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PROJECT REPORT

Physical and biological environmental properties as predictors of the broad scale spatial distribution of pelagic seabirds

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Foundation for Nature Research and Cultural Heritage Research

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Fachald, P., Erikstad, K. E. & Skarsfjord, H. 1996. Physical and biological environmental properties as predictors of the broad scale spatial distribution of pelagic seabirds. - NINA•NIKU Project Report 06: 1-20.

Tromsø, September 1996

ISSN 0807-3082
ISBN 82-426-0720-6

Management areas:
English: Marine ecology
Norwegian: Marin økologi

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Nature Research and Cultural Heritage Research

The report can be quoted by references to the source.

Editor: Per Fauchald
NINA, Tromsø

Design og layout:
Elin Skoglund

Type: NINA•NIKU

Prints: Norservice

Stock: 200

Printed on environment paper

Address to contact::
NINA•NIKU
Storgt. 25
9005 Tromsø
Tel: +47 77 60 68 80
Fax: +47 77 60 68 82

Availability: Open

Project no.: 18643

Signature of personal responsible:

Assignment sponsor:
Working Group of Environmental Impact Assessments of Petroleum Activities on the Norwegian Continental Shelf (AKUP)

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Abstract

Fauchald, P., Erikstad, K.E. & Skarsfjord, H. 1996. Physical and biological environmental properties as predictors of the broad scale spatial distribution of pelagic seabirds. - NINA•NIKU project report 06: 1-20

Both seabirds and their prey generally have a highly patchy and variable spatial distribution. As a consequence, it is difficult to assess the effect of oil exploration on seabirds in given geographical areas solely on the basis of survey data. The spatial distribution of both seabirds and their prey, can however often be described by more stable physical properties of the sea. In this report we use a new method of classifying a seabird habitat, according to the distribution of different environmental variables. The habitat of guillemots (*Uria* spp.) in the Barents Sea is classified using survey data of birds and environmental factors in the period January-March in 1986-94. Environmental variables included in the models are surface temperature gradients (frontal areas), surface temperature and the distribution of the main prey Capelin (*Mallotus villosus*). These variables had independently a substantial influence on the probability of encountering concentrations of guillemots. Even though Capelin is the major factor that determines the distribution of guillemots in the Barents Sea at this time of the year, the actual distribution of Capelin could not be used to describe the general distribution of guillemots. This was a consequence of the highly patchy and variable spatial distribution of Capelin. In the concluding model we used mean surface temperatures and mean distribution of frontal areas (all years included in the study) as variables to predict the general spatial distribution of guillemots. This model indicates that the major part of the central areas of the Barents Sea are relatively important with respect to guillemots at this time of the year. The lowest predicted probability (5%) of encountering concentrations of guillemots was found in the warm south-western part (mean surface temperature = 6°C) and in the cold north-eastern part (mean surface temperature = -1°C) of the Barents Sea. The predicted probability increased towards the polar front, and reached a maximum (50%) in areas with mean surface temperatures of 3°C and in areas adjacent to the polar front. This general distribution of guillemots matches the most important wintering areas and spawning migration routes of Capelin. By using already existing environmental data, we were thus able to significantly predict the general distribution of guillemots in the Barents Sea in the period January-March on the basis of a limited data set with scattered observations. The method described is strongly recommended in future assessments of oil exploration and pelagic seabirds.

Key words: Marine oilspills - seabirds - sensitivity analysis - spatial distribution

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Referat

Fauchald, P., Erikstad, K.E. & Skarsfjord, H. 1996. Den romlige fordelingen av sjøfugl i åpent hav prediekert ved hjelp av fysiske og biologiske miljøvariable. -NINA•NIKU project report 06: 1-20

Emneord: Marine oljesøl - sjøfugl - sårbarhetsanalyse - romlig fordeling.

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Både sjøfugl og deres byttedyr har ofte en svært klumpet og variabel utbredelse. Som et resultat av dette, har det vist seg vanskelig å gi vurderinger av sjøfugl sin sårbarhet overfor oljeutvinning innenfor gitte geografiske områder. Det er imidlertid vist at fordelingen av både sjøfugl og deres byttedyr ofte kan beskrives ved hjelp av stabile fysiske egenskaper i deres miljø. I denne rapporten beskriver vi en ny metode for å klassifisere habitatet til sjøfugl ved hjelp av fordelingen av forskjellige miljøvariable. Det atlantiske habitatet til lomvi (*Uria* spp.) i Barentshavet blir klassifisert ved hjelp av data over fordelingen av fugl og miljøvariable fra tokt utført i perioden januar-mars fra 1986-94. Miljøvariable som inngår i modellene er overflatetemperatur, gradienter i overflatetemperatur (frontområder) og utbredelsen av det viktigste næringemnet; lodde (*Mallotus villosus*). Disse variablene hadde uavhengig av hverandre en betydelig effekt på sannsynligheten for å treffe konsentrasjoner av lomvi. Lodde er en viktig faktor som bestemmer fordelingen av lomvi i Barentshavet på denne tiden av året. Mesteparten av den totale mengden lodde som lokaliseres iløpet av et tokt, finnes innenfor svært små områder. Disse områdene har en svært variabel utbredelse både mellom år og innen sesonger. Den faktiske utbredelsen av lodde som man observerer iløpet av et tokt, er derfor uegnet til å beskrive den generelle utbredelsen av både lomvi og lodde. I den endelige modellen brukte vi gjennomsnittlig overflatetemperatur og den gjennomsnittlige utbredelsen av frontområder (data fra alle år) som variable for å forklare fordelingen av lomvi. Modellen indikerer at største delen av de sentrale områdene i Barentshavet vil være sårbare med hensyn til lomvi i den aktuelle tidsperioden av året. Sannsynligheten for å finne konsentrasjoner av lomvi er lavest (5%) i den varme sydvestlige delen (gjennomsnittlig overflatetemperatur = 6°C) og den kalde nordøstlige (gjennomsnittlig overflatetemperatur = -1°C) delen av Barentshavet. Sannsynligheten øker når man nærmer seg polarfronten, og når et maksimum (50%) i områder med gjennomsnittlige overflatetemperaturer på 3°C, og i områder nært polarfronten. Denne generelle utbredelsen av lomvi samsvarer med den generelle utbredelsen av overvintringsområdene og gytevandringene til lodde. Ved å bruke allerede eksisterende miljødata, er vi istand til å beskrive fordelingen av lomvi i Barentshavet i perioden januar - mars med basis i et begrenset datasett med spredte observasjoner. Metoden som er beskrevet anbefales i framtidige konsekvensutredninger over oljeutvinning med hensyn på sjøfugl.

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Forord

Som en følge av mulig prøveboring etter olje og gass i den nordlige delen av Barentshavet, skal det utføres konsekvensutredninger av mulige effekter av denne typen aktivitet på miljøet i området. Ansvaret for disse utredningene ligger hos den uavhengige interdepartementale arbeidsgruppen for konsekvensutredning av petroleumsvirksomhet (AKUP) nedsatt av Nærings og energidepartementet (NOE).

Som et ledd i konsekvensutredning av petroleumsvirksomhet i Barentshavet Nord, har Norsk institutt for naturforskning, avd. for arktisk økologi vært engasjert i kartleggingen av fordeling av sjøfugl i området. I et tidligere prosjekt har vi studert forutsigbarheten av fordelingen av sjøfugl i Barentshavet. Som en oppfølging av dette prosjektet, ønsket vi å studere muligheten for å gi bedre og mer generelle vurderinger av sjøfugl sin sårbarhet for oljesøl innenfor gitte geografiske områder ved å bruke fordelingen av fysiske og biologiske miljøvariable. I denne rapporten presenterer vi resultatene fra prosjektet "Sårbarhetsanalyser av sjøfugl i åpent hav", finansiert av NOE gjennom AKUP.

Dessverre har det på grunn av tidspress, ikke vært mulig å bruke de nye metodene som presenteres i denne rapporten i den endelige sårbarhetsanalysen for Barentshavet Nord. Vi håper imidlertid at metodene vil bli benyttet ved senere anledninger.

Vi vil takke Rob Barrett (Tromsø Museum) som har gitt faglig vurdering av rapporten, og også har forbedret engelsken.

Tromsø , juni 1996
Per Fauchald

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1 Introduction

In the assessments of oil exploration and seabirds in Norwegian waters, much effort has been put into ship-borne surveys of the spatial distribution of seabird species (e.g. Anker-Nilssen et al. 1988; Isaksen 1995). To assess the vulnerability of particular species to oil spill within given geographical areas, the resulting survey data from these cruises are used as source data in general models (Anker-Nilssen 1987).

The general spatial distribution of seabirds during the breeding season can often be described by the geographical distribution of their colonies (e.g. Isaksen, 1995). In general, it is simple to identify geographical areas which are very vulnerable to oil spill during the breeding season, especially for seabirds with a restricted activity range. However, outside the breeding season, and also within the breeding season for species that roam over large areas, the spatial distribution of seabirds is not influenced by geographical areas per se, but rather by areas with enhanced availability of prey. Their foraging areas are frequently associated with specific physical properties of the sea, such as depth and hydrographic structure (see Hunt & Schneider 1987; Hunt 1990 for reviews).

Fauchald & Erikstad (1995) found a low predictability in the geographical distribution of wintering guillemots (*Uria* spp.) in Barents Sea from year to year. Their findings question the relevance of using pelagic seabird survey data directly in assessment models. Fauchald & Erikstad (1995) point out two major factors that probably contribute to the large variation in the geographical distribution of guillemots. First, the availability of food that naturally regulates the distribution of seabirds often has a variable spatial distribution with respect to time (e.g. Piatt 1987; Anker-Nilssen & Lorentsen 1990; Fauchald et al. in prep.). Secondly, seabirds have a highly aggregated distribution over a large range of scales (Hunt & Schneider 1987). The effect of these statements when trying to assess the vulnerability within specified geographical areas on the basis of limited source data, is best illustrated in an example: Suppose that on a cruise, 20% of all individual guillemots are observed within a small continuous area of only 1% of the total area covered. The cause of this large concentration in that particular area might be generated by coincidence; e.g. local wind and currents have generated large concentrations of normally unimportant prey items (own obs.). A classification of this area as being vulnerable to an oil spill with respect to guillemots would, in this case be wrong. On the other hand, and more likely, the concentration of guillemots might be associated with specific physical properties such as, for instance, the continental edge, where one normally finds a frontal system with high densities of prey (e.g. Schneider 1982; Briggs et al. 1987). In this case, a classification of the area as being vulnerable would be correct. However, since guillemots have a highly patchy distribution, the concentration would probably be found in only a small part of the area associated with the continental edge (i.e. Veit & Hunt 1991). Accordingly, even if the chances of finding concentrations of guillemots all along the continental edge are equal, only a small part would be classified as vulnerable on the basis of limited survey data. In other words, the possibility of wrongly classifying areas as non-vulnerable on the strict basis of survey data is probably large.

This example illustrates the importance of incorporating environmental variables when trying to assess the vulnerability of pelagic seabirds to oil exploration in specified geographical areas. In other words, due to the patchy distribution of seabirds, it is important to classify habitats according to their physical properties. This becomes even more important when the data on seabirds are scarce and limited. According to the results of Fauchald & Erikstad (1995), the value of the conclusions drawn on the strict basis of such data are limited. In this report we describe a new method of developing models that, on the basis of environmental data and data on distributions of seabirds, overcome this problem. As a consequence of the patchy distribution of most seabird species, the method used is based on categorical analyses and estimates the probability of encountering concentrations of seabirds within large geographical areas. The source data used are counts of wintering guillemots made in the Barents Sea in 1986-94. The major prey item for guillemots at this time of the year is Capelin (*Mallotus villosus*) (Erikstad & Vader 1989; Erikstad et al. 1990; Skarsfjord, 1995; Fauchald & Erikstad, in prep.). The environmental data are taken from survey reports published by the Norwegian Institute of Marine Research.

2 Materials and methods

2.1 Study area

Counts of seabirds were made by joining one of the Norwegian Institute of Marine Research's vessels on their regular winter cruises (January - March) in the Barents Sea in 1986-94. These cruises are carried out by several ships that together cover all ice-free parts of the Barents Sea. Detailed descriptions of sea temperature, salinity and several fish species are published in survey reports. We have thus environmental data from most of the ice-free parts of the Barents Sea in the period of interest for all years, but note that due to variable ice-condition, not all parts of the study area where covered all years (**figure 1**). The study area was further divided into geographical areas constituting 1° latitude x 2° longitude (**figure 1**), and each area was given a set of environmental variables (when covered) each year. Seabird counts covered slightly different parts of the study area each year. As a result, the total guillemot dataset for all years is scattered throughout most of the study area (**figure 1**).

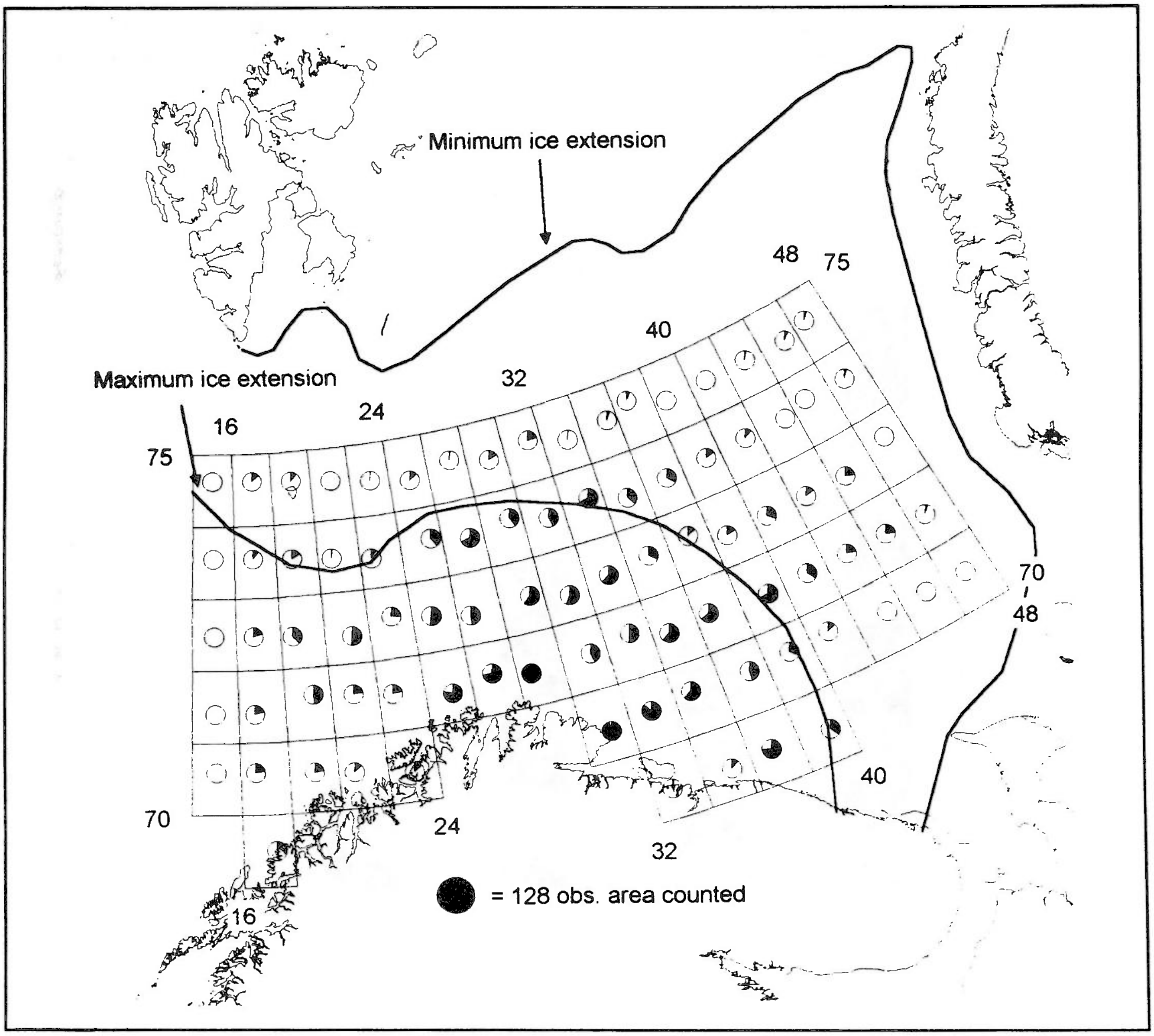

***Figure 1**: Study area, effort (all years from 1986-94) and the minimum and maximum ice extensions in the Barents Sea(from Loeng 1989). The study area covers most of the ice-free part of the Barents sea from January to march. Due to the variable extension of ice from year to year, a large part of the study area will be covered by ice in some years (max extension). Surveys were only occasionally conducted into ice-covered waters. The study area was divided into geographical areas constituting 1°latitude x 2°longitude. Each geographical area was given a set of environmental variables. Effort with respect to counts of guillemots is given by the number of observation areas (25km^2) totally counted within each geographical area.*

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2.2 Counts of birds

It is difficult to discriminate between Common (*Uria aalge*) and Brünnich's Guillemots (*Uria lomvia*) during the winter. It is however known from earlier investigations that about 90% of the guillemots in the study area at this time of the year are Brünnich's Guillemots (Erikstad et al. 1990; own obs.). The two species are treated together, and referred to as guillemots. Birds were counted from the top of the vessel's bridge (10 m above sea level) in 300 m transects and 10 min blocks on one side of the ship. The speed of the ship was about 10 knots, such that counts covered an area of about 0.92 km^2 every 10 min.

The datasets were divided into observation areas of 5x5 km UTM 33-zones, and the densities of guillemots were estimated for each observation area covered. In 45% of the totally 2900 observation areas there were observed densities of from 0 - 1 guillemots per km^2. In 20% of the areas there were observed 1 -10 guillemots per km^2. In 35% of the areas there were observed from 10 to more than 1000 guillemots per km^2 (**figure 2**). Due to the highly patchy spatial distribution of guillemots (cf. **figure 2**), we adopted to investigate the distribution of «concentrations», rather than the actual density of guillemots among the geographical areas. We defined an observation area as containing a concentration of guillemots if the density within the area was equal to or more than 10 birds per km^2 (equal to or more than 250 birds within the obs. area). According to this criteria, 35% of the observation areas were classified as containing guillemot concentrations, and 65% were classified as empty. The number of observation areas with and without concentrations of guillemots were counted for each geographical area.

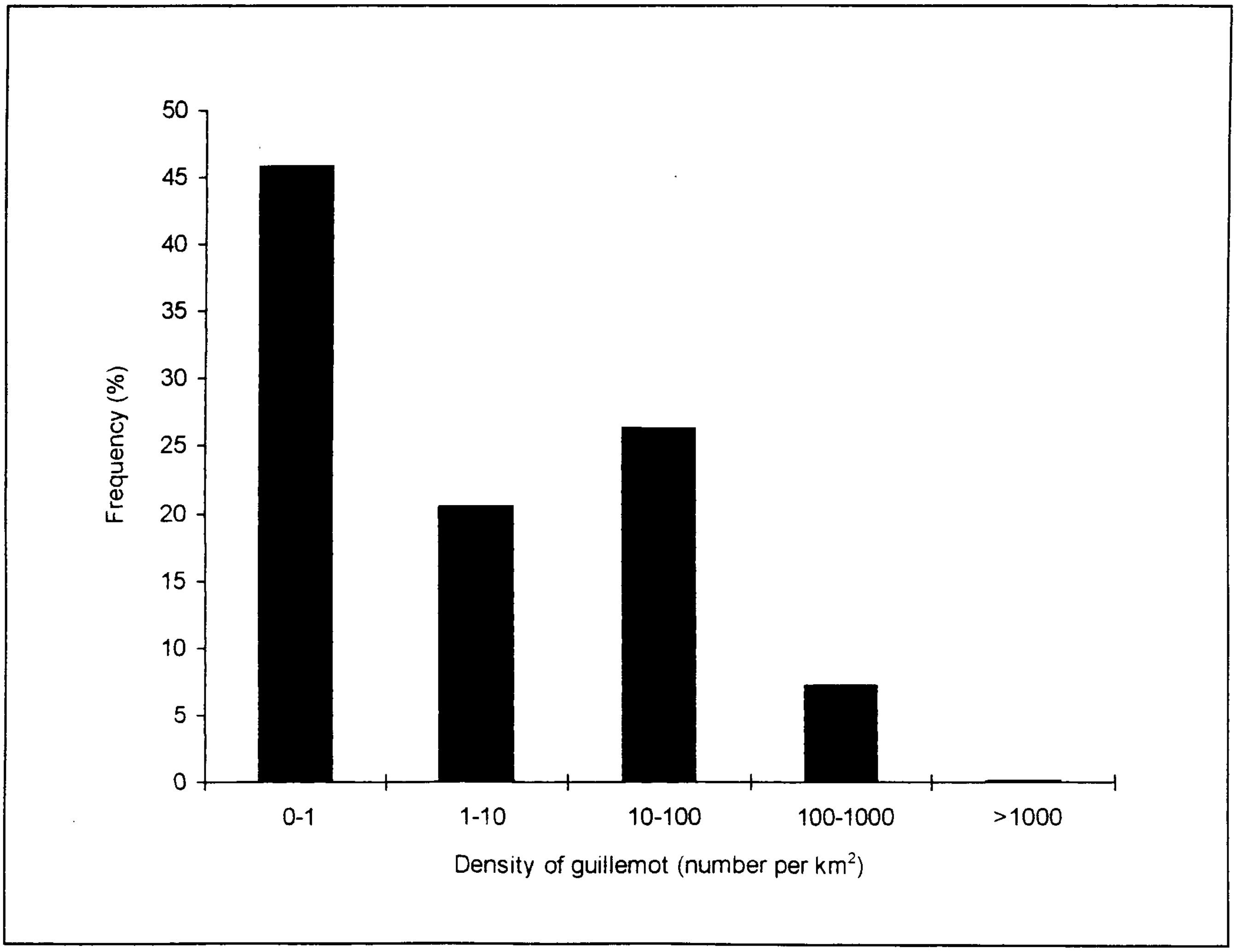

Figure 2: *Histogram of the densities of guillemots (numbers per square kilometer) within an observation area (25 km^2), all years combined.*

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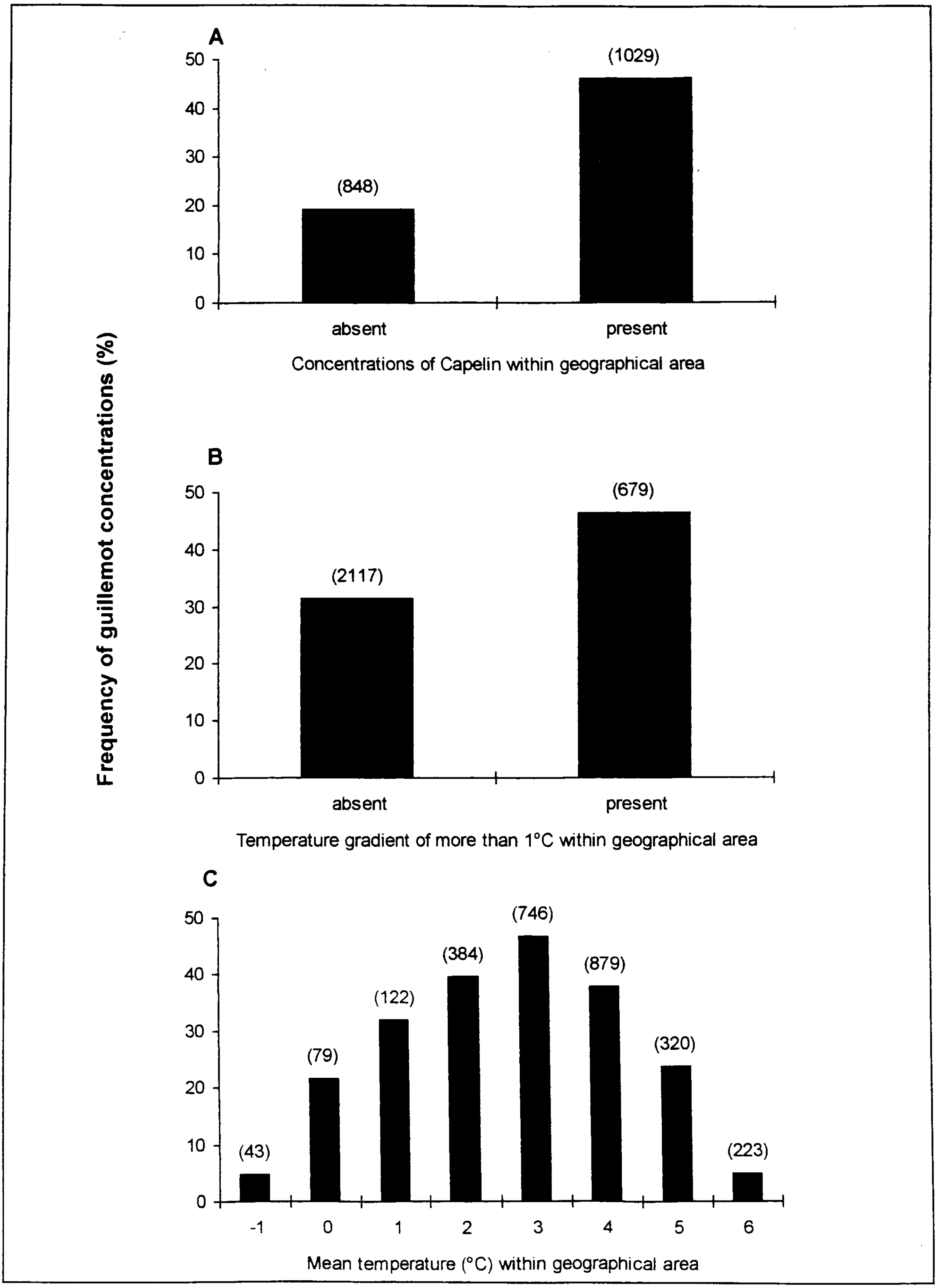

Figure 3: *Frequency of observation areas (25 km^2) containing more than 250 Guillemots for different environmental variables. A) Concentrations of Capelin giving more than 10 echo sound integral per 5 nm. B) Surface temperature gradient of more than 1°C. C) Mean surface temperature. Sample size is given in brackets.*

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2.3 Environmental variables

When data were available, we consigned each geographical area one or more of 3 distinct environmental variables (**table 1**). They were; the presence or absence of Capelin, mean surface temperature, and the presence or absence of surface temperature gradients (front). All variables are defined in **table 1**.

The variables front and surface temperatures are taken from maps given in survey reports from each survey. References are: Hylen et al. 1986; Godø et al. 1987; Hylen et al. 1988; Jakobsen et al. 1989; Jakobsen et al. 1990; Hylen et al. 1991; Godø et al. 1992; Korsbrekke et al. 1993; Mehl & Nakken 1994.

The Capelin distribution data are based on echo sound integrator values from each survey. Echo sound integrator values were obtained through standard methods (see references above). We have only satisfactory data on the geographical distribution of Capelin from 6 of the 9 years of surveys, that is 1986, 87, 88, 89, 92, 93. In 1986-89 there were extremely low densities of Capelin, and only small and scattered concentrations of Capelin at low densities were found. In 1992 and 93, there were high densities of Capelin, and large concentrations with high densities were found. As a consequence of the patchy distribution of Capelin we adopted to define only two categories of Capelin in the analyses; present or absent. In order to reduce the effect of the large year to year variation in Capelin abundance, we defined a geographical area to contain Capelin at a relatively low limit, viz. concentrations of Capelin with more than 10 echo sound integrator values in a 5 nm period (**table 1**).

Table 1: *Definitions of environmental variables used in the models. All variables refers to characteristics within a geographical area (1°lat. x 2°long.).*

Variable name *Variabel navn*	*Definition* *Definisjon*	*Values* *Verdier*
Cap	*Concentration(s) of Capelin of more than 10 echo sound integral per* $5nm^2$	*0 = absent* *1 = present*
	Konsentrasjon(er) av lodde med tetthet over 10 ekkointegraler per $5nm^2$	*0 = ikke tilstede* *1 = tilstede*
Temp1	*Mean surface temperature*	*0 = -1, 0, 1 or 6°C* *1 = 2, 3 or 4°C*
	Gjennomsnittlig overflatetemperatur	*0 = -1, 0, 1 eller 6°C* *1 = 2, 3 eller 4°C*
Temp2	*Mean surface temperature*	*0 = -1 or 6°C* *1 = 0, 1 or 5°C* *2 = 2 or 4°C* *3 = 3°C*
	Gjennomsnittlig overflatetemperatur	*0 = -1 eller 6°C* *1 = 0, 1 eller 5°C* *2 = 2 eller 4°C* *3 = 3°C*
Front	*Surface temperature differences of more than 1°C*	*0 = absent* *1 = present*
	Overflatetemperaturgradient på mer enn 1°C	*0 = ikke tilstede* *1 = tilstede*

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Table 2: *Model when Capelin is included. A) Analyses of variance table for variables and interactions. Variables and interactions with a non-significant contribution to the model have been removed. B) Population profiles and observed and predicted values for the response function.*

A

Source	DF	Chi-Square	Prob
Intercept	1	3053	<0.001
Cap	1	71	<0.001
Temp1	1	69	<0.001
Front	1	23	<0.001
Cap x Front	1	6	0.013
Residuals	3	27	<0.001

B

Sample				**Observed**	**Predicted**		Pred. prob. of Uria spp.
Cap	Temp 1	Front	n	Response ±S.E.	Response ±S.E.	Residuals	concentrations
0	0	0	230	0.93 ±0.017	0.95 ±0.016	-0.025	0.05
0	1	0	434	0.82 ±0.019	0.79 ±0.016	0.029	0.21
0	0	1	43	0.91 ±0.044	0.78 ±0.033	0.13	0.22
1	0	0	172	0.73 ±0.034	0.68 ±0.023	0.044	0.32
1	0	1	59	0.54 ±0.065	0.63 ±0.033	-0.084	0.37
0	1	1	117	0.47 ±0.046	0.61 ±0.034	-0.14	0.39
1	1	0	522	0.5 ±0.021	0.52 ±0.019	-0.018	0.48
1	1	1	250	0.48 ±0.032	0.46 ±0.029	0.02	0.54

We used two different variables on surface temperature in the analyses (temp1 and temp2 in **table 1**). The variables were defined according to the frequencies of guillemot concentrations with respect to temperature (**figure 3C**). Temp1 was defined as absent when the mean surface temperature was -1, 0, 1, 5 or 6°C, and present when the mean surface temperature was 2, 3 or 4°C. Temp2 was defined such as to give four distinct possible outcomes: Temp2 = 0 for temperatures = -1 or 6°C, 1 for temperatures = 0, 1 or 5°C, 2 for temperatures = 2 or 4°C and 3 for temperature = 3°C.

Front was defined as the presence or absence of surface temperature gradients of more than 1°C within a geographical area (**table 1**). Such gradients were only found in the border areas between Atlantic (T > 3°C) and arctic (T < 0°C) waters, these areas are thus associated with the polar front. For interpretation reasons the position of the polar front is indicated in some of the figures. The polar front is defined as the border between two geographical areas with mean temperatures above 1°C (Atlantic side), and mean temperatures below 1°C (arctic side).

2.4 Analyses

The data were analysed using the procedure CATMOD in SAS (SAS Institute Inc. 1989). CATMOD is a procedure for analysing categorical data that can be represented by a contingency table. The density of birds was entered as the independent variable with binary response defining areas with birds (equal to or more than 10 birds per km^2) and areas without birds (less than 10 birds per km^2), and the following 3 dependent variables; Capelin, surface temperature and front (**table 2**).

All explanatory variables and their interactions were initially entered. We then sequentially deleted variables which had no significant effect in the model until all remaining variables and interactions were significant.

For statistics we used maximum-likelihood estimation of parameters for log-linear models. We also used models for predicted probabilities based on least-square estimates to predict birds in different areas when different variables were entered into the model. These predicted values can be used as scores representing the likelihood that concentrations of birds are present in an area given that a certain combination of variables in the model is present.

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3 Results

The frequencies of guillemot concentrations with respect to different environmental variables are given in **figure 3**. The frequency was higher when Capelin was present than when Capelin was absent within the geographical areas (**figure 3A**). Likewise, the presence of temperature gradients (fronts) had a positive influence on the frequency of guillemot concentrations (**figure 3B**). Finally, mean surface temperature within the geographical areas had a strong influence on the frequency, with maximum frequency at 3°C, and decreasing frequencies for temperatures above or below 3°C (**figure 3C**).

3.1 Capelin included in the model

In order to reduce the number of variables in this model, we used temp1 with only two possible outcomes (**table 1**) as the temperature variable in this model.

Using temp1, Capelin and front as independent variables, and the presence or absence of guillemot concentrations as the dependent variable in the categorical analysis gave a significant model when removing all non-significant interactions (**table 2A**). The model had, however significant residuals ($\chi^2 = 27$, $p < 0.001$), indicating a low fit. The interaction in the model (front x Capelin) had a low chi-square value ($\chi^2 = 6$, $p = 0.013$), and the predicted response in probability for different combinations of variables had therefore a straightforward interpretation (**table 2B**). The presence of Capelin, front and temperatures between 2°C and 4°C (temp1 = 1) all gave higher probabilities of finding guillemot concentrations appearing alone or in combinations. The lowest probability (5 %) was found when temperatures were above 4°C or below 3°C (temp1 = 0) and front and Capelin were absent. Highest probability (54 %) was found when front and Capelin were present and surface temperatures were between 2 °C and 4°C (temp1 = 1).

The geographical interpretation for the model is given for two years; 1988 and 1992 (**figure 4A and B**). 1988 was a year with low abundance of Capelin and relatively low surface temperatures, whereas 1992 was a year with high abundance of Capelin and relatively high surface temperatures. Low probabilities of finding concentrations of guillemots, were found in the south western part of the study area in both years. In these areas, surface temperatures were above 4°C, and we found no fronts or Capelin concentrations. In 1988 there was a corresponding area in the north east where surface temperatures were below 2°C. Medium temperatures with increased probabilities of finding concentrations of guillemots, were found in the central part of the study area in both years. In 1988 there were frontal areas in the north west and in the central and eastern part of the study area. These frontal areas were associated with the polar front. In both years Capelin were scattered throughout the whole study area, increasing the probabilities of finding guillemot concentrations.

3.2 Capelin excluded from the model

In this model we used temp2 as the variable of mean surface temperature, giving four distinct outcomes (**table 1**).

Using temp2 and front as independent variables, and the presence or absence of guillemot concentrations as the dependent variable in the categorical analysis, gave a highly significant model when removing all non-significant interactions **(table 3A)**. The model had non-significant residuals ($\chi^2 = 6$, $p = 0.09$), and had therefore a better fit than the model incorporating Capelin. No significant interactions were found in the model, and the interpretation of the predicted response for different combinations of variables was straightforward (**table 3B**); increasing values of temp2, and the presence of front, independently increased the probability of finding concentrations of guillemots. The lowest probability (4 %) was found for temp2 = 0 and absence of front. Highest probability (57 %) was found for temp2 = 3 and front present.

The geographical interpretation is given for the two years 1988 and 1992 (**figure 5 A and B**). Since this model has a larger dissolution of surface temperatures, the polar front (defined according to mean temperatures, see above) is indicated for interpretational reasons in both years. Starting on the Atlantic side of the polar front where surface temperatures were high in both years, the probabilities of finding concentrations of guillemots were low. As temperature decreased moving eastwards, the probability increased. Note that the temperatures decreased faster in the cold year (1988) than in the warm year (1992). After passing the southernmost extension of the polar front in the central part of the study area (both years), still on the Atlantic side of the front, the temperatures decreased below 3°C, and the probability of finding guillemot concentrations decreased. In the frontal areas on the Atlantic side, adjacent to the polar front, there were high probabilities of finding guillemot concentrations. Passing the polar front in 1988, the probabilities decreased fast into cold polar water.

3.3 Concluding model

The models so far presented are based on environmental variables with a variable geographical year to year distribution. In order to find a model with a fixed geographical distribution, we used the mean environmental variables from the best fit model (that is the model with Capelin excluded), and reanalysed the dataset.

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On the basis of the model with Capelin excluded (see above), the average presence of frontal areas (front present in most years vs. no front present in most years) and mean temperatures where found for each geographical area. This gave six distinct outcomes: A: non-frontal areas with mean surface temperatures of -1 or 6°C, B: non-frontal areas with mean surface temperatures of 0,1 or 5°C, C: frontal areas with mean surface temperatures of 0 or 1°C, D: non-frontal areas with mean surface temperatures of 2 or 4°C, E: non-frontal areas with mean surface temperatures of 3°C, and F: frontal areas with mean surface temperatures of 2, 3 or 4°C. The geographical interpretation of these areas is given in **figure 6**. Using these outcomes as a variable in the categorical analysis gave a highly significant model (**table 4A**). The predicted probability of finding concentrations of guillemots varied between 5 % in area A and 50 % in area E (**table 4B**).

The geographical interpretation for the concluding model is given in **figure 6**. For interpretational purposes the mean position of the polar front (after Loeng 1989) is indicated. The probability of finding concentrations of guillemots is low in the warm western part of the study area, and increases as temperatures decrease moving eastwards. Passing the southernmost extension of the polar front, still on the Atlantic side of the front, mean temperatures decrease below 3°C and the probabilities decrease moving into cold Atlantic/polar water in the eastern part of the study area. The probabilities of finding guillemot concentrations are high in frontal areas on the Atlantic side of the polar front. After passing the front, the probabilities decrease fast when moving into true polar water.

Table 3: *Model when Capelin is removed A) Analyses of variance table for variables and interactions. Variables and interactions with a non-significant contribution to the model have been removed. B) Population profiles and observed and predicted values for the response function.*

A

Source	*DF*	*Chi-Square*	*Prob*
Intercept	*1*	*4246*	*<0.001*
Temp2	*1*	*391*	*<0.001*
Front	*1*	*41*	*<0.001*
Residuals	*3*	*6*	*0.09*

B

Sample			***Observed***	***Predicted***		*Pred. prob. of Uria spp.*
Temp2	*Front*	*n*	*Response ±S.E.*	*Response ±S.E.*	*Residuals*	*concentrations*
0	*0*	*254*	*0.95 ±0.013*	*0.96 ±0.013*	*-0.002*	*0.04*
0	*1*	*12*	*0.92 ±0.08*	*0.82 ±0.024*	*0.097*	*0.18*
1	*0*	*329*	*0.79 ±0.022*	*0.79 ±0.02*	*-0.003*	*0.21*
1	*1*	*192*	*0.67 ±0.034*	*0.66 ±0.024*	*0.006*	*0.34*
2	*0*	*952*	*0.66 ±0.015*	*0.65 ±0.014*	*0.012*	*0.35*
3	*0*	*582*	*0.55 ±0.02*	*0.56 ±0.019*	*-0.014*	*0.44*
2	*1*	*311*	*0.47 ±0.028*	*0.51 ±0.021*	*-0.042*	*0.49*
3	*1*	*164*	*0.48 ±0.039*	*0.43 ±0.025*	*0.049*	*0.57*

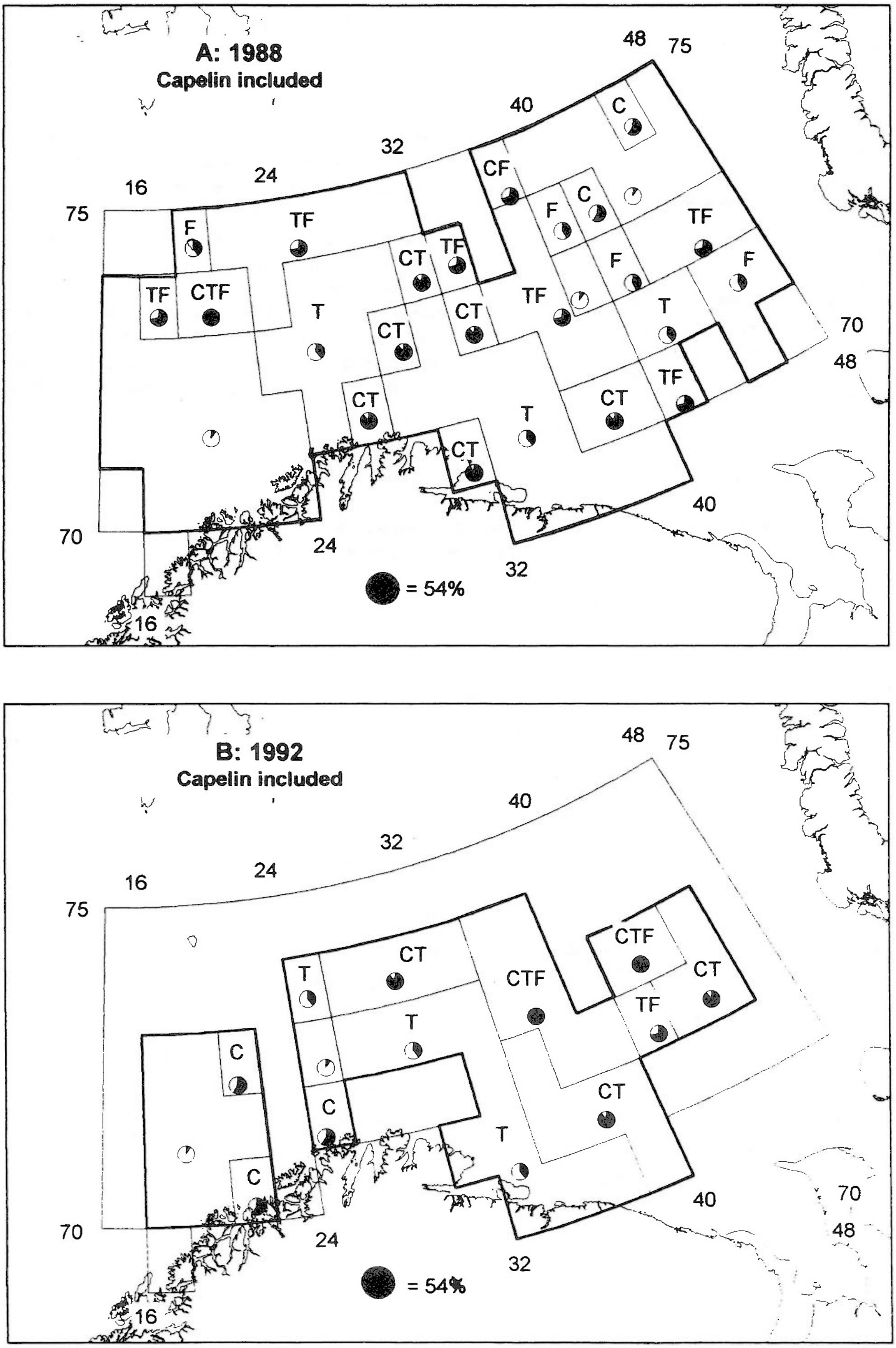

Figure 4: Geographical interpretation of the model when Capelin is included (table 2) for 1988 (A) and 1992 (B). Estimated probabilities of encountering a concentration of Guillemots (more than 250 birds) within a 25 km² area, are given as pie charts. Symbols are given for variables present within geographical areas. Symbols are (see table 1 for definitions): C - Cap, T - Temp1 and F - Front. Note that 1988 was a year with relatively low sea temperatures and low capelin abundance while 1992 was a year with relatively high sea temperatures and high capelin abundance.

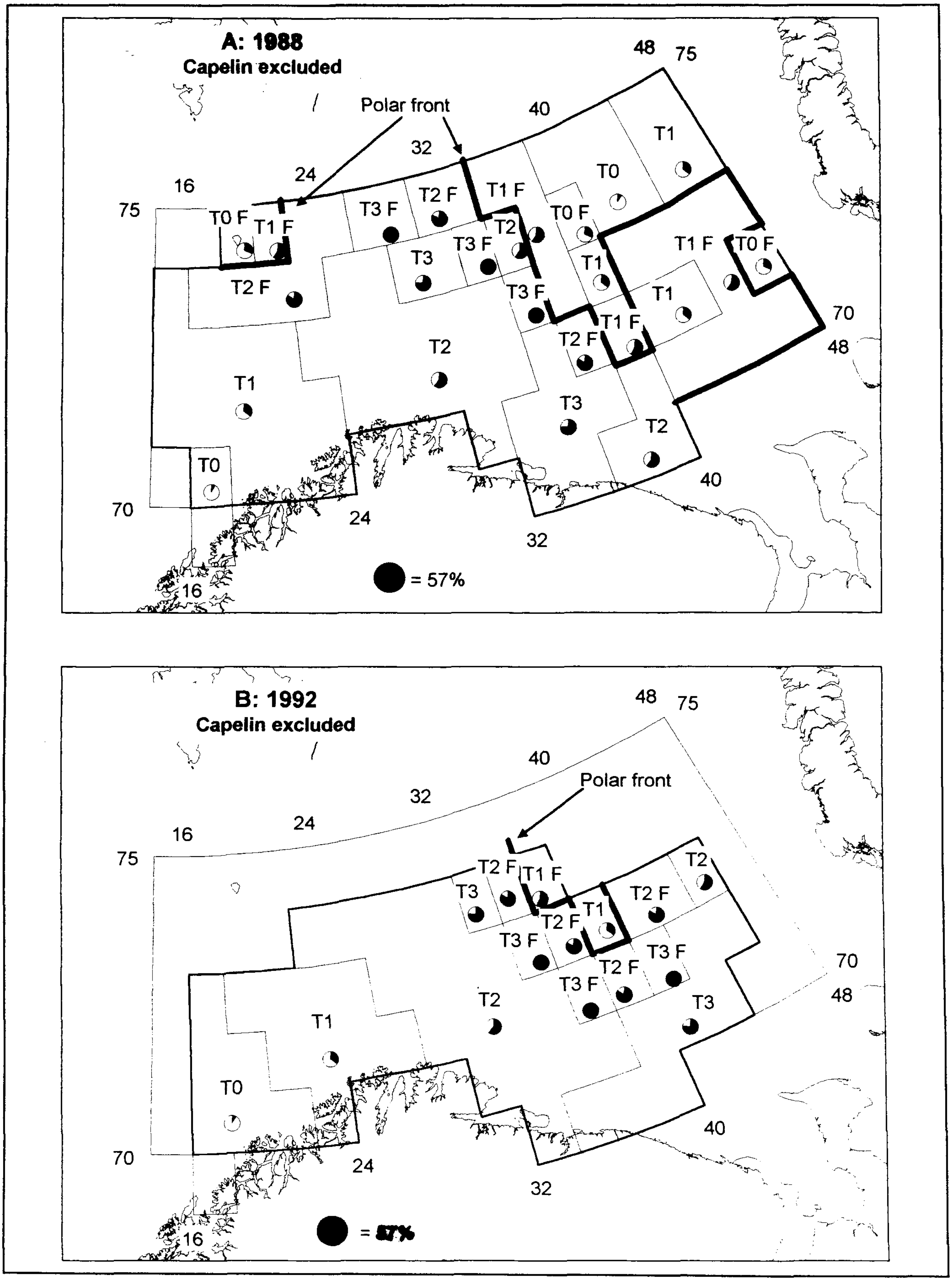

*Figure 5: Geographical interpretation of the model when Capelin is excluded (see **table 3**) for 1988 (A) and 1992 (B). Estimated probabilities of encountering a concentration of Guillemots (more than 250 birds) within a 25 km^2 area, are given as pie charts. Symbols are given for variables present within geographical areas. Symbols are (see **table 1** for definitions): T0 - Temp2 = 0, T1 - Temp2 = 1, T2 - Temp2 = 2, T3 - Temp2 = 3 and F - Front. The position of the polar front is indicated. Note that 1988 was a year with relatively low sea temperatures, while 1992 was a year with relatively high sea temperatures.*

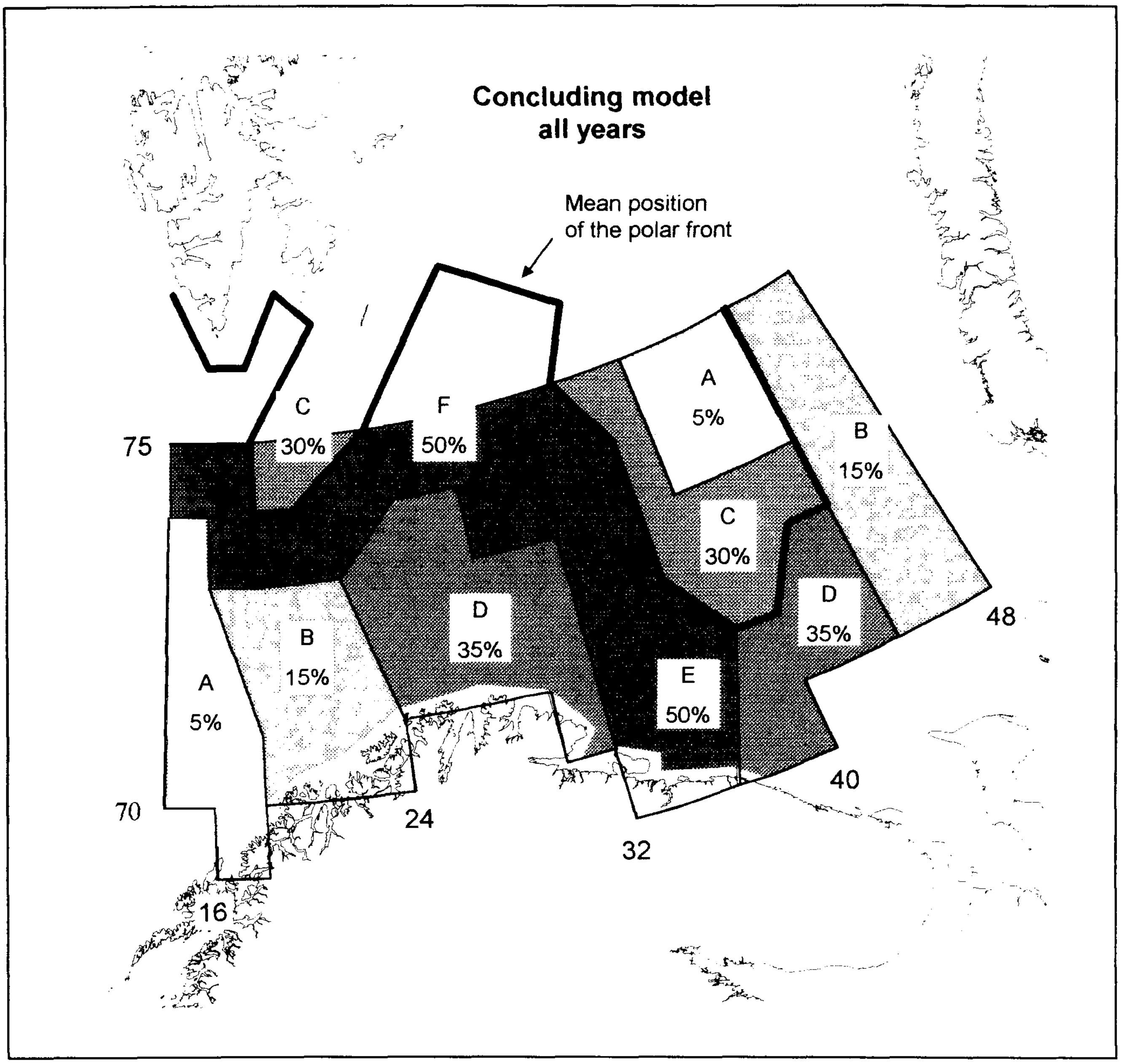

*Figure 6: Geographical interpretation of the concluding model, where the areas (A-F) were defined according to mean surface temperature and average presence of frontal areas (all years included). Percentage values are probability estimates from the model (see **table 4**), and give the probability of encountering a concentration of Guillemots (more than 250 birds) within a 25 km² area. Mean position of the polar front is indicated. Symbols are: A -non-frontal areas with surface temperatures of 6°C in the south-west and -1°C in north-east area. B -non-frontal areas with surface temperatures of 5°C in the south-west and 0 or 1°C in the north-east area. C -frontal areas with surface temperatures of 0 or 1°C. D -non-frontal areas with surface temperatures of 4°C in the west and 2°C in the east area. E -non-frontal area with surface temperature of 3°C. F -frontal area with surface temperature of 2, 3, or 4°C. The probability of encountering concentrations of Guillemots is low in the warm south-west area (A), and increase as the surface temperature decrease towards the polar front (B and D). The probability reach a maximum at the non-frontal area with mean temperature of 3°C (E) and at the Atlantic side of the polar front (F). The probability decrease on the polar side of the front (C) and in cold mixed water (B), and finally approach zero in true polar water (mostly ice covered) (A).*

4 Discussion

In assessments of the possible effect of oil exploration on seabirds, it is often advantageous to be able to give general broad scale predictions of the distribution of seabirds. As a consequence of the high mobility and patchiness of seabirds, such predictions have been hard to obtain (i.e. Fauchald & Erikstad, 1995). In the present report we use more stable broad scale environmental properties (surface temperatures and frontal areas) in predicting the probability of encountering concentrations of guillemots within large geographical areas. Albeit the model was highly significant, the environmental variables used have a slightly variable distribution from year to year. Thus, in the concluding model we used the mean distribution of frontal areas, and mean surface temperature to explain the distribution of guillemots. This model was highly significant, the geographical interpretation was relatively simple and matched the general distribution of Capelin, the major prey item at this time of the year. This is consistent with numerous earlier studies that find close relationships between the spatial distribution of seabirds and physical properties of the sea (reviewed by Hunt & Schneider 1987; Hunt 1990). By using already existing environmental data, we were thus able to make significant predictions for the general distribution of guillemots in the Barents Sea in the period January to March on the basis of a limited dataset with scattered observations.

It must be emphasised that the cruises used for seabird counts only occasionally were conducted into ice-filled areas, and never in ice-covered areas. Thus, the probability estimates are only valid in areas not covered by ice. However, we argue that the probability estimates give a fairly good description of the relative importance of the different areas of the Barents Sea for wintering guillemots.

4.1 The effect of the spatial structure

As a consequence of the patchy distribution of guillemots, we chose to perform categorical analyses. This is partly because frequency distributions of seabirds often are hard to transform into normality (e.g. Schneider & Piatt 1986; Erikstad 1990; Piatt 1990; Skarsfjord, 1995) and thus enabling the use of ANOVA/ANCOVA models, and partly because we believe that the probability of encountering a patch/concentration of seabirds is a more suitable estimator for assessment purposes than an estimation of mean density. The last is because an estimation of the mean densities may give the false impression of an evenly distribution of seabirds.

In order to perform the categorical analyses we had to define a «concentration» of guillemots, and the distributional pattern of guillemots is according to this definition, given by the estimated probability of finding more than 250 individual birds within a small area of only 25 km^2. Because there is a large variation in the actual number of guillemots among these concentrations (**figure 2A**), it must be stressed that a possible impact of an oil spill will have a variable outcome.

***Table 4:** Concluding model; the areas (A-F) were defined according to mean surface temperature and average presence of frontal areas (all years included). Variables are: A -non-frontal areas with temperatures of -1 or 6°C. B -non-frontal areas with temperatures of 0, 1 or 5°C. C -frontal areas with temperatures of 0 or 1°C. D -non-frontal areas with temperatures of 2 or 4°C. E -non-frontal area with temperature of 3°C. F -frontal area with temperature of 2, 3, or 4°C. A) Analyses of variance table. B) Population profilesandobserved/predicted values for the response function.*

A

Source	DF	Chi-Square	Prob
Intercept	1	5945	<0.001
Conc. model	5	367	<0.001

B

Sample Area	n	Observed/predicted Response ±S.E.	Pred. prob. of *Uria* spp. concentrations
A	96	0.95 ±0.023	0.05
B	394	0.87 ±0.017	0.13
C	242	0.7 ±0.029	0.30
D	1207	0.66 ±0.014	0.34
E	601	0.5 ±0.002	0.50
F	360	0.52 ±0.026	0.48

Another important factor to take into consideration is the effect of autocorrelation in the survey data on the distribution of seabirds (Schneider 1990; Veit et al. 1993). Since seabirds have an aggregated distribution, there is a high correlation between the densities of birds in observations that are close to each other (Schneider 1990; Legendre 1993; Fauchald et al. in prep.). Autocorrelation has probably no effect on the measured association between guillemots and the environmental variables, but has certainly a detrimental effect on the confidence interval (making it larger) (Legendre 1993; Skarsfjord 1995). Thus, there is a relatively large probability of wrongly detecting significant associations between environmental variables and the distribution of seabirds in the analyses (i.e. Legendre 1993).

Furthermore, autocorrelation between observation areas adjacent to each other will further increase the variation in the possible impact of an oil spill. If the spill occurs in an observation area with a concentration of guillemots, the probability that adjacent areas also contain concentrations of guillemots would be larger than the predicted probability. On the other hand, if the spill occurs in an area not containing guillemots, the probability that adjacent areas contain concentrations of guillemots would be smaller than the predicted probability. As a consequence, there will always be a certain probability that a considerable part of the population of guillemots is affected by a possible oil spill though-out the study area. In other words, the large variation in the number of guillemots affected in confined geographical areas greatly increases the vulnerability of the population to a possible oil spill (cf. Pimm 1991 with examples, for the effect of spatial structure on population extinction).

4.2 Biological relevance

The effect of autocorrelation upon the confidence intervals in the models, stresses the importance of biological relevance when selecting a suitable model. In the Barents Sea, one generally find a high degree of overlap between the distribution of guillemots and their main prey Capelin (Erikstad & Vader 1989; Erikstad et al. 1990, Skarsfjord 1995, Fauchald & Erikstad in prep.). Capelin overwinter in Atlantic water, close to the polar front in the central part of the Barents Sea. In January when the cruises started, maturing Capelin ascend to the surface layers and start their spawning migration to the coasts of Kola, Finnmark and occasionally Troms (Ozhigin & Luka 1984). The spawning and wintering areas are primarily determined by sea temperatures (Ozhigin & Luka 1984; Tjelmeland 1986). However, due to the highly aggregated spatial distribution, only a small part of the areas with optimal sea temperatures are at any time occupied by Capelin (own obs.).

In accordance with the general distribution Capelin we found high probabilities of encountering concentrations of guillemots in Atlantic water close to the polar front and in Atlantic water with temperatures between 2 and 4°C. Low probabilities were found in warm Atlantic water and in polar water. Furthermore, we found increased probabilities of encountering concentrations of guillemots when Capelin was present.

4.3 Geographical suitability

Although the presence of concentrations of Capelin significantly increases the probability of finding concentrations of guillemots within a geographical area (cf. **figure 3A**), Capelin was removed as a variable from the concluding model. This was partly due to the fact that Capelin had a negative influence on the model's fit. However, more important is that Capelin, like guillemots are highly mobile and have a highly aggregated distribution. Thus, using the distribution of Capelin from a limited dataset is probably no better than using the distribution of guillemots themselves, when predicting the broad scale distribution of guillemots (i.e. Fauchald & Erikstad 1995). This is illustrated in the model where Capelin is included (cf. **figure 5**). Geographical areas with Capelin, and consequently high probability of finding guillemot concentrations, are found scattered throughout the whole study area in an *apparently* random fashion. Furthermore, due to migration, the distribution of geographical areas with Capelin changes from week to week (Fauchald et al. in prep.). Accordingly, the distribution of Capelin is unsuitable when giving geographical predictions for the distribution of guillemots.

4.4 Concluding model

On the basis of the results from the model with Capelin excluded, we used mean surface temperature and the presence of temperature gradients (frontal areas) from the years 1986-94 when dividing the study area into six distinct areas in the concluding model (cf. **figure 7**). The geographical interpretation of this model match fairly well the general wintering and spawning distribution of the Barents Sea Capelin as given by Ozhigin & Luka (1984). Variation in the flow of Atlantic water into the Barents Sea and variation in regional cooling generate displacement of the polar front and variation in surface temperatures between years (Loeng 1989; Midtun 1990). Wintering areas and spawning grounds used by Capelin are largely determined by sea temperatures and the distribution of the polar front (Ozhigin & Luka 1984). Accordingly, large scale changes in the inflow of Atlantic water generate displacements both in the wintering area and the main spawning grounds for maturing Capelin. The years used comprise, according to data given in Korsbrekke et. al (1995), 3 cold years (1986-88), 1 medium year (1989) and 5 warm years (1990-94). Some year to year variation in the probabilities given in the concluding model should therefore be expected. This was however not investigated in this study.

4.5 Polar habitats - Atlantic habitats

Mehlum & Isaksen (1995) found higher densities of guillemots associated with pack ice compared to open waters in late winter and spring in the Barents Sea. The birds preferred large leads some distance away from the ice edge, and were presumably feeding on Polar Cod (*Boreogadus saida*) and the pelagic amphipod *Parathemisto libellula* (Mehlum & Gabrielsen 1993). The cruises attended in our study only occasionally entered ice-filled waters, and never ice-covered areas. We found however, low probabilities of finding concentrations of guillemots in polar waters, that is; open areas close to the ice edge. In conclusion, it seems likely that one part of the population of guillemots in the Barents Sea winters in the Atlantic ecosystem, foraging on Capelin, while another part winters in ice-filled waters in the polar ecosystem, foraging on Amphipods and Polar Cod. Such a spatial splitting of the population of guillemots could eventually serve as a buffer on the possible detrimental effect of an oil spill (cf. Pimm 1991).

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ISSN 0807-3082
ISBN 82-426-0720-6

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