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Aims and effort in seabird monitoring: an assessment based on Norwegian data

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Environmental monitoring programmes are often confined by limited funds. By use of Monte Carlo simulations and GLM procedures, it is examined to what extent trends documented for some Norwegian seabird populations could have been obtained with less field effort. Changes in both breeding and wintering numbers are analysed. To minimise bias from merging different populations, only regional trends are considered. The results strongly suggest that some populations can be monitored adequately by less effort than that applied, i.e. still ensuring that the counts will reveal the various sources of variation in reliable proportions to the total variance in bird numbers. This may be achieved either by reducing the number of plots or by counting them less frequently, for example in alternate years only. General advise with respect to what changes deserve special attention from conservation authorities, and a discussion of the principles and considerations which should be taken into account when designing monitoring programmes for seabirds are presented.

Key words: seabirds, monitoring, assessment, population trends, Norway

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In a management perspective, the purpose of seabird monitoring programmes is to document the state and trends of selected populations, thereby enabling a targeting of attempts to counteract undesirable tendencies as early as possible. However, changes in seabird populations result from the combined effects of adult mortality, emigration and recruitment rates (which in turn are affected by a number of factors, including both stochastic and long-term climatic changes), as well as factors directly imposed on their environment by human interference (e.g. Nisbet 1989, Nettleship 1991, Cairns 1992, Croxall & Rothery 1991, Wooller et al. 1992).

The traditions of Norwegian seabird monitoring go back to the early 1960s when the late Einar Brun (Brun 1965, 1966, 1969a,b) paved the way by censusing most of the major breeding cliffs for auks (Alcidae) along the mainland coast. Brun was the first to use systematic census methods for cliff-nesting seabirds in Norway. By repeating many of his counts in the 1970s, he was able to demonstrate marked changes in several species and colonies (Brun 1979), thus illustrating the most important purpose of population monitoring: namely to document notable trends in numbers.

A dramatic decrease in breeding numbers of common guillemots *Uria aalge* in the 1960s and 1970s (Brun 1979) caused much concern and was one of the main reasons why the Norwegian Directorate for Wildlife and Freshwater Fish (now the Directorate for Nature Management) organised a national seabird programme (The Seabird Project) in 1979-1984. The programme was aimed at "gathering data and material to use as a basis for the estimation of population sizes, detection of population changes and the effects of negative factors thereon, plus suggesting action which would result in a reasonable management of seabirds as a national and international resource" (Røv et al. 1984).

The monitoring of breeding seabirds in Norway was expanded and reorganised in 1988 (Lorentsen 1990) to involve nation-wide monitoring of eight species and regional monitoring of another six species. Except for the Brünnich's guillemot *Uria lomvia*, which has only marginal populations in mainland Norway, and the common eider *Somateria mollissima*, which is only monitored in southeastern Norway, we report results for all these species (see Table 1 for species names). Monitoring of wintering seabirds was primarily motivated by the concern for Norway's internationally important winter populations of great northern diver *Gavia immer*, white-billed diver *G. adamsii*, red-necked grebe *Podiceps grisegena*, common eider, king eider *Somateria spectabilis*, Steller's eider *Polysticta stelleri*, long-tailed duck *Clangula hyemalis* and velvet scoter *Melanitta fusca* (Røv et al. 1984). We therefore restricted our analyses to those species, but omitted the white-billed diver due to its small and highly variable numbers (Nygård 1994). In practice, however, all marine birds observed on localities within the 10 fixed counting areas (see Table 2) were monitored. The monitoring results for breeding populations have been reported annually (the latest by Lorentsen 1995), and an analysis of the national trends for wintering seabirds was recently presented by Nygård (1994).

Any environmental monitoring programme should be subjected to critical evaluations from time to time, to ensure that it will, in due time, produce answers to the questions it aims to address, that these questions are still relevant, and that the answers are sought in a rational way with respect to available resources. Using results from an assessment of Norwegian seabird monitoring, this paper deals with statistical and strategic considerations of general relevance in this context. The distance between the two points farthest apart on the Norwegian mainland coast, the lighthouses at Lista and Hornøy, is almost 1,800 km (or equal to the distance between London and Gibraltar). To minimise the risk of bias from merging different populations of each species, we therefore restrict our analyses to focus on regional trends only. We aim at illustrating what trends can be unveiled from the Norwegian monitoring data, and to examine by more extensive statistical methods to what extent they could have been obtained with less field effort. The results of this exercise are discussed on the background of what we consider to be the principal purpose of the activity, which can be summarised as follows:

The monitoring of seabird populations should, in as short a time scale as possible, document any significant changes in numbers of any population recognised as being particularly important, either from a conservation point of view (e.g. when numbers are of national or international importance, or when the population is threatened) or when the population is known to play a key role in its natural environment (e.g. by its transport of nutrients from sea to land). This is the ideal objective. In practice, the establishment of any monitoring programme necessitates a number of shortcuts to make the most out of the available funds. In this process, representativeness and realism are key aspects. Consequently, the monitoring of seabirds should be focused on a set of species for which appropriate monitoring methods are available and which reflect the variety of coastal habitats, ecological adaptations, environmental threats, and special concerns. No doubt, any such selection will be controversial in a cost-benefit perspective. Although the principal aim of monitoring is to document the trends, and not to explain them, we argue that seabird ecology and life-history patterns make it necessary to consider a number of other aspects when deciding on the distribution and sampling frequency of study plots.

Methods

Field methods

In the breeding season, Norwegian seabirds are monitored using internationally standardised methods (e.g. Birkhead & Nettleship 1980, Evans 1980, Hanssen 1982, Wanless & Harris 1984, Anker-Nilssen & Røstad 1993, Walsh et al. 1995), and a Norwegian manual was prepared for use by the field personnel (Lorentsen 1989). For most species monitored, the counting unit is an apparently occupied nest site, and the counts are made as soon after egg-laying as possible. However, common eider, black guillemot *Cepphus grylle* and some gull species *Larus* spp. are monitored by counting the number of adults present in the breeding area, and for common eider (which is not formally included in the programme) such counts are restricted to include adult males only. Common and Brünnich's guillemots are counted late in the brooding period or shortly after hatching. For these two species, the counting unit is an individual on a ledge. In order to minimise the effects of day-to-day variations, their numbers are averaged from 5-10 counts made on different days (e.g. Stowe 1982). The other species are only counted once each year. For all colonial species except auks (Alcidae) and kittiwakes *Rissa tridactyla*, whole colonies are counted. Auks and kittiwakes are counted in fixed study plots, including (where feasible) at least 10% of the total colony area (Evans 1980). All study plots are permanently marked in the field, and they are also documented in detailed photographs and maps to ensure exact repeatability at any time. The documentation is filed at the Norwegian Institute for Nature Research (NINA) who is in charge of the seabird monitoring in Norway.

Wintering seabirds are monitored in 10 different areas spread along the coast from Østfold to Varanger (e.g. Nygård 1994, see Table 2). The counting unit is always an individual bird situated within a geographically delimited subarea referred to as a locality. The borders of localities are documented on maps, and the same localities are counted each year, usually by the same persons. When possible, individual birds are sexed and aged. The counts are performed during 2-3 weekends in late January and early February, preferably when weather conditions are calm.

Statistical analysis

The statistical probability (P) of a population change was computed using Monte Carlo simulations. By this method we compared the linear regression slope estimated for the real data set with the corresponding slopes for up to 10,000 different randomised sequences of the same data values. The P-value for a positive or negative trend was then computed as the fraction of the generated slopes which were greater or smaller than the real slope, respectively. Results of Monte Carlo simulations when N (here the number of census years) is small should be treated with great caution. When $N = 3$ only six permutations are possible and the lowest P-value obtainable is 0.166 (1/6), while these numbers rise to 24 permutations and $P = 0.042$ when $N = 4$. Also, Monte Carlo simulations may fail to discover non-linear trends, especially when N is large. In such cases, the most proper methods involve breaking up the data into several linear segments that are treated independently (Underhill & Prŷs-Jones 1994).

Considering the primary purpose of seabird monitoring, which is to detect population changes as soon as possible, we believe that the act of rejecting a true population trend (type-I error) is generally more severe than accepting a false one (type-II error). We therefore chose 0.1, 0.05 and 0.01 as the three levels of significance for our trend analyses.

The power of the Monte Carlo simulation procedure described above is limited because it is based on only one data point (the total number of birds) per year, but there is no other powerful trend analysis that can be used on such simple data sets. However, in some colonies, and within all the winter areas, several sample plots or localities have been counted each year. Using the within-year variation in numbers between these sampling areas (hereafter referred to as plots) we were able to apply much more powerful models and statistics to detect significant variation in bird numbers over the years. Such analyses were restricted to a selection of species and areas, including only the colony data for common guillemots at Runde (Møre and Romsdal), puffins *Fratercula arctica* at Røst (North Nordland) and kittiwakes at Hornøy (East Finnmark), and winter data for common eiders in Trondheimsfjorden (Sør-Trøndelag) and red-necked grebes at Smøla (Møre and Romsdal). This selection is meant to reflect the most conspicuous ecological, geographical and temporal diversity of seabird populations within Norway.

We examined the importance of within-year variation in two ways. First, we examined the components of variance in bird numbers (i.e. including variance both within and between years) while selecting an increasing number of plots. When more than 5,000 different combinations of plots were possible, 500 combinations were selected at random using a Monte Carlo procedure, otherwise all possible combinations of plots were used. Data for all years in which all plots were counted were included in each simulated data set, which were examined one by one using two-way ANOVA (without replication). For each number of plots the test results were used to calculate the mean sums-of-squares (SS) partitioned into its three components: year SS, plot SS and remainder SS. The values were expressed as percentages of the total SS to allow a direct comparison between species. The relationship between these parameters and the number of plots will indicate how many study plots should be counted each year in order to detect any real variation in bird numbers between years.

Secondly, we used general linear models (PROC GLM, Littell et al. 1991) in order to detect the effect of using only counts of birds from alternate years and of reducing the number of study plots counted each year. Such analyses will give additional information concerning the level of effort needed to detect seasonal trends and thus how future monitoring programmes for seabirds should best be designed. GLM is designed for normally distributed data. Since counts of birds are not normally distributed we ranked the data before applying the tests. This procedure is more powerful than the traditional nonparametric statistics and is recommended as a useful tool for solving ecological problems (Conover & Iman 1981).

Results

Monitoring of breeding seabirds

Among the breeding seabirds, the overall population trends differed highly from species to species as well as between different regions (Table 1). This was also evident for the species and areas selected for the more detailed analyses (Fig. 1). Fulmars *Fulmar glacialis* and gannets *Sula bassana* increased considerably in numbers during the monitoring period, but the fulmar is only counted in the southernmost colonies. The cormorant *Phalacrocorax carbo carbo* increased in most parts of the country, while shag *P. aristotelis* numbers increased in southern and central Norway only and may have decreased further north. There was an extreme year to year variation in the number of breeding pairs in the large shag colony at Lille Kamøy (ranging from 0 to 2,400), and the colony was empty during 1986-87 and 1992-94. Common gulls decreased in Telemark and maybe also in Nordland,

Table 1. Population trends for 12 breeding seabird species at individual localities or within different regions along the Norwegian coast. The significance of each trend was tested using Monte Carlo simulations. Where the number of study plots is zero, the whole locality or area was counted.

Species	Locality or area	County	Time period	No of years counted	No of colonies/ study plots	Annual change (%)	Trend	Sign. (P)
Fulmar	(several)	Rogaland	1973-94	20	2/0	20.9	+	<0.001
Gannet	Runde	Møre & Romsdal	1946-91	18	1/0	12.9	+	<0.001
	Hovsflesa	Nordland	1979-91	6	1/0	10.4	+	0.054
	Skarvklakken	Nordland	1967-91	14	1/0	24.1	+	<0.001
	Syltefjordstauran	Finnmark	1961-90	19	1/0	19.2	+	<0.001
Cormorant	Sula	Sør-Trøndelag	1979-94	11	4/0	16.5	+	0.005
	Grogna	Sør-Trøndelag	1980-94	12	10/0	10.9	+	0.007
	Froan	Sør-Trøndelag	1974-94	11	9/0	0.22	0 (+)	0.622
	Melstein	Sør-Trøndelag	1979-94	12	1/10	6.2	+	0.002
	Vikna	Nord-Trøndelag	1979-94	12	7/0	6.4	+	0.025
	Sklinna	Nord-Trøndelag	1979-94	12	5/0	0.5	0 (+)	0.479
	S Helgeland	Nordland	1980-94	9	7/0	5.6	+	0.053
	Vega	Nordland	1982-94	10	8/0	6.5	+	0.014
	S of Træna	Nordland	1985-94	9	2/0	9.9	+	0.041
	Træna-Myken	Nordland	1985-94	8	5/0	9.0	+	0.072
	Vesterrålen	Nordland	1983-91	6	1/0	2.9	0 (+)	0.284
	W Finnmark	Finnmark	1983-94	10	3/0	4.1	0 (+)	0.437
	Kongsfjord	Finnmark	1987-94	8	3/0	10.1	+	0.068
Shag	(several)	Rogaland	1979-94	10	4/0	16.3	+	0.003
	Sklinna	Nord-Trøndelag	1984-94	10	3/0	7.1	+	0.006
	Ellefsnyken, Røst	Nordland	1985-94	10	1/0	-0.3	0 (-)	0.329
	(several)	Troms	1985-93	6	3/0	-4.2	0 (-)	0.300
	Lille Kamøy	Finnmark	1985-94	9	1/0	-20.8	0 (-)	0.254
Common gull	(several)	Telemark	1974-94	21	24/0	-6.8	-	0.001
	(several)	Telemark[1]	1989-94	6	8/0	-4.0	0 (-)	0.287
	(several)	Vest-Agder	1989-94	6	2/0	3.4	0 (+)	0.278
	(several)	Nordland	1989-93	5	6/0	-23.9	0 (-)	0.127
Lesser black-backed gull	(several)	Telemark	1974-94	21	16/0	2.1	+	0.047
	(several)	Telemark[1]	1989-94	6	7/0	-0.6	0 (-)	0.309
	(several)	Vest-Agder	1989-94	6	10/0	4.1	0 (+)	0.111
	(several)	Rogaland	1988-93	5	2/0	-9.2	0 (-)	0.145
	Sortna	Møre & Romsdal	1986-94	8	1/0	3.1	0 (+)	0.318
	(several)	Nord-Trøndelag	1980-88	5	2/0	-16.0	-	0.068
	(several)	Nordland	1980-94	7	11/0	-12.7	-	0.070
Herring gull	(several)	Telemark	1974-94	21	16/0	8.1	+	0.001
	(several)	Telemark[1]	1989-94	6	8/0	7.3	0 (+)	0.234
	(several)	Vest-Agder	1989-94	5	5/0	7.9	0 (+)	0.131
	(several)	Nordland	1989-93	5	2/0	26.6	+	0.031
Great black-backed gull	(several)	Telemark	1974-94	21	25/0	5.7	+	0.002
	(several)	Telemark[1]	1989-94	6	7/0	50.4	+	0.098
	(several)	Vest-Agder	1989-94	5	3/0	26.1	0 (+)	0.163
	(several)	Nordland	1989-93	5	7/0	17.1	0 (+)	0.165
Kittiwake	Runde	Møre & Romsdal	1980-94	11	1/10	-4.0	-	0.001
	Sklinna	Nord-Trøndelag	1980-94	13	1/1	-7.9	-	0.023
	Vedøy, Røst	Nordland	1980-94	12	1/5	-0.9	0 (-)	0.165
	Hjelmsøy	Finnmark	1991-94	4	1/2	-7.9	0 (-)	0.373
	Hornøy	Finnmark	1982-94	11	1/6	-1.8	-	0.054
Common tern	(several)	Telemark	1974-94	21	16/0	-2.8	-	0.010
	(several)	Telemark[1]	1989-94	6	15/0	-10.8	0 (-)	0.146
	(several)	Vest-Agder	1989-94	6	2/0	-17.4	0 (-)	0.149
Common guillemot	Runde	Møre & Romsdal	1980-94	11	1/25	-4.1	-	0.045
	Vedøy, Røst	Nordland	1981-94	10	1/3	-10.3	-	0.063
	Hjelmsøy	Finnmark	1989-94	6	1/9	-20.4	-	0.049
	Hornøy	Finnmark	1982-94	11	1/4	-14.6	-	0.064
Puffin	Runde	Møre & Romsdal	1980-94	10	1/11	1.1	0 (+)	0.122
	Sklinna	Nord-Trøndelag	1981-94	14	1/2	-0.2	0 (-)	0.226
	Hernyken, Røst	Nordland	1979-94	16	1/415	-6.5	-	0.002
	Anda	Nordland	1981-88	4	1/8	-1.5	0 (-)	0.163
	Bleiksøy	Nordland	1988-93	4	1/46	-1.6	0 (-)	0.208
	Hornøy	Finnmark	1982-93	9	1/6	2.7	+	0.031

[1] Based on nest counts

although the latter trend was not significant. Populations of lesser black-backed gull *Larus fuscus intermedius* in South Norway seemed fairly stable, whereas the populations of the northern subspecies *L. f. fuscus* have decreased so severely that there is a risk they may disappear. In contrast, both the herring gull *L. argentatus* and the great black-backed gull *L. marinus* tended to increase in all colonies monitored. The kittiwake decreased in most colonies along the coast. Large annual fluctuations make common terns *Sterna hirundo* difficult to monitor, but the population in Telemark has decreased significantly. Common guillemots decreased significantly along the entire coast. In northern Norway, dramatic reductions in numbers took place during 1985-87, when the stock of Barents Sea capelin collapsed. During those years, breeding numbers dropped by 80-90% and more than half the population was lost (e.g. Anker-Nilssen & Barrett 1991). The puffin was stable in the southwest and increased slightly in eastern Finnmark (Hornøy), whereas colonies in Lofoten and Vesterålen, and particularly at Røst which hold the largest populations, have decreased markedly (Anker-Nilssen & Røstad 1993, Anker-Nilssen & Øyan 1995).

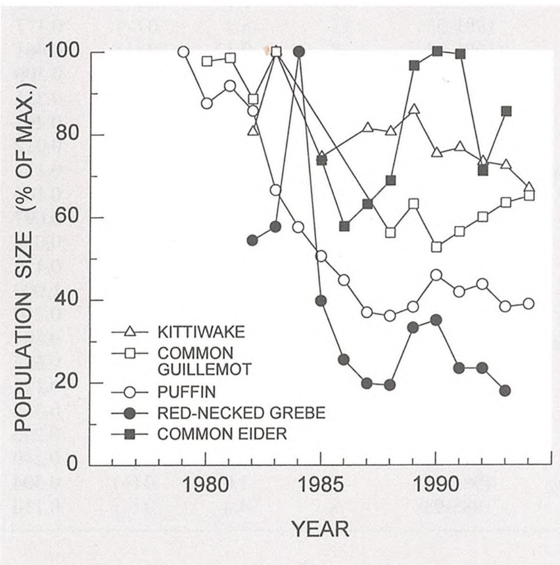


Figure 1. Variation in numbers (expressed as percentages of the maximum year) within the monitoring plots for kittiwakes breeding at Hornøy (N_{max} = 2,123 apparently occupied nest sites), common guillemots breeding at Runde (N_{max} = 2,791 individuals) and puffins breeding at Hernyken (N_{max} = 2,993 apparently occupied burrows) and within the monitoring localities for red-necked grebes wintering at Smøla (N_{max} = 274 individuals) and common eiders wintering in Trondheimsfjorden (N_{max} = 8,531 individuals, see Tables 1 and 2). Only plots counted in all years are included. For common guillemot, the mean of the 7-10 annual counts is used. The results of more detailed statistical analyses are presented in Table 3.

Monitoring of wintering seabirds

In general, there have been few significant regional changes in the wintering populations of the seven focal species of the programme (Table 2). No significant trends were found for the great northern diver, but the results may suggest that the number of birds wintering south of Troms, which is probably the northern limit of the wintering range, increased slightly. The trend was negative for red-necked grebe in most areas, although it was only significant at Jæren and Smøla. For velvet scoter there was no general pattern, but the number of birds wintering in Smøla and Salten has decreased. The long-tailed duck tended to decrease in all areas except Østfold. There were no uniform trends in the wintering populations of any of the three eider species, but numbers of common eider decreased significantly both at Smøla and in Troms.

The significance of plot numbers

For all five species analysed, a decreasing proportion of the variance was explained by year, while the effects of plot numbers and other factors became proportionally more important when the number of plots was increased (Fig. 2). However, all ratios levelled off before the plot number reached 10-15, indicating that counting a larger number of plots will rarely increase the reliability of a trend analysis. Even for our kittiwake example, which had only six plots, the ratios were stabilised. Among the example populations, variation which could not be attributed to plot numbers or year (remainder SS) was 3-10 times more important for wintering than for breeding populations and amounted to 40-50% of the total variance. Much of this variation is probably due to the birds being far less philopatric to their wintering sites than to their breeding sites. As it is impossible to control for such variation in the analyses, it severely reduces the possibility of documenting significant trends for wintering populations.

The significance of counting frequency

For the five species studied, the GLM procedure on ranked data (Table 3) revealed the same population trends as found by Monte Carlo simulations (see Tables 1 and 2), but the trends were substantiated to a much higher probability. It was also evident that when using this variance in bird numbers between plots, the trends could be detected even after halving the number of plots or localities counted or reducing the count frequency to every second year. As could be expected, there were also significant differences in bird numbers between plots, but after controlling for this variation the year effect was still evident in most cases. For common eider, however, no year effect was found, but the counts in Trondheimsfjor-

Table 2. Population trends for a selection of seven seabird species wintering within the regular counting areas along the Norwegian coast. The significance of each trend was tested using Monte Carlo simulations.

Species	Area	County	Time period	No of years counted	Annual change (%)	Trend	Sign. (P)
Great northern diver	Vest-Agder	Vest-Agder	1987-93	5	6.1	0 (+)	0.314
	Jæren	Rogaland	1980-93	13	3.2	0 (+)	0.342
	Smøla	Møre & Romsdal	1982-93	12	1.5	0 (+)	0.490
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-90	2	0	0	1.000
	VestvÂgøy	Nordland	1990-93	3	48.1	0 (+)	0.328
	Troms	Tromsø	1982-87	4	-4.8	0 (-)	0.665
Red-necked grebe	Østfold	Østfold	1982-85	3	0	0	1.000
	Vest-Agder	Vest-Agder	1987-93	7	-3.7	0 (-)	0.383
	Jæren	Rogaland	1980-93	13	-10.6	-	0.002
	Smøla	Møre & Romsdal	1982-93	12	-10.1	-	0.023
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	9	4.4	0 (+)	0.180
Velvet scoter	Østfold	Østfold	1982-85	4	-26.2	0 (-)	0.252
	Vest-Agder	Vest-Agder	1987-93	7	-4.2	0 (-)	0.587
	Jæren	Rogaland	1980-93	13	2.7	0 (+)	0.237
	Smøla	Møre & Romsdal	1982-93	12	-9.8	-	0.033
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	9	-2.1	0 (-)	0.363
	Salten	Nordland	1988-93	6	-52.2	-	0.063
	Vestvågøy	Nordland	1985-93	9	10.1	0 (+)	0.245
	Troms	Troms	1981-93	13	-6.8	0 (-)	0.391
	Varanger	Finnmark	1985-93	8	1.6	0 (+)	0.177
Long-tailed duck	Østfold	Østfold	1981-86	6	23.4	0 (+)	0.472
	Vest-Agder	Vest-Agder	1987-93	7	-4.7	0 (-)	0.372
	Jæren	Rogaland	1980-93	13	-1.4	0 (-)	0.164
	Smøla	Møre & Romsdal	1982-93	12	-2.8	0 (-)	0.101
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	9	-2.9	0 (-)	0.428
	Salten	Nordland	1988-93	6	-18.7	-	0.051
	Vestvågøy	Nordland	1985-93	9	-7.1	0 (-)	0.102
	Troms	Troms	1981-93	13	-5.3	0 (-)	0.177
	Varanger	Finnmark	1985-93	8	-0.12	0 (-)	0.461
Common eider	Østfold	Østfold	1980-86	7	29.0	0 (+)	0.306
	Vest-Agder	Vest-Agder	1987-93	7	-6.0	0 (-)	0.255
	Jæren	Rogaland	1980-93	13	3.9	0 (+)	0.293
	Smøla	Møre & Romsdal	1982-93	12	-5.7	-	0.012
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	9	4.2	0 (+)	0.133
	Salten	Nordland	1988-93	6	-5.4	0 (-)	0.166
	Vestvågøy	Nordland	1985-93	9	0.07	0 (+)	0.697
	Troms	Troms	1981-93	13	-12.3	-	0.038
	Varanger	Finnmark	1985-93	8	1.9	0 (+)	0.439
King eider	Jæren	Rogaland	1980-88	6	0	0	1.000
	Smøla	Møre & Romsdal	1982-89	5	12.7	0 (+)	0.210
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	7	-5.5	0 (-)	0.481
	Salten	Nordland	1988-93	6	-0.2	0 (-)	0.683
	Vestvågøy	Nordland	1985-93	9	5.0	0 (+)	0.112
	Troms	Troms	1981-93	13	7.1	0 (+)	0.358
	Varanger	Finnmark	1985-93	8	-9.5	0 (-)	0.266
Steller s eider	Vest-Agder	Vest-Agder	1989-93	5	-18.8	0 (-)	0.249
	Trondheimsfjorden	Sør/Nord-Trøndelag	1985-93	5	1.0	0 (+)	0.504
	Varanger	Finnmark	1985-93	8	-4.4	0 (-)	0.110

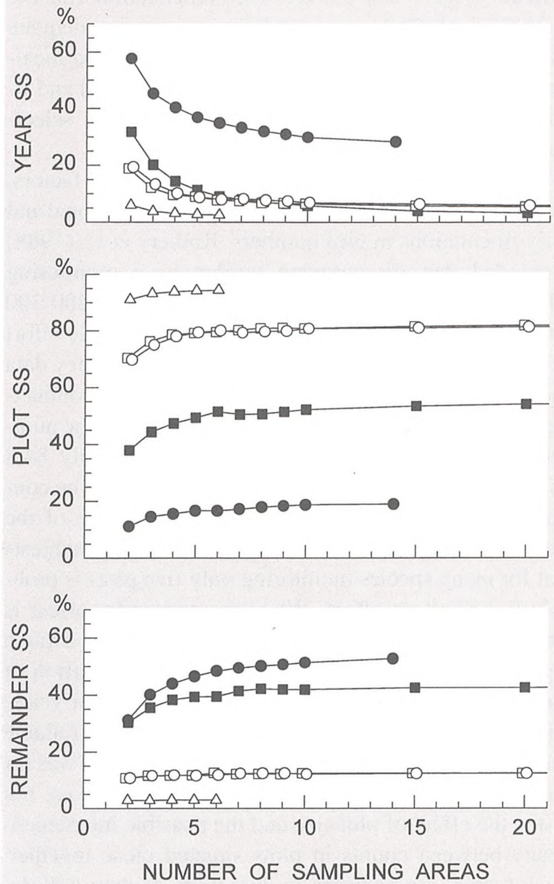
den only indicated an annual increase of about 4% (see Table 2).

Discussion

Our analyses are based on data for a wide range of species and geographical areas and show that for breeding seabirds significant trends in population size could be detected in many cases. For monitoring based on only one annual count of total bird numbers, there are few other appropriate methods which can be used to reveal such trends than the use of Monte Carlo simulations (but see Underhill & Prŷs-Jones (1994) for bootstrapping procedures and Thomas (1996) for a review of methods). This method has, however, obvious limitations and statistically significant trends can only be detected after a number of years (see Methods).

The existence of multiple plots for the estimation of

Figure 2. Relationship between the number of sampling areas monitored and the sum-of-squares (SS) in a two-way ANOVA, partitioned into three components: year SS, plot SS and remainder SS, all expressed as percentages of total SS. Each plot represents a mean value derived from 500-5,000 ANOVAs performed for a corresponding number of randomised data sets (see Methods for details of the statistical procedure). Data sets and symbols as in Figure 1.



within-year variation in bird numbers allows the use of more powerful statistical analyses that are capable of detecting trends at an earlier stage and often to a much higher probability. This conclusion was supported by the cases we examined using both methods, and where all trends could be detected by the GLM procedure even after halving the number of plots or localities and reducing the count frequency to every second year. This strongly suggests that some populations can be monitored adequately by less effort than at present, although this involves the risk of missing the chance to pinpoint when any disastrous reductions in numbers take place.

Our examination of the relationship between sums-of-squares and plot number also substantiates the conclusion that the effort can be reduced in some cases. All sources of variation tended to level off before the number of plots exceeded 10-15. For puffin and common eider this was far less than the actual number of plots being counted. Accordingly, a reliable measurement of the total variance in numbers of these species could have been obtained by reducing the number of plots or localities. It is, however,

Table 3. Population trends and differences between plots for five selected seabird species and areas. The data sets are the same as those presented in Figure 2; the trends were also analysed after reducing the numbers of years and localities. The significance of each trend was first tested by Monte Carlo simulations using the total number of birds within the plots (i.e. only one data point per year). PAC indicate the percental annual change recorded for the selection. Then a GLM procedure (Littell et al. 1991) was applied to ranked data for individual plots, where the F-values and P-levels indicated are based on type III sum of squares. When choosing every second year or plot, the first year or plot was always included.

Species	Analysis based on		No of plots	No of years	Monte Carlo simulations		GLM on ranked data			
							Plots		Years	
					PAC	P	F	P	F	P
Red-necked grebe	I	All data	14	12	-10.1	<0.05	4.4	<0.001	26.3	<0.001
	II	Every 2nd year	14	6	-10.4	n.s.	2.5	<0.001	11.7	<0.001
	III	50% of plots	7	12	-10.0	<0.05	3.9	<0.001	15.9	<0.001
	IV	II+III combined	7	6	-13.4	n.s.	0.84	n.s	7.3	<0.01
Common eider	I	All data	56	9	4.2	n.s.	8.8	<0.001	0.94	n.s.
Kittiwake	I	All data	6	13	-1.8	<0.1	195.6	<0.001	3.0	<0.01
	II	Every 2nd year	6	7	-1.4	<0.05	105.8	<0.001	2.6	<0.05
Common guillemot	I	All data	26	11	-4.1	<0.05	156.6	<0.001	18.2	<0.001
	II	Every 2nd year	26	6	-3.6	n.s.	82.6	<0.001	9.3	<0.001
	III	50% of plots	13	11	-3.6	<0.05	87.1	<0.001	5.7	<0.001
	IV	II+III combined	13	6	-3.1	n.s.	31.2	<0.001	5.7	<0.001
Puffin	I	All data	222	12	-3.5	<0.05	180.3	<0.001	291.2	<0.001
	II	Every 2nd year	222	6	-4.6	n.s.	136.0	<0.001	122.2	<0.001
	III	50% of plots	111	12	-3.4	<0.05	142.0	<0.001	132.6	<0.001
	IV	II+III combined	111	6	-4.2	n.s.	106.1	<0.001	105.0	<0.001
	V	7% of plots	15	6			81.0	<0.001	4.5	<0.05

difficult to give any general recommendations on the number of sampling areas needed to capture an adequate proportion of the variance. The existing plots and localities are not mutually exclusive and, for logistical and financial reasons, there is no great effort saved by selecting such sampling areas at random.

The variance in bird numbers depends on many factors, including the size of study plots, and annual, seasonal and daily fluctuations in bird numbers. Rothery et al. (1988) concluded that for common guillemots a monitoring scheme consisting of five plots of approximately 200-300 birds counted on 10 days in June was a reasonable effort (see also Wanless et al. 1982, who analysed Orkney data and concluded there was little extra to gain from conducting more than 10 counts). Even at Runde, where the number of guillemots within the plots averaged only 84.8 ($N_{plots} = 25$, $N_{years} = 11$, SE = 5.5), 5-7 plots could be considered sufficient to produce a reliable estimate of the year-to-year variation. Nevertheless, our study suggests that for many species monitoring only five plots is probably too small an effort. When the remainder effect is large, as it was for the two wintering populations, a much higher effort is needed to determine what proportion of the variance is attributable to variation between years. Vice versa, little effort is needed to produce very reliable estimates when the remainder effect is small, as it was for the three breeding populations examined. We have not tested the effect of plot size and the possible interdependency between counts in plots situated close together. Such factors are complex to deal with, as they will depend on both the physical structure of the area and the biological composition of the sample population (e.g. Anker-Nilssen & Røstad 1993).

A key question to nature management is how much a population should change before it deserves special attention, either through conservation measures or by beginning research aimed at explaining the underlying causes of the change. For seabirds, there is no simple answer to this question. Not only is there a great variety of life history strategies and ecological adaptations among the species monitored, but in many cases our understanding of the birds origins, and variations in their demography and distribution, is too poor to differentiate between actual population changes and bias caused by other sources of variation. The latter is particularly applicable to the winter populations. The different monitoring methods also represent a varying bias, for example by being unequally sensitive to daily changes in weather conditions and, in winter, to annual changes in ice conditions.

Population trend is most robust as an indicator of environmental changes that affect the survival of birds that have started to breed. Most seabirds have a delayed onset of breeding, and changes in survival of the younger life stages, i.e. nestlings, juveniles and immatures, will not be reflected in the breeding numbers until one to several years later, by which time the effects may well be obscured by other factors. With respect to food supply, seabird foraging and reproductive success are parameters more sensitive to changes than adult survival, although periods of extreme food shortage may be accompanied by high mortality of adults (e.g. Cairns 1987). In relation to oil pollution and fishing gear, however, acute reduction of immature and adult survival is the most likely consequence.

Thus, both the progress and the importance of a numerical change are highly dependent on a number of different factors. These factors also make it difficult to select a common mathematical model to describe the course of the various changes that are documented or predicted. However, with respect to major unidirectional changes occurring over a few (2-4) consecutive years, the shape of the trend deserves less concern than the total change in numbers, unless it indicates that numbers may bounce back the following year (see Greenwood et al. 1995). Similarly, slow but long-lasting changes represent no crucial statistical problem, as in most cases GLM or Monte Carlo simulation procedures will then be considered appropriate analysis tools for identifying the overall trends.

Kirby & Bell (in press) have recently proposed a quantitative method to identify alert conditions in population trends (i.e. what changes may deserve particular concern). Their method, which is based on the Underhill index and bootstrapping procedures (Underhill & Prŷs-Jones 1994), seems to be very sound and may well become an international standard for such decision-making. However, the principle will at least require considerable time to establish, and many will need an easier way to obtain reasonable advice. Considering the natural variation in seabird numbers and attempting to simplify a complex task (being well aware of the risk of oversimplification), we therefore suggest, as a rule of thumb, that conservation authorities should pay special attention to any change greater than ±25%, provided it is statistically significant at the 10% level. Such an event may well be the result of important changes in survival or recruitment rates, whether they are linked to altered conditions for the local population (e.g. affecting adult survival or reproductive performance) or (less frequently) to changes in the exchange rates between different breeding populations (especially in cormorants, terns, and some gull species). Intentionally, our criterion is made irrespective of the species and time spans involved. Whenever the 25% limit has been exceeded, the most probable explanatory hypothesis should be discussed and form a basis for consideration of relevant actions or additional research.

It is important to bear in mind that statistical probability of detecting a trend is not the only consideration to be made when deciding on the number of plots and their sampling frequency. The need to use the data in a wider context deserves particular attention. Monitoring only population numbers may well tell us something about the present status of the populations, but as most seabirds are characterised by low reproductive rates, delayed maturity and high adult survival, the time scale for population changes are long (e.g. Nisbet 1989). In addition, small or short-term episodes in the marine environment may first affect the number of breeding birds several years later, although survival rates or breeding performance may be affected more suddenly. Consequently, when a population change of special concern has been documented, it is often too late to unveil its causes and, thereby, to produce reliable predictions and identify proper actions. To overcome some of these difficulties, it is clearly necessary to 1) design sampling schemes that permit running comparisons of population trends with any parallel data series on other population parameters and environmental factors, and 2) to extend the seabird monitoring concept to include parameters that are likely to be among the most important for the regulation of the populations. In this context, increasing plot numbers and sampling frequency may well be essential in order to increase the sensitivity of statistical comparisons. One example is the puffin scheme at Hernyken, where a large number of small and evenly distributed sampling areas (only 10 m^2 each) enables the documentation of density-dependent population changes between successive years, which, in turn, can be correlated with recruitment rates (Anker-Nilssen & Røstad 1993, Anker-Nilssen & Øyan 1995).

Theoretical seabird population studies have demonstrated the importance of adult survival rates (e.g. Croxall & Rothery 1991, Erikstad et al. 1994), and even small changes in adult survival may have profound effects on population development. For instance, if the annual adult survival rate drops from 95 to 90%, a population will need to double its recruitment rate in order to maintain its numbers. Thus, adult survival should clearly be included in population monitoring programmes. Furthermore, breeding success, and preferably also food choice, should be monitored to be able to address the causes of possible changes in survival and recruitment rates (Nisbet 1989, Wooller et al. 1992), and to detect rapidly any major impact on these parameters.

The dynamics of seabird populations may only be understood when the principal population parameter data are coupled with long-term population trends. However, to fully understand also the dynamics of the ecosystem that seabirds inhabit and to be able to predict future changes in the populations, it is also necessary to include information concerning their most important food supplies in the analyses. The bulk of seabirds breeding in northwestern Europe are fish-eating species, and several species have been affected by variations in commercial fish stocks (e.g. Furness & Ainley 1984, Montevecchi 1993). Regrettably, up to now, multidisciplinary cooperation between seabird scientists and fisheries researchers has been almost totally lacking.

Monitoring programmes are often implemented with limited funds (e.g. Nisbet 1989), emphasising the selection of a limited number of key species and sites where it is possible to combine the monitoring of population numbers with the monitoring of adult survival rates and parameters affecting recruitment (e.g. breeding success and food supply). For breeding seabirds such key sites should, preferably, be selected in different oceanographical regions, and species representing the main trophic positions of seabirds in the marine ecosystem should be selected. When choosing between species and localities, special attention should be paid to the long data series that exists for some colonies with respect to population numbers, adult survival, food supply and breeding success.

In order to indicate the validity of results of the more extensive monitoring, key sites should be supplemented by a net of sites where the main purpose is to reveal an adequate proportion of the total variance in bird numbers at the lowest possible effort. At the low-effort sites, 10-15 monitoring plots will usually be enough, and in some cases it may also be sufficient to count every second year only. Caution is needed, however, as there may be substantial variation between years due to various sources of variation that cannot easily be controlled for (e.g. differences in weather conditions, field personnel, age distribution of birds present, timing of breeding, and the proportion of adults that skip breeding), but which clearly will reduce the possibility of detecting any factual trends in bird numbers from year to year.

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