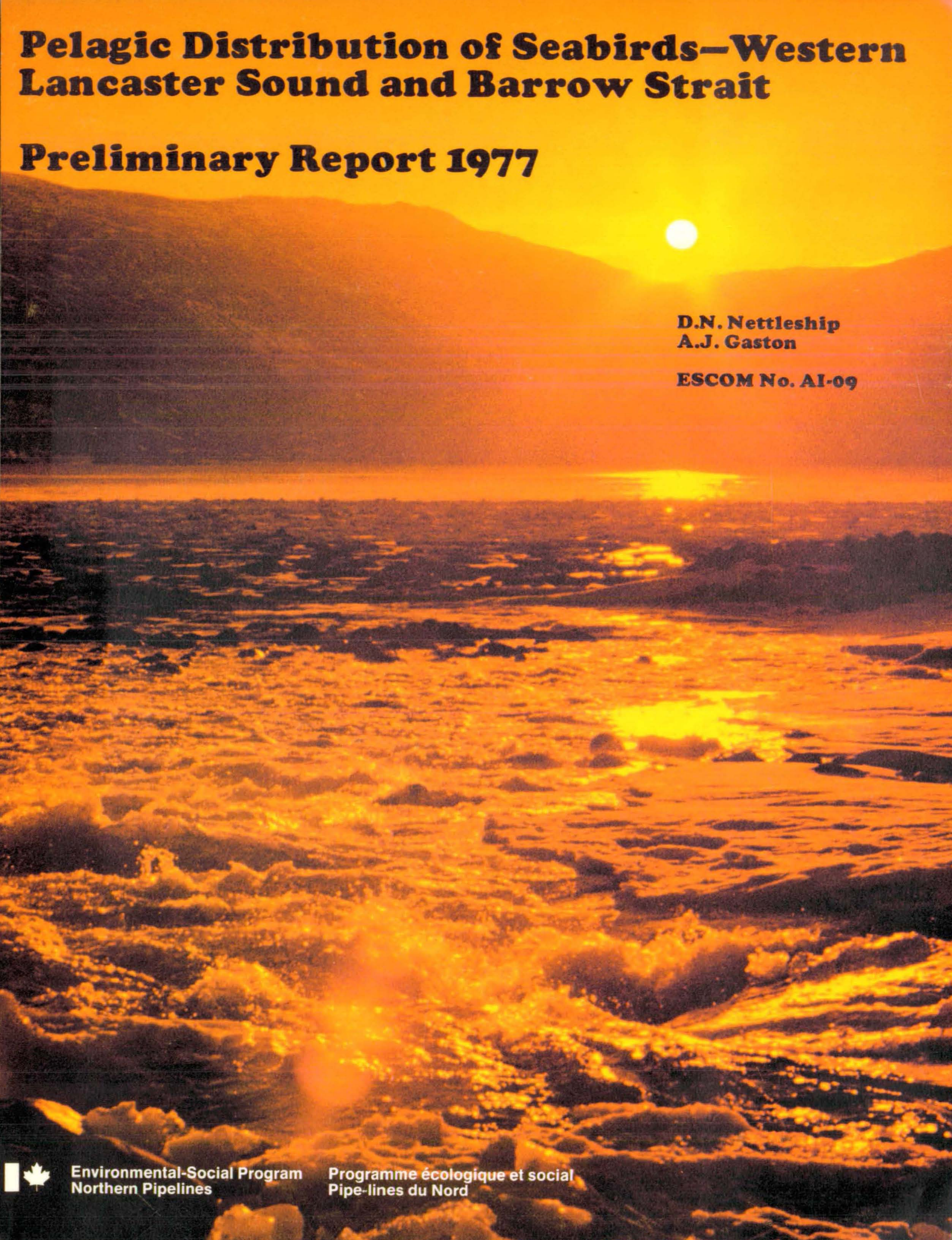
Pelagic Distribution of Seabirds—Western Lancaster Sound and Barrow Strait

Preliminary Report 1977



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Patterns of Pelagic Distribution of Seabirds in Western Lancaster Sound and Barrow Strait, Northwest Territories, in August and September, 1976

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This report presents preliminary data and results obtained by Fisheries and Environment Canada for use by the Arctic Islands Pipeline Program. These investigations were carried out under the Environmental-Social Program, Northern Pipelines of the Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of hydrocarbon transportation proposals, the knowledge gained is equally useful in planning and assessing other development projects.

RÉSUMÉ

Nous avons étudié les caractéristiques de la répartition, de l'utilisation des habitats aquatiques et de l'aire d'alimentation des quatres espèces principales d'oiseaux de mer (le fulmar boréal, *fulmarus glacialis*, la mouette tridactyle, *Rissa tridactyla;* la marmette de Brünnich; *Urici Comvia;* et le guillemot noir, *Cepphus grylle)* qui se sont reproduites dans un territoire de 24 000 km2, dans le détroit de Barrow et l'ouest du détroit de Lancaster, durant l'été 1976. Une grande partie du million ou plus d'oiseaux de mer qui nichent chaque été dans cette région se concentre dans l'île Prince-Léopold: 100 % des marmettes, 95 % des mouettes, au moins 40 % des guillemots et des fulmars. Toutes les eaux marines délimitées par les latitudes 73°30' et 75°05' N et les longitudes 87°00' et 95°10' O (c.-à-d. la région étudiée) ont fait l'objet de cinq séries de relevés aériens en août et en septembre afin de déterminer la répartition des oiseaux de mer et d'identifier les régions importantes pour leur alimentation en cette période cruciale de l'élevage des jeunes.

Nous avons relevé 18 616 oiseaux répartis en 13 espèces, sur 6 455 km de transects, et 98 % des oiseaux appartenaient à l'une des quatre espèces principales nichant dans la région du détroit de Barrow. La répartition de toutes les espèces était très systématique: on décelait une tendance significative chez toutes les espèces à se concentrer près des côtes plutôt qu'au large. Près des côtes, les espèces étaient fortement groupées et les plus fortes concentrations se rencontraient le plus souvent dans les baies ou aux endroits où il y avait des banquises côtières ou des cours d'eau s'écoulant dans la mer. La concentration de la morue polaire *(Boreogadus saida).* qui vient frayer dans ces eaux estuariennes, est probablement responsable de ces rassemblements d'oiseaux car elle constitue la majeure partie du régime estival de la plupart des oiseaux de mer de la région.

Le fulmar boréal était l'espèce la plus nombreuse avec 55 % de tous les oiseaux de la région inventoriée. Son territoire de pêche s'étendait beaucoup plus loin que celui des autres espèces. La mouette tridactyle était plus fréquente près des côtes et ne s'éloignait généralement pas à plus de 48 km de l'île Prince-Léopold, même si on en a vu de grands nombres jusqu'à 96 km de la colonie. La distance parcourue en mer par la marmette de Brünnich était beaucoup plus variable, et on en retrouvait jusqu'à 112 km de la colonie. Cette espèce a soudainement changé sa préférence de territoire de pêche entre le 2 et le 6 août, probablement à cause d'une forte accumulation de glaces à la dérive le long de la côte nord de l'île Somerset, où cette espèce s'était auparavant concentrée pour pêcher. Certains guillemots noirs se limitaient aux eaux côtières près desquelles ils nichaient, mais des oiseaux provenant de la grande colonie de l'île Prince-Léopold voyageaient sur une distance considérable, le long de la côte nord-est de l'île Somerset, au moins jusqu'à la baie Garnier, à 55 km de la colonie.

Cet inventaire ainsi que des observations faites dans l'île Prince-Léopold en 1975 et en 1976 portent à croire que la protection des zones de pêche et des aires de nidification constitue l'aspect le plus important de la conservation et de l'aménagement des populations d'oiseaux de mer et de leurs habitats. La concentration des oiseaux à l'entrée de quelques petites baies et estuaires, où la morue polaire semble être l'espèce la plus abondante, porte à croire que la disponibilité de la nourriture est très limitée et qu'elle constitue un facteur déterminant de la façon sélective dont les oiseaux de mer utilisent les divers types d'habitats. De telles aires d'alimentation sont extrêmement vulnérables aux activités industrielles et devraient être soigneusement protégées. Tout changement environnemental dans ces baies et détroits, qu'il soit naturel ou anthropique, pourrait aboutir à une sérieuse réduction de l'abondance et de l'accessibilité de la morue polaire, ce qui réduirait sans doute d'autant les populations d'oiseaux de mer dans la région du détroit de Barrow.

L'endroit qui est actuellement le plus menacé par le tracé proposé du gazoduc est l'inlet Cunningham, sur l'île Somerset. La construction et l'utilisation du gazoduc, de même que la pollution et les perturbations qui s'ensuivront auront un effet néfaste sur les populations d'oiseaux de mer et leurs sources de nourriture. Ceci est aussi vrai pour tout changement apporté par l'homme au régime d'écoulement des eaux et au ruissellement des basses terres adjacentes.

D'autres études sont nécessaires pour déterminer l'utilisation de l'habitat et les besoins alimentaires des oiseaux de mer pendant la saison de reproduction. Il est nécessaire d'obtenir des renseignements plus détaillés sur les changements d'aires d'alimentation qui surviennent à l'intérieur d'une même saison ou d'une année à l'autre, si on veut assurer un aménagement efficace des populations d'oiseaux de mer.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Features of the distribution, use of water habitats and foraging range were studied for the four major species of seabirds (Northern Fulmar *Fulmarus glacialis*, Black-legged Kittiwake *Rissa tridactyla*, Thick-billed Murre *Uria lomvia*, and Black Guillemot *Cepphus grylle*) found in a 24000 km^2 area of Barrow Strait and western Lancaster Sound during the 1976 summer season. A large proportion of the more than one million seabirds that reproduce in the survey area each summer nest at one location, Prince Leopold Island: 100% of murres, 95% of kittiwakes, at least 40% of guillemots, and 40% of fulmars. Five sets of aerial sample surveys were conducted over marine waters between latitudes 73°30' and 75°05'N and longitudes 87°00' and 95°10'W in August and September to determine the distribution of seabirds and to identify areas which were important to them for feeding during the crucial period when chicks were being reared.

A total of 18616 birds of 13 species was recorded in 6455 km of transects. Ninety-eight percent of all birds observed belonged to the four major breeding species. The distributions of all species were highly non-random, all occurring at higher density in coastal than in off-shore waters. In coastal waters, major concentrations most often occurred in bays or waters with land-fast ice or where streams or rivers flowed into the sea. The concentration of Arctic Cod *Boreogadus saida* in these estuarine water habitats during the summer is believed responsible for the high numbers of feeding birds associated with such sites, as this fish forms a major portion of the summer diet of most seabirds in the region.

Northern Fulmar was the most numerous species, comprising 55% of all birds seen, and foraged over much greater distances than other species. Black-legged Kittiwakes were more frequent on coastal than off-shore transects, usually foraging within 48 km of Prince Leopold Island, though large numbers were seen as far as 96 km from the colony. Thick-billed Murres showed a relatively dispersed feeding pattern on the open sea with a foraging range up to 112 km from the breeding colony. They showed an abrupt shift in preferred feeding area between 2 and 6 August, probably due to heavy accumulations of pack-ice along the north coast of Somerset Island where they had previously concentrated. Some Black Guillemots were restricted to coastal waters adjacent to where they were breeding, but birds from the large population at Prince Leopold Island foraged at least as far along the northeast coast of Somerset Island as Garnier Bay, 55 km to the west.

On the basis of these aerial surveys and observations made on Prince Leopold Island in 1975 and 1976, we conclude that the most important aspect of the conservation and management of the seabird fauna and its habitats is the protection of critical feeding areas and breeding sites. The concentrations of birds near the mouths of only a small number of bays, estuaries and ice-edges, suggest that available food is very limited and is a major determinant in the way that seabird populations selectively use habitats. Such feeding areas are extremely vulnerable to industrial activities and should be carefully protected. Any environmental changes in these bays and inlets, man-made or natural, could cause severe reductions in the abundance and accessibility of Arctic Cod which undoubtedly would lower seabird productivity in the Barrow Strait area.

The site most immediately threatened by the proposed route for a gas pipeline is Cunningham Inlet, Somerset Island. Construction, operation and associated pollution and disturbance would adversely affect seabird populations and their food resources, as would any man-made alteration in patterns of water flow and run-off from adjacent lowlands.

Further studies are required to determine patterns of habitat usage and nutritional requirements of seabirds throughout the breeding season. Detailed information on changes and shifts of preferred feeding areas both within a single season and from year to year is necessary if effective protection of this seabird resource is to be achieved.

1. INTRODUCTION

More than one million seabirds reproduce and spend the summer in Lancaster Sound, Barrow Strait and associated water channels (Parry Channel, Wellington Channel and northern Prince Regent Inlet) located in the Canadian arctic islands. (Nettleship 1974, Brown *et al.* 1975, Nettleship & Smith 1975, Nettleship 1977*a*). The Northern Fulmar *Fulmarus glacialis*, Glaucous Gull *Larus hyperboreus*, Black-legged Kittiwake *Rissa tridactyla*, Thick-billed Murre *Uria lomvia*, and Black Guillemot *Cepphus grylle* are the principal species. These species are colonial and concentrate during the breeding season at a small number of locations where oceanographic conditions provide a suitable food supply and suitable breeding sites within range of this food supply. Sites having both these properties are rare in the Canadian arctic.

This general area is critical to the reproduction and survival of a large proportion of the seabirds in the Canadian high arctic. Strong currents from Barrow Strait and Lancaster Sound converge on Prince Leopold Island and may produce considerable upwelling and nutrient enrichment of the sea, perhaps resulting in unusually high biological productivity (Figure 1). The chief breeding site in the Barrow Strait area is Prince Leopold Island, but birds from this colony feed,at different times during the season, over most of the area comprising Barrow Strait, Wellington Channel, Prince Regent Inlet and western Lancaster Sound. The distribution of birds away from their colonies tends to be highly aggregated, presumably in response to local concentrations of food, and this pattern of dispersal for both breeding and feeding exposes seabird populations to high risk from disturbances and changes in the environment, especially those caused by industrial developments. Possible gas pipeline construction and operation (Polar Gas), already active lead-zinc mining (Arvik Mines Ltd., Cominco, Mineral Resources International) and deep-water oil drilling (Norlands Petroleums) are all likely to result in changes in the marine environment. These changes, and especially associated pollution and disturbances, will undoubtedly affect seabird populations and essential components of the marine ecosystem.

In the present study, five sets of aerial surveys were conducted over Barrow Strait and adjacent waters in August and September 1976 to determine the distribution of seabirds and to identify areas which were important to them for feeding during the crucial period when chicks were being reared. The surveys were designed to provide uniform coverage of all marine waters between latitudes 73°30' and 75°05'N and longitudes 87°00' and 95°10'W, and, in addition, to cover representative strips of coastal waters along all adjacent coasts. Methods used were based on techniques developed in the course of surveys over the Beaufort Sea (Searing *et al.* 1975), the central Canadian arctic (Davis *et al.* 1974, Alliston *et al.* 1976) and Lancaster Sound (Nettleship 1974, 1976, 1977*b*; Johnson *et al.* 1976) between 1972 and 1976. Data from the aerial surveys were supplemented by observations made from the CSS Hudson (R.G.B. Brown, CWS) cruising in Lancaster Sound and the eastern end of Barrow Strait during 17-19 August 1976.

The only previous attempt to sample the complete area systematically through the season to identify changes in the abundance, distribution and habitat utilisation of seabirds was that carried out by Alliston *et al.* (1976) in 1975. Their survey complements the present study by including data from the pre-laying and incubation periods (June and July). Other information available includes some aerial surveys conducted in June and August 1974 by

Davis *et al.* (1974), some shipboard observations made on 9 September 1970 and 10-12 August 1974 (Brown *et al.* 1975, and CWS files) and a series of helicopter transects flown on 10 June 1975 (Nettleship 1977*b*). To the east of the present survey area, however, detailed marine transects were flown throughout May - September 1976 by Johnson *et al.* (1976) using a gate-monitoring system to describe patterns of birds at sea in eastern Lancaster Sound. Their report gives the most detailed statement so far of changing patterns of use by seabirds of a major marine water area in arctic regions and assists the interpretation of our observations in the Barrow Strait area.

The specific objective of our report is to provide a detailed analysis of the way in which four species of seabirds utilize the various habitat types and water areas of western Lancaster Sound and Barrow Strait. The results are to be used to better our understanding of the environmental requirements of these species, and also to identify zones most critical to seabird reproduction and survival. This study is a part of a larger and continuing investigation concerning the reproductive ecology, community structure and resource allocation of populations of seabirds in Lancaster Sound (Nettleship 1977*b*) and the eastern Canadian arctic (Nettleship 1973).

2. STUDY AREA

2.1 Location and Seabird Fauna

The study area comprises 24000 km^2 of coastal and off-shore waters from Cape York (Brodeur Peninsula, Baffin Island) and Hobhouse Inlet (Devon Island) west to Limestone Island (northwest Somerset Island) and Allen Bay (Cornwallis Island) (Figure 2). All aerial surveys were initiated from a base camp located at Prince Leopold Island (74°02'N, 90° 00'W), approximately 13 km from Cape Clarence, the northeastern corner of Somerset Island (Figure 2). The island is flat-topped, oblong in shape and measures about 11 km long and 8 km wide. It is surrounded by vertical sandstone-limestone cliffs about 245-265 m high with numerous escarpments and pinnacles which are used for nesting by the largest breeding colonies of seabirds in the Barrow Strait - Lancaster Sound region.

The community of seabirds breeding on Prince Leopold Island comprises about: 60000 Northern Fulmars nesting almost continuously around the upper portions of the cliffs, 140000 Thick-billed Murres and 58000 Black-legged Kittiwakes on the east and north cliffs; 4000+ Black Guillemots among the talus and rock crevices on the cliffs; and 400+ Glaucous Gulls scattered above the murre, kittiwake and guillemot colonies (Nettleship 1977*b*). The only other significant colonies of seabirds within the survey area are of fulmars located at Cape Liddon (*c*. 10000 birds) and Hobhouse Inlet (*c*. 70000 birds) on the south coast of Devon Island (Nettleship 1974; CWS, in prep.).

2.2 General Pattern of Sea Currents

Strong currents flow south through Wellington Channel and east through Barrow Strait from Viscount Melville Sound into Lancaster Sound where they converge and meet a distinct current flowing westward along the south coast of Devon Island (Figure 1). There is also a significant southward water transfer from Barrow Strait through Prince Regent Inlet. These interactions of major water masses in the vicinity of Prince Leopold Island and northern Somerset Island may be expected to cause a local enrichment of nitrates, phosphates and other nutrients which promote the production of phytoplankton (e.g., Dunbar 1951, 1968). The structure of the seabird community at Prince Leopold Island, unique in the Canadian arctic in its high species diversity and bird numbers, may be related to exceptional productivity in the vicinity (see Nettleship 1977*b*). The oceanographic features of the Barrow Strait - Lancaster Sound region have been described in detail by Bailey (1957) and Collin (1962).

2.3 Notes on Ice, Sea and Weather Conditions during the Aerial Surveys

2 August. Shore-fast ice covered most of Wellington Channel, except for a tongue of open water which extended up the east shore of the channel, to just south of Bowden Point. Radstock and Maxwell Bays were also covered with shore-fast ice. Heavy concentrations of pack ice (more than 50% of the water surface covered) occurred on the north coast of Somerset Island from west of Garnier Bay to Limestone Island and across Barrow Strait between Limestone and Griffith Islands. Winds were NW gusting to more than 48 km/hr off the coast of Devon Island creating rough seas and considerable spray. Seas were moderate off the coast of Somerset Island and the Brodeur Peninsula.

6 August. The fast ice present in Wellington Channel on 2 August had disappeared completely and Radstock and Maxwell Bays also contained less shore-fast ice. The southern third of Barrow Strait, to the east of Wellington Channel, was 80-100% covered by pack ice consisting of medium to vast floes (100-10000 m across), many piled up against the coast of Somerset Island. Further west along the north coast of Somerset Island the area of pack ice extended only a few miles off-shore. Winds were moderate during this survey, but thick fog, which developed during the day on the north coast of Somerset Island, prevented part of Transect 8 and Transects 9-13 from being covered. The configuration of the other transects was altered somewhat to increase coverage of other areas, particularly the southwest coast of Devon Island.

29 August. Land-fast ice was confined to small areas in the inner parts of Radstock and Maxwell Bays, though some thin new ice was developing in Cunningham Inlet and at the west end of Barrow Strait, north of Limestone Island. The north coast of Somerset Island was still solid with pack ice, extending 8-16 km off-shore and filling the area between Somerset and Prince Leopold Islands. A heavy concentration of pack ice was also encountered in Prince Regent Inlet on Transects 17 and 22 and a rather lighter concentration (20-50%) on Transect 19 across Lancaster Sound. Sea conditions were moderate but fog on the coast of the Brodeur Peninsula necessitated the truncation of Transects 17, 21 and 22, and Transect 18 was flown at 11-16 km off-shore (see Figure 2).

11 September. Concentrations of pack ice were confined to the north coast of Somerset Island between Cunningham Inlet and Garnier Bay where they extended about 1.5 km off-shore. Sea conditions were generally good. Light fog was encountered south of Elwin Bay on the east coast of Somerset Island. Inadequate light forced the abandonment of Transects 21 and 22.

12 September. Ice and sea conditions were similar to 11 September. The survey was initiated earlier, which allowed all 22 transects to be flown during the daylight period.

3. METHODS

3.1 Survey Procedures

Surveys were flown in a twin-engined DeHavilland Twin Otter aircraft using two observers on each survey: one stationed in the co-pilot's seat on the right front side of the aircraft (observer R) and the other in the front passenger seat on the left side (observer L) directly behind the pilot. This disposition gave the best available view for two observers, but meant that there was a difference between the fields of view covered since observer R could see well ahead of the aircraft whereas observer L could not.

Each survey was divided into 16-22 transects, varying in length from 14-167 km. A brief pause to realign the aircraft was usually taken at the end of each transect line and this allowed the observers a moment to relax. Figure 2 shows the routes of all transects flown and Table 1 the co-ordinates for starting and finishing points. Approximately half of the survey distance flown was coastal and the rest over off-shore waters.

Navigation on open water transects was facilitated by the use of the global navigation system (GNS-200) in the aircraft, which also provided exact ground speed and position where necessary. Coastal transects were flown at 1000 m off-shore or 200 m from land-fast ice. Major coastal indentations were followed as closely as possible, but variations in the distance from shore were considerable.

Altitude was maintained at 30.5 m above the sea by means of a radar altimeter except where turbulence forced the pilot to seek safety at a slightly higher altitude. In a few cases strong down-draughts from cliffs made close approach at the specified altitude impossible. The ground speed was maintained as far as possible at 185 kph (100 kts), but actual mean speeds were higher than this because with a strong tail wind it became unsafe to maintain this ground speed. In September it became necessary to increase the mean speed in order to fit the necessary mileage into the daylight period. Dates, distances flown, areas sampled and mean ground speeds for each survey are given in Table 2.

Observers counted all birds seen within 200 m of the line of flight. This transect width was estimated by eye. To facilitate this estimation, trial runs were made over markers placed on the ground 200 m apart. Three observers were involved in the five surveys: A.J. Gaston flew in the co-pilot's seat on three with Erick Greene in the left for the first two and Barbara Dodge for the third. On the other two surveys Barbara Dodge flew in the co-pilot's seat and Erick Greene on the left. The observer in the co-pilot's seat instructed the pilot as to flight direction and speed.

Both observers recorded data on Panasonic cassette-tape recorders, using a microphone with a built in switch. They also carried stop-watches and wrist watches. Birds sighted within the transect were recorded by speaking into a tape recorder, for example: "one fulmar flying", "two murres on water", two kittiwakes taking off from water". An automatic timer, sounding every two minutes, was activated at the start of each transect and both observers recorded the time, ice conditions (cover, type of ice) and sea conditions each time it sounded. The total duration of the transect was measured with a stop-watch.

All birds sighted within the transect were recorded, identified (normally to species), and sexed and aged where possible. Whether the bird was on the water or flying at time of first sighting was also recorded. Where birds were too dense for counts to be made, numbers were estimated. Any unusual concentrations or species observed off-transect were also recorded and specified as "off-transect".

A comparison of the numbers of birds recorded by the two observers revealed significant differences between left and right sides. The right side observer recorded more birds than the left on four of the five transect sets, and overall recorded 19% more birds on the water ($n=982$, $z=2.68$, $P<0.005$, binomial test) and 14% more in flight ($n=994$, $z=2.03$, $P=0.02$, binomial test). The same relationship held for Northern Fulmars, Black-legged Kittiwakes and Thick-billed Murres when compared separately, the discrepancy being greatest for the murres.

Significant differences in bird counts between observers were also found by Johnson *et al.* (1976) who used the same aircraft type and seating arrangements. They provide correction factors for all species and express numbers seen by observer L in terms of the numbers seen by observer R. Because these correction factors were derived from much larger samples than ours, they have been applied to our data and are used in this report to estimate the total numbers of birds within the survey area (see section 3.4).

Surveys were carried out on 2, 6 and 29 August and 11 and 12 September 1976. For the first two surveys all the four main seabird species (Northern Fulmar, Black-legged Kittiwake, Thick-billed Murre, and Black Guillemot) were in the early part of the chick-rearing period. On 29 August most murres had departed from the survey area, but fulmar chicks were about half-grown and kittiwakes were in the process of fledging. By the time of the September surveys, fulmar chicks were almost fully grown but still being fed by their parents at the colony, while practically all kittiwakes had deserted their breeding colony on Prince Leopold Island.

3.2 Possible Effects of Sea and Weather Conditions on Numbers of Birds Observed.

Studies of bird attendance on Prince Leopold Island suggest that weather conditions do not affect the numbers of fulmars, kittiwakes and murres present (breeders and pre-breeders) on their sites at the colony except in very extreme conditions (CWS, in prep.). This means, therefore, that similar numbers of birds should be found at sea irrespective of weather conditions. Large differences between the numbers of certain species recorded on surveys with different weather conditions did occur, however, which suggest that weather and associated sea conditions may have affected the ability of observers to see birds within the transect area. The small number of replicate surveys did not permit quantitative comparisons to be made to assess the effect of weather and sea on the visibility of birds, but it seems likely that species vary in this respect (see also Johnson *et al.* 1976 for further discussion).

Fulmars and kittiwakes, being pale above (fulmars vary in upper-surface colouration), were easily seen and most individuals of these species were probably recorded, although some misidentification is possible. Black Guillemots, though predominantly black above, have conspicuous white patches on the upper surface of the wings which make them easy to spot in flight. Observers agreed that murres were the most difficult species to detect, especially when sitting on the water. The observer in the co-pilot's seat sometimes saw murres dive below the surface well ahead of the approaching aircraft. Most of these birds would have been missed by observer L, as they would still have been submerged when the aircraft passed over them. In conditions of heavy seas, such as those encountered off the coast of Devon Island on 2 August, many murres sitting on the water may have been missed. This is suggested by the fact that counts of murres on 2 August (517) were much lower than those on 6 August (930), despite the fact that fewer miles were flown on the second survey.

3.3 Data Analysis

In analysing data from the transects, numbers recorded by each observer in each two-minute period were summed, keeping observations of birds on the water and birds flying separate. Birds seen rising from the water were treated as being on the water. Figures for both observers were then added together to give totals per species for each two-minute period and these figures were used to prepare species distribution maps. In mapping the position of each two-minute period ground speed was assumed to be uniform for each transect and the total distance was divided by the number of periods. Since the mean ground speed of the aircraft was about 190 kph and the width of the transect was 400 m, each period corresponds to approximately 2.6 km^2 of water sampled. This varies slightly with the speed of the aircraft. The final period of each transect varied in duration. Where it lasted one minute or more it was included on the map as a separate interval. Where it constituted less than one minute it was lumped with the preceding period. The positions mapped for each two-minute period represent the estimated position of the survey aircraft at the mid-point of each period. For coastal transects, notes taken of prominent features on the shore were also used in plotting the positions of periods.

Birds seen flying and on the water are represented on the maps by different symbols. It seems reasonable to assume that most birds seen on the water away from their breeding colonies were engaged in feeding and the locations of birds recorded on the water are therefore likely to indicate feeding areas. Numbers of birds seen flying are mapped only where more were counted than those on the water.

In calculating the density of birds on each survey, coastal and off-shore transects were treated separately. The total area covered by each survey on each type of transect was determined from the product of the total transect length, measured from a map, and the estimated width (400 m). The number of birds recorded was then divided by the area covered to give a density expressed in birds/km^2. Transects flown off-shore along the edge of land-fast ice were included with coastal transects for this analysis. For the sake of clarity the position of coastal transects on the maps of species' distribution have been shown further off-shore than their actual position.

3.4 Methods used in calculating Estimates of Birds within the Survey Area

Experience with aerial surveys over terrestrial and fresh-water habitats has shown that, even under ideal conditions, not all birds within the transect area are detected by the observers (Diem & Lu 1960, Davis *et al.* 1974). The proportion of those actually present which are recorded depends, among other variables, on the structure of the habitat and the detectability of individual species. The open nature of the marine environment and the fact that most seabirds are moderately large and not cryptically coloured probably makes the open sea a particularly suitable area for the application of aerial survey techniques. Since no studies have been performed so far to compare actual densities of birds at sea with those obtained by aerial surveys, there is, at present, no way to correct for the proportion of birds missed. Estimates based on densities derived from aerial surveys must therefore represent minimum approximations.

Given the reservations noted above, the total numbers of each species in the survey area were estimated using the following assumptions:

(1) that all birds in the right-hand half of the transect were recorded by observer R and that, for each species, observer L recorded a constant proportion of those in the left-hand half;

(2) that the proportion of birds seen by observer L was similar to that recorded by Johnson *et al.* (1976) in the course of similar surveys over eastern Lancaster Sound during the same period (see Johnson *et al.* 1976, Table 103);

(3) that the transects employed constituted an evenly distributed sample of the marine waters contained within the survey area;

(4) that, given the scale of variation in density between different parts of the survey area, the area covered by the transects constituted a sufficient sample; and

(5) that the transect width remained constant at 200 m.

The total area considered is that bound by the outer edges of Transects 5, 9, 17 and 19, which enclose 24000 km^2 of marine waters. On 2 August 1800 km^2 of Wellington Channel and Maxwell and Radstock Bays were covered by 100% land-fast ice and this area is not included for that survey. During the first two surveys practically all records of kittiwakes and murres were within 112 km of Prince Leopold Island and hence only the water area within this radius and the transects falling at least partly within it are considered for these species. This means the omission of Transects 5, 6, 7, 8, 9, 10 and 11, and thus densities for these dates differ from those given in Tables 8 and 10 which were based on the entire surveys.

Densities of birds on coastal and off-shore transects are considered separately. The density on coastal transects is arbitrarily considered to apply to all waters within 4 km of the coast (coastal zone), while the density observed on off-shore transects is considered applicable to all other waters (off-shore zone). The total length of coast within the survey area is 790 km, giving a maximum area for the coastal zone of 3160 km^2 (this excludes inner parts of Maxwell and Radstock Bays, which remained covered in fast ice throughout the survey period). Fast ice edges are treated as coastline in calculating the lengths of coast on 2 and 6 August. By the time of later surveys the amount of fast ice within the survey area was negligible.

Since a large proportion of the seabirds in the survey area nest on Prince Leopold Island (100% of murres, 95% of kittiwakes, at least 40% of guillemots, 40% of fulmars), the distribution of areas sampled in relation to distance from this island is important; a disproportionately large amount of time devoted to the area immediately adjacent to it would tend to bias estimates upwards. Table 3 shows the area of water sampled in relation to the area available at different distances from Prince Leopold Island. This proportion varied from 1.5-3.6%, the maximum ratio being at distances greater than 96 km from the island. Since about one third of the area surveyed fell outside this radius, estimates may be biased downwards slightly.

4. RESULTS

4.1 General Introduction

A total of 18616 birds of 13 species was recorded in the course of 6455 km of transects. Totals for each species are given in Table 4, which shows that 98% of all birds recorded belonged to Northern Fulmar, Black-legged Kittiwake, Thick-billed Murre and Black Guillemot. Analysis will be concentrated on these four species. Data are presented by species, each account being divided into two sections: distribution and dispersal, and population estimates.

4.2 Northern Fulmar

4.2.1 Distribution and dispersal

The Northern Fulmar breeds within the area covered by the surveys only at Prince Leopold Island, Cape Liddon, and Hobhouse Inlet. The last colony is situated at the extreme eastern end of the area and presumably only a part of the population forages within the area. Fulmars are the most commonly noted seabirds in the Barrow Strait area, comprising 55% of all the birds recorded on the surveys. They occurred in 59% of all two-minute periods and were recorded on the water in 25%. Table 5 compares the frequency with which fulmars were recorded on coastal and off-shore transects, showing that the species occurred in 65% of all two-minute periods on coastal transects and 53% on off-shore transects ($P < 0.01$). Overall, the proportion of birds recorded on the water in coastal and off-shore transects was similar (58% and 55%, respectively).

The proportion of two-minute periods in which fulmars were recorded declined from 75% on 2 August to 47% on 29 August, remaining similar on the September surveys. This difference between surveys is significant ($P < 0.001$, Table 5). The proportion of periods in which fulmars were recorded on the water was highest on 6 August (38%), possibly because a higher proportion of the total survey was devoted to the coast of Devon Island. The proportion of periods in which fulmars were recorded on the water varied between 19-26% on other surveys, showing no significant heterogeneity.

The density of fulmars was highest on coastal transects on 2 August (10.34 birds/km^2) falling to 5-7 birds/km^2 on all later surveys. The density on off-shore transects was highest on 29 August (2.01 birds/km^2) and lowest on 2 August (0.90 birds/km^2).

2 August (Figure 3). Heavy concentrations of fulmars were present on the north coast of Somerset Island, near the edge of the land-fast ice in Cunningham Inlet (300+) and Garnier Bay (300+) and on the east coast, near the mouth of Elwin Bay (450+). Large numbers were also seen along the edge of the fast ice in Wellington Channel (400+ on transect, but many more just off transect over the ice).

6 August (Figure 4). Between 2 and 6 August the entire ice cover of Wellington Channel was flushed out and consequently the concentration of fulmars observed at the ice edge on 2 August had dispersed. Heavy concentrations were seen around Cape Liddon (450+) and at the edge of the fast ice in Maxwell Bay (200+ with birds seen off-transect). A smaller concentration was seen on the coast of the Brodeur Peninsula (100+ with birds seen off-transect). Large numbers of birds were noted flying north and south along the east coast of Somerset Island.

29 August (Figure 5). The majority of fulmars seen on the water were close to the coast of Devon Island. Apart from concentrations close to the colonies at Cape Liddon and Hobhouse Inlet, large numbers were also observed north of Beechey Island (300+ with birds seen off-transect) and off Wallis Point (250+). Very large numbers were moving north and south along the east coast of Somerset Island.

11 September (Figure 6) and 12 September (Figure 7). Heavy concentrations were observed on both days on the west coast of Devon Island, north of Beechey Island (400+) and on the south coast between Radstock and Maxwell Bays (250+). The stream of fulmars flying down the east coast of Somerset Island was followed by extending Transect 16 further south, but no heavy feeding concentrations were encountered as far south as Batty Bay.

The most notable change in the distribution of fulmars occurred between 2 and 6 August. During the earlier survey large numbers of birds were encountered along the north coast of Somerset Island and along the edge of the fast ice in Wellington Channel. By 6 August the fast ice had cleared out entirely from Wellington Channel and large areas of water along the north coast of Somerset Island were covered by large ice-floes. These major changes in the distribution of ice were reflected in the distribution of fulmars which were found mainly on the south coast of Devon Island and in Prince Regent Inlet on 6 August. The pattern of distribution on 29 August was similar to that observed on 6 August, but the September surveys revealed moderate numbers again on the north coast of Somerset Island. Large numbers of birds flying north and south off the east coast of Somerset Island (Transects 16 and 16A) were recorded on all surveys, with an apparent peak on 29 August.

R.G.B. Brown (pers. comm.), from CSS Hudson, recorded large numbers of fulmars feeding in the vicinity of a current line 24 km NE of Prince Leopold Island on 17 August 1976 and also at the edge of dense pack ice about 16 km ESE of the island. From the numbers of birds seen on aerial surveys flying steadily north and south parallel to the east coast of Somerset Island, there must have been an important feeding area somewhere to the south of Batty Bay.

This stream of birds was noted on all surveys, with highest numbers recorded on 29 August. It seems likely that the birds involved were moving to and from Creswell Bay, where large numbers were reported by Davis *et al.* (1974, 1975) in late August 1974 and by Alliston *et al.* (1976) in August 1975. Another concentration was recorded to the south of Creswell Bay on the east side of Bellot Strait at the same period.

Figure 8 summarises the distribution of observed concentrations of fulmars over the five surveys. In general this coincides rather closely with that given by Davis *et al.* (1974), except for the area north of Beechey Island on the west coast of Devon Island, where no concentrations were recorded by the earlier study. Their findings of major concentrations just off Prince Leopold Island probably represent birds which were disturbed from the cliffs by the approach of the survey aircraft. Concentrations of fulmars feeding on the seas around Prince Leopold Island were rarely observed by biologists stationed on the island during the summers of 1975 and 1976. In late August Davis *et al.* (1974) recorded large numbers of fulmars between Griffith Island and Allen Bay. Relatively small numbers were seen in this area on the 1976 surveys, but observations from the shore on 4 September revealed a steady movement of fulmars out of Allen Bay around Cape Martyr.

In 1975 the edge of the fast ice in Barrow Strait extended from Cape Liddon to Maxwell Bay via Prince Leopold Island throughout June and fulmars were found to be concentrated in this area, both at the edge of the fast ice and also along the margins of dense floating pack ice north of Prince Leopold Island. Concentrations away from breeding colonies in August were noted on the south (8 August) and east (13 August) coasts of Cornwallis Island. Only small numbers were recorded in these areas in 1976. At Creswell Bay large numbers appeared from 20 August 1975 and more than 5000 were estimated to be present on that date; by 2 September numbers had apparently increased (Alliston *et al.* 1976).

4.2.2 Estimates of total numbers of birds

Numbers of fulmars estimated to be present in the survey area on each survey are given in Table 6. The total corrected estimates are highest for 29 August (70190), falling to 42151 by 11 September. On all surveys except 2 August, more than half the total number estimated were in the off-shore zone. On 2 August only 20% of birds in the off-shore zone were recorded on the water, compared to 50% in the coastal zone (Table 5), which suggests that on this date the coastal zone was more important than the off-shore zone for feeding. On all other surveys more birds were estimated on the water in the off-shore zone.

The number of fulmars attending the Prince Leopold Island colony has been estimated at 100000 birds (CWS, in prep.). This estimate is based on the assumption, derived from counts of non-breeding birds on the colony, that non-breeders constitute 40% of the entire population, and hence the 60000 breeders comprise 60% of the population. If the proportion of non-breeding birds is similar at the other two colonies in the survey area (Cape Liddon and Hobhouse Inlet, Devon Island), and the available data suggest that it is, then the total population of fulmars must be about 230000 birds. In early August, with chicks still being brooded constantly by one parent, an average of about 48% of these birds are away from their colony at any one time, although this varies within wide limits (CWS, in prep.). Assuming that half of the population of the Hobhouse Inlet colony forages within the survey area, then about 85000 birds should be at sea at that period. This figure agrees reasonably well with the numbers estimated for 2 and 6 August and rather better if one considers that several thousand may have been foraging in Creswell Bay, outside the survey area, at that time (Davis *et al.* 1974). Nettleship (1974) found large numbers of fulmars feeding off the southeast coast of Devon Island in early August 1972 and this concentration, continuing from early August until mid-September, was confirmed by Johnson *et al.* (1976). The colony at Hobhouse Inlet is only 100 km from this area and it is possible that a large proportion of the population from this colony was feeding there. If so, the estimates for 2 and 6 August may be a little higher than would be anticipated on the basis of local breeding populations, although estimates of these are liable to a wide margin of error.

Observations at the colony on Prince Leopold Island showed that by 29 August only 13% of the population was present on the cliffs at any time, since chicks were no longer being brooded. The estimate of 70000 birds in the survey area on that date suggests that a substantial proportion of the population had left the survey area. By mid-September, when the last two surveys were conducted, very few adult fulmars were present at the Prince Leopold Island colony and the estimates of *c.* 40000 birds in the survey area suggest that only about 30% of the population remained. On Prince Leopold Island only 40% of pairs that attempted to breed were still attending chicks by that date. Extrapolating this figure to the other colonies suggests that about 50000 adults were still involved with breeding. These successful breeders may account for a large proportion of the birds remaining in the survey area by mid-September. Davis *et al.* (1974) found major concentrations of fulmars to the north of Cornwallis Island and on the SE coast of Somerset Island in late August, and these feeding areas may become more important as attendance at the breeding colonies declines.

4.3 Black-legged Kittiwake

4.3.1 Distribution and dispersal

Practically all kittiwakes breeding within the survey area nest on Prince Leopold Island (29000 pairs, Nettleship 1977*b*), although small colonies are located just outside the area on Browne Island (1000 pairs) and Separation Point, Cornwallis Island (125 pairs) (Nettleship 1974, Brown *et al.* 1975), and Batty Bay (2000 pairs). Numbers of kittiwakes recorded on each survey are given in Table 7. Overall they occurred in 33% of all two-minute periods, but birds sitting on the water occurred in only 5%. A significantly greater proportion of birds seen on coastal transects was on the water compared to off-shore transects ($chi^2 = 633$, df 1, $P < 0.001$).

The densities of kittiwakes on coastal and off-shore transects are also given in Table 7. They were more frequent on coastal than on off-shore transects on all surveys. On coastal transects they were recorded in 25% of two-minute periods on 2 August, but the proportion rose to 47% on 6 August and remained at a similar frequency on the remaining three surveys. The frequency on off-shore transects was 17-23% of two-minute periods in August, but rose to 30-33% in September. Densities fluctuated widely. Very few kittiwakes were recorded on 6 August, when the bulk of the population must have been concentrated in areas not sampled by the survey. Highest densities on coastal transects were recorded on 2 August (10.11 birds/km^2), and densities on off-shore transects were highest on 11 September (0.70 birds/km^2).

2 August (Figure 9). Large concentrations were recorded slightly to the east of Garnier Bay (300+) and just off Cape Clarence (1850). Practically all sightings were from the north coast of Somerset Island east of Garnier Bay and from Prince Regent Inlet.

6 August (Figure 10). Only 111 kittiwakes were recorded on this survey, and these, as on 2 August, were mainly east of Garnier Bay or in Prince Regent Inlet. Small numbers were also present along the coast of Devon Island. It seems necessary to conclude that the bulk of the birds breeding on Prince Leopold Island were feeding in an area not covered by the survey on this date.

29 August (Figure 11). In contrast to the surveys earlier in the month, major concentrations were recorded only from the south coast of Devon Island: Radstock Bay (200+), the east side of Maxwell Bay (*c*. 1000, including birds off transect) and just west of Blanley Bay (*c*. 200). Smaller numbers were recorded over open water in Barrow Strait and Lancaster Sound and along the north coast of Somerset Island. By this date about one third of the young reared on Prince Leopold Island had fledged, but most of these were probably still visiting their nest sites (CWS, in prep.).

11 September (Figure 12) and 12 September (Figure 13). Practically all young kittiwakes reared on Prince Leopold Island had dispersed away from the breeding colonies by this time. The only major concentration observed was off-transect in Radstock Bay (300+ on 12 September), but the species was well distributed on both surveys in moderate numbers, particularly around Cunningham Inlet and the south coast of Devon Island. Immature birds were widely distributed, but constituted only 5% of sightings on both dates. The breeding success of birds observed on Prince Leopold Island during 1976 was slightly less than one fledgling per pair, on which basis (ignoring non-breeders) fledglings should have constituted 30% of the population in September. Either heavy post-fledging mortality or an earlier southward movement of birds-of-the-year might account for the small numbers observed, or possibly a combination of both factors.

Kittiwakes showed a progressive dispersal from the area of their main breeding colony on Prince Leopold Island during the course of the survey period. In early August most sightings were within 80 km of the colony, but by 29 August large numbers were present on the south coast of Devon Island, beyond the 80 km radius. By September, kittiwakes were fairly evenly dispersed over the entire survey area. The proportion of two-minute periods on off-shore transects during which kittiwakes were seen rose from 17% on 2 August to 31% on 11 and 12 September, respectively. The proportion of all periods in which kittiwakes were recorded also rose, being lowest on 2 August (20%) and highest on 11 September (44%, Table 7). Variation between surveys was significant ($P < 0.01$).

On 17-19 August R.G.B. Brown (pers. comm.) observed kittiwakes flying NE away from Prince Leopold Island, about 16 km from the colony, but recorded only small numbers off the coast of Devon Island. This suggests that most breeding kittiwakes did not forage as far as the Devon coast while feeding nestlings. Dispersal after fledging appears to be relatively rapid, however, since large numbers were present in Maxwell and Radstock Bays by 29 August. Some of these birds may have been failed breeders or non-breeders. Areas in which major concentrations of kittiwakes were recorded are indicated in Figure 8.

On 29 June 1974 a survey recorded very large numbers of kittiwakes off the SW coast of Devon Island (Davis *et al.* 1974). By this date in 1975 and 1976 egg-laying had already begun on Prince Leopold Island, so that it is possible that these were birds which had begun incubation, although laying dates in 1974 are not known. In 1975 the main concentration of kittiwakes recorded by Alliston *et al.* (1976) was on the northeast coast of Somerset Island and, although some birds were concentrated along the edge of fast ice to the north of Prince Leopold Island, the species did not show the same preference for the fast ice edge that was exhibited by fulmars.

On 7 July 1975 fairly large numbers of kittiwakes were recorded on the south coast of Devon Island, west of Cape Liddon. On this date most breeding kittiwakes on Prince Leopold Island were incubating and it seems likely that during this phase of the breeding cycle birds were foraging further from the colony than was observed during the chick-rearing period. The distribution of kittiwakes recorded by Davis *et al.* (1974) in August 1974 was similar to the pattern observed on 29 August 1976. The moderate numbers recorded in 1976 flying down the east coast of Somerset Island may have been travelling to and from Creswell Bay, where large numbers were recorded on 24 August 1974 (Davis *et al.* 1974) and on 20 August 1975 (Alliston *et al.* 1976).

4.3.2 Estimates of total numbers of birds

The estimates obtained for kittiwakes are shown in Table 8. These show much greater variability than those obtained for fulmars. The estimate for 2 August is greatly inflated by a single flock of 1850 birds, and from the known size of the breeding population on Prince Leopold Island (29000 pairs), the estimate of 6 August is clearly too low. It seems likely that the pattern of dispersal of kittiwakes in early August is too patchy to fulfil the fourth assumption listed above (see section 3.4).

By 11 September most kittiwakes had left the cliffs on Prince Leopold Island and the species was more widely dispersed over the study area than in August (see Table 7). For this reason the September estimates, which suggest 10000-30000 kittiwakes remaining in the survey area, may be more reliable than those in August.

On 2 and 29 August much larger numbers of kittiwakes were estimated in the coastal zone than in the off-shore zone. In September numbers were somewhat higher in the off-shore zone, but only 9% and 11% of these birds were on the water. The proportion of birds on the water was much higher in the coastal zone (36% and 43%), which suggests that this continues to be the most important feeding zone for the species.

4.4 Thick-billed Murre

4.4.1 Distribution and dispersal

Thick-billed Murres nest within the survey area only at Prince Leopold Island, where there are two colonies comprising 70000 pairs (Gaston & Nettleship 1976, Nettleship 1977*b*). The large colony at Cape Hay (Brown *et al.* 1975) is probably too far away for more than a very small proportion of the population to forage within the survey area. Observations by R.G.B. Brown (pers. comm.) from CSS Hudson in 1976 support this conclusion.

During the surveys murres were seen in large numbers only on 2 and 6 August. By 29 August less than 10% of chicks reared on Prince Leopold Island were still present at the colony and all adults had departed apart from those still attending chicks. The numbers of murres recorded on each survey are given in Table 9. On 2 August they occurred in 40% and on 6 August in 54% of all two-minute periods. It seems possible that some murres may have been missed on 2 August because of rough seas (see section 2.3 for details). Records of murres on the water constituted 56% of all observations.

Table 9 also compares the densities and numbers of periods in which murres were recorded on coastal and off-shore transects. The significant difference between 2 and 6 August in the proportions of periods on coastal transects in which murres were recorded ($P < 0.001$) probably reflects the fact that a greater proportion of coastal transects on 6 August were flown off the south coast of Devon Island where murres were concentrated at that time. Significantly more of the murres recorded on coastal transects were on the water than those on off-shore transects ($chi^2 = 43.6$, df 1, $P < 0.001$).

2 August (Figure 14). The only large concentration of murres recorded was just off the edge of land-fast ice in Garnier Bay (300+ with birds off-transect). Birds heading towards Prince Leopold Island were recorded on off-shore Transects 13 (across Barrow Strait) and 21 (across Lancaster Sound). This suggests that many murres may have been feeding in a relatively dispersed fashion on the open sea. Observations from the cliffs at Prince Leopold Island at this period revealed large numbers of murres heading W or SW towards the sea between Rodd Bay and Cape Admiral McClintock. Almost no birds were seen along the edge of the fast ice in Wellington Channel, in contrast to the observations of Davis *et al.* (1974) who recorded large numbers at this ice edge in June 1974, during the pre-laying period.

6 August (Figure 15). Concentrations of murres were observed on the edge of the fast ice in Radstock and Maxwell Bays (500+ in both). Quite large numbers were scattered along the south coast of Devon Island and also in the water of Lancaster Sound on Transect 26 (Fellfoot Point to Cape York).

29 August. Murres with newly fledged young were recorded to the south of Prince Leopold Island in Prince Regent Inlet (2), and to the east in Lancaster Sound (3). Those in Prince Regent Inlet were entirely surrounded by dense ice pans and it seems possible that they may have been carried south, unable to get clear of the ice.

Between 17-19 August, R.G.B. Brown (pers. comm.) observed many murres from CSS Hudson (Figure 16). Large numbers of adults and fledged young were present on the water to the east of Prince Leopold Island. The flight directions of incoming and outgoing birds seen during a circumnavigation of the island showed that the majority of murres were then feeding to the north and east of the colony (Figure 17), confirming the impression of observers on the island. Some murres were seen carrying fish towards Prince Leopold Island close to the south coast of Devon Island, a distance of 56 km, and this suggests that birds feeding chicks were foraging up to at least this distance from the colony.

Observations of birds arriving at and departing from the East Cliff colony on Prince Leopold Island in 1976 suggested that there was an abrupt shift in preferred feeding area during early August. The rate of birds arriving along the south side of the island from the west was 50-100 birds/minute in the middle of the day from late July to 1 August. After 7 August, however, the rate decreased to 1-13 birds/minute and large numbers were noted arriving from the north, although these birds were approaching the colony on a broad front, making numbers difficult to estimate. In 1975 large numbers of birds were feeding to the west of the island throughout the chick-rearing period and up to 200 birds/minute were estimated arriving from this direction on 11 August (Gaston & Nettleship 1976). The heavy concentration of pack ice along the north coast of Somerset Island in 1976, which developed between 2-6 August, may have caused the observed decline in the numbers feeding to the west, since after 6 August little open water was available in this sector.

Figure 18 indicates the position of major concentrations of feeding murres recorded in early August. It seems reasonable to assume that all the birds seen belonged to the Prince Leopold Island population (see Nettleship 1977*b*). Combining records for 2 and 6 August, 99% of all murres were seen within 110 km of the colony, which probably represents about two hours flying time for a murre (Tuck 1961). On 2 August, 89% were within 64 km of the island, but on 6 August only 80% were within 80 km. Part of this difference may be attributed to different transects covered, but comparing replicate transects on the coast of Devon Island numbers rose from 0 to 58 on Transect 4 and from 59 to 118 on Transect 14 between 2 and 6 August. Table 10 shows the numbers of murres recorded at different distances from the island on both surveys. Figure 19 illustrates the densities of murres per two-minute period in relation to distance from the colony, and suggests that on 2 August most murres were feeding within 64 km of the colony, while on 6 August most were feeding between 48-96 km from the colony. A rapid switch in direction and distance of foraging from the colony must therefore have taken place within a few days.

Surveys by Davis *et al.* (1974) in August 1974 revealed no concentrations of murres except around Prince Leopold Island and in a small area 240 km to the west, north of Prince of Wales Island. No concentrations were recorded along the coasts of Devon or Somerset Islands and it is possible that murres were feeding mainly in off-shore waters, which were relatively little sampled in 1974.

On 10-12 August 1974 moderate numbers of murres were recorded from a ship off the north coast of Somerset Island between Garnier Bay and Cunningham Inlet, and off Devon Island around the mouth of Radstock Bay, but no observations were made elsewhere except off the south coast of Cornwallis Island where no murres were seen (CWS files). These observations are difficult to interpret but suggest that densities of murres at that period were similar on both sides of Barrow Strait and that in that year, as in 1976, birds were foraging up to 110 km from the colony. On the basis of survey observations, and observations made on Prince Leopold Island in 1975 and 1976, it seems likely that murres may change their feeding areas from year to year and also within a single season, in response to changes in the distribution of ice-free water or the fish which form their principal food, Arctic Cod *Boreogadus saida*.

A helicopter survey conducted on 10 June 1975 found high numbers of murres at the edge of fast ice in Prince Regent Inlet, about 60 km south of Prince Leopold Island, but relatively few at the Barrow Strait ice edge (Gaston & Nettleship 1976, Nettleship 1977*b*). On 16 June 1975, however, Alliston *et al.* (1976) found high numbers along the edge of the fast ice immediately to the north of Prince Leopold Island. More than 10 times as many murres were counted in the 'inner' half of the transect, adjacent to the ice edge, as were seen in the 'outer' half, demonstrating the importance of the actual ice/water interface. In contrast with fulmars, relatively fewer murres were seen around loose pack ice nearby (Alliston *et al.* 1976).

In July 1975 large numbers of murres were present along the edge of fast ice across the south end of Wellington Channel and southwest of Griffith Island, and along the south coast of Devon Island (Alliston *et al.* 1976). All these observations were made prior to 20 July, when the first chicks were observed to hatch on Prince Leopold Island and they suggest that during the incubation period murres forage much further from the colony than during the chick-rearing period. This is not unlikely because incubation shifts at the Prince Leopold Island colony averaged about 24 hours, decreasing slightly as the season progressed, but probably allowing time for birds to make the 400 km round-trip to feed along the ice-edge off Griffith Island (Gaston & Nettleship 1976).

In August 1975, as in 1976, concentrations were observed in Maxwell Bay and elsewhere on the south coast of Devon Island, but Alliston *et al.* (1976) suggest that most birds may have been feeding in open water off-shore. Intervals between feeding visits to chicks at the Prince Leopold Island colony were similar in 1975 and 1976, which suggests that foraging distances were probably similar also during this period (CWS, in prep.).

4.4.2 Estimates of total numbers of birds

Estimates of the numbers of Thick-billed Murres present in the survey area are given in Table 11. The highest estimate is for 6 August (41541). Numbers estimated on 2 August were much lower, probably because rough seas made the birds difficult to see (see section 3.2). The estimate for 6 August is lower than would be predicted on the basis of the known size of the breeding population on Prince Leopold Island (70000 pairs). In early August the colony was in the middle of the chick-rearing period and at this stage one member of each pair remains constantly at the nest-site, irrespective of whether a chick or egg is still present. The length of time during which both members of the pair are present at the site averages no more than one hour a day, however, so that nearly half of the breeding population should be away from the colony at any one time. If non-breeders are included this should amount to at least 70000 birds and hence the figure obtained on 6 August appears to be a considerable underestimate, indicating that a relatively high proportion of murres go undetected on a survey of this type.

4.5 Black Guillemot

4.5.1 Distribution and dispersal

Unlike the preceding three species, Black Guillemots nest in a dispersed fashion along most of the coasts adjacent to the survey area, particularly where rocky cliffs afford suitable nesting sites. A major breeding concentration occurs on Prince Leopold Island where at least 2000 pairs were present in 1976, and there is another large concentration just south of the survey area between Batty Bay and Fury Point (Alliston *et al.* 1976). Most other localised concentrations probably number less than 100 pairs (Nettleship 1974, Davis *et al.* 1974).

Table 12 shows the numbers of guillemots counted on each survey. They occurred in 20% and 34% of all two-minute periods during the first two surveys on 2 and 6 August, but this fell to 7% on 29 August and very few were seen in September. Birds seen on the water constituted 43% of all records. Table 12 also shows the densities of Black Guillemots on coastal and off-shore transects. Maximum densities on coastal transects occurred on 6 August (1.33 birds/km^2), and on off-shore transects on 29 August (0.15 birds/km^2). The high density on coastal transects on 6 August may be due to the greater length of the south coast of Devon Island flown on that survey. Suitable nesting areas are common on that coast.

The observed distribution of Black Guillemots on 2 August (Figure 20) and 6 August (Figure 21) probably reflects, in part, the distribution of breeding areas. The major concentration recorded on the north coast of Somerset Island on 2 August, however, probably comprised birds from the Prince Leopold Island colony. On the same day many (200+) were present in leads close to the fast ice edge in Wellington Channel, just off-transect. It seems unlikely that any of these were from Prince Leopold Island since none were observed on intervening off-shore transects. The distribution of Black Guillemot sightings is summarised in Figure 18.

The difference between the number of Black Guillemots recorded on the first two surveys and those recorded on 29 August (Table 12) suggests that a significant proportion of the population had already left the survey area by that date. Observations of 27 nests on Prince Leopold Island suggested that most chicks had not fledged until after 25 August (CWS, in prep.) and the post-breeding emigration appears, therefore, to be just as rapid as that of the Thick-billed Murre. A small proportion (<2%) of birds seen on 29 August were in immature plumage, but by 11 September the species had practically vanished from the survey area.

In June 1975 most concentrations of guillemots were close to known breeding areas, although large numbers north of Elwin Bay on the coast of Somerset Island on 18 June may have included birds from the Prince Leopold Island population (Alliston *et al.* 1976). In 1974 large numbers were present in June along the edge of fast ice at the south end of Wellington Channel and this aggregation may have included birds nesting over quite a wide area, because numbers known to nest on adjacent coasts are insufficient to account for the concentration (Davis *et al.* 1974). In 1975 large numbers were present at the same ice-edge in July, as well as at the ice-edge south of Griffith Island. A concentration recorded in August 1975 on the east coast of Somerset Island, north of Elwin Bay, may have come from Prince Leopold Island, because relatively little evidence of nesting along this coast was seen in 1976, when no large numbers were recorded there.

4.5.2 Estimates of total numbers of birds

Estimates of the numbers of Black Guillemots present in the survey area are shown in Table 13, and these suggest that in early August at least 10000 to 12000 birds were present. Many birds counted in flight on coastal transects, however, had probably been disturbed from nearby cliffs by the survey aircraft and there may therefore be a considerable error in these estimates. During the chick-rearing period both parent guillemots forage simultaneously, leaving the chick alone and the number of birds present at sea may represent a substantial proportion of the entire population (CWS, in prep.). Comparison of the estimates with the size of the breeding population within the survey area is not possible because of uncertainty regarding the numbers nesting on Prince Leopold Island and elsewhere too.

4.6 Interspecific Comparisons

Comparisons of the first two surveys, carried out while all species were feeding chicks, are made in Figure 22. Fulmars were the most widespread species within the survey area, being recorded in 74% of all two-minute periods. If only observations of birds on the water are considered, which presumably indicate feeding, then murres and fulmars occurred over similar areas, although murres were more concentrated in the vicinity of Prince Leopold Island.

A comparison of the proportion of all records that occurred on coastal transects (Table 14) shows the Black Guillemot to be the most coastal species and the fulmar the least. Considering only birds seen on the water, the Thick-billed Murre is the least coastal species, with fulmars and kittiwakes being intermediate and similar in distribution.

Pearson contingency coefficients were calculated for the observed frequencies with which each combination of two species was observed on the water within the same two-minute interval and results are given in Table 15. Kittiwakes on 6 August and murres on 29 August were omitted because of the small number of sightings. Strongest degrees of association were found between kittiwakes and fulmars. This might be anticipated because these species exhibit similar feeding techniques and observations on Prince Leopold Island showed that there is a broad overlap in the types of food fed to their chicks (CWS, in prep.).

The dispersion of all four species was analysed by calculating the variance/mean ratios for the numbers of birds recorded on the water in each two-minute period. This ratio increases with the degree of clumping of the distribution (Southwood 1966). Ratios are given in Table 16. Surveys for which a species was recorded in less than 10 periods are omitted. All species were found to be very significantly clumped; the degree of association was greatest for fulmars and kittiwakes, less for murres and smallest for Black Guillemots. Fulmars varied considerably, being more clumped in surveys during early August than in later surveys (29 August, 11 and 12 September). The degree of clumping exhibited by kittiwakes also decreased in September. This might be expected since after the young become independent there is less reason for birds to concentrate around their breeding colonies.

5. DISCUSSION AND CONCLUSIONS

5.1 Distribution and Foraging Patterns

The Barrow Strait - Lancaster Sound area constitutes one of the most important marine water bodies in Canada from the point of view of breeding seabirds. The western end of these waters is currently threatened with disturbance in the form of the natural gas pipeline proposed by Polar Gas Ltd. A primary objective of this study was to assess the populations potentially endangered by such disturbance, to estimate the period over which birds are likely to be most at risk, and to pinpoint critical species and areas.

The usefulness of aerial surveys for assessing the distribution of birds at sea has been discussed by Davis *et al.* (1974), Searing *et al.* (1975) and Johnson *et al.* (1976). Because open water allows unrestricted vision and because most seabirds are moderately large and often conspicuously patterned, this habitat probably offers optimum conditions for applying aerial survey techniques. In comparison with surveys from ships, aircraft observations cover much larger areas over a shorter time period, allow transects to be made in shallow waters close inshore, and do not attract the seabirds which often confuse shipboard observations. Specific identification is more difficult from an aircraft than from a ship, but in the arctic, where species diversity is low, this is a minor problem. The general correspondence between the known size of breeding populations in the Barrow Strait area, and the estimates of total numbers based on the 1976 survey samples, suggest that, with reservations, the method can be very effective in assessing the distribution and approximate abundance of seabirds away from their breeding sites.

The distribution of all species in the Barrow Strait area was highly non-random and there was a significant tendency for all species to occur at higher density in coastal than off-shore waters. Along coasts, distributions were also clumped, major concentrations often occurring in bays or waters where there was land-fast ice or where streams flowed into the sea. Studies of food brought to the chicks of fulmars, kittiwakes and murres at Prince Leopold Island show that the Arctic Cod forms a major component in the diet of all three species (CWS, in prep.). According to Andriyashev (1954) these fish are adapted to life underneath sea-ice, feeding on organisms attached to the under-surface of ice-floes. During the summer, they move into shallow waters of low salinity in the mouths of rivers. Concentrations of Arctic Cod may account for the numbers of birds associated with ice-edges and the mouths of fresh-water streams.

Foraging ranges determined for Thick-billed Murres during the chick-rearing period in 1976 correspond quite well with those observed elsewhere. Kolthoff (1903) found murres carrying fish landwards up to 200 km from their colonies at Spitsbergen and Swartz (1966) found the main feeding area of murres from the Cape Thompson colony in Alaska to extend at least 60 km from the breeding site. R.G.B. Brown (pers. comm.) found large numbers feeding more than 80 km from the huge colony at Digges Island, Hudson Bay, and moderate numbers as far as 160 km away. Tuck (1961) considered that most murres from the Akpatok Island colonies foraged within 16 km of the island, but his off-shore observations were rather limited. The foraging range of 112 km determined as the maximum for the Prince Leopold Island colony in 1976 appears quite normal.

The surveys by Alliston *et al.* (1976) in 1975 indicated that during the incubation period murres may forage much further from the colony, up to 200 km in the case of birds visiting the edge of fast ice off Griffith Island. The Wellington Channel ice-edge was probably an important feeding area in both 1974 and 1975 during the incubation period and in 1974, when ice was cleared from Barrow Strait by early June, this area was also important during the pre-laying period.

Foraging ranges of kittiwakes are less well-known than those of murres. Swartz (1966) found kittiwakes well dispersed off-shore up to 130 km from the nearest colony, but some of these may have been non-breeders. Pearson (1968) considered, on the basis of the duration of foraging periods, that kittiwakes breeding on the Farne Islands, England, probably fed within 56 km of the colony. Distributions observed on the 1976 surveys suggested that most birds fed within 48 km of the Prince Leopold Island colony during the chick-rearing period. Mean intervals between feeding visits to chicks on Prince Leopold Island in 1976 ranged from 3-18 hours, which increased with the age of the chicks (CWS, in prep.), and it is therefore possible that foraging distance increases as the season progresses.

Fulmars spend much longer periods away from the colony than the other species during both incubation and chick-rearing periods (Nettleship & Taylor 1976; CWS, in prep.) and they clearly forage over much greater distances. All parts of the survey area, as well as places such as Creswell Bay outside it, are probably within range of birds from all three colonies. It is possible that fulmars from the large colony at Baillarge Bay, northern Baffin Island, could also forage within the survey area. Whether the areas used by birds from different colonies are distinct or overlapping could not be determined, but some overlap seems inevitable since fulmars were seen almost everywhere.

Black Guillemots, essentially a coastal species, probably do not normally forage far from their breeding sites during the nesting season. The large colony on Prince Leopold Island may be an exception in this respect, however, because large numbers were rarely observed feeding close to the island. It seems likely that birds must forage as far as the north coast of Somerset Island and observations on 2 August suggested that they may range up to Garnier Bay, 55 km away. Birds seen at the ice-edge in Wellington Channel on the same date probably come from colonies on Beechey Island and adjacent parts of the coast of Devon Island, up to 40 km from where they were feeding.

The distribution of seabirds in the Barrow Strait area during the first half of the breeding season is probably determined largely by the distribution of ice. In most years the fast ice in Barrow Strait persists until late June (Lindsay 1975). In 1974, open water was present as far west as Griffith Island at the beginning of June and Davis *et al.* (1974) found a major concentration of murres at the edge of fast ice across the mouth of Wellington Channel and large numbers of kittiwakes on the south coasts of Cornwallis and Devon Islands. These concentrations cannot occur until July in most years because the breakup of ice in Barrow Strait usually begins later. The ice-edge itself appears to be the most important feeding area for fulmars, murres and guillemots during the period when fast ice is present (Alliston *et al.* 1976). Because the position of the ice-edge is likely to be unpredictable, the position of the most crucial feeding area during the period prior to the hatching of chicks in late July probably alters substantially from year to year.

Later in the season, species differ in their behaviour, especially during the post-fledging period. While murres and guillemots leave the survey area soon after their chicks fledge, kittiwakes remain until at least mid-September, dispersing over the entire survey area. The timing of departure for both kittiwakes and fulmars from the survey area is not known.

Davis *et al.* (1974) recorded a sudden influx of kittiwakes at Creswell Bay from 24 August 1974 onwards and suggested that this constituted a post-breeding dispersal. If so, the birds concerned were probably non-breeders or failed breeders because only 10% of young kittiwakes had fledged on Prince Leopold Island by that date in 1975 and 1976 (CWS, in prep.) and even after fledging most continue to be fed in the vicinity of the nest for several days. Numbers of adult kittiwakes present on the cliffs at Prince Leopold Island fell steadily from the middle of August suggesting a progressive departure of birds not still involved in breeding.

5.2 Discussion of Estimates of Total Numbers of Birds within the Survey Area.

The estimates given in Tables 6, 8, 11, and 13 may be used to validate the aerial survey method by comparing the estimates with predictions based on the size of breeding populations within the survey area, as well as to assess the proportion of birds remaining within the survey area after they have dispersed from their breeding sites. Estimates appear to be most consistent for fulmars, the most common and widespread species, and come fairly close to those expected on the basis of the known breeding population. The estimates for guillemots, the least clumped species in their pattern of dispersal, also appear relatively consistent. For kittiwakes, however, areas sampled by the surveys in August were probably not sufficient to provide accurate estimates because of the highly aggregated dispersal pattern of this species at sea. The degree of aggregation was less after fledging of the young and estimates in September may have been more accurate. The underestimate for murres is more difficult to explain, but seems to be related to their relative inconspicuousness (body size and colour) and diving behaviour when sitting on the water.

Apart from the unknown fraction of birds within the transect area not recorded by either observer, the main sources of error in the estimation of densities and the calculation of overall population estimates appear to be:

(1) the number of birds diving or moving out of the transect area before being counted;

(2) variations in estimating the width of the transect; and

(3) the extent of the coastal zone and variations in the distance flown from the shore on coastal transects.

The first error is reduced by the correction made for the left-side observer. The second is hard to assess and seems likely to diminish only with repeated practice over measured markers on the ground, or better still placed out at sea.

The effect of proximity to the coast on the distribution of birds was investigated in greater detail by Johnson *et al.* (1976). Coastal surveys in eastern Lancaster Sound were flown at two distances from the shore: 200 m and 1200 m. Comparisons of the numbers recorded in the near-shore and off-shore halves of each of these transects showed that for most species densities plotted against distance from the shore produced a concave hyperbolic curve. From this evidence it seems likely that densities inshore of the coastal transects on the present surveys would have been considerably higher than those recorded for the transects themselves and that the actual densities observed represent averages of a zone extending more than twice the distance of the transects from the shore. Without knowing the exact shape of the relationship between density and distance from shore, which presumably varies with species, the arbitrary figure of 4 km was chosen.

5.3 General Conclusions

The distinct differences in patterns of distribution at sea, habitat usage and foraging of the major seabird species show the intricacy and complexity of the relationships between this avian community and components of its marine environment. Observations of water usage by birds during the chick-rearing period indicate that the requirements of individual species vary, with some species relatively common and widespread throughout the survey area (e.g., fulmar) and others highly aggregated and restricted in distribution (e.g., kittiwake). There also is strong evidence that requirements critical to populations such as preferred feeding areas change not only from year to year but also within a single season and over short periods of time. This means that any general conclusions derived from this study must be taken for what they are, no more than an indication of areas important to populations of seabirds in the Barrow Strait area during the chick-rearing period in 1976.

Given these limitations, areas of major importance to seabirds within the region covered by the 1976 surveys can be identified and summarized as follows:

(1) Prince Leopold Island, surrounding waters and adjacent coasts of Somerset Island.

Important for all species from April to early October.

(2) North coast of Somerset Island between Cunningham Inlet and Cape Admiral McClintock.

Important for all species, particularly murres and guillemots, from the time of ice breakup to at least the end of September. The area of coast between Garnier Bay and Cape Admiral McClintock seems especially critical.

(3) Southwest and south coasts of Devon Island from Bowden Point to Hobhouse Inlet.

Important for fulmars, murres and guillemots from June to October. Also important for kittiwakes in the pre-laying period (June) and post-breeding period (August). Within this length of coastline the two main indentations, Radstock and Maxwell Bays, appear to be of particular importance for all species.

(4) Edges of land-fast ice.

The edge of land-fast ice appears to be of great importance to fulmars, murres and guillemots. Although the position of ice-edges varies enormously, there appear to be certain areas in which a stable ice-edge frequently persists for long periods. The most important of these are: the line from Prince Leopold Island to Maxwell Bay, where the ice-edge often remains during June; the south end of Wellington Channel, where the edge often persists for most of July; and the Allen Bay-Griffith Island-Somerset Island area, where the edge may persist for part of July and in some years (e.g., 1974) for most of June also (Lindsay 1975).

Although the areas mentioned above are outstandingly important for the concentrations of birds observed, it must be underlined that the lower densities of birds in off-shore waters or away from ice-edges may constitute a larger fraction of the whole population because the area involved is much greater. For both Northern Fulmars and Thick-billed Murres the total numbers of birds estimated in off-shore waters on all transects was greater than the totals estimated in coastal waters. Hence, although the main concentrations occurred in coastal waters, off-shore waters can be considered equally important to the populations of these species. Only a more extended survey, covering a larger percentage of the total survey area and sampling all parts of the breeding season, will permit a more detailed assessment of the relative importance of the lower density areas in off-shore waters.

The generalized distribution of seabirds along the coastline in the Barrow Strait area indicates a concentrating effect of estuaries during the summer. The largest concentrations of birds were consistently observed near the mouths of large inlets and bays where there was land-fast ice or where streams and rivers flowed into the sea, particularly Garnier Bay and Cunningham Inlet along north Somerset Island and Radstock and Maxwell Bays on the southwest coast of Devon Island. It is likely that large numbers of Arctic Cod occur in these habitats since they enter streams with warm water of low salinity during the summer (Andriyashev 1954), and this, therefore, may be a primary cause in concentrating seabirds at these locations. Arctic Cod comprises a major portion of the summer diet of most seabirds breeding in the area, and is particularly important during the chick-rearing period (CWS, in prep., Bradstreet 1976). Since it appears that in the survey area major feeding areas occur only in or near a small number of estuaries, it is essential to determine which of these bays or estuaries are utilized by birds regularly from year to year and the vulnerability that each has to potential industrial activity. Disturbances resulting in geographic shifts of such fish concentrations could have disastrous consequences for the seabird population of the area.

These critical feeding areas are vulnerable not only to major disturbances such as the development of ports or terminals and the associated pollution, but also to less conspicuous environmental changes. For example, any alteration of the water flow pattern off lowlands into Cunningham Inlet, or disturbances related to the construction of a pipeline and its maintenance and operation, and even operating noise made by compressors either in or out of the water, could alter the distribution and availability of Arctic Cod or alternatively reduce the hunting efficiency of the birds themselves. Similarly, changes in the patterns of ice breakup caused by human activities, either in a local area or over a large geographic region, might cause shifts in feeding areas due to concentrations of pack-ice where they would normally not occur, possibly making important concentrations of fish inaccessible.

Disturbance at a critical site and time of season, especially during the period of greatest food demand by the population (i.e., at times of peak hatching and chick growth at the breeding site), could result in a food failure with a correspondingly high mortality of young and overall reduction in productivity. Since sites with high feeding concentrations of birds in 1976 were limited, it seems possible that a large proportion of the Barrow Strait seabird population could be dependent on a small number of rich but very localized areas for food. Thus, careful consideration must be given to industrial developments in critical areas to ensure that proposed activities are compatible with requirements of seabirds and other renewable resources.

Given the distribution and habitat usage characteristics of the Barrow Strait seabird population outlined above, it seems clear that in an environment as unpredictable and changeable as arctic marine waters a single season of work is not sufficient to assess the real and potential variability of any of the parameters measured. Two, or perhaps three, further seasons of similar observations are necessary to provide information on the variation between years of accurately measurable features of pelagic distribution and use of water habitats by birds. The 1976 surveys demonstrate that changes in major feeding areas can take place over very short periods of time and appear to reflect changes in food abundance or accessibility, especially due to changes in concentrations and distribution of pack-ice. How flexible birds are in response to a rapidly changing food supply in space and time requires further investigation. It is possible that for the seabirds in Barrow Strait and Lancaster Sound, colonial nesting may be partly an adaptation to the need for such switches of feeding areas, through the transfer of information on the whereabouts of food, as proposed by Ward & Zahavi (1973). In this context, large colonies may not be merely symptoms of a successful population, but their size may in part determine the success of their numbers. If this is true, then any change, natural or man-made, which causes a large reduction in the number of birds occupying the colony may also adversely affect the survival of the remainder.

5.4 Specific Recommendations

On the basis of observations made through the survey area in 1976, the most important aspect of the conservation and management of the seabird fauna and its habitats is the protection of critical feeding areas and breeding sites. Since the major breeding colonies of birds in Barrow Strait and western Lancaster Sound occur at Prince Leopold Island and on the southwest coast of Devon Island at Cape Liddon and Hobhouse Inlet, it is essential to preserve and prevent any disturbance at these locations (for details of sites see Nettleship & Smith 1975, Nettleship 1977*b*). The protection of key feeding areas, however, is more difficult.

The most striking food-habitat relationship of seabirds in the Barrow Strait area was the concentrating of birds near the mouths of major estuaries, where more abundant food resources, particularly Arctic Cod, are likely to be found. Thus, food availability, which seems to be very limited during the chick-rearing period, is apparently a major determinant in the way that seabird populations selectively use habitat types. Such feeding areas are vulnerable to industrial activities and developments at such localities and should be safeguarded from irreparable damage.

The location most obviously at risk by the proposed route for a gas pipeline by Polar Gas Ltd. is Cunningham Inlet, Somerset Island. Construction and operation, and associated pollution and disturbance, would undoubtedly affect seabird populations and their fish foods, as would any man-made alteration to water characteristics in the Inlet (e.g., rate of water run-off from lowlands [Neu 1970, pers. comm.]).

Much more needs to be known about the use of water habitat by the Barrow Strait birds and their nutritional requirements throughout the breeding season if effective management is to be achieved. It will be essential to determine how important certain locations are to species for successful reproduction and the availability and distribution of primary summer foods. All this indicates that further studies are required and that all industrial development in the region must be carefully reviewed and implemented to prevent catastrophic deterioration of this uniquely rich arctic seabird area.

To summarize, there is an immediate management need for:

(1) further study of the effects of estuaries and ice-edges on the distribution and habitat usage of seabirds, as well as the causal link to the concentration and availability of Arctic Cod. Since the food resources in or near estuaries appear to attract and concentrate seabirds, the future pollution or alteration of rivers and estuaries could affect the most productive and critical areas for seabird feeding. Moreover, these same areas and their food resources are presumably also important, directly or indirectly, to toothed whales, seals and bears.

(2) further study of the nutritional requirements and food preferences of seabirds in the area and also a measure of the food resources that are being utilized by these seabird species.

A more general review of environmental problems related to seabird populations in the eastern Canadian arctic and the nature of the management task has been presented in Nettleship (1977*a*).

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TABLE 1. Location and co-ordinates for start and end points of transects surveyed in the Barrow Strait area in 1976. (Letter designations are marked on Figure 1.)

Location	Transect Co-ordinates	
	Latitude	Longitude
A. Prince Leopold Island	74°00'N.	90°00'W.
B. Cape Admiral McClintock	74°00'N.	91°00'W.
C. Garnier Bay	74°01'N.	92°00'W.
D. Cape Spencer	74°45'N.	92°00'W.
E. Bowden Point	75°02'N.	92°15'W.
F. Just south of Read Bay	75°02'N.	93°28'W.
G. Cape Hotham	74°12'N.	93°28'W.
H. Cape Rennell	74°11'N.	93°28'W.
I. Limestone Island	74°02'N.	95°16'W.
J. Allen Bay	74°45'N.	95°16'W.
K. Coast of Cornwallis below Prospect Hills	74°37'N.	94°25'W.
L. Coast of Somerset, east of Cape Anne	74°08'N.	94°25'W.
M. Radstock Bay	74°44'N.	91°06'W.
N. Cape William Herschel	74°35'N.	89°12'W.
O. Cape Hurd	74°31'N.	90°00'W.
P. Elwin Bay	73°30'N.	90°53'W.
Q. Coast of Brodeur north of Jackson Inlet	73°30'N.	88°30'W.
R. Cape York	73°50'N.	87°00'W.
S. Hobhouse Inlet	74°27'N.	87°00'W.
T. Fellfoot Point	74°30'N.	88°35'W.
U. Batty Bay	73°17'N.	91°13'W.

TABLE 2. Distances flown, numbers of two-minute observation periods, and duration of surveys flown in the Barrow Strait area during August and September 1976. (For details of individual transects, see Appendix 1.)

Survey Detail	Survey Date					Totals
	2 Aug	6 Aug	29 Aug	11 Sep	12 Sept	
Distance (km):						
Off-shore	721.5	369.7	782.6	646.4	796.3	3316.5
Coastal	601.5	521.4	609.8	687.8	718.2	3138.7
Totals	1323.0	891.1	1392.4	1334.2	1514.5	6455.2
Numbers of 2-minute periods:						
Off-shore	115	57	133	97	124	512
Coastal	84	80	94	99	106	477
Totals	199	137	227	196	230	989
Time (minutes):	393.5	273.0	448.0	395.5	447.5	1957.5
Mean speed (km/hour):	201.7	195.8	186.5	202.4	203.1	197.9
Area sampled (km^2):	529.2	356.4	557.0	533.7	605.6	2582.1

TABLE 3. Proportion of marine waters sampled by aerial transects on 2 August 1976 in relation to distance from Prince Leopold Island.*

	Distance from Prince Leopold Island (km)						
	< 16	16-32	33-48	49-64	65-80	81-96	> 96
Total area (km^2)	749	2100	3359	4273	4794	3717	4838
Area sampled	23	31	67	98	73	62	176
% area sampled	3.1	1.5	2.0	2.3	1.5	1.7	3.6

*Transect set performed on 2 August is representative of all surveys (i.e., variation in areas covered between surveys was low).

TABLE 4. Total numbers of all species of birds recorded in five aerial surveys of the Barrow Strait area. (Total distance flown, 6455 km, total area sampled, 2590 km^2.)

Species		Total Numbers Recorded
Northern Fulmar	*Fulmarus glacialis*	10243
Black-legged Kittiwake	*Rissa tridactyla*	5667
Thick-billed Murre	*Uria lomvia*	1594
Black Guillemot	*Cepphus grylle*	720
Eider	*Somateria* spp.	139
Arctic Tern	*Sterna paradisea*	113
Glaucous Gull	*Larus hyperboreus*	80
Jaegers	*Stercorarius* spp.	29
Ivory Gull	*Pagophila eburnea*	13
Brant	*Branta bernicla*	11
Dovekie	*Plautus alle*	4
Sabine's Gull	*Xema sabini*	2
Thayer's Gull	*Larus thayeri*	1
Total		18616

TABLE 5. Numbers and densities of Northern Fulmars on coastal and off-shore transects, and the proportion of two-minute periods in which they were recorded on each of five surveys in the Barrow Strait area during 1976.

Survey Detail	Survey Date					Totals
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept	
Coastal:						
Total birds	2489	1317	1558	1440	1712	8516
Density (birds/km^2)	10.34	6.30	6.32	5.39	5.97	
% birds on water	46%	57%	63%	72%	60%	58%
Numbers of 2-minute periods with fulmars	70(83%)	61(76%)	49(52%)	74(74%)	58(55%)	312(65%)
Off-shore:						
Total birds	261	229	658	261	318	1727
Density (birds/km^2)	0.90	1.54	2.01	1.00	0.95	
% birds on water	20%	59%	70%	55%	52%	55%
Numbers of 2-minute periods with fulmars	79(69%)	39(68%)	57(43%)	32(33%)	62(50%)	269(53%)
Grand Total (Coastal + Off-shore)	2750	1546	2216	1701	2030	10243
Total numbers of 2-minute periods:						
On water	39(20%)	52(38%)	57(25%)	38(19%)	59(26%)	245(25%)
All records	149(75%)	100(73%)	106(47%)	106(54%)	120(52%)	581(59%)
Ratio of densities: (Coastal/Off-shore)	11.49	4.09	3.59	5.39	6.28	

Testing the number of two-minute periods in which fulmars were recorded against those in which fulmars were not recorded, there is significant heterogeneity between surveys: $chi^2 = 54.2$, df 4, $P < 0.001$.

TABLE 6. Estimates of total numbers of Northern Fulmars present in the survey area.

Survey Detail	Survey Date				
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept
Coastal zone:					
Area (km^2)	3080	3160	3160	3160	3160
Density (birds/km^2)	10.34	6.30	6.72	5.39	5.97
Estimates	31847	19908	21235	17032	18865
Off-shore zone:					
Area (km^2)	18870	20670	20670	20670	20670
Density (birds/km^2)	0.90	1.54	2.01	1.00	0.95
Estimates	16983	31832	41547	20670	19636
Total estimates:					
Coastal + Off-shore	48830	51740	62782	37702	38501
Corrected estimate*	58840	62347	70190	42151	43044

*Correction factors applied to compensate for birds missed by observer L are derived from Johnson *et al.* (1976): before 10 August, 1.205; after 10 August, 1.118.

TABLE 7. Numbers and densities of Black-legged Kittiwakes on coastal and off-shore transects, and the proportion of two-minute periods in which they were recorded on each of five surveys in the Barrow Strait area during 1976.

Survey Detail	Survey Date					Totals
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept	
Coastal:						
Total birds	2433	96	1407	774	408	5118
Density (birds/km^2)	10.11	0.46	5.77	2.81	1.42	
% birds on water	92%	0%	85%	36%	43%	76%
Numbers of 2-minute periods with kittiwakes	21(25%)	38(47%)	37(39%)	54(54%)	47(44%)	197(41%)
Off-shore:						
Total birds	141	15	95	182	116	549
Density (birds/km^2)	0.49	0.10	0.30	0.70	0.36	
% birds on water	35%	20%	56%	9%	11%	25%
Numbers of 2-minute periods with kittiwakes	19(17%)	11(19%)	31(23%)	32(33%)	37(30%)	130(25%)
Grand Total (Coastal + Off-shore)	2574	111	1502	956	524	5667
Total number numbers of 2-minute periods:						
On water	8(4%)	1(1%)	22(10%)	13(6%)	10(4%)	54(5%)
All records	40(20%)	49(36%)	68(30%)	86(44%)	84(37%)	327(33%)
Ratio of densities: (Coastal/Off-shore)	20.63	4.60	19.23	4.01	3.94	

Testing the proportion of two-minute periods in which kittiwakes were recorded for heterogeneity between surveys: $chi^2 = 25.9$, df 4, $P < 0.001$.

TABLE 8. Estimates of total numbers of Black-legged Kittiwakes present in the survey area.

Survey Detail	Survey Date				
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept
Coastal zone:					
Area (km^2)	2360	2440	3160	3160	3160
Density (birds/km^2)	13.52	0.49	5.77	2.81	1.42
Estimates	31907	1196	18233	8880	4487
Off-shore zone:					
Area (km^2)	17560	17760	20670	20670	20670
Density (birds/km^2)	0.33	0.11	0.30	0.70	0.36
Estimates	5795	1954	6201	14469	7234
Total estimates:					
Coastal + Off-shore	37702	3150	24434	23349	11721
Corrected estimates*	44036	3679	28563	27295	13702

*Correction factors applied to compensate for birds missed by observer L are derived from Johnson *et al.* (1976): before 10 August, 1.168; after 10 August, 1.169.

TABLE 9. Numbers and densities of Thick-billed Murres on coastal and off-shore transects, and the proportion of two-minute periods in which they were recorded on each of five surveys in the Barrow Strait area during 1976.

Survey Detail	Survey Date					Totals
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept	
Coastal:						
Total birds	354	762	19	82	0	1217
Density (birds/km^2)	1.47	3.65	0.08	0.29	-	
% birds on water	53%	66%	16%	100%	-	64%
Numbers of 2-minute periods with murres	38(45%)	63(79%)	4(4%)	4(4%)	0	109
Off-shore:						
Total birds	175	171	27	2	2	377
Density (birds/km^2)	0.61	1.16	0.09	<0.01	< 0.01	
% birds on water	18%	64%	59%	100%	100%	43%
Numbers of 2-minute periods with murres	41(36%)	11(19%)	11(8%)	1(1%)	1(1%)	65
Grand Total (Coastal + Off-shore)	529	933	46	84	2	1594
Total numbers of 2-minute periods:						
On water	31(16%)	63(46%)	9(4%)	3(3%)	1(1%)	107
All records	79(40%)	74(54%)	15(7%)	5(2%)	1(<1%)	172
Ratio of densities: (Coastal/Off-shore)	2.41	3.15	0.89	-	-	

TABLE 10. Numbers of Thick-billed Murres recorded and their densities per two-minute period, in relation to distance from the main (East Cliff) colony on Prince Leopold Island. Figures in brackets give percentages.

	Distance from colony (km)								
	1-16	17-32	33-48	49-64	65-80	81-96	97-112	113-128	> 128
2 August									
Total numbers of 2-minute periods	7	12	25	39	32	21	17	16	30
Numbers of 2-minute periods with murres	7(100)	9(75)	17(72)	23(59)	9(28)	7(33)	2(12)	1(6)	4(13)
Numbers of 2-minute periods with murres on water	3(44)	4(33)	6(24)	7(18)	4(13)	5(24)	0	0	2(7)
Total number of murres	125	25	120	195	29	18	3	1	13
Murres/2-minutes	17.9	2.1	4.8	5.0	0.9	0.9	0.2	0.1	0.3
Murres on water	8	6	44	136	9	7	0	0	8
Murres on water/2-minutes	1.1	0.5	1.8	3.5	0.3	0.3	0	0	0.4
6 August									
Total numbers of 2-minute periods	6	6	6	33	29	14	12	17	14
Numbers of 2-minute periods with murres	6(100)	5(84)	3(50)	22(67)	19(66)	12(86)	5(42)	3(18)	1(7)
Numbers of 2-minute periods with murres on water	6(100)	3(50)	3(50)	21(64)	15(52)	7(50)	5(42)	3(18)	1(7)
Total number of murres	173	11	6	262	269	146	57	5	4
Murres/2-minutes	28.8	1.8	1.0	7.9	9.3	10.4	4.7	0.3	0.29
Murres on water	114	7	4	192	175	80	36	5	1
Murres on water/2-minutes	19.0	1.2	0.7	5.8	6.0	5.7	3.0	0.3	0.1

TABLE 11. Estimates of total numbers of Thick-billed Murres present in the survey area.

Survey Detail	Survey Date				
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept
Coastal zone:					
Area (km^2)	2360	2440	3160	3160	3160
Density (birds/km^2)	1.92	4.26	0.08	0.29	0
Estimates	4531	10394	253	916	0
Off-shore zone:					
Area (km^2)	17560	17760	20670	20670	20670
Density (birds/km^2)	0.72	1.28	0.09	<0.01	< 0.01
Estimates	12643	22733	1860	103	124
Total estimates:					
Coastal + Off-shore	17174	33127	2113	1019	124
Corrected estimates*	21536	41541	2584	1246	152

*Correction factors applied to compensate for birds missed by observer L are derived from Johnson *et al.* (1976): before 10 August, 1.254; after 10 August, 1.223.

TABLE 12. Numbers and densities of Black Guillemots on coastal and off-shore transects, and the proportions of two-minute periods in which they were recorded on each of five surveys in the Barrow Strait area during 1976.

Survey Detail	Survey Date					Totals
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept	
Coastal:						
Total birds	236	278	99	2	2	617
Density (birds/km^2)	0.98	1.33	0.41	<0.01	< 0.01	
% birds on water	37%	42%	44%	100%	100%	41%
Numbers of 2-minute periods with guillemots	31(37%)	38(47%)	12(13%)	2(2%)	2(2%)	85
Off-shore:						
Total birds	36	17	48	0	2	103
Density (birds/km^2)	0.12	0.11	0.15	0	< 0.01	
% birds on water	0%	76%	85%	-	100%	54%
Numbers of 2-minute periods with guillemots	9(8%)	9(16%)	5(4%)	-	2(2%)	25
Grand Total (Coastal + Off-shore)	272	295	147	2	4	720
Total numbers of 2-minute periods:						
On water	16(8%)	34(25%)	10(4%)	2(1%)	4(2%)	64
All records	40(20%)	47(34%)	17(7%)	2(1%)	4(2%)	108
Ratio of densities: (Coastal/Off-shore)	8.17	12.09	2.73	-	(1.0)	

TABLE 13. Estimates of the total numbers of Black Guillemots present in the survey area.

Survey Detail	Survey Date				
	2 Aug	6 Aug	29 Aug	11 Sept	12 Sept
Coastal zone:					
Area (km^2)	3080	3160	3160	3160	3160
Density (birds/km^2)	0.98	1.33	0.41	0.01	$<$ 0.01
Estimates	2526	4203	1232	32	22
Off-shore zone:					
Area (km^2)	18870	20670	20670	20670	20670
Density (birds/km^2)	0.12	0.11	0.15	0	$<$ 0.01
Estimates	5472	2274	2687	0	129
Total estimates:					
Coastal + Off-shore	7998	6477	3919	32	151
Corrected estimates*	12373	10020	6063	50	234

*Correction factor applied to compensate for birds missed by observer L is derived from Johnson *et al.* (1976): for all surveys, 1.547.

TABLE 14. Proportion of two-minute periods in which each species was recorded on coastal transects. (Expected frequencies for chi^2 calculations are based on total number of two-minute periods flown in coastal and off-shore transects. Only August surveys are included.)

Species	Number of 2-minute periods with species present				
	All records	Coastal only	% coastal	chi^2	P
Northern Fulmar:					
Total	355	190	54	2.5	>0.1
On water only	148	93	63	10.8	<0.01
Black-legged Kittiwake:					
Total	157	102	65	15.9	<0.01
On water only	31	21	68	6.0	<0.01
Thick-billed Murre:					
Total	168	105	62	11.5	<0.01
On water only	103	60	58	3.9	*c*0.05
Black Guillemot:					
Total	108	85	79	53.0	<0.01
On water only	64	50	83	26.7	<0.01

TABLE 15. Pearson contingency coefficients for the degree of association between different species pairs.

Species Associations	2 August	6 August	29 August
Fulmar/kittiwake	0.23*	-	0.35*
Fulmar/murre	0.1	0.29*	-
Fulmar/Black Guillemot	0.31*	0.17	0.1
Kittiwake/murre	0.1	-	-
Kittiwake/Black Guillemot	0.23*	-	0.1
Murre/Black Guillemot	0.1	0.23	-

*chi^2 values significant at $P < 0.05$

TABLE 16. Variance/mean ratios for numbers of birds recorded per two-minute period during surveys in the Barrow Strait area in 1976.

Survey Date	Species			
	Northern Fulmar	Black-legged Kittiwake	Thick-billed Murre	Black Guillemot
2 August	277.0	1425.0	47.3	7.5
6 August	238.5	-	22.9	5.1
29 August	87.6	364.2		11.1
11 September	129.6	28.1		
12 September	110.2	29.2		

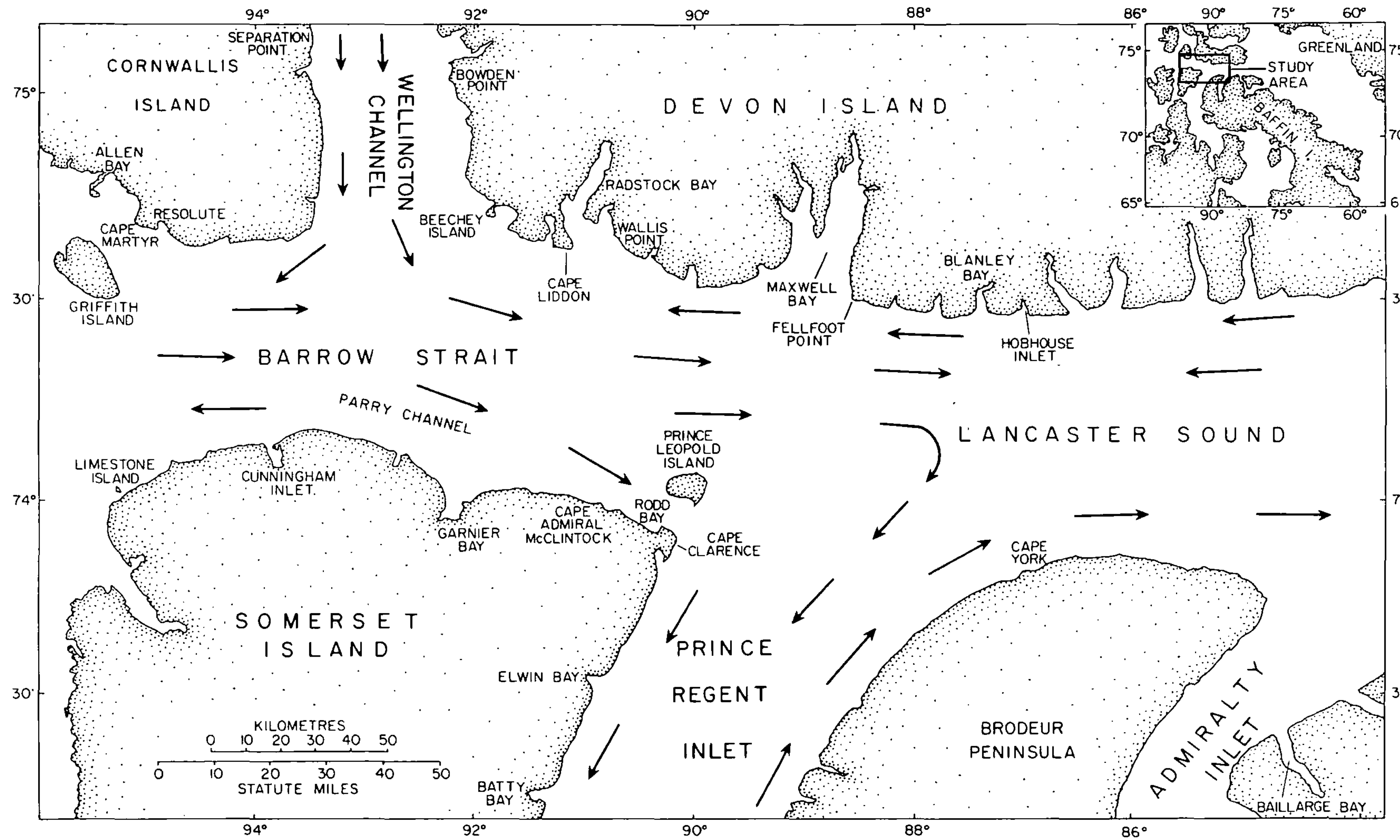

Figure 1. General pattern of surface currents in the Barrow Strait-Lancaster Sound region. (After Collin 1962.)

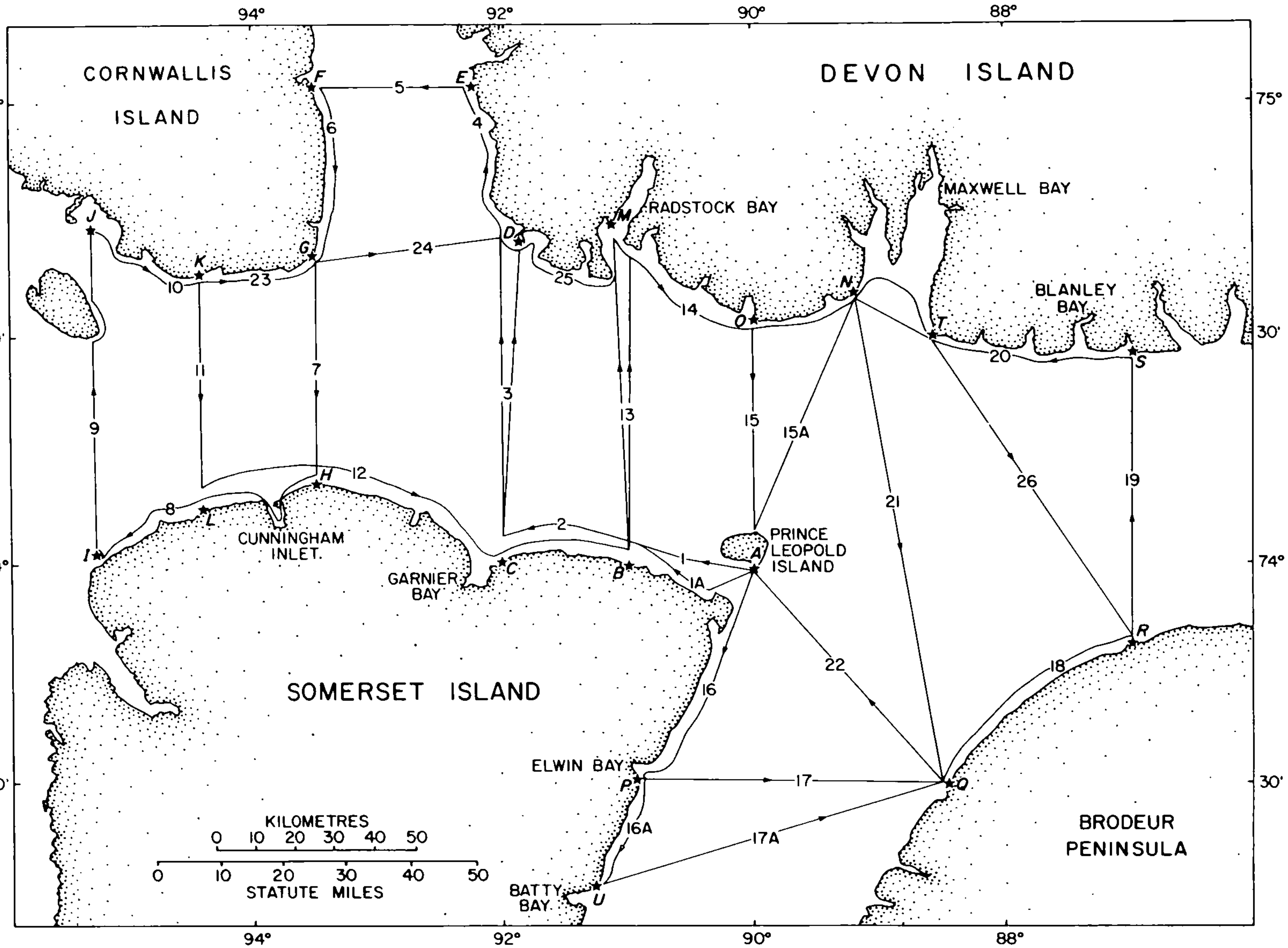

Figure 2. Map of Barrow Strait survey area showing positions of transect lines. Co-ordinates for starred points are given in Table 1.

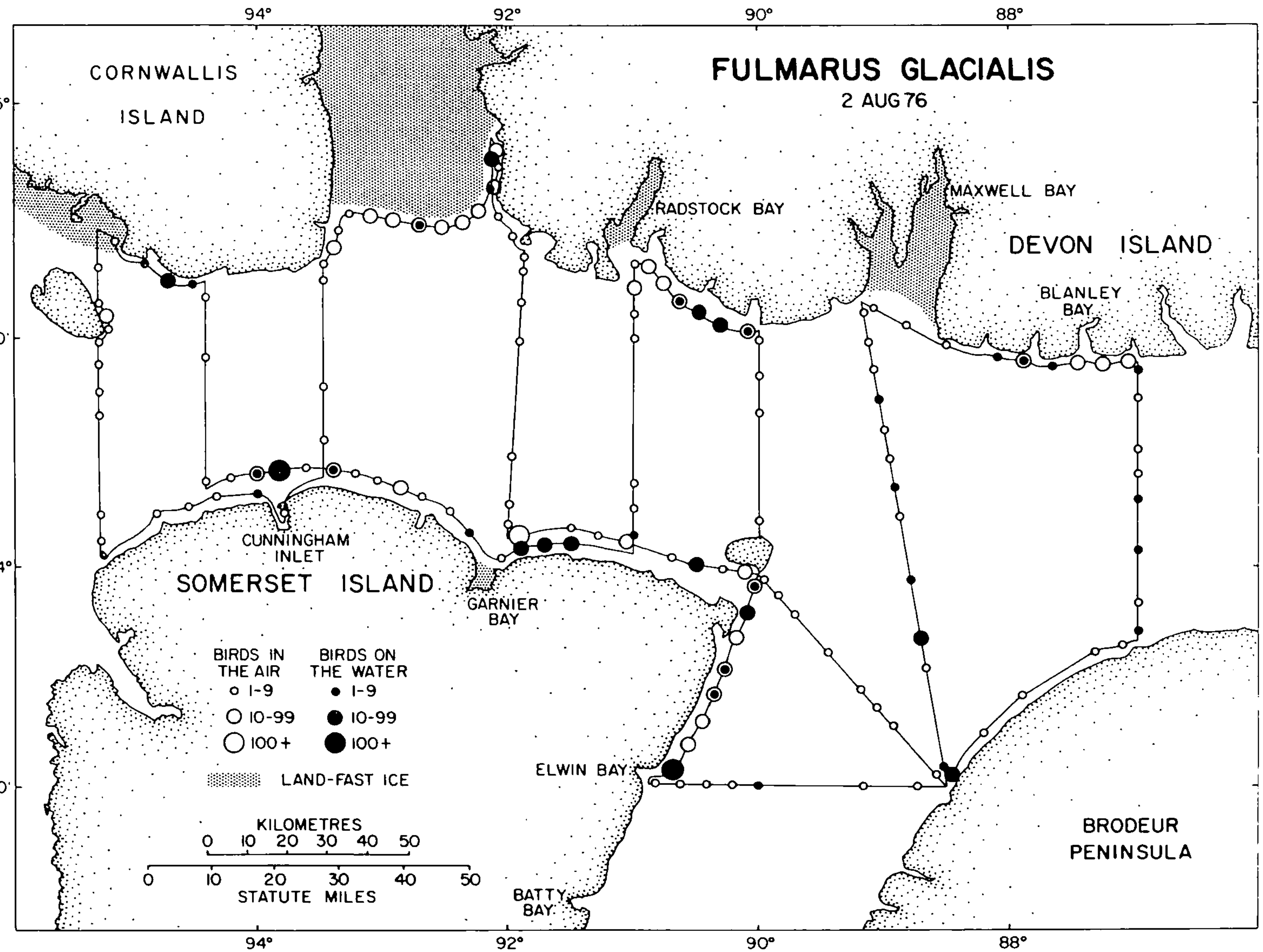

Figure 3. Distribution of Northern Fulmars *Fulmarus glacialis* in the Barrow Strait survey area on 2 August 1976.

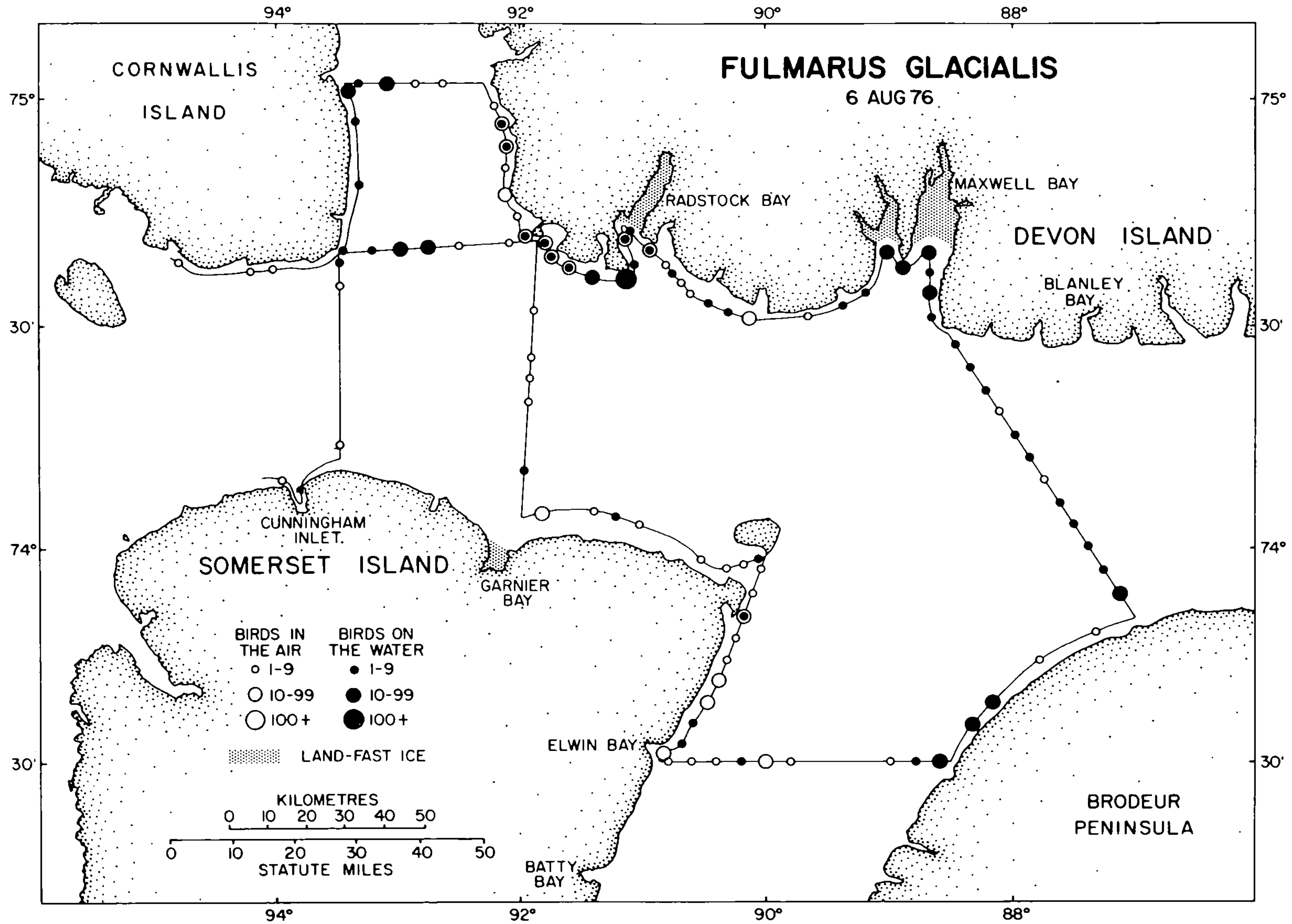

Figure 4. Distribution of Northern Fulmars *Fulmarus glacialis* in the Barrow Strait survey area on 6 August 1976.

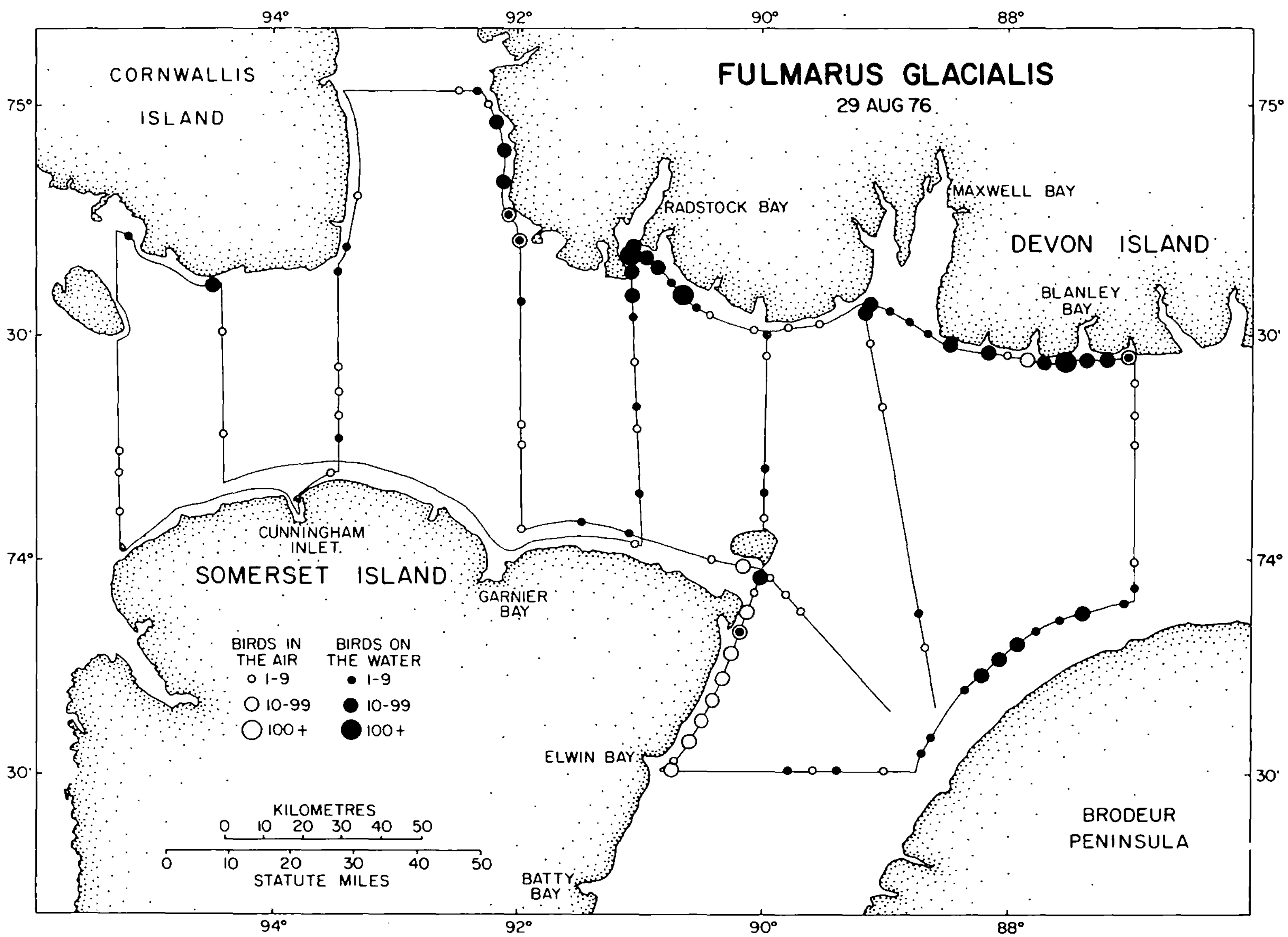

Figure 5. Distribution of Northern Fulmars *Fulmarus glacialis* in the Barrow Strait survey area on 29 August 1976.

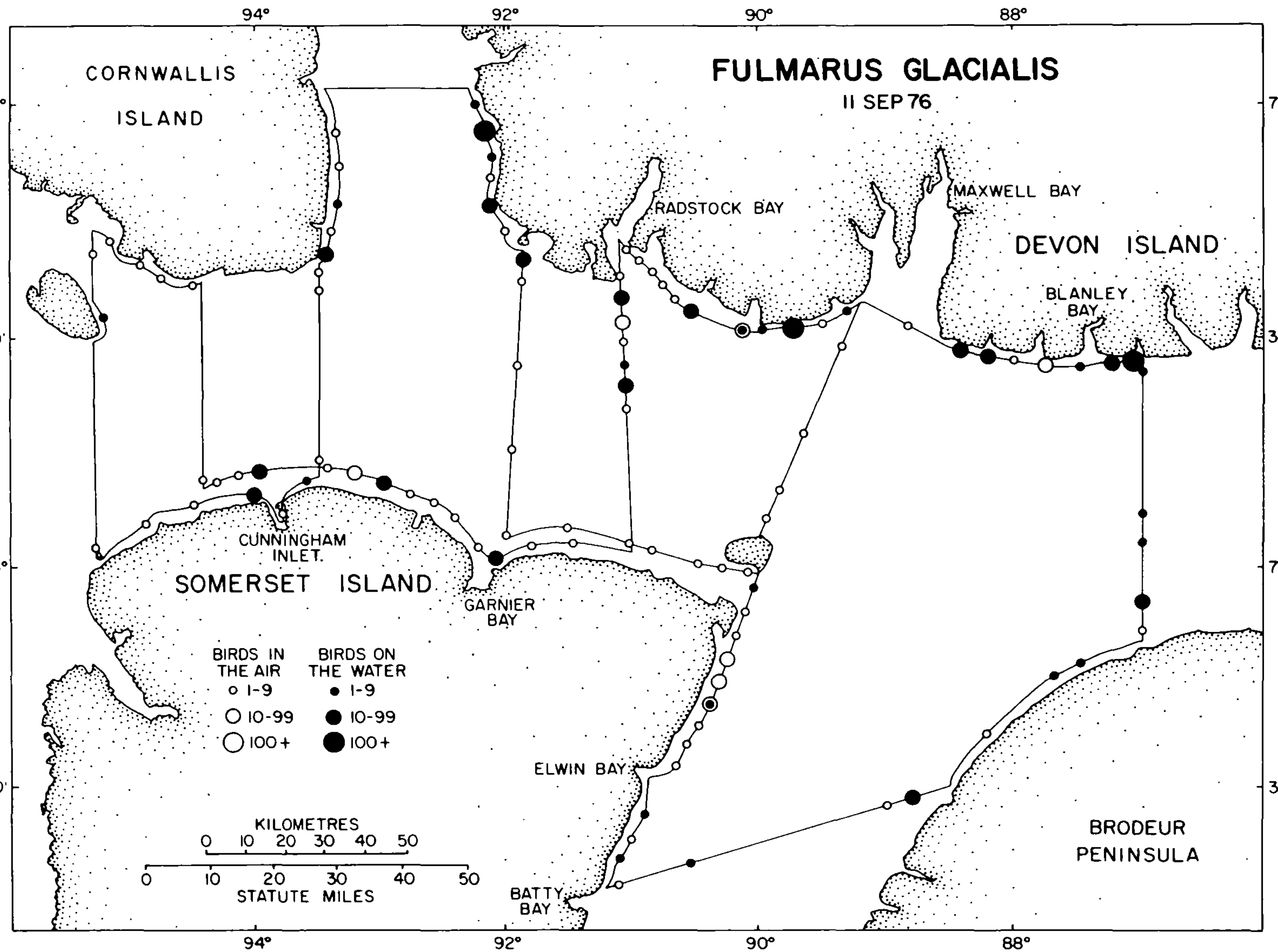

Figure 6. Distribution of Northern Fulmars *Fulmarus glacialis* in the Barrow Strait survey area on 11 September 1976.

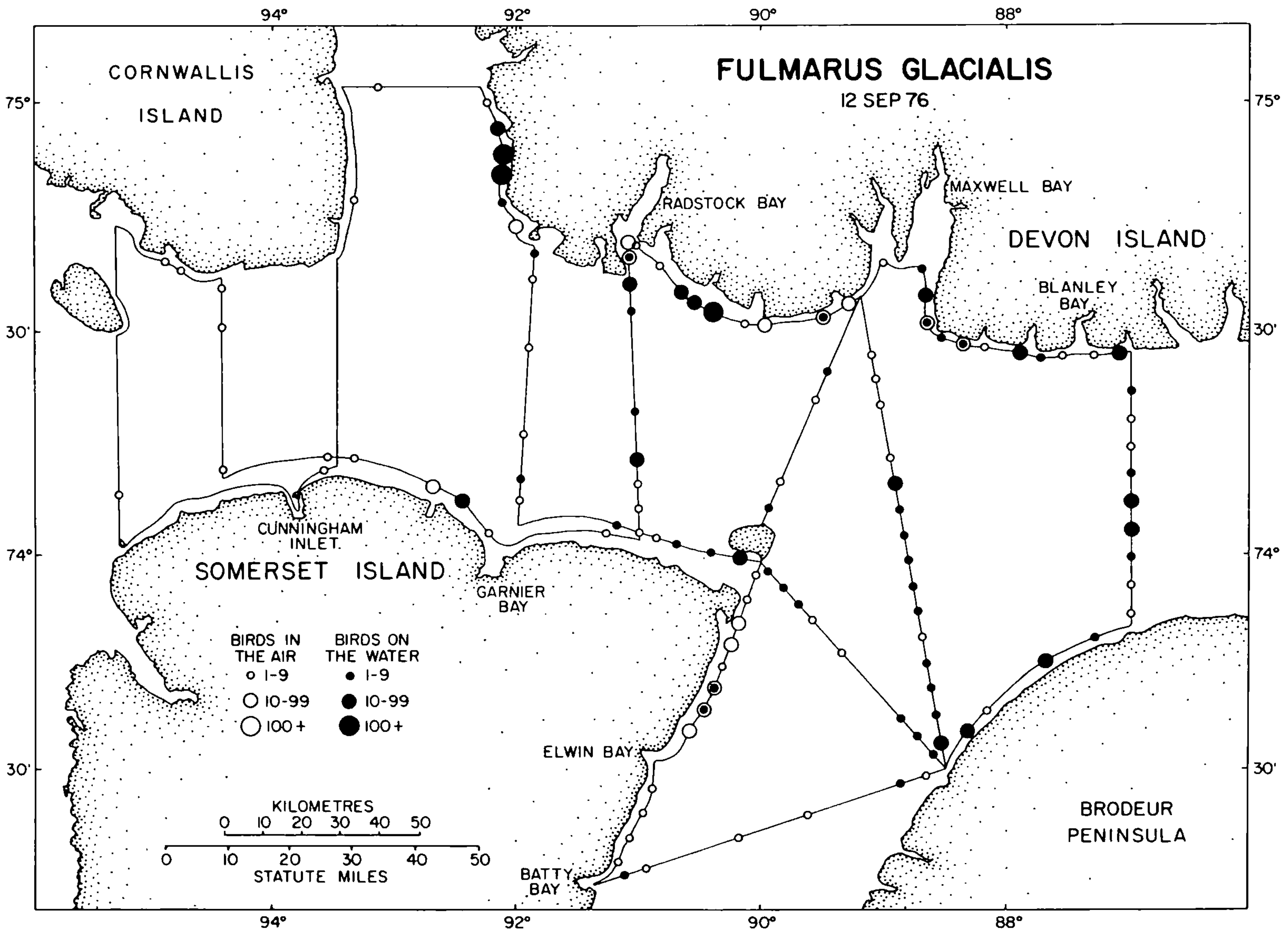

Figure 7. Distribution of Northern Fulmars *Fulmarus glacialis* in the Barrow Strait survey area on 12 September 1976.

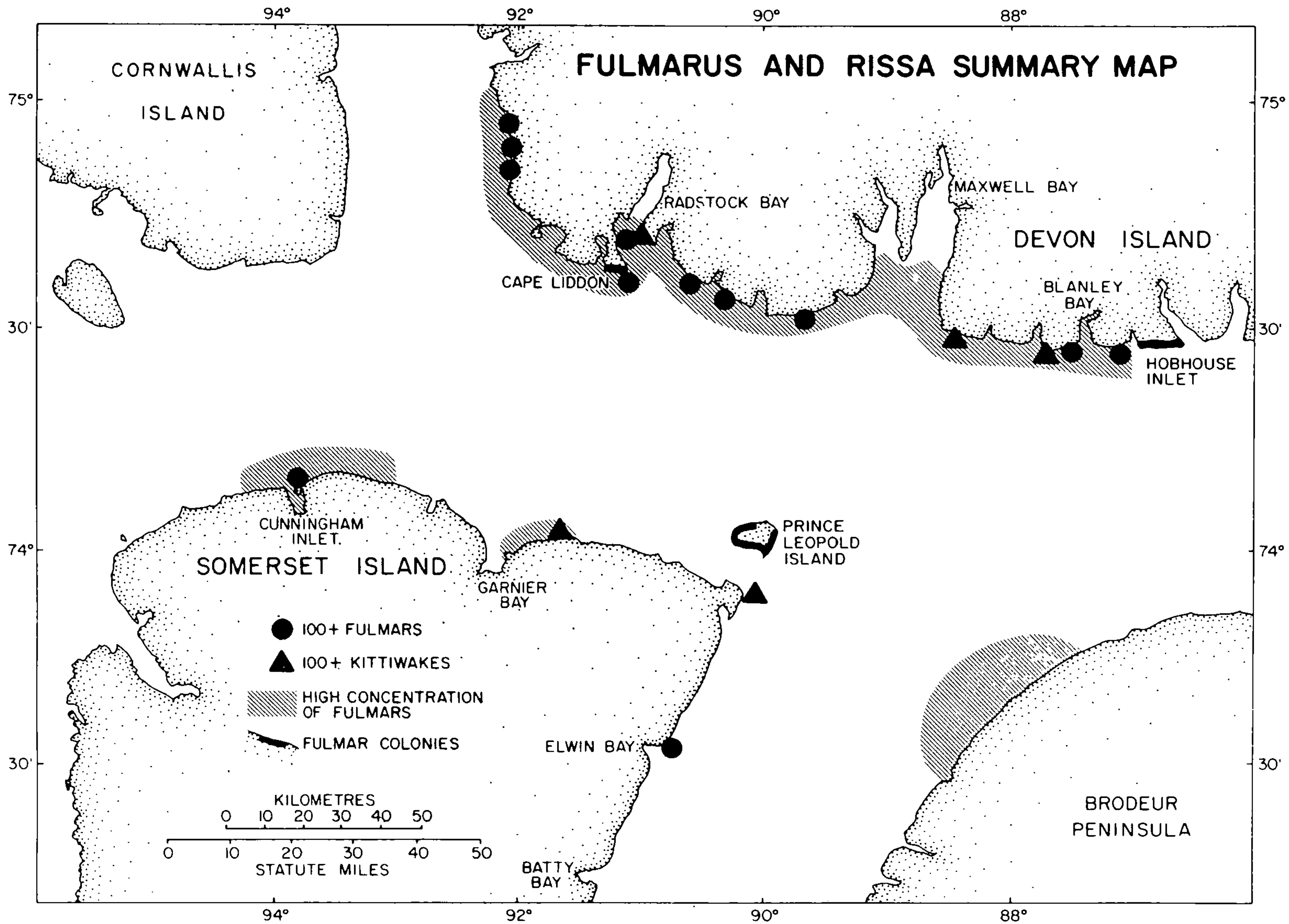

Figure 8. Summary map showing the positions of major concentrations of Northern Fulmars *Fulmarus glacialis* and Black-legged Kittiwakes *Rissa tridactyla* for all surveys in 1976.

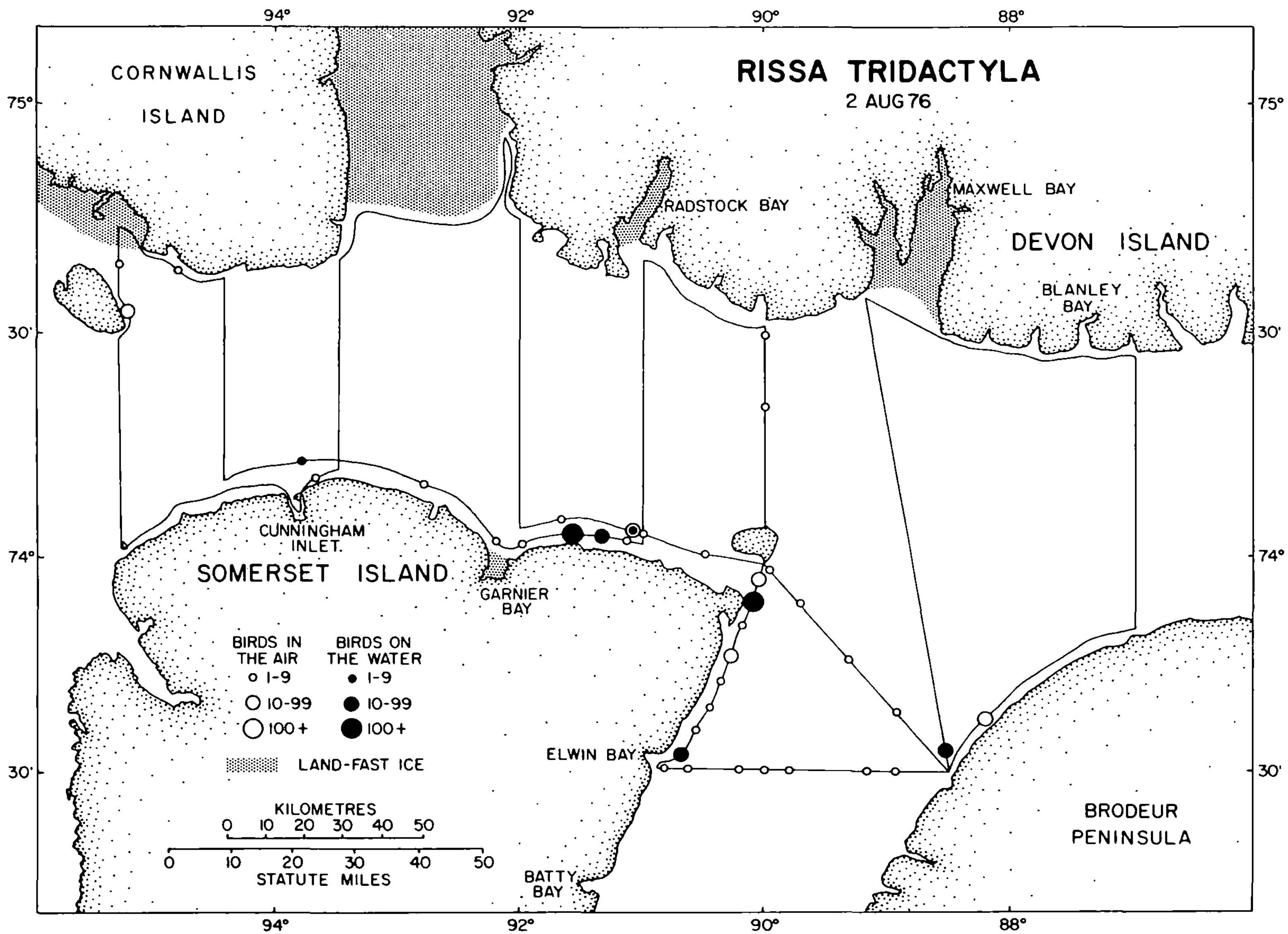

Figure 9. Distribution of Black-legged Kittiwakes *Rissa tridactyla* in the Barrow Strait survey area on 2 August 1976.

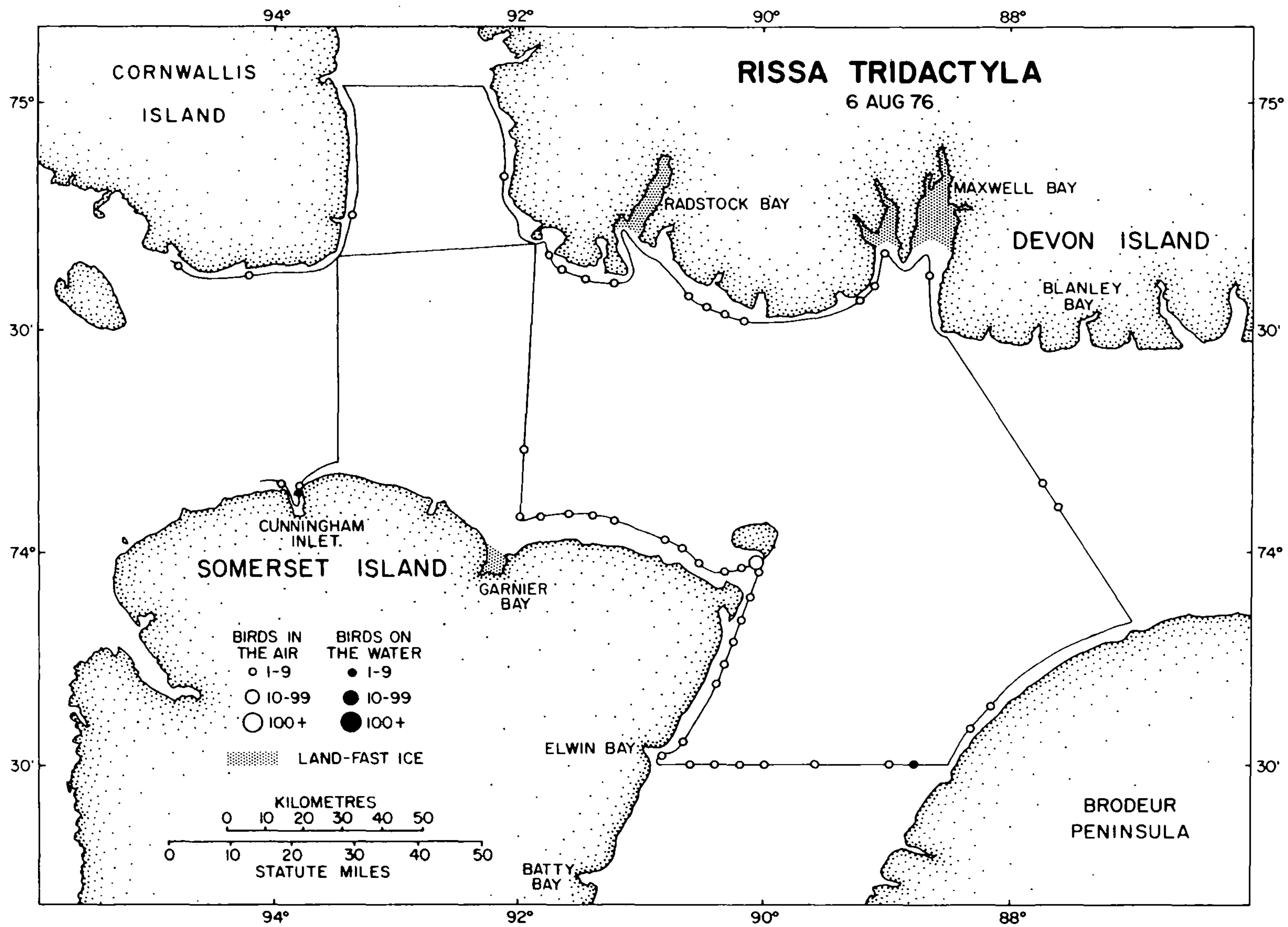

Figure 10. Distribution of Black-legged Kittiwakes *Rissa tridactyla* in the Barrow Strait survey area on 6 August 1976.

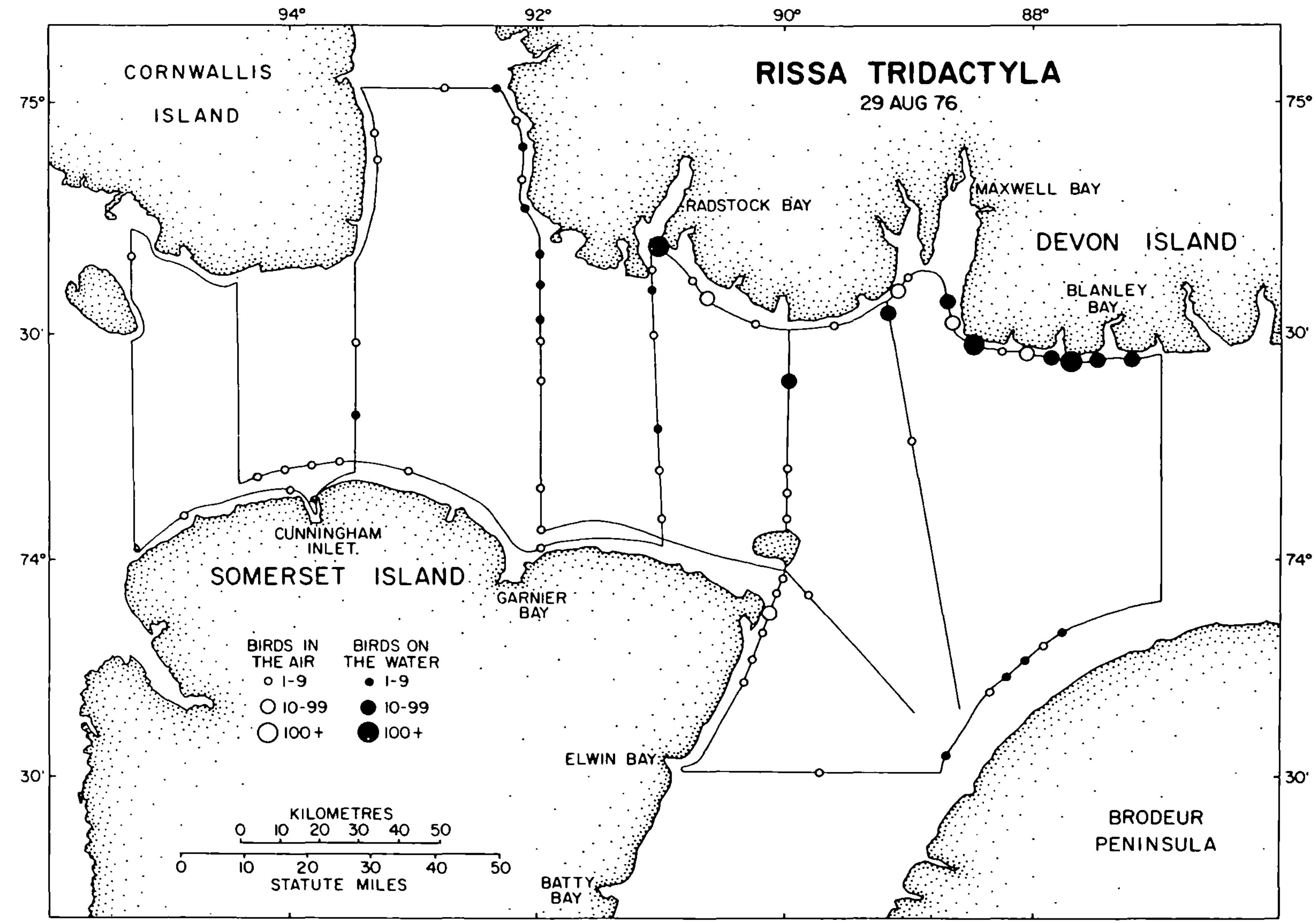

Figure 11. Distribution of Black-legged Kittiwakes *Rissa tridactyla* in the Barrow Strait survey area on 29 August 1976.

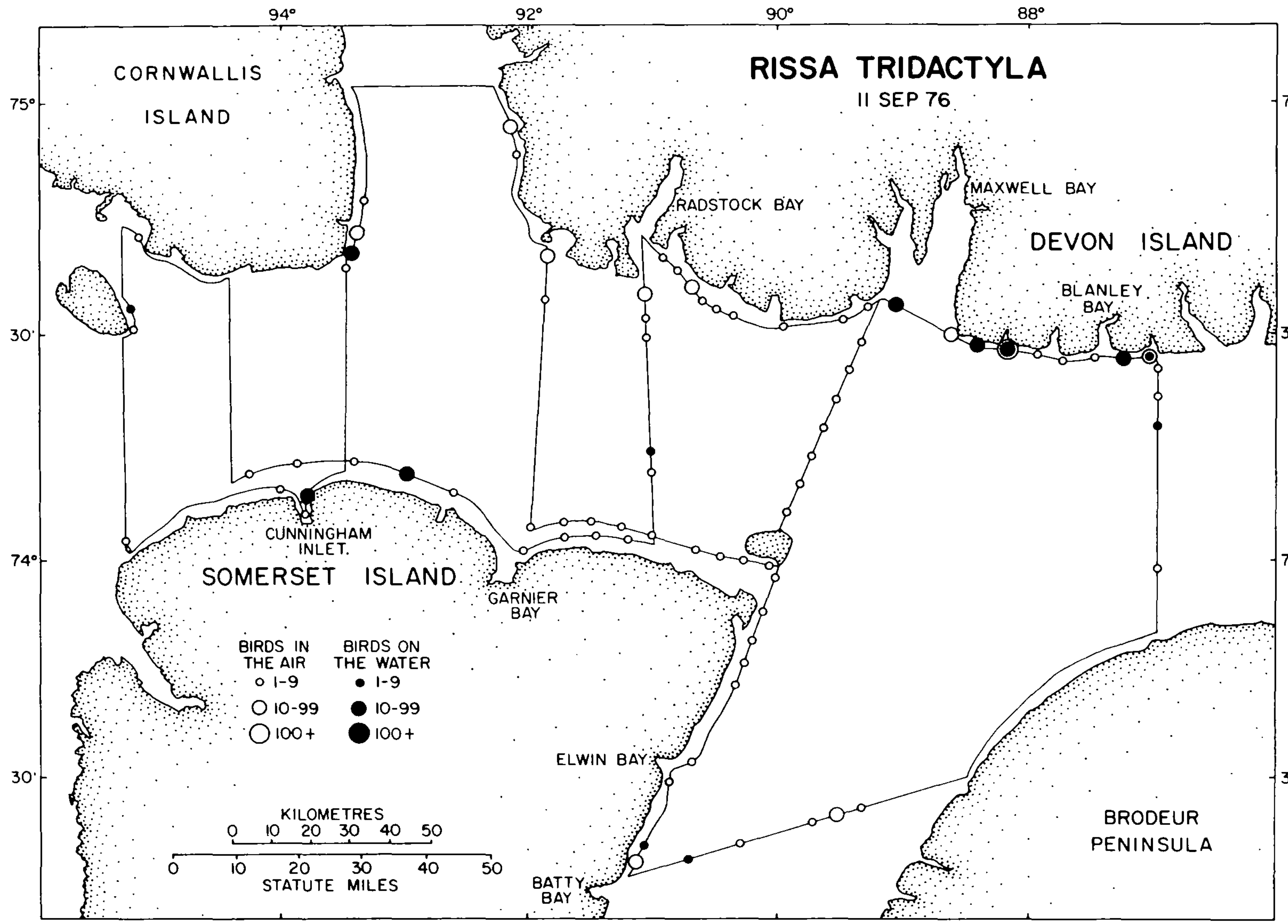

Figure 12. Distribution of Black-legged Kittiwakes *Rissa tridactyla* in the Barrow Strait survey area on 11 September 1976.

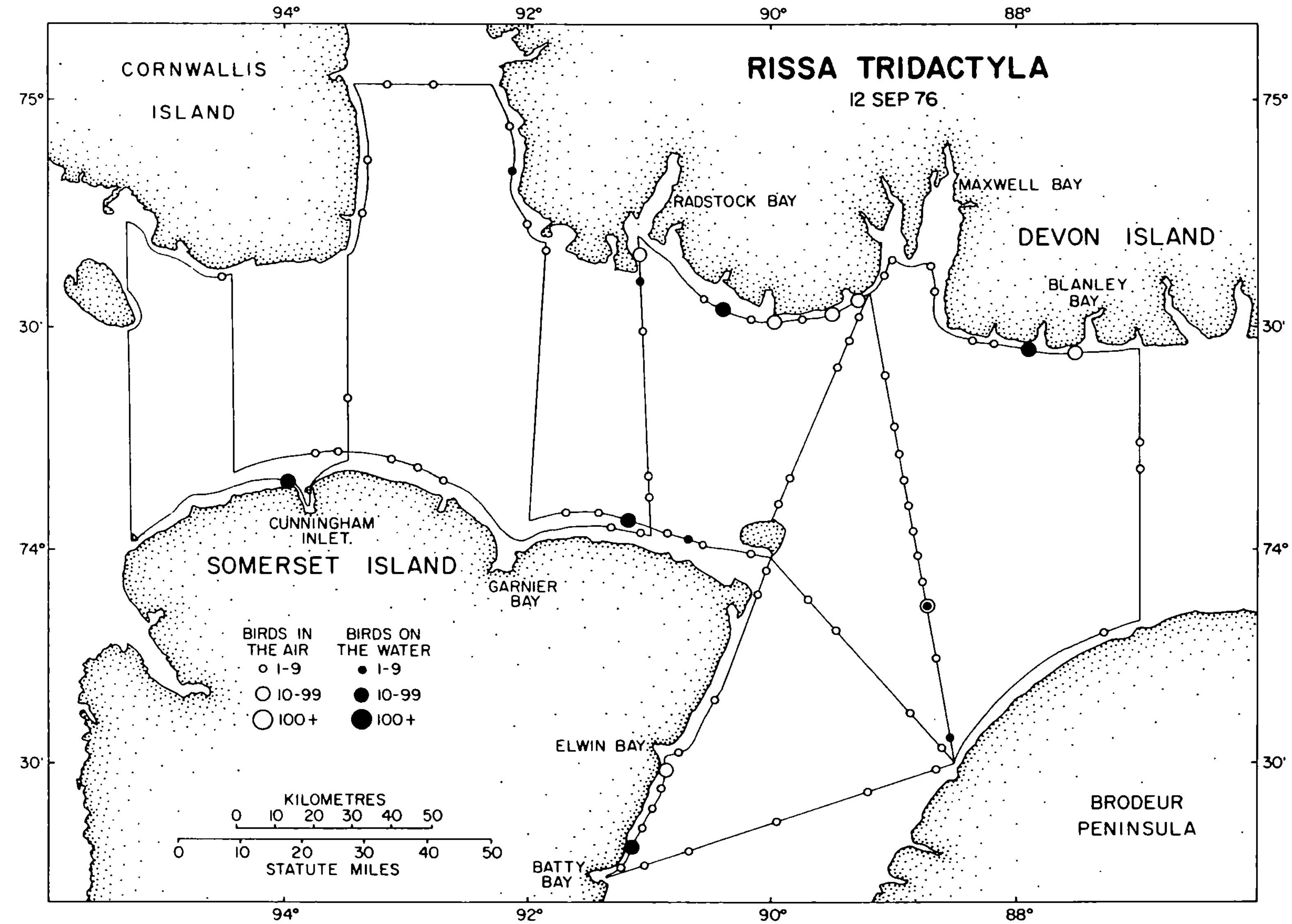

Figure 13. Distribution of Black-legged Kittiwakes *Rissa tridactyla* in the Barrow Strait survey area on 12 September 1976.

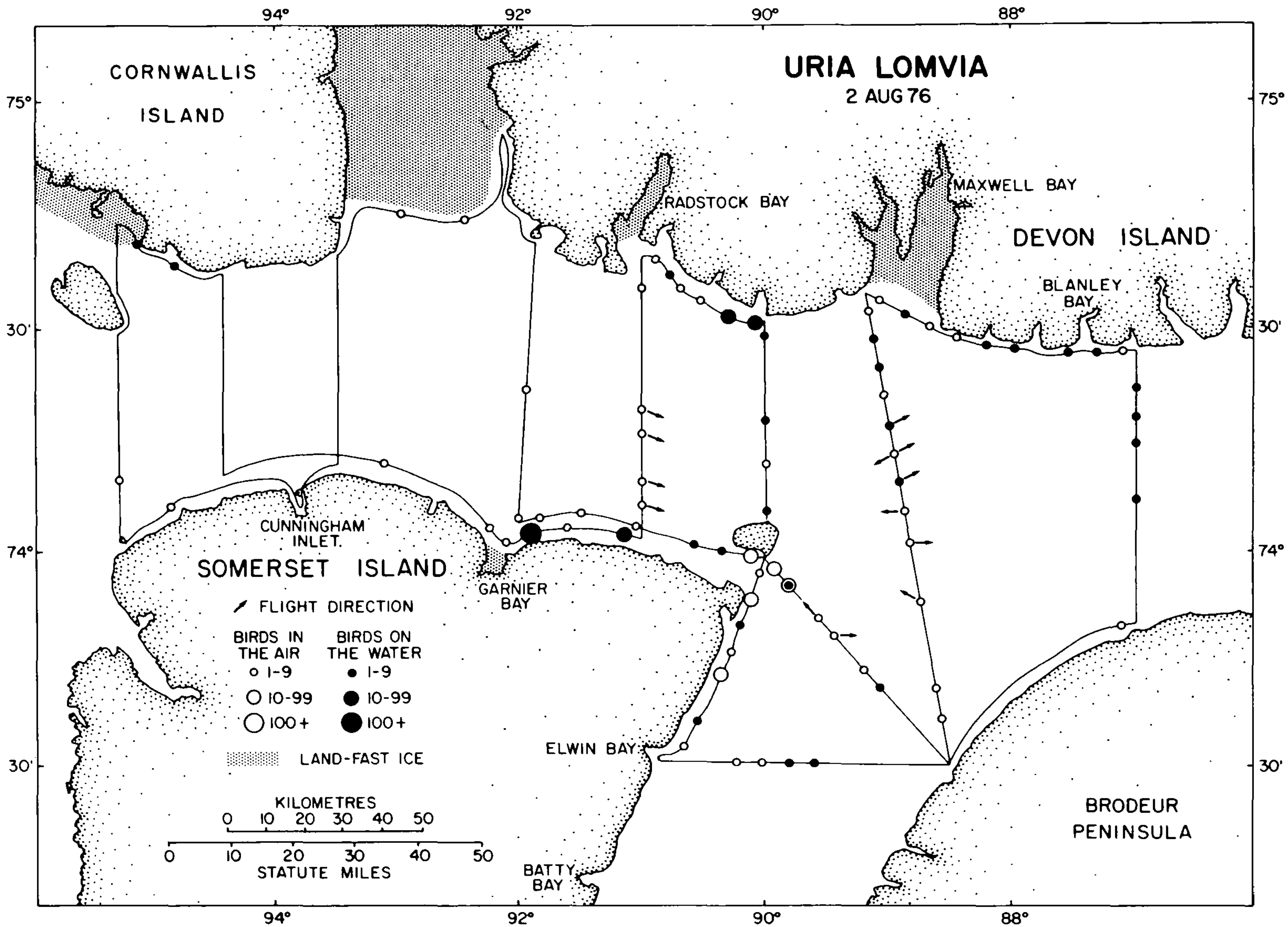

Figure 14. Distribution of Thick-billed Murres *Uria lomvia* in the Barrow Strait survey area on 2 August 1976.

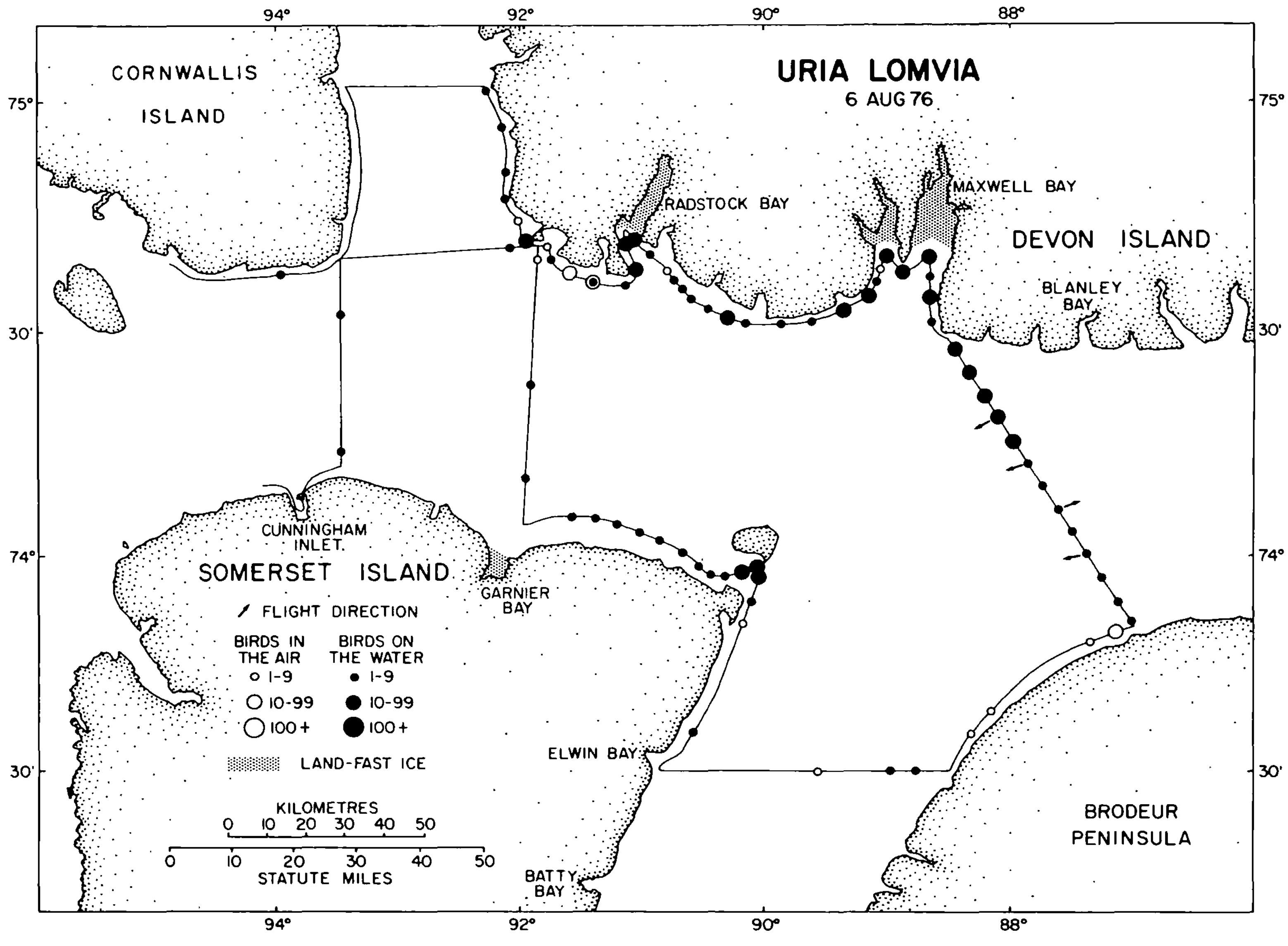

Figure 15. Distribution of Thick-billed Murres *Uria lomvia* in the Barrow Strait survey area on 6 August 1976.

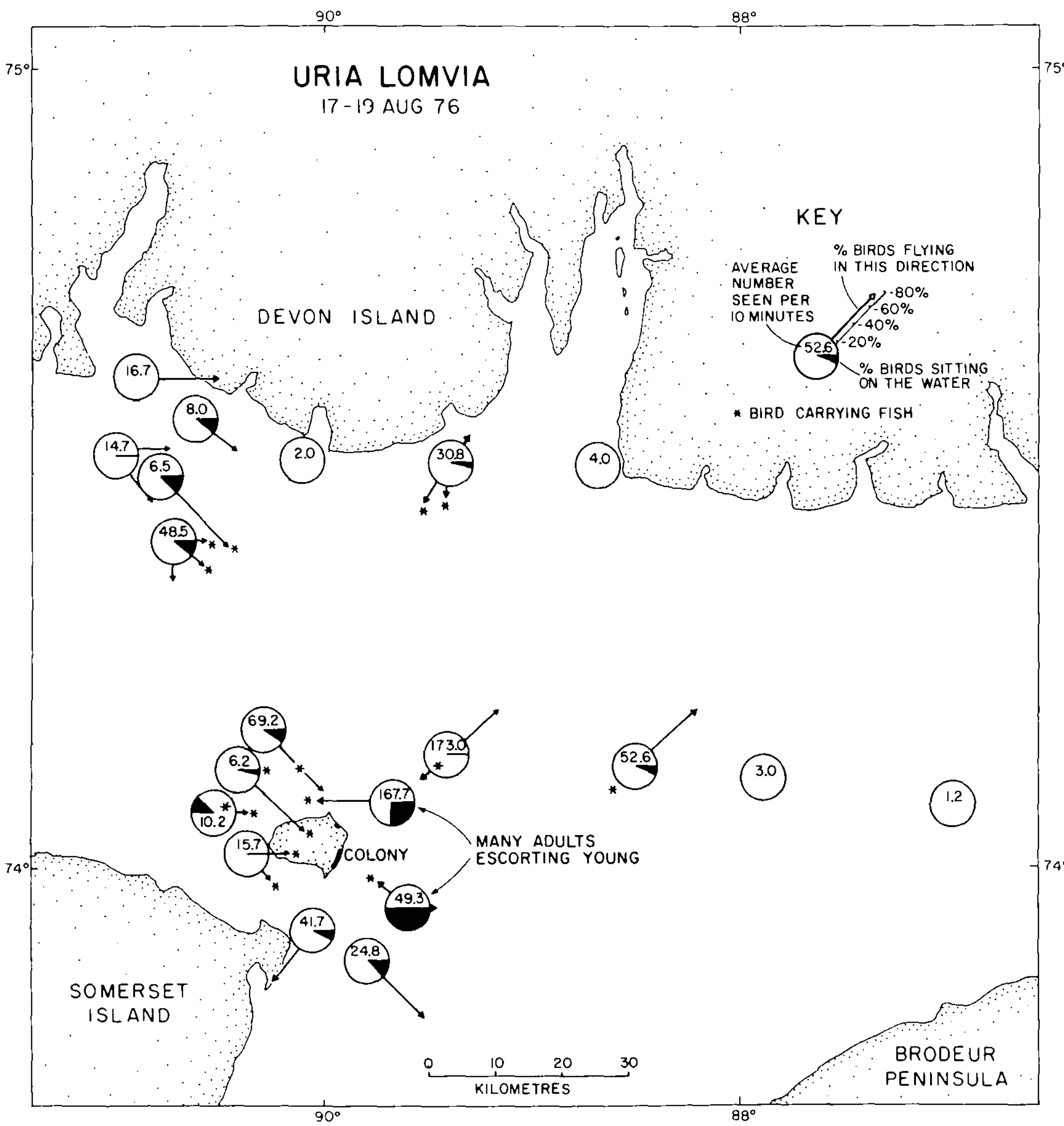

Figure 16. Distribution of sightings of Thick-billed Murres *Uria lomvia* from CSS Hudson during 17-19 August 1976. (Data from Dr. R.G.B. Brown.)

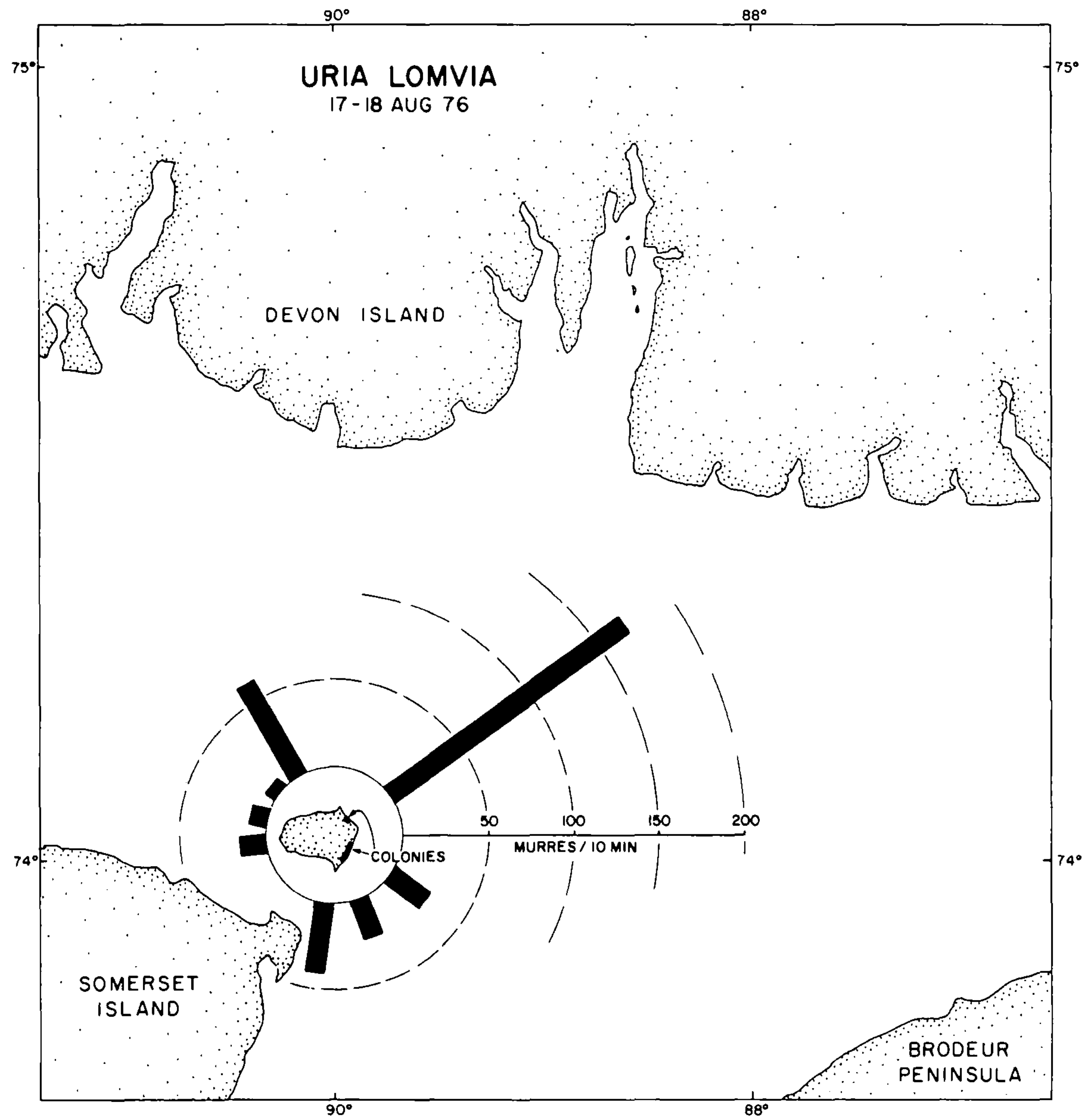

Figure 17. Flight directions and numbers of Thick-billed Murres *Uria lomvia* observed from CSS Hudson flying toward or away from Prince Leopold Island during 17-18 August 1976. (Data from Dr. R.G.B. Brown.)

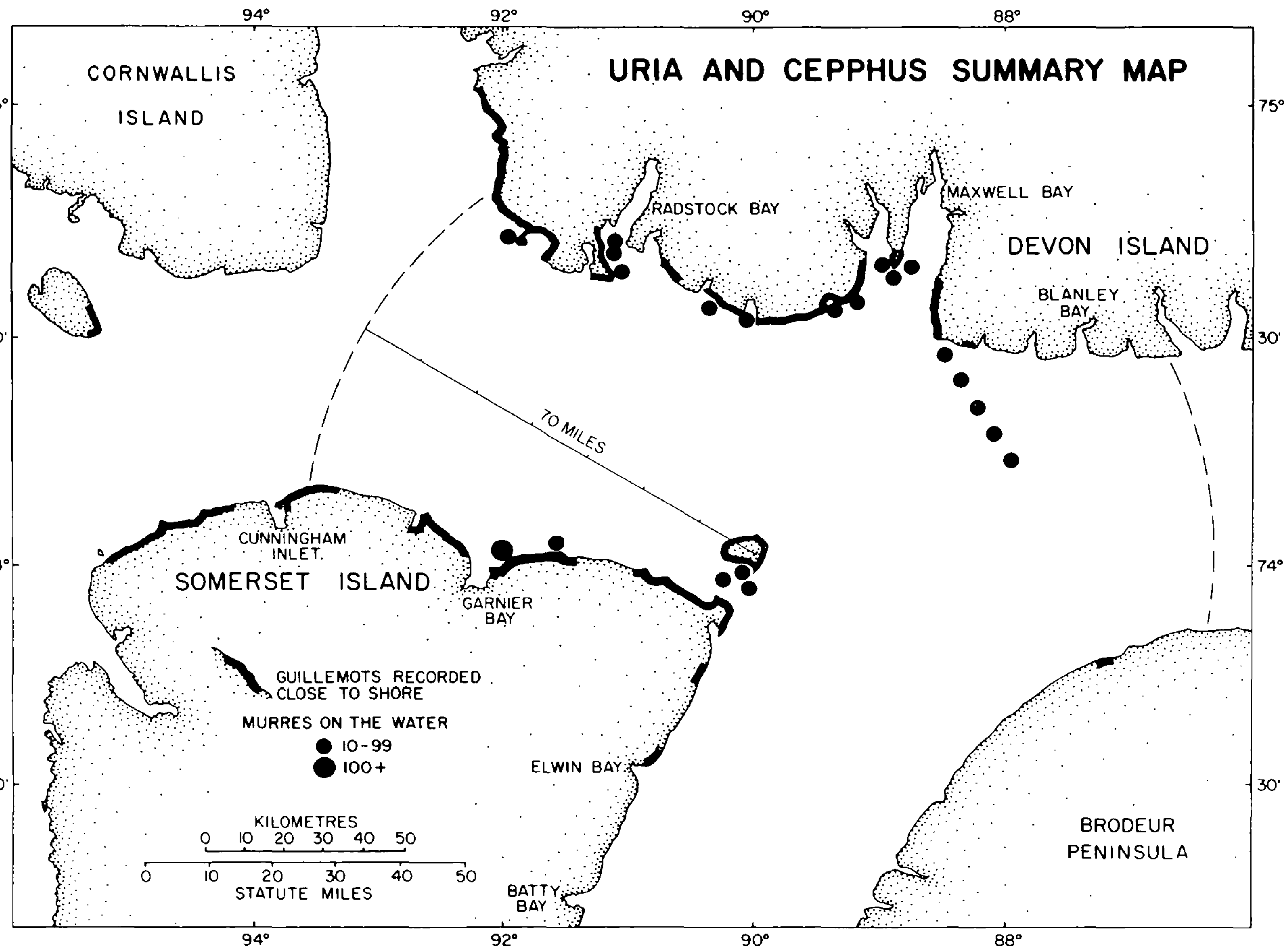

Figure 18. Summary map showing positions of major concentrations of Thick-billed Murres *Uria lomvia* at sea and coasts where Black Guillemots *Cepphus grylle* were recorded for all surveys in 1976.

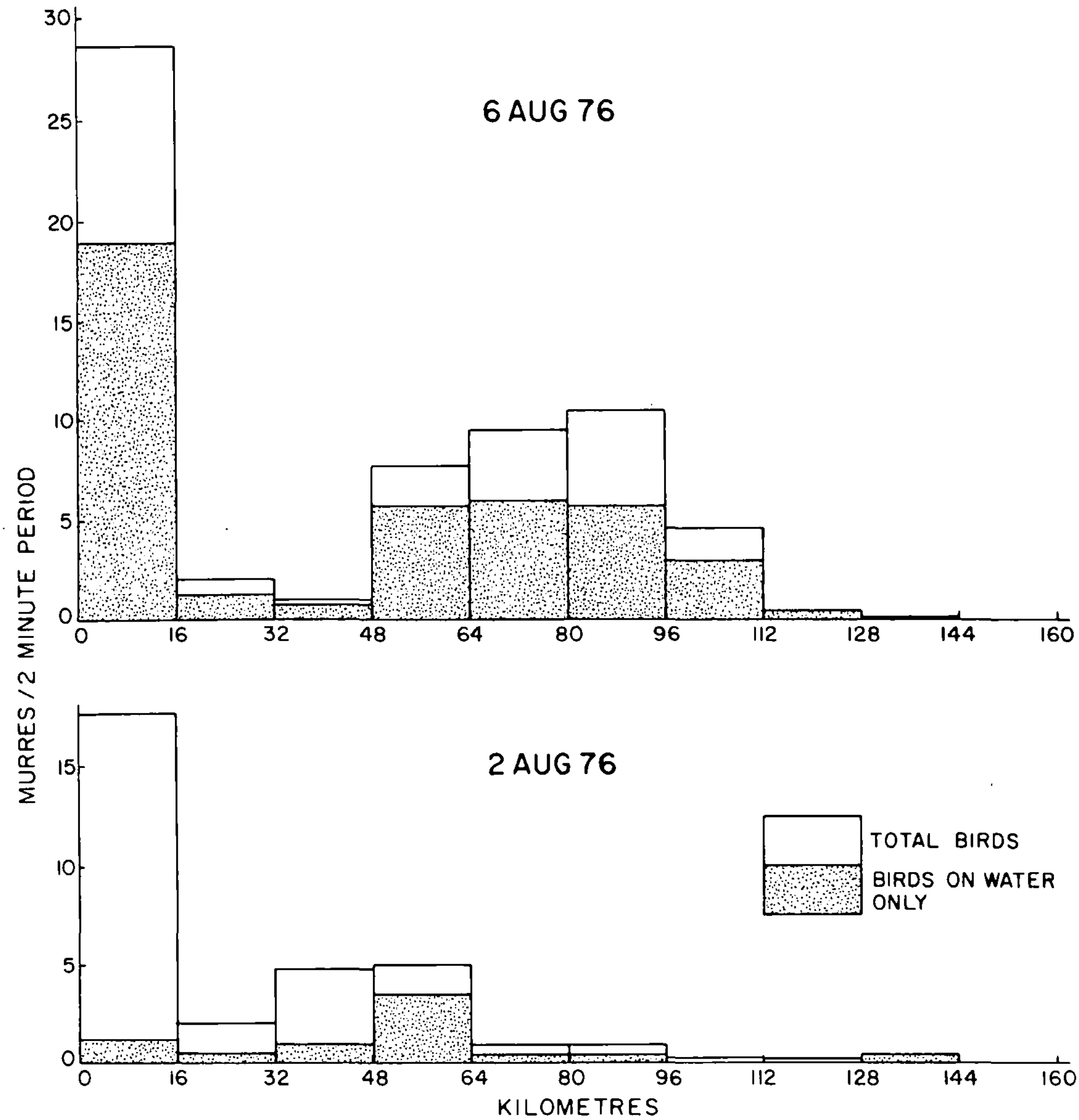

Figure 19. Distribution of Thick-billed Murres *Uria lomvia* in relation to distance from Prince Leopold Island, 2 and 6 August 1976.

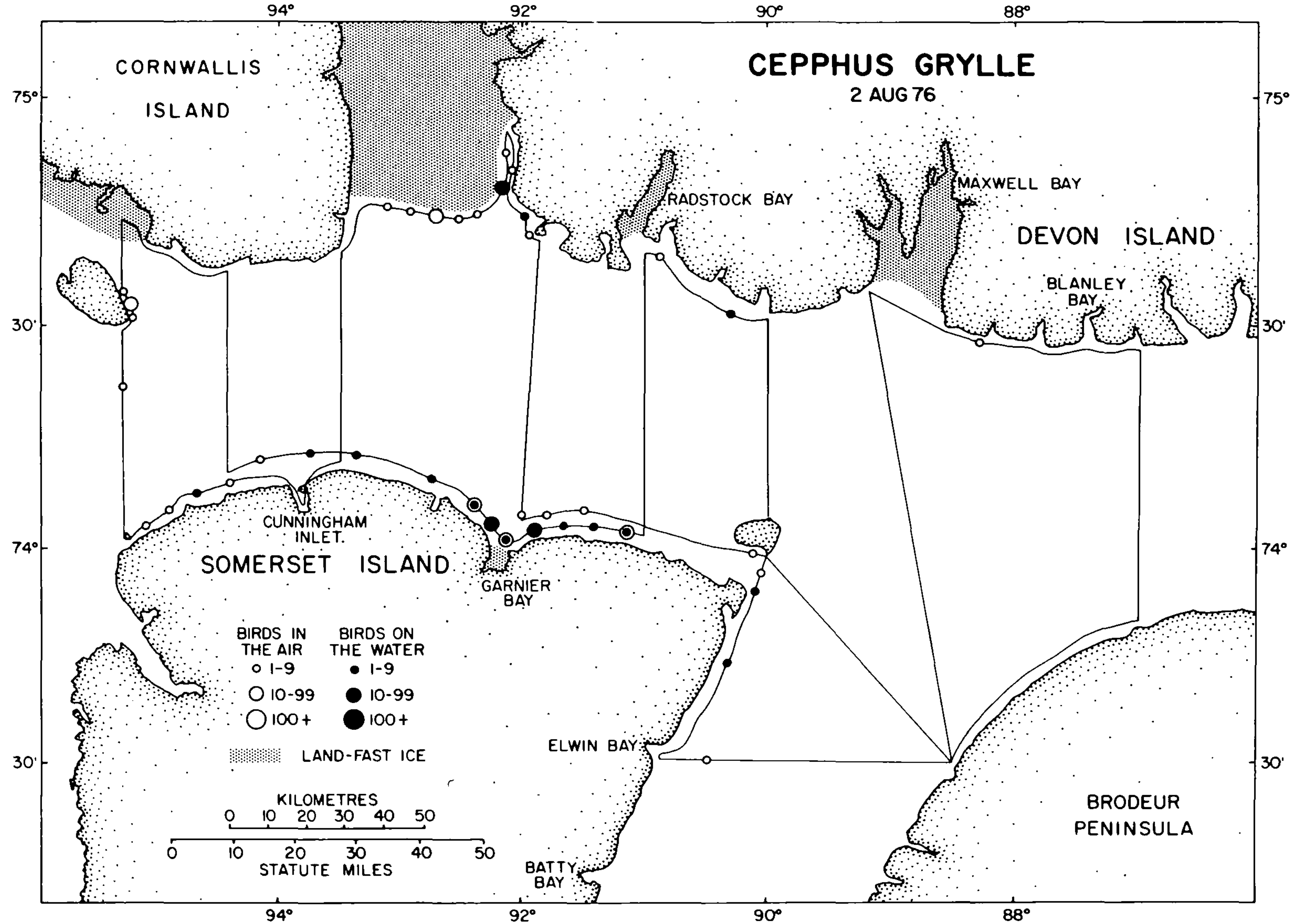

Figure 20. Distribution of Black Guillemots *Cepphus grylle* in the Barrow Strait survey area on 2 August 1976.

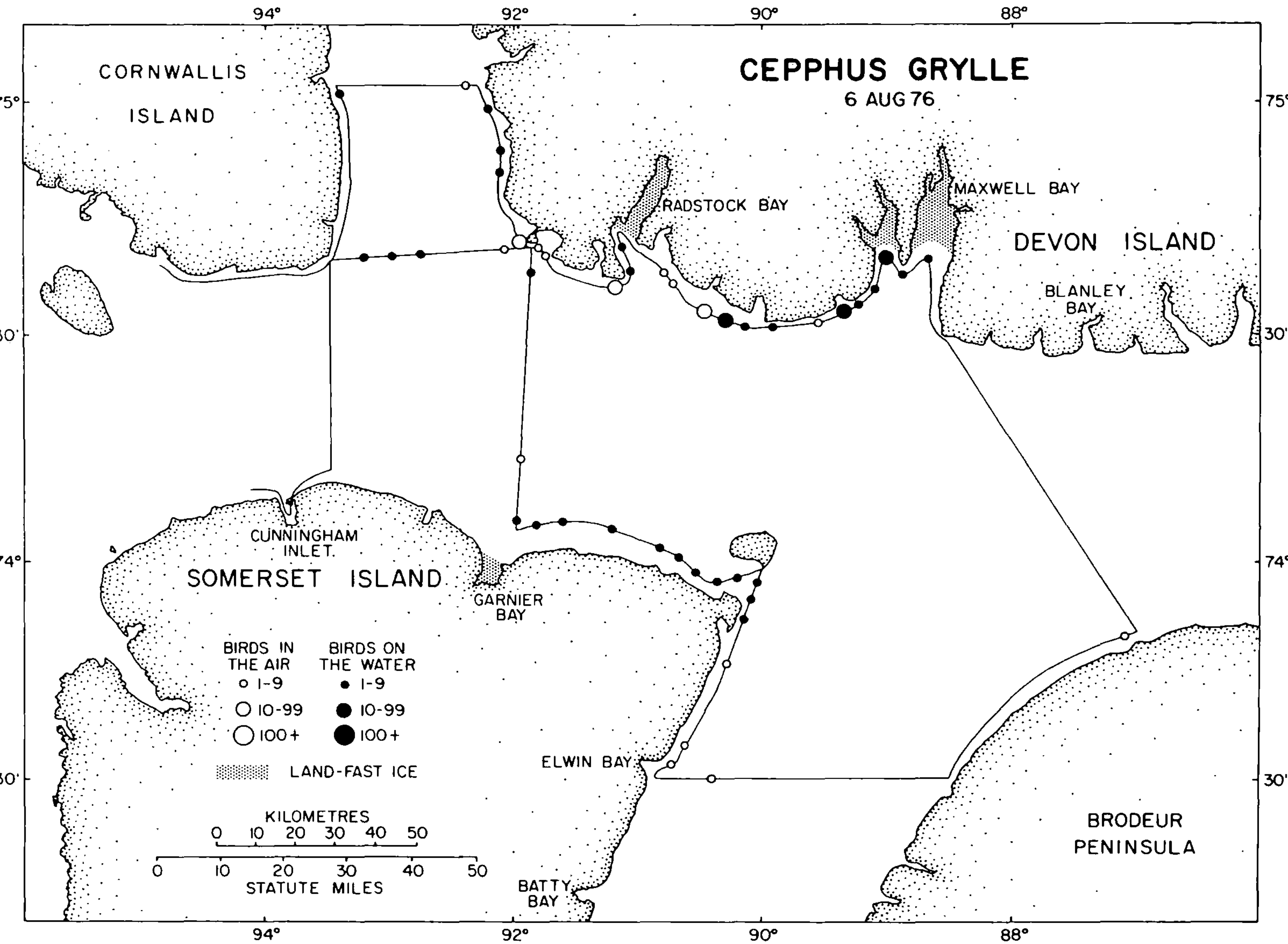

Figure 21. Distribution of Black Guillemots *Cepphus grylle* in the Barrow Strait survey area on 6 August 1976.

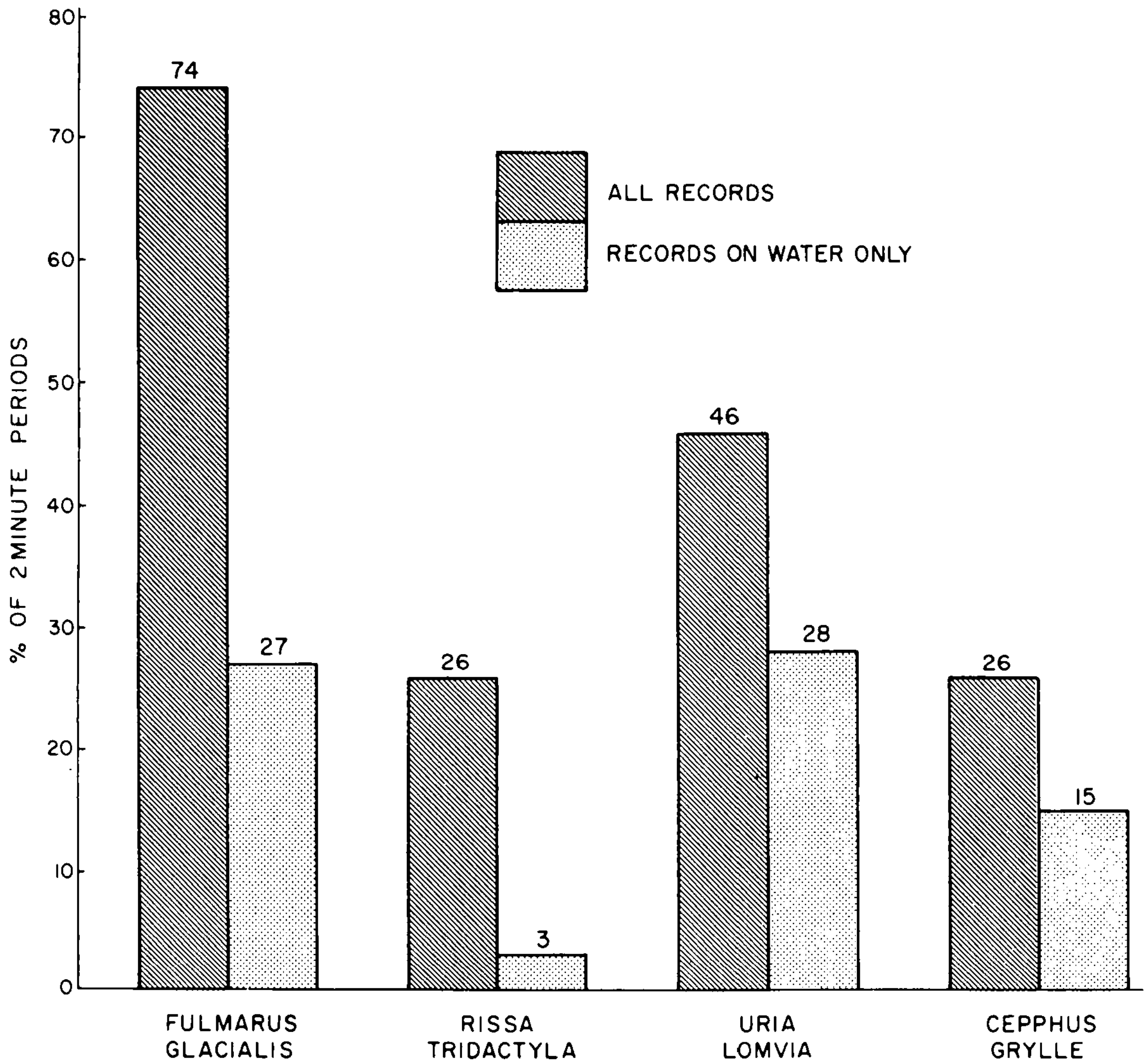

Figure 22. Proportions of two-minute periods in which individual species were recorded during surveys on 2 and 6 August 1976.

8. APPENDIX 1

APPENDIX 1. Distances flown and time taken on all transects flown during surveys of the Barrow Strait area in August and September 1976. D, distance in km; T, time in minutes; C, coastal; O, off-shore.

Transect		Survey Details									
		2 Aug		6 Aug		29 Aug		11 Sept		12 Sept	
Number	Zone	D	T	D	T	D	T	D	T	D	T
1	C	29.9	9	-		29.9	9.5	29.9	11	29.9	10
2	C	32.8	10	32.8	10.5	32.8	15	32.8	10	32.8	9
3	O	80.5	29	82.6	24.5	82.6	31	82.6	28	82.6	26
4	C	27.8	10	40.6	15	40.6	10	40.6	13	40.6	11
5	O	56.2	18*	35.4	10	35.4	12.5	35.4	10	35.4	11
6	C	14.5	5	38.0	11	38.0	12	38.0	11	38.0	13
7	O	55.7	14	55.7	15.5	55.7	18	55.7	17	55.7	15
8	C	57.9	15	20.9	6.5	75.5	25	75.5	21.5	75.5	22
9	O**	78.4	27.5	-		85.0	31	85.0	28	85.0	26
10	C	21.7	7	-		29.8	9	34.4	9	34.4	10.5
11	O	56.2	14.5	-		56.2	19	56.2	15	56.2	15
12	C	116.4	33.5	-		116.4	37	116.4	28.5	116.4	31
13	O	78.4	23	-		78.4	26	78.4	28	78.4	25
14	C	38.0	11	-		74.8	23	74.8	23.5	74.8	22
15	O	45.1	10.5	-		45.5	16	45.5	15	-	
16	C	60.7	17	60.7	20	60.7	19	60.7	17	60.7	18
17	O	76.0	24	76.0	24	76.0	21	-		-	
18	C	60.2	18	60.2	15	83.5	26.5***	60.2	18	60.2	18
19	O	71.8	21	-		53.6	16.5	71.8	19	71.8	20
20	C	69.4	20	-		95.3	28	69.2	19	95.1	29
21	O	123.0	32	-		101.2	27.5	-		123.0	35
22	O	72.4	24.5	-		45.5	15.5	-		72.4	23
23	C	-		44.6	12	-		-		-	
24	O	-		47.0	14	-		-		-	
25	C	-		167.4	56	-		-		-	
26	O	-		89.0	26	-		-		-	
1A	C	-		40.2	13	-		-		-	
15A	O	-		-		-		60.7	14	60.7	16
16A	C	-		-		-		39.3	11	43.8	13
17A	O	-		-		-		91.1	29	91.1	29

*On 2 August transect 5 was flown 200 m from the edge of land-fast ice at the mouth of Wellington Channel (see Figure 3). This transect is included with coastal transects for this date.

**Part of the off-shore transect 9 passed along the coast of Griffith Island (see Figure 2) and this section (16 km) is included with coastal transects.

***Transect 18, otherwise a coastal transect, was flown off-shore on 29 August because of thick fog on the coast and is included with off-shore transects for that date.