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Abstract

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Methods are presented for estimating (a) population size and (b) population status of Common Murres *(Uria aalge)* and Thick-billed Murres *(U. lomvia)*. Four colony types in which murres breed are described and methods for estimating population size for major colony types are presented. Population status can be determined only through the use of study plots within selected study colonies. Two methods of determining populations status are described. Type I counts provide a precise record of the number of breeding pairs on study plots, but require at least 6 weeks to complete. Type II counts provide a record of mean numbers of individuals on study plots and take only 10 days to complete, but the results are more difficult to interpret than those for type I. The geographic location of study colonies, frequency of counts and potential sources of error are discussed.

Résumé

Sont présentées ici les méthodes d'évaluation (a) de la taille et (b) de la nature des effectifs de marmettes communes, *Uria aalge* et de marmettes de Brünnich, *U. lomvia*. Quatre types de colonies propres à la reproduction sont décrites et l'on présente les façons d'évaluer le nombre d'oiseaux dans les grandes colonies. Quant à la nature des effectifs, elle se détermine sur des parcelles choisies à l'intérieur des colonies étudiées. Deux manières de procéder sont présentées: Le rencensement de type I donne une image précise du nombre de couples reproducteurs sur les parcelles, mais il faut six semaines au moins pour le faire. Le recensement de type II détermine le nombre moyen d'oiseaux sur les parcelles, ce qui ne prend que dix jours, mais les résultats, dans ce cas, sont plus difficiles à interpréter. L'emplacement des colonies, la fréquence des recensements et les sources d'erreurs possibles font l'objet d'une discussion.

Introduction

Many seabird species are currently at risk as a result of increases in pollution and the exploitation of non-renewable resources in the marine environment. Auks (Alcidae) have decreased throughout much of the North Atlantic during the last 30 or 40 years. The reasons for the decline are not known, but seem likely to involve a number of factors. The main threats to auks include factors which affect the birds both directly (e.g., oil fouling, drowning in fish nets, disturbance and predation) and indirectly (e.g., toxic chemical poisoning, fisheries developments and other activities which may affect the food supply) (Nettleship 1977).

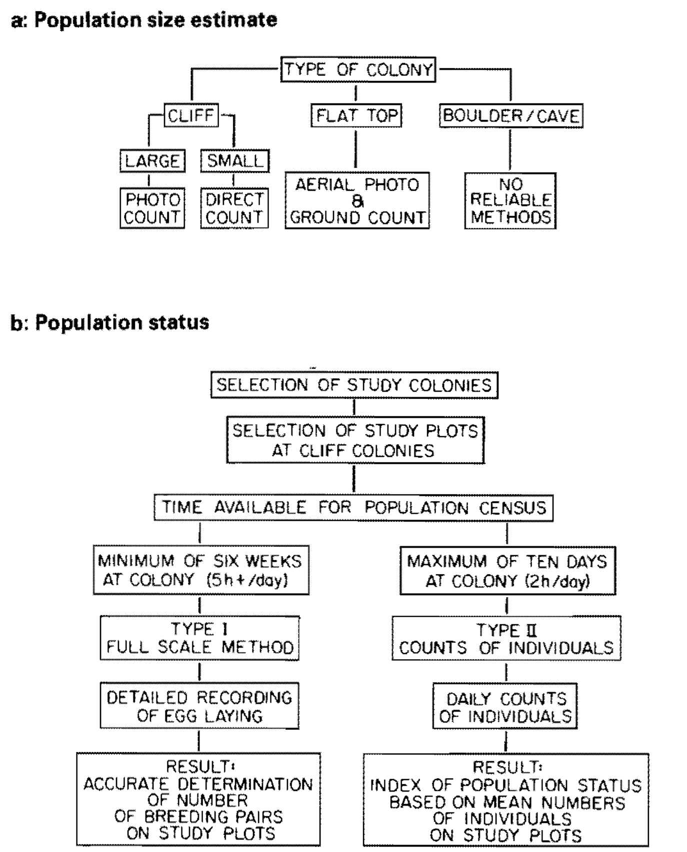
Murre populations are threatened because offshore oil drilling and commercial fisheries developments are occurring in their habitats. We therefore urgently need to establish a unified monitoring system to detect real population changes in murre numbers throughout their ranges, so as to establish a baseline for comparing population changes over both short and long periods. This can be accomplished only through a carefully integrated management program undertaken jointly by nations responsible for the welfare of migratory bird populations inhabiting the waters of the Arctic, Atlantic and Pacific oceans.

The two murre species, Common Murre *(Uria aalge)* and Thick-billed Murre *(U. lomvia)* are probably the 'best' alcid species to serve as indicators of the quality of the marine environment for a number of reasons. First, they are highly colonial with several million individuals breeding at a limited number of locations extending over a wide latitudinal range in both the North Atlantic and North Pacific (see Tuck 1961 for details of breeding distribution). Second, they are especially vulnerable to oiling (Brown *et al.* 1975). Third, they are the easiest of the alcid species to census, though this is a relative term (Nettleship 1976; Cramp, *et al.* 1974).

Censusing has two main objectives: (1) to obtain an estimate of numbers in a particular area or population and (2) to determine the status of a particular population (i.e., population trend). The first objective necessitates locating and plotting all colonies and assessing their approximate size. The second is tackled by selecting representative study plots in study colonies and counting the birds regularly to assess change. This paper describes methods for estimating population size and population status in Common Murres and Thick-billed Murres. Figure 1 comprises two diagrams showing the steps necessary to conduct a census of murres according to its purpose; that is, population size estimate (Fig. 1a) or population status estimate (Fig. 1b).

Much effort has been channelled into documenting the locations of murre colonies and determining their population size (Cramp *et al.* 1974, Brown *et al.* 1975, Brun 1969, Hedgren 1975, Dyck and Meltofte 1975, Harris 1976). Some authors describe their census methods in considerable detail (e.g., Swartz 1966, Dyck and Meltofte 1975, Hedgren 1975) while others present little or no information on techniques employed (e.g., Tuck 1961, Cramp *et al.* 1974). Where descriptions of methods are lacking or insufficiently precise, it is often impossible to assess previous estimates of population size and thus determine whether any change has occurred between censuses, since observed changes may be due to differences in technique alone. Clearly it is essential to have both a unified approach to censusing and consistency in methods.

Figure 1
Diagram showing colony type and census procedures for determining (a) population size and (b) population status of murres at breeding sites



Colony types

Murre colonies can be classified into four main types based on characteristics of the habitat used for breeding: (1) cliff, (2) flat top (either on low-lying islands or stacks), (3) boulder scree and (4) cave. Different colony types require different techniques for censusing. A short description of each colony type follows.

1. Cliff colonies

Common Murres and Thick-billed Murres breed either on narrow ledges in long rows, on broad ledges in dense groups, or on many small ledges each large enough for only one or two pairs. They do, however, display certain differences in their selection of habitat for breeding: Thick-billed Murres prefer individual sites and narrow ledges, and never form dense groups as Common Murrres do on broad ledges and on stacks or low-lying islands (see below and Williams 1974). Examples of cliff colonies are shown in Figures 2 and 3.

2. Flat-top colonies

Only Common Murres form colonies of this type. Birds breed in densely packed groups consisting of tens, hundreds or thousands of individuals, depending upon the topography. At Funk Island, off east Newfoundland (49°46′N, 53°51′W) (Figs. 4 and 5), a flat, low-lying granite slab, Common Murres breed in three vast groups each composed of about 100 000 pairs. In contrast, at the Gannet Islands (54°00′N, 56°31′W), Labrador, where the topography is very uneven, Common Murre colonies are composed of many small groups of tens or just a few hundred birds (Fig. 6). For colonies on stacks [e.g., Farne Islands, England (55°40′N, 01°39′W) and at Bear Island, Spitsbergen Archipelago (74°25′N, 18°46′E)], group size is determined by the area of the stack top (Fig. 7).

3. Boulder-scree and cave colonies

Both species of murre form colonies of these types, but they are more frequent among Common Murres. In boulder-scree colonies, birds may either breed in the open between boulders or in the spaces beneath (Fig. 8). In most cliff and flat-top colonies, a small proportion of Common Murres breed in cracks between rocks or under boulders.

Figure 2
Common Murre cliff colony, Skomer Island, Wales. (a) General view of 60-m high cliffs at Bull Hole colony, mid June 1975. Population density at this location is low due to reduction in population between 1934 and early 1970s (see Birkhead and Ashcroft 1975). Study plot B is outlined in white. (b) Specific view of study plot B, which contained 63 breeding pairs in 1974

a

b

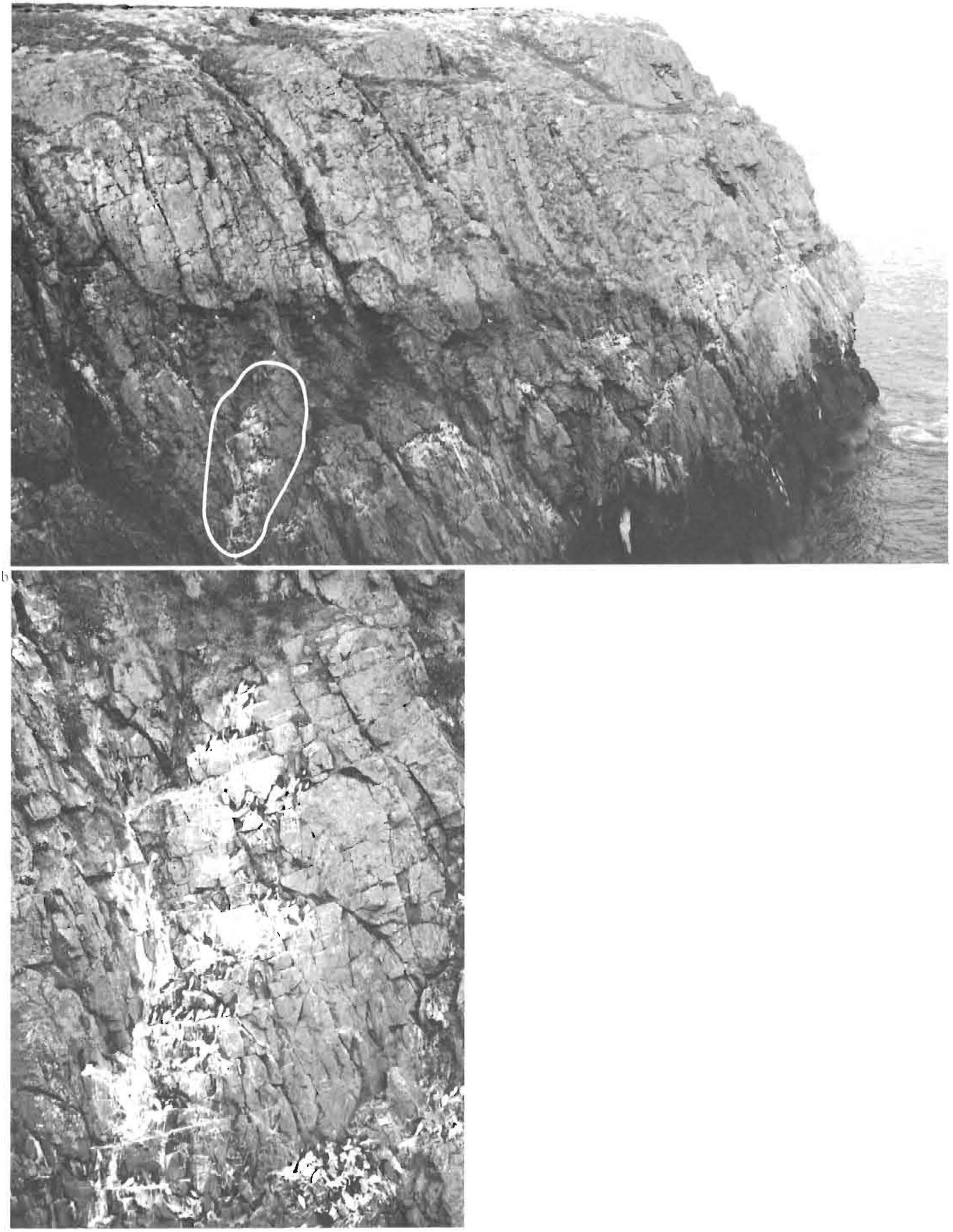
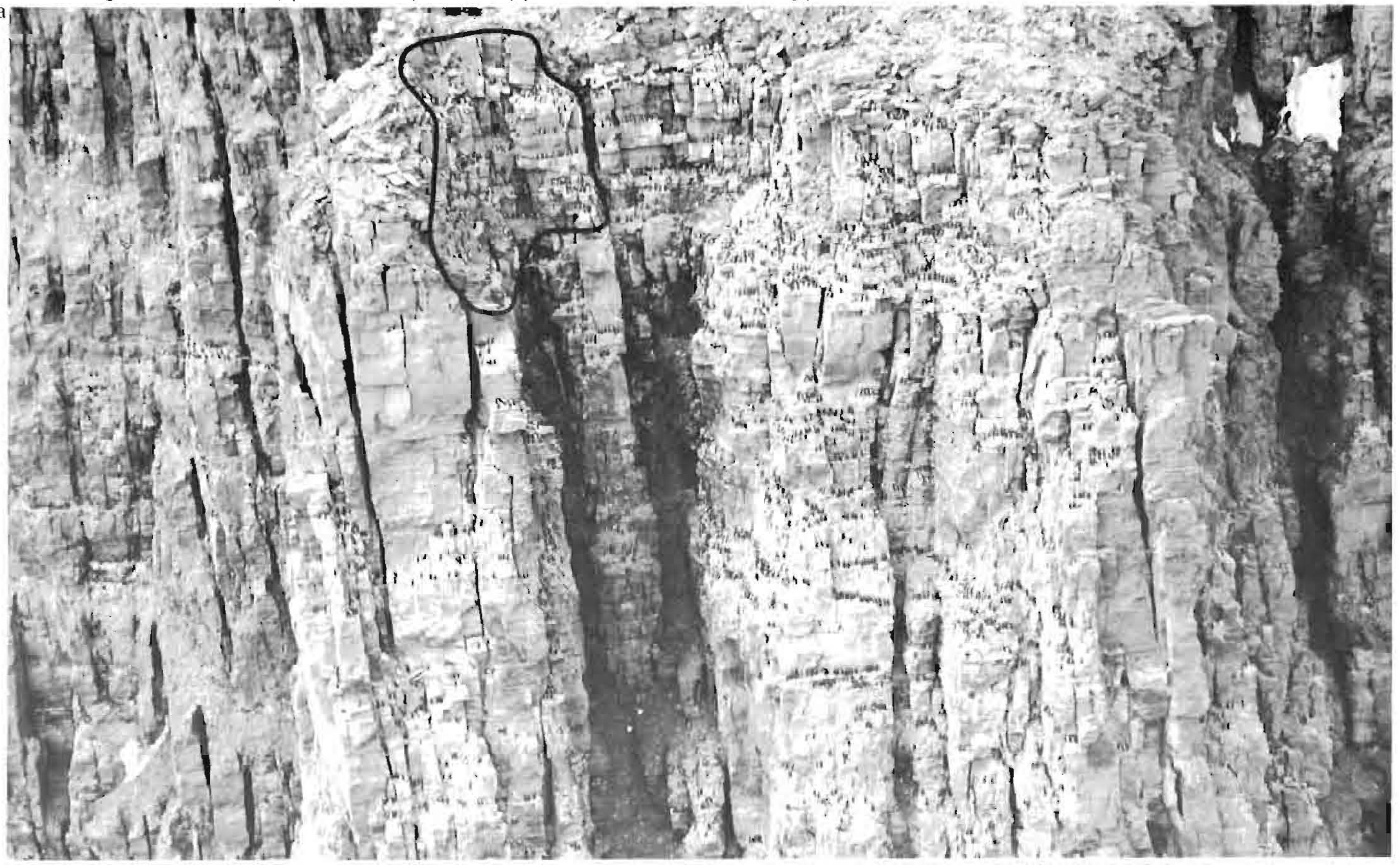


Figure 3
Thick-billed Murre cliff colony, Prince Leopold Island, NWT. (a) General view of 300-m high cliffs around study plot S, late July 1971. Study plot S is outlined in black. (b) Specific view of study plot S, 23 June 1975, which contained 178 breeding pairs

a



b

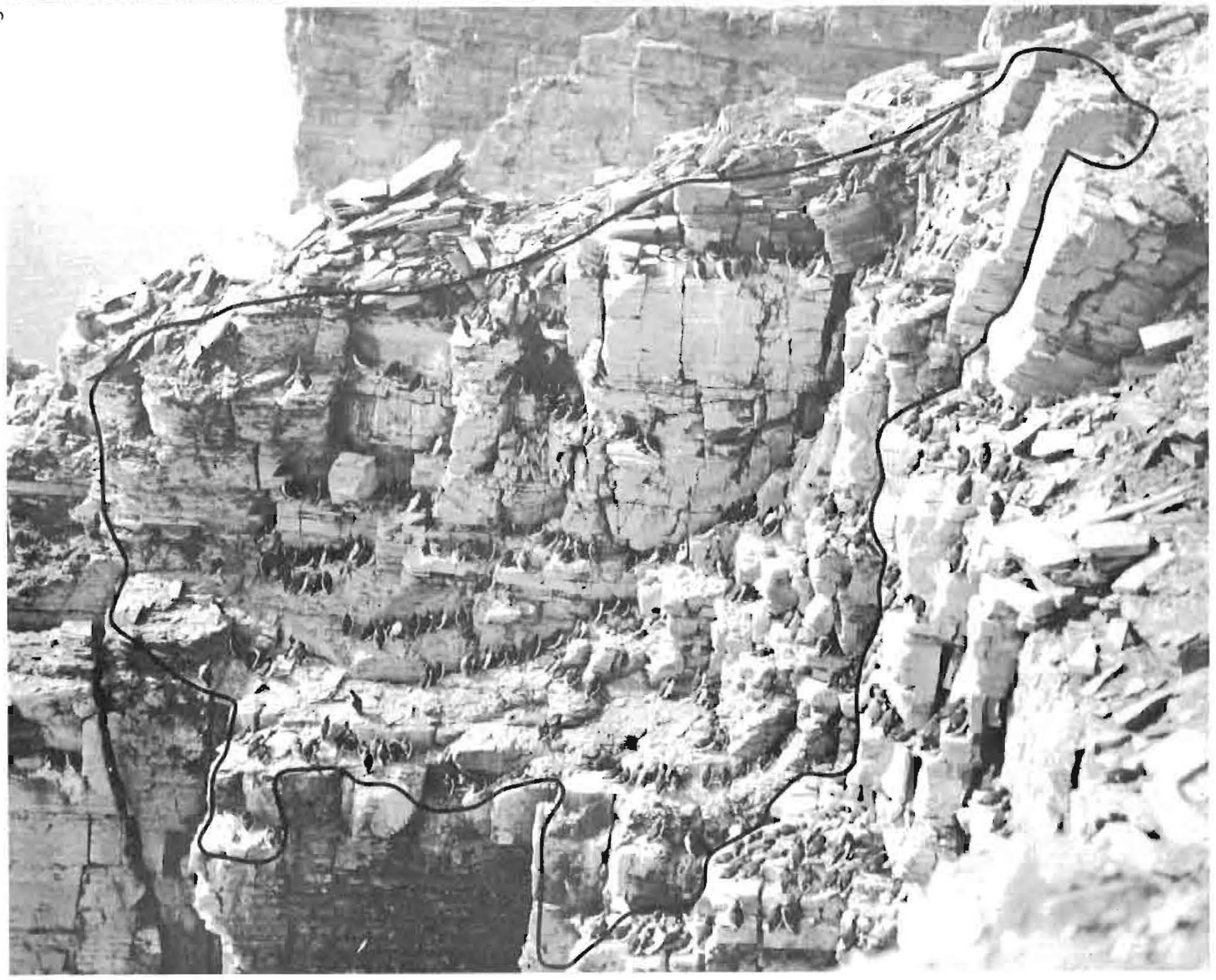


Figure 4
Common Murre flat-top colony at Funk Island, Nfld. (a) Aerial photograph of Funk Island, 19 June 1972. (b) Sketch map drawn from enlarged aerial photograph of (a), showing the three subcolonies of murres: Southwest, Central and Indian Gulch (see also Fig. 5 and Table 2)

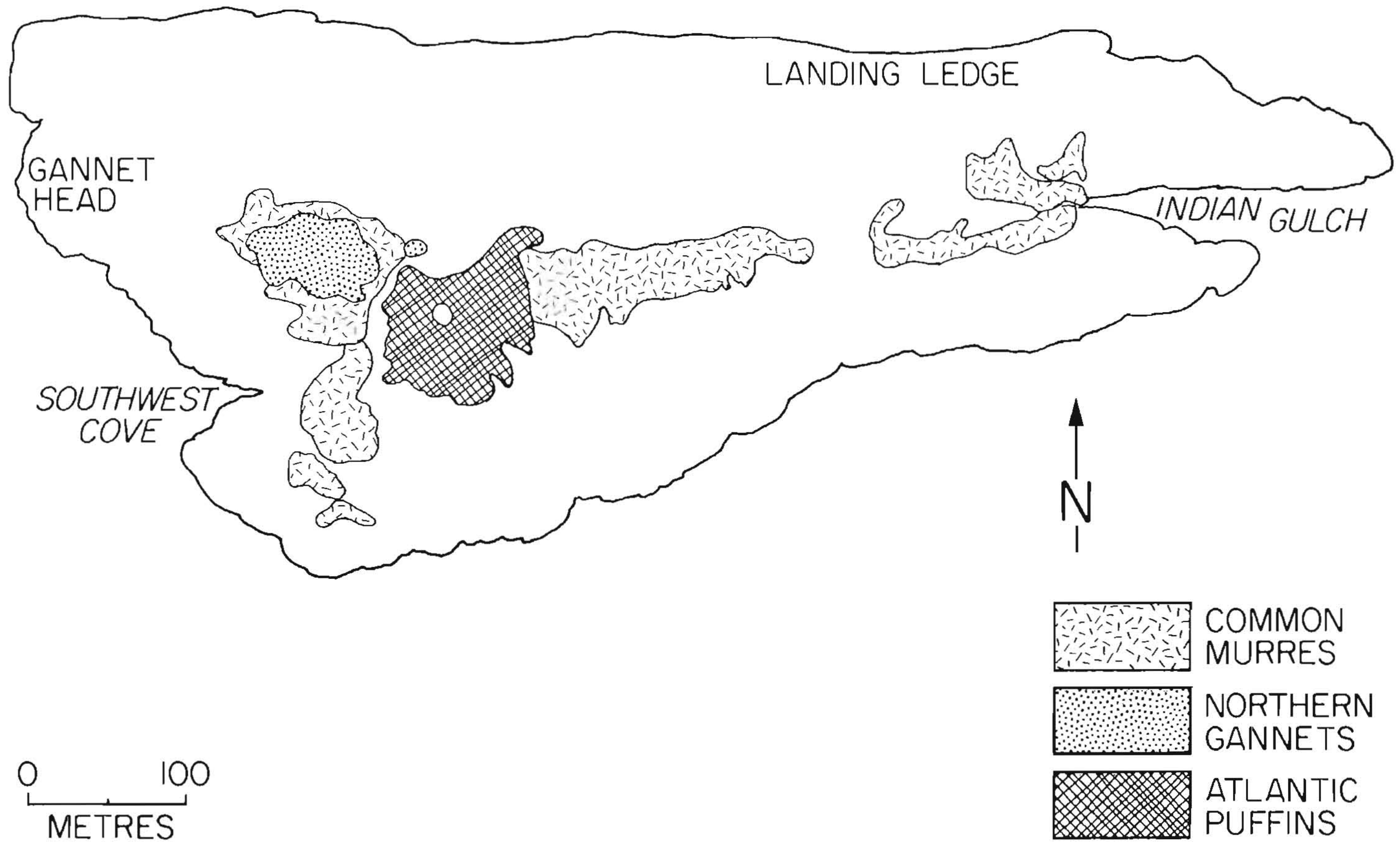


Figure 5
Common Murre flat-top colony at Funk Island, Nfld. from ground, 11 July 1975. This view of Central subcolony shows the almost continuous carpet of breeding birds

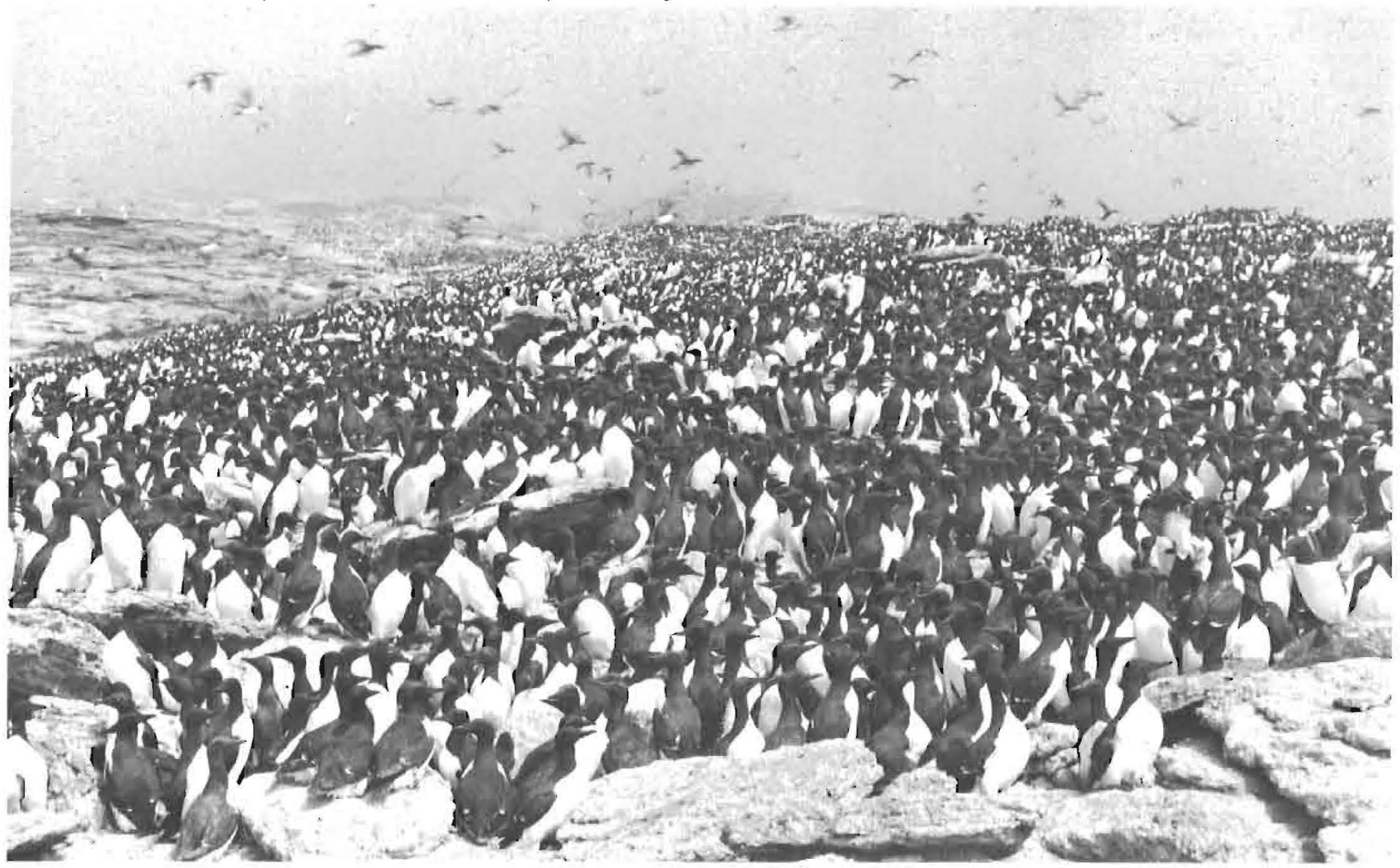


Figure 6
Part of Common Murre flat-top colony at Gannet Islands, Labrador, early July 1978. This view is typical of the colony and shows irregular nature of breeding habitat, with many small breeding groups of birds (compare with Figs. 4 and 5; see also Fig. 10)

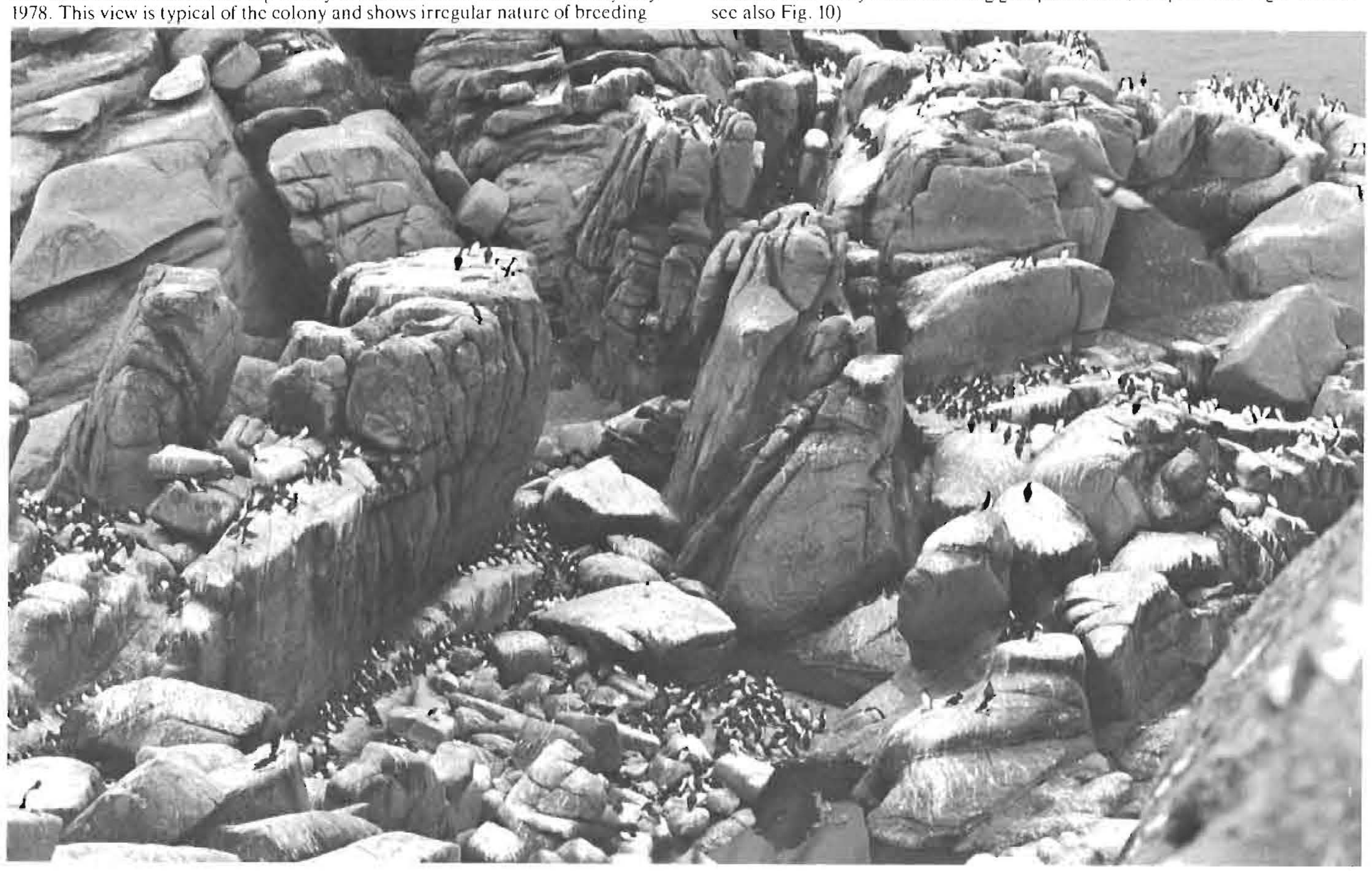


Figure 7
Part of Common Murre flat-top colony on the Stacks in the Farne Islands, northeast England

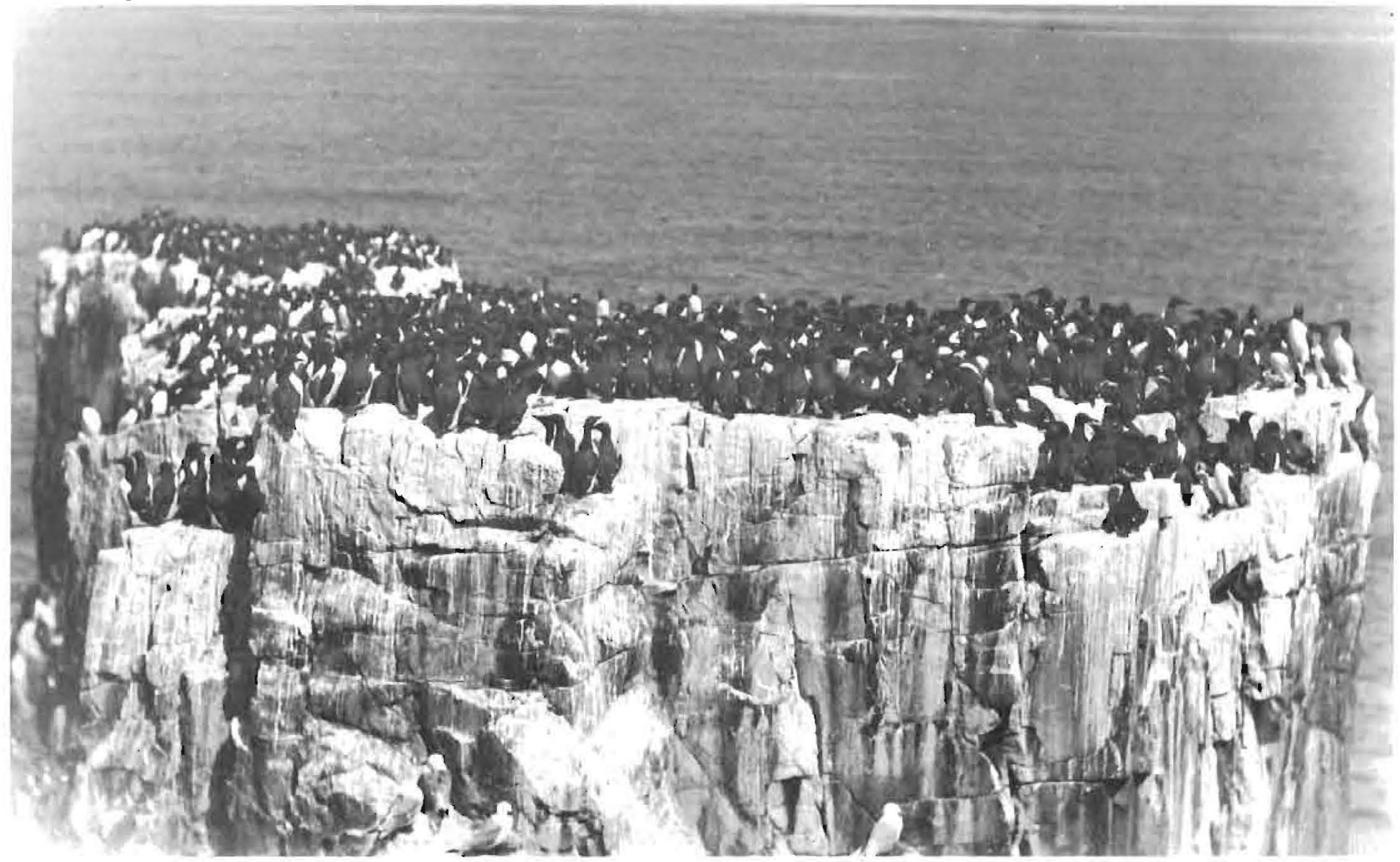


Figure 8
Common Murre boulder colony at Compass Head, Shetland, 1974. Colonies of this type are difficult to count accurately, because an unknown proportion of birds are hidden beneath boulders

Population size

1. Time of counting

The census period, during which all counts must be made, runs from the end of egg-laying to the start of fledging (i.e., early chick-rearing period). Murre numbers at this time are less variable than at any other stage of the breeding cycle (Lloyd 1975, Gaston and Nettleship in press). Unfortunately, it is sometimes difficult to predict the dates for the census as the timing of murre breeding seasons is often unknown, and because timing of breeding varies between colonies and between years. At British murre colonies (50°–60°N) the census period usually falls during June and counts are made then regardless of whether the season is early or late (Table 1). At high latitudes, breeding takes place later; for example, at Prince Leopold Island (74°02′N, 90°00′W) in 1975–1977, the census period fell between mid July and mid August (Table 1).

Counts or photographs should be made during the middle part of the day (Lloyd 1975, Gaston and Nettleship in press). It is essential that *all* details of counts be recorded (App. 1). We describe methods appropriate for each major colony type below.

2. Cliff colonies

The entire length of the colony should be photographed, either from the cliff tops, the sea or the air, to produce a permanent record of the precise limits of the colony. With populations of less than 10 000 birds on cliffs 125 m high or less, it may be possible to count all individuals directly (from the cliff-tops and/or the sea) (e.g., see Fig. 2). Alternatively, counts can be made from photographs as long as their accuracy has been previously checked by counting samples of about 200 birds and then photographing the area immediately. This procedure should be repeated with at least five sample counts. It is *not* sufficient to quote other studies which may provide "correction factors", since such factors will vary according to local conditions (e.g., lens and camera quality, weather, lighting, distance from colony).

With larger populations on higher cliffs, difficulties of counting are increased and accuracy reduced (e.g., see Fig. 3). If direct counting is impossible, estimate the density of murres per unit area of cliff either from photographs or from the cliff top. Estimate the total area of cliffs occupied by birds from photographs and delineate the areas occupied. These figures can then be used to estimate the population size, as shown in the example below. It is important to note that such a method is only feasible if the colony is not greatly indented and does not vary in height, so that all areas can be seen on photographs.

Example 1: Cape Hay, Bylot Island (73°46′N, 80°23′W). An estimate of population size was made on 13–14 August 1976. The entire length of the colony was photographed from the air from a near-horizontal viewpoint, and as much of the colony as was visible from the cliff-top. The aerial photographs were used to produce a photo-mosaic (Fig. 9), from which the extent and area of the colony were measured. Four representative areas, examined and photographed from the cliff-top, and counted from photographs, contained 23 175 individuals.

Table 1
Timing of breeding in Common and Thick-billed Murres at different localities

Species	Locality	Median date of laying (n)	Spread (days)	Census period*	Source
Common Murre	Skomer Island, Britain (51°40′N, 05°15′W)	20 May 1973 (149)	31	—	Birkhead (in press)
		18 May 1974 (108)	39	—	
		16 May 1975 (580)	36	4–19 June	
Common Murre	Puffin Island, Eire (51°50′N, 10°23′W)	22 May 1973 (81)	26	5–21 June	P.G.H. Evans (in prep.)
Common Murre	Stora Karlsö, Baltic Sea (57°17′N, 17°58′W)	9 May 1974 (287)	32	2–19 June	S. Hedgren (pers. comm.)
		14 May 1975 (372)	29	4–24 June	
		16 May 1976 (389)	34	10–27 June	
		19 May 1977 (427)	40	16–29 June	
Thick-billed Murre	Kipako Island, Greenland (73°43′N, 56°45′W)	27 June 1974 (32)	20**	8 July–10 August	P.G.H. Evans (in prep.)
Thick-billed Murre	Prince Leopold Island, Canada (74°02′N, 90°00′W)	29 June 1975 (109)	24**	18 July–11 August	Gaston & Nettleship (in press)
		28 June 1976 (288)	34	24 July– 7 August	
		2 July 1977 (275)	39	30 July–12 August	

* Period between end of egg-laying and start of fledging.
** Based on one study plot only.

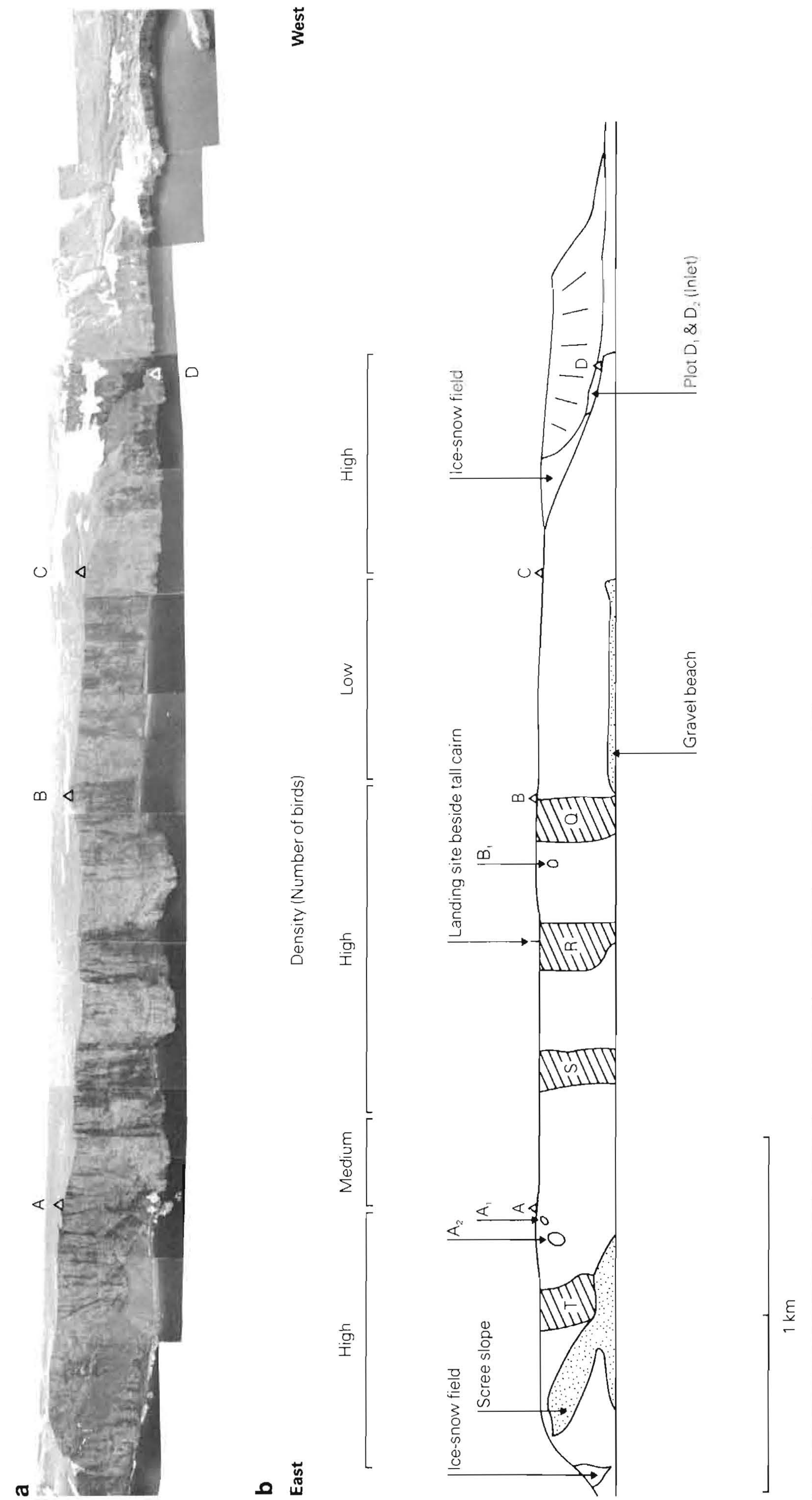


Figure 9
Thick-billed Murre cliff colony near Cape Hay, Bylot Island, NWT.
(a) Photomosaic made from a series of over-lapping aerial photographs taken 30 July 1972.
(b) Sketch map of colony drawn from photo-mosaic showing general distribution of breeding birds and details of 1976 survey

areas counted from photos taken from cliff-top

arrows indicate positions of study plots counted on location at site

△ indicate rock cairns erected to mark positions from which counts were made

The area counted was estimated at 15% of the colony, leaving out an area of unoccupied screes at the east end and the low cliffs on the west end of the colony. The number of individual birds present was estimated to be 100/15 × 23 175 = 154 500. To this estimate was added a further 8300 individuals (counted directly from the land and not visible in the air photos) located in an inlet at the west end of the colony, and an estimated 5000 individuals on the low cliffs west of the inlet, visible only from a survey aircraft. The total number of individuals present was thus 154 500 + 8300 + 5000 = 167 800 (Gaston and Nettleship 1978).

Example 2: Skomer Island, Wales (51°40'N, 05°15'W) (see Fig. 2). This is a small colony of Common Murres comprising 3815 individuals in 1975 (Birkhead 1978). Cliffs are all less than 60 m and 90% of birds breed on narrow ledges, with about 5% in dense groups on broad ledges and 5% under boulders and in caves. A direct count of all individuals in the Skomer population has been made annually since 1963, in mid June during the middle part of the day, and the locations of all breeding areas on the island have been mapped (see Birkhead and Ashcroft 1975).

3. Flat-top colonies

Vertical aerial photographs are essential for measuring the area occupied by breeding birds. Workers should produce detailed photo-maps (*not* rough sketches) of the colony. Ground counts are also essential for checking the composition of breeding groups. In accessible colonies, this can be done in the following way: count (and if possible photograph) birds in specific groups without disturbing them. Then, extremely carefully, drive the birds from their eggs and count the eggs. If breeding groups consist mainly of incubating birds, the egg:bird ratio should be near 1:1. After counting the eggs, measure the area occupied by the breeding groups using either 1 × 1 m or 2 × 2 m quadrats, whichever are appropriate. If possible, take a photograph (from a high vantage point) of the eggs with a quadrat in place as a permanent record. This will provide a measure of density (i.e., eggs or incubating birds per m^2). Count all eggs, but distinguish between those which were being incubated and those abandoned (i.e., eggs which were cold, broken or addled, or wedged in cracks). Using these figures together with a figure for total area occupied (derived from aerial photographs), you can then estimate population size.

For isolated stacks which cannot be climbed, or where it is particularly undesirable to disturb incubating birds (e.g., because the colony is small or the risks from predators are high), the following method can be used. Densities where there are few spaces between birds and relatively few erect, non-incubating individuals (i.e., off-duty birds), are probably fairly constant at an "average" maximum density figure of 20 pairs/m^2. This method can be used together with the total area occupied to estimate population size.

Example 1: Funk Island, Nfld. An extremely large colony of Common Murres, composed of three discrete sections (Figs. 4 and 5). The area occupied by each section was measured from an aerial photograph and found to total 17 049 m^2 (see Fig. 4 and Table 2). On the basis of counts of eggs and chicks, the density of breeding pairs was measured using 10 rope quadrats, 2 × 3 m, which provided the estimates of population size given in Table 2.

Example 2: Gannet Islands, Labrador. Here Common Murres are distributed in a large number of relatively small breeding groups. Because of this, very large black-and-white aerial photographs (Fig. 10) must be used to estimate the area covered by incubating birds. Ground counts showed that

Table 2
Distribution and estimate of population size of Common Murres at Funk Island, 1972

Sub-colony	Area occup. (m^2)	Mean density (pairs/m^2)	No. breeding pairs
Southwest	6483	23.5	152 350
Central	6187	25.3	156 531
Indian Gulch	4379	20.0*	87 580
Totals	17049		396 461

* Estimate only; counts not made.

breeding groups consisted of mainly incubating birds (i.e., a bird:egg ratio of 1:1) and that the density of eggs/m^2 was similar to Funk Island's.

4. Boulder-scree and cave colonies

Birds in these habitats are very difficult to count. Fortunately, as far as we are aware, such colonies are relatively infrequent and rarely hold large numbers of birds. Perhaps the only feasible way to determine the order of magnitude of scree-and-boulder colony size is to make a number of counts of individuals and compare annual maxima. There is no obvious method of counting birds in cave colonies.

Figure 10
Part of Common Murre flat-top colony at Gannet Islands, Labrador, 1978. This aerial photograph shows fragmented nature of breeding groups. Photographic coverage of this type, of the entire colony together with density values for breeding groups, would be necessary to estimate the size of this colony (see Fig. 6)

Population status

To detect changes in population status, one must first select study colonies and then study plots within them. We use two methods employing study plots for estimating population status (see Fig. 1b). The full-scale method (referred to here as type I) provides the most accurate measure of the number of breeding pairs in a particular area, but is very time-consuming because an observer has to be present at the colony for at least 6 weeks, from just before the start of egg-laying until 10 days after it ends. However, the observer can obtain additional data on the timing of hatching, fledging and overall breeding success by staying until the end of the breeding season.

The second method (type II) requires an observer at the colony for about 10 days during the census period. Since counts are not particularly time-consuming, an observer can count several study plots each day.

1. Study colonies

Each organization (government or independent body) responsible for executing and co-ordinating counts of seabirds must decide, within its own geographic area of concern, the locations of representative study colonies. Ideally, study colonies should be located throughout the species' ranges, but for economic and logistic reasons this is not always feasible. Since financial resources and manpower are limiting, it is important to consider the location of study colonies rather carefully. As far as possible, colonies selected for monitoring the population status of a species through a large geographic area should together satisfy the following criteria.

(1) Choose easily accessible sites, such as mainland colonies, islands that are easy to reach, or islands with either resident wardens or other individuals who could conduct the counts.

(2) Include sites within areas which are vulnerable; for example, populations breeding or wintering in areas with offshore drilling or commercial fishery developments.

(3) Include a number of control colonies which are not currently at risk for purposes of comparison.

(4) Colonies should be spaced so as to cover as much of the range as possible. Be sure to select some study colonies at the edge of the range, since colonies in those areas may be the first to respond to changes in environmental conditions. The decline in Common Murres in the northeast Atlantic over the last 30–40 years was most pronounced towards the southern limit of their distribution (Cramp *et al.* 1974).

2. Study plots

Careful selection of study plots is essential to the success of these two methods. Ideally, study plots should be selected only by experienced observers, and the plots must meet the following criteria.

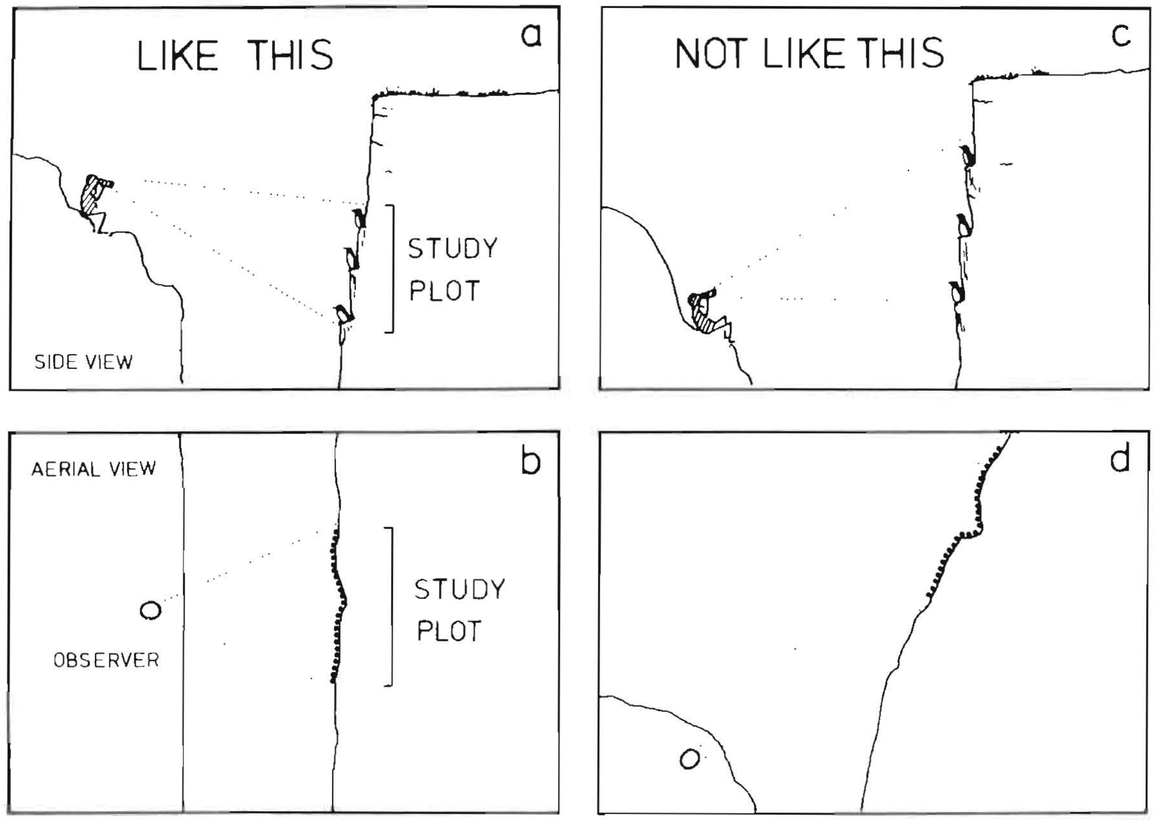
(1) *Location and characteristics of study plots.* Counts of types I and II can be made only at cliff colonies, where birds breed in single ranks on narrow ledges or on many small ledges. Study plots must be clearly visible from a suitable and safe viewing location, where an observer can look down on to the breeding birds (Fig. 11). Mark the position of the observer in some way to ensure that precisely the same position is used from year to year. This should be sufficiently close to provide a clear view of each bird, but far enough away that the birds are not disturbed.

(2) *Numbers of birds per study plot.* Each plot must be limited to a manageable number of birds; we suggest in the order of 100 individuals (equivalent to 70–80 breeding pairs). Study plots should be chosen so that all birds and their breeding sites are clearly visible — do not use particularly dense clumps of birds.

(3) *Distribution and number of study plots per colony.* The number of plots at each colony will depend partly upon the size of the colony and partly upon the time or manpower available. Ideally, larger colonies should have a greater number of study plots than smaller ones. We suggest one study plot per 1000 birds up to a maximum of 10 plots. Study plots should be selected from areas both at the centre and the edge of the colony, with others placed through the remainder to form a series which would allow differences within the colony (centre, middle or edge) to be detected.

An important assumption implicit in the use of study plots is that they reflect changes in numbers in the whole colony. In some seabirds [e.g., Northern Fulmar (*Fulmarus glacialis*), Dunnet *et al.* 1979] numbers in different parts of a colony may change independently of each other. We have checked for this effect in the few Common Murre colonies for which we have data on a sufficient number of years, and in each case there were significant positive correlations between different study plots, suggesting that numbers at such plots change in parallel. However, investigators responsible for the analysis of numbers at study plots must be aware of the possibility that this might not always be the case. In expanding colonies, certain areas may become saturated and new areas subsequently utilized. The same effect may occur in reverse in declining colonies.

Figure 11
Correct positioning of observer for viewing and counting at study plots:
(a) side view — observer should be slightly above breeding birds;
(b) aerial view — observer should be directly opposite study plot



3. Type I: full-scale method

3.1. General details

This method involves plotting for each study plot the precise position of each egg soon after it has been laid. Ideally, the observer should have a photograph of each study plot taken the year previously, at a time when most birds had laid, to show the position of incubating birds. To accomplish this, the observer in the first year of the study should number each site as eggs are laid and, if possible, check the presence and fate of each egg on subsequent days (Fig. 12). Since inter-colony differences in the behaviour of the bird and the topography cannot be standardized, these represent irreducible contraints. However, the intensity of observation and sizes of study plots can be standardized to a certain extent. On the basis of detailed study by Gaston and Nettleship (in press), we recommend the selection of study plots containing about 80 breeding pairs and observation for about 3 h daily. This should enable you to observe about 60% of eggs each day and detect about 50% of new eggs within 48 h. It means that a single observer could monitor three plots comprising a total of 200–250 breeding pairs by working 9 h every day. The only source of inaccuracy, and it is probably slight, is the chance of missing eggs that were laid and lost before the observer had detected them. There is no practical way to measure the number lost in this manner, but in two field studies where this method has been employed, workers considered that they overlooked only a very small proportion of eggs. Moreover, since many birds replace lost eggs, the observer has a second chance to record the location of a breeding pair (Birkhead and Hudson 1977, Gaston and Nettleship in press).

In addition, the observer must count all birds present on the study plot at the same time each day during the census period, so that the relationship between the number of breeding pairs and the mean number of individuals present (k) can be calculated for a particular time of day. This value is used to determine the number of breeding pairs at study plots using type II counts.

3.2. Specific details

The procedure for type I counts is as follows.

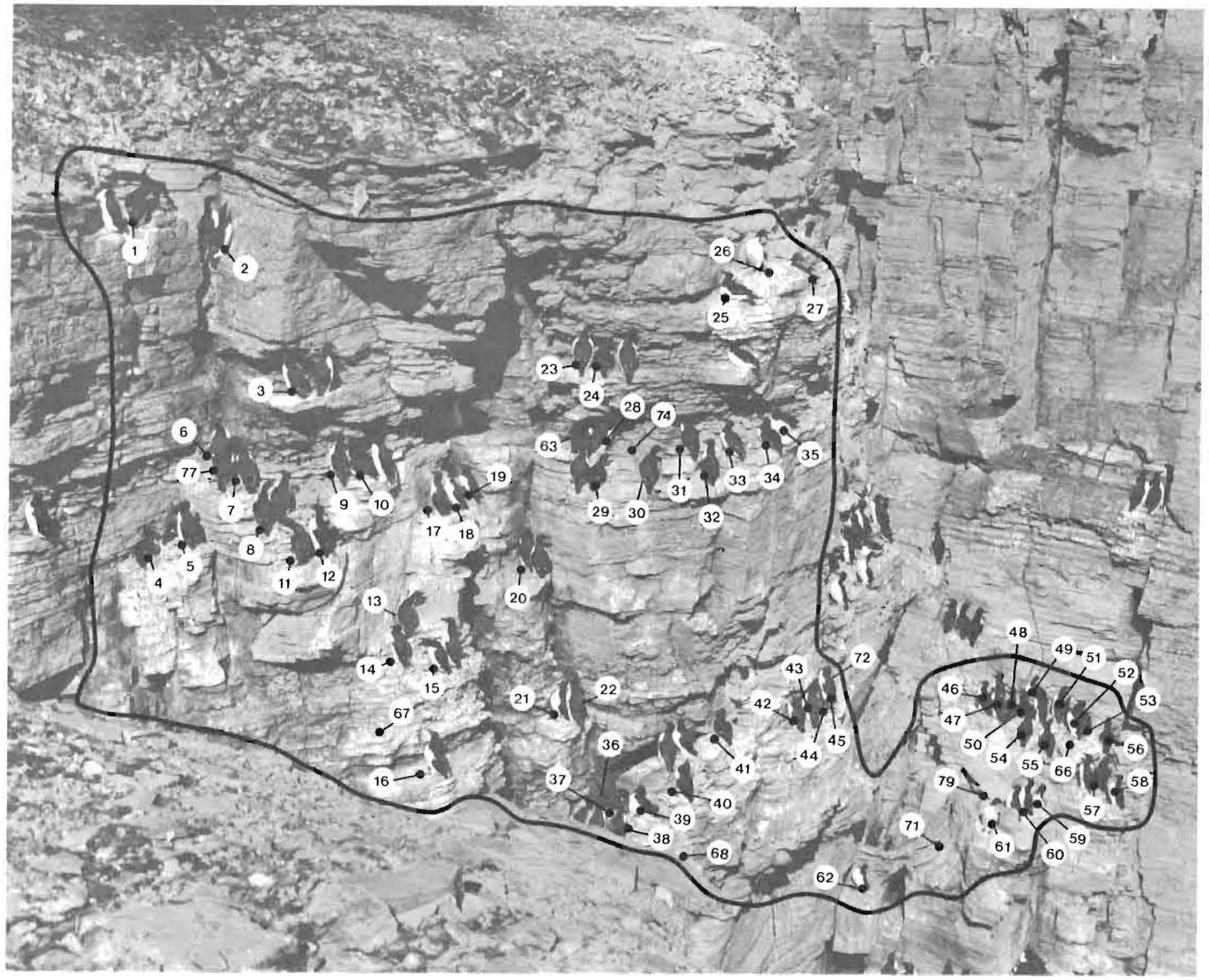
(1) Observers require a number of large, good quality, black-and-white prints of each study plot, showing the positions of incubating birds and the limits of the plot.

(2) The study plot observation point for counting birds should be fixed and identified by a permanent marker (e.g., iron stake, rock cairn) and photographed with an observer *in situ*.

(3) Observers should visit the colony at least once each day (at a standard time) prior to laying to ensure that first eggs are recorded. At most colonies of Common Murres in boreal regions, non-incubating birds leave their colony at dusk (i.e., spend the night at sea and return early next morning), and therefore evening checks may make new eggs easier to detect.

(4) Once observers have recorded the first eggs, they should revisit the plots at least once each day at a standard time. Observers should *not* assume that birds in an incubating position have an egg. Each site should be checked in turn for the presence or absence of an egg, and each site assigned a number as an egg is recorded. This method depends upon the movements of incubating birds, which expose the area beneath their broodpatch. Normal bird activity can provide the observer with a chance to see and record the presence or absence of an egg (e.g., rising slightly from their egg in order to wing-flap or turn the egg). Birds without eggs make similar movements, so do not use any activity or posture alone to decide

Figure 12
Thick-billed Murre cliff colony at Prince Leopold Island, NWT: part of study plot U showing individually numbered sites. Such plots are suitable for type I counts



whether or not an egg is present — the egg *must* be seen. Since the intensity of observation strongly affects the results obtained, you should keep a precise record of time spent daily examining the birds within each study plot.

(5) Record data in a tabular form using standard symbols as shown in Appendix 2.

(6) Egg-laying usually follows a similar pattern, with a larger number of birds producing eggs early in the laying period (i.e., a slightly skewed distribution). Continue to check sites each day for at least 40 days, to record both the fate of eggs and the appearance of first eggs at sites late in the season. If possible, continue to check each site until all chicks have fledged, since this will yield valuable information on both timing of breeding and breeding success. Note that the start of the census period should coincide with the end of egg-laying.

(7) Determine k values by making one count each day for 5–10 days through the census period (as described in the methods for type II counts given below) and calculating the mean number of individuals for each study plot. Divide the known number of breeding pairs (value derived from a completed study plot data sheet) by the mean number of individuals for each study plot to obtain k.

4. Type II: counts of individuals

4.1. General details

This much less time-consuming method is widely used in Britain (NERC 1977), but there are problems with the interpretation of counts (see below). Counts should be made between the end of egg-laying and the start of fledging.

For Common Murres breeding in boreal regions where there is a marked light-dark regime, studies at a number of colonies (e.g., Birkhead 1978, Jones 1978, Hedgren 1975, C. Bibby pers. comm., P.G.H. Evans pers. comm.) have shown that consistent diurnal patterns in colony attendance occur throughout the census period. In general terms, the pattern seems to be as follows: lowest numbers occur at night, increase after dawn, with a fairly constant level during the middle part of the day, and then decline again towards dusk. Since numbers remain fairly stable during the middle part of the day, most counts are conducted at this time over a number of consecutive days to obtain a mean of known accuracy for each study plot (NERC 1977). Such counts use the following assumptions:
(1) that diurnal patterns of colony attendance are similar from year to year; in fact it seems that diurnal patterns of attendance

are similar from year to year for a particular colony, though patterns vary between colonies (Birkhead 1978, Hedgren 1975, Jones 1978, Gaston and Nettleship in press); (2) that k values (ratio of breeding pairs: mean number of individuals) remain constant from year to year. The latter assumption is more difficult to assess because k values have been calculated in few studies. The only data for boreal Common Murres are from Stora Karlsö in the Baltic (Hedgren 1975) and Skomer Island (Birkhead 1978), and these show similar k values within each colony from year to year. However, among Thick-billed Murres at Prince Leopold Island, NWT, marked differences in k values occurred between 1976 (k = 0.72) and 1977 (k = 0.62) (Gaston and Nettleship in press). Clearly, we need much more information before we can assess the "normal" variation in k values between years. Furthermore, since k values vary from colony to colony, extrapolation from one to another could be extremely misleading. For example, between 1973–1975 the Skomer value was 0.67, but at the Gannet Islands in Labrador, at the same phase of the breeding cycle, k values in 1978 were much closer to 1.0. Application of the Gannet Islands k values on Skomer Island would result in overestimation by about 50% (the reverse would underestimate by about 30%).

Another problem is that differences in mean counts between years could be statistically significant, but would not necessarily mean that a change in the breeding population had occurred. This could happen in a number of ways due to: (1) differences between years in weather conditions (see Discussion), (2) changes between years in the size of the non-breeding population owing to differences in breeding success and juvenile mortality, and (3) differences between years in the amount of time off-duty breeding birds and non-breeders spend at the colony, perhaps as a result of differences in the relative abundance of food. For example, for Thick-billed Murres at Prince Leopold Island, NWT (Gaston and Nettleship in press), the number of breeding pairs on study plots in 1976 and 1977 was almost identical, but there was a 10% difference in the mean number of birds counted during the census periods of the 2 years. As a result, k values also varied between years.

Variation of the size observed at Prince Leopold Island may occur frequently, and emphasizes the need for extreme caution in interpreting counts. In particular, we believe that it is dangerous to draw conclusions about population changes from just 2 years' counts. Annual monitoring over a number of years will provide the most sensitive measure of population status. For each year a mean $\pm$ SD of 5 to 10 counts made during the census period, at the same time each day, for each study plot will provide an index of the status of the population.

For high arctic colonies, where there is only slight diurnal variation in light intensity, there is no 'best' time to make counts, though peaks in attendance should be avoided (e.g., bird numbers were consistently higher in the evening at Prince Leopold Island). Thus it is essential for observers to determine the fluctuations in numbers over a 24-h period on at least two occasions during or immediately before the census period (Gaston and Nettleship in press).

4.2. Specific details

The procedure for type II counts is as follows.

(1) Observers require a large-scale photograph of each study plot, with the limits of each plot clearly marked on it. Accuracy will be increased if the observer is familiar with the study plot (Gaston and Nettleship in press), and if possible the observer should have visited the plot earlier in the season to make a number of practice counts.

(2) The observation point for counting birds should be fixed and identified by a permanent marker (e.g., iron stake, rock cairn) and photographed with an observer *in situ*.

(3) Counts of individual birds should be conducted at the same time each day for 5–10 days during the census period.

(4) On at least two occasions the observer should count individual birds present on the study plot at 2-h intervals over the entire daylight period.

(5) The observer should complete a census form for each daily count at each study plot (App. 1).

Discussion

We have described a census sytem which, at the first level, will enable observers to estimate population size in different colony types. At a second level, the methods described will provide figures from which we will be able to assess population status. We have emphasized the need for a unified approach with standardized procedure, so that in 50 years' time, if need be, we can produce counts which are directly comparable with those being made now (App. 3).

The next point concerns the availability and use of observers. At certain study colonies, resident wardens and enthusiastic amateurs living near the colony would be able to conduct type II counts. In addition, both kinds of observer would be in a position to make trial counts prior to the census period as suggested earlier. It may also be possible for co-ordinating organizations to employ biologists specifically to make type II counts at certain remote study colonies.

1. Frequency of counts

From our experiences of trying to interpret census figures collected many years apart, we believe that type II counts should be conducted annually at accessible colonies and every 2–3 years at those colonies which are less easily accessible and/or more expensive to reach.

Annual monitoring has several advantages: (1) it facilitates interpretation of type II counts in that one can use statistics to detect trends within the data, and (2) it provides a more sensitive method of detecting dramatic population changes. Rapid detection of such changes may mean that we can determine the cause of the decline and, possibly, prevent any further decrease. Clearly, monitoring on a less frequent basis makes interpretation of counts more difficult, and reduces the chances both of rapidly detecting a decline and of being able to do something about it.

2. Sources of error

Several sources of error arise in type II counts. First, heavy seas, high winds (greater than force 5, Beaufort scale) and heavy rain all depress counts and can make counting difficult. Environmental factors must be recorded at the time of each count (App. 1). Fog can obscure study plots and prevent any count being made. However, an observer might be able to compensate by making another count later in the censusing period, after the count would normally have been finished. Second, disturbance by the close approach of other observers, low-flying aircraft and predators can lower the counts. Most of these factors can be checked and appraised if the observer is present for some time prior to or after making the count.

Finally, observers differ in their counting ability. This is undoubtedly a real problem, but error can be reduced by: (1) recording each observer's name and address, so that those responsible for analyzing and interpreting the counts can record changes of observer between years; (2) choosing good study plots in the first instance, so that all birds are clearly visible, which will undoubtedly reduce inter-observer error; (3) arranging for a 1-year overlap between observers — this would enable them to compare counts and provide the analyst with some indication of possible differences between the counting ability of the two observers; and (4) conducting counts conscientiously. We know of instances in which observers 'farmed out' their counting responsibilities to inexperienced persons, so that prescribed procedures were not followed and spurious results were obtained.

To summarize, efforts in applying census techniques on murres for management purposes must focus upon determining both population size and population status. It is essential to know precisely when bird numbers are changing, because rapid detection of such changes permits an early assessment of their significance, and affords the opportunity to do something about them after identification of possible causes. Improved methods for estimating species population size at individual colonies should provide the means for a more precise measure of overall numbers, but population status can only be determined by using representative study plots within the colony area. We recognize that the application of population status methods (types I and II) are demanding both in time and effort. Nevertheless, we view these methods as the only available approach to accurate monitoring of population levels of murres in a way that enables biologists and wildlife managers to identify species' problems and the factors responsible.

Appendices

Appendix 1
Study plot recording form to be completed for all murre counts; i.e., counts to be used to estimate population size and status (form modified from Nettleship 1976 and Jones 1978)

Item	Information
1. Observer	name and address
2. Colony	name and location
3. Study plot	number, letter, or name designation
4. Study plot location	grid reference and position (latitude and longitude)
5. Date of count	day, month and year
6. Time of count	start and finish times using GMT—24-h clock; maintain precise record of actual time spent daily observing the study plot (minutes/hours)
7. Species	*Uria aalge* or *U. lomvia*
8. Total count	number of individuals counted
9. Observation method	binoculars or telescope (with or without tripod) or unaided eye
10. Photography	details of photograph(s) taken and filing location
11. Weather during count	details of cloud cover (clear 0/10 to overcast 10/10) and precipitation (none, drizzle, light rain, heavy rain, intermittent showers, fog, hail, snow, other conditions — give details)
12. Wind during count	direction (N, NE, E, SE, S, SW, W, NW) and speed (assess using an anemometer or according to Beaufort scale)
13. State of sea during count	from flat calm (no waves) to rough sea (waves over 6 m) — elaborate where necessary using the Beaufort scale
14. State of tide during count	high, low, half-ebb, half-flood, or storm
15. Count visibility	good, fair or poor, and study plot in sun or shade
16. Phase of breeding cycle	comments and details of counts of eggs and chicks
17. Disturbance factors	none, or comments and details of source (shooting, aircraft, etc.)

Appendix 2
Example of study plot data sheet for recording data of type I (full-scale method) counts using standard symbols: Prince Leopold Island, NWT, study plot U, 1977 (Gaston and Nettleship in press)

	Site number*							
Date	8	9	10	11	12	13	14	15
28 June	0**	0	0	0	0	0	0	0
29	0	$\underline{e}$	e?	0	0	0	$\underline{e}$	0
30	$\underline{e}$	√ok	e?	0	$\underline{e}$	0	√ok	0
1 July	√	√	0	0	√ok	0	√	$\underline{e}$
2	√	√ok	e?	0	√	0	√ok	√ok
3	√ok	√	$\underline{e}$	$\underline{e}$	√ok	$\underline{e}$	√ok	√ok
4	√	√ok	√	√ok	√	√ok	√ok	√ok
5	√	√ok	√ok	√ok	X	√ok	√ok	√ok
6	√	√ok	√	√	0	√ok	√ok	√ok
†								
17	√	√ok	√	X	0	√ok	X	X
†								
20	√	√	√	0	$\underline{e}_r$	√ok	0	0
21	√	√	√	0	√ok	√ok	0	0
†								
31	√ok	C	√	0	√ok	√ok	0	0
1 August	√ok	√ok	√	0	√ok	√ok	0	$\underline{e}_r$
2	√ok	√ok	√	0	√	√ok	$\underline{e}_r$	√
†								
18	0	F	√ok	0	√ok	√ok	√ok	√ok

* Each site represents location of one breeding pair (see Fig. 12 for exact position of sites within study plot U).
** Key to symbols: 0, definitely no egg or chick present; $\underline{e}$, egg seen for first time; e?, bird sitting but egg not seen; $\underline{e}_r$, replacement egg seen for first time; √, status apparently unchanged—for site where egg or chick had been recorded previously; √ok, status unchanged, egg or chick definitely seen; C, chick recorded for first time; F, chick fledged; X, egg or chick disappeared prematurely.
† Data collected for missing days but not included on sample sheet.

Appendix 3
Records and materials for each study plot in each colony to be held by co-ordinating organization (government or independent body)

Item	Information
1. Colony	name, precise location of colony and map reference
2. Study plots	(a) details of precise location of *each* study plot including large-scale map with exact positions identified (each plot must be numbered, lettered or named) (b) details of identification marker at each study plot (e.g., metal stake, rock cairn) (c) original negative (taken when study plot first established) and photo-prints of each study plot showing limits of plot and subsections (where used) for counting. (Note: plot boundaries should follow geological features rather than being straight lines: study plot photos are essential to successful counts by observers.) (d) negatives and photo prints of study plots taken in subsequent years
3. Count data	copies of all raw data and completed count forms (App. 1)
4. Summary form	summary sheets for each study plot giving mean ± SD and the number of counts for each year

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