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Final Report

Contract No. 03-5-002-72

Research Unit No. 83 RU-083

1 January 1980-30 September 1981

Pelagic Distribution of Marine Birds

and

Analysis of Encounter Probability for the Southeastern Bering Sea

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ACKNOWLEDGEMENTS

Throughout the years of this project, we have become indebted to many people, without whose help our task would have been impossible. The success of our pelagic studies was aided and supported by the captains and crews of the Discoverer, Moana Wave, Surveyor and T.G. Thompson and the helicopter pilots assigned to the Surveyor. Others helped us gather data: Zoe Eppley, Doug Forsell, Sue Hills, Bobbie Mayer, Maura Naughton, Jay Nelson, Bill Rodstrom, Melody Roelke, Doug Schwartz, Sam Sharr, Doug Siegal-Causey and Doug Woodby. These people all put in unreasonably long hours of hard work. The project would not have succeeded without their enthusiasm and support. In addition, for the analyses the proportion of transects with large densities (Figures 1-8) and the evaluations of encounter risk (Figures 17-26), data gathered by other OCSEAP contractors (J. Wiens, P. Myers and the U.S. Fish and Wildlife Service) were used.

Grace Bush, Mike Crane, and Jim Mershman were instrumental in our data management processes. Hal Petersen and the Data Projects Group, University of Rhode Island were instrumental in the analysis and development of computer graphics for our pelagic studies. Zoe Eppley played a major role in production of the final report. Karin Fouts provided illustrations, and Pam McDonald and Tana Forstrom typed the manuscript.

We acknowledge the assistance provided by the Juneau NOAA-OCSEAP project office and particularly want to thank George Lapienne, Bob Myers and Rod Swope. We appreciate the discussions and comments of Lawrence Coachman, Ted Cooney, Tom Kinder, and Peter McRoy.

Data collection was supported by NOAA (OCSEAP) contract No. 03-5-002-72 to George Hunt and by NSF grants DPP-7910386 to G. Hunt and DP76-23340 to PROBES.

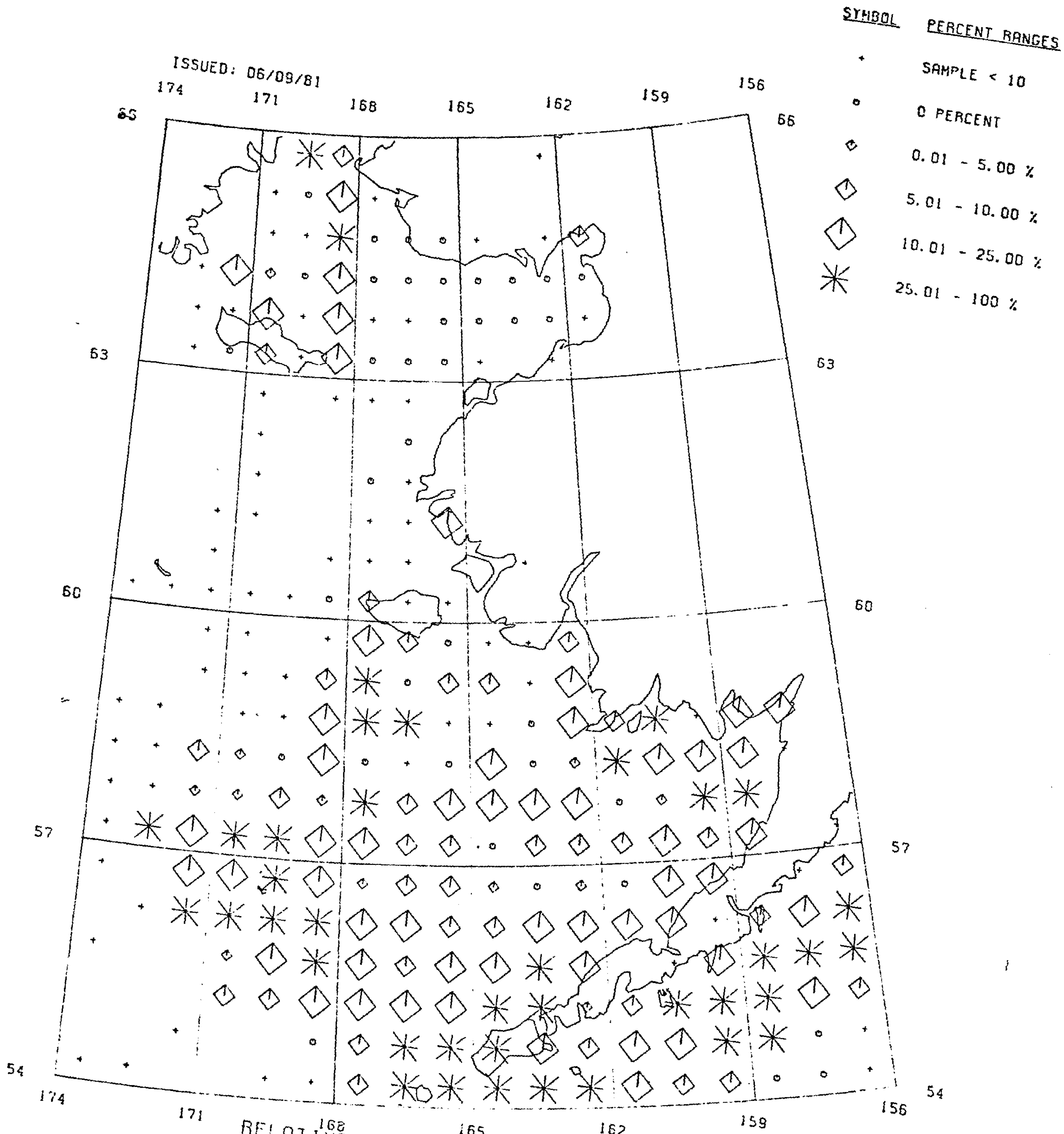
SUMMARY OF OBJECTIVES, CONCLUSIONS AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

The objective of this project was to investigate the pelagic distribution of birds in the southeastern Bering Sea and to identify areas in which high densities of birds were frequently found (sensitive areas). We also wished to identify the characteristics of areas supporting large numbers of birds and to develop a rationale for sampling programs for the examination of new regions.

Around the Pribilof Islands, foraging seabirds are concentrated within 50 km of the colonies, although a few species (e.g. Northern Fulmar, _Fulmaris glacialis_, Red-legged and Black-1egged Kittiwakes, _Rissa brevirostris_ and _R. tridactyla_) forage at greater distances from their colonies. Crucial foraging areas for Pribilof seabirds are located at the shelf break southeast of St. George Island, on the shelf 100 km east of St. Paul, and generally within 50 km of the islands. The reduction of food resources, or the occurrence of oil spills in these areas would affect a great number of birds.

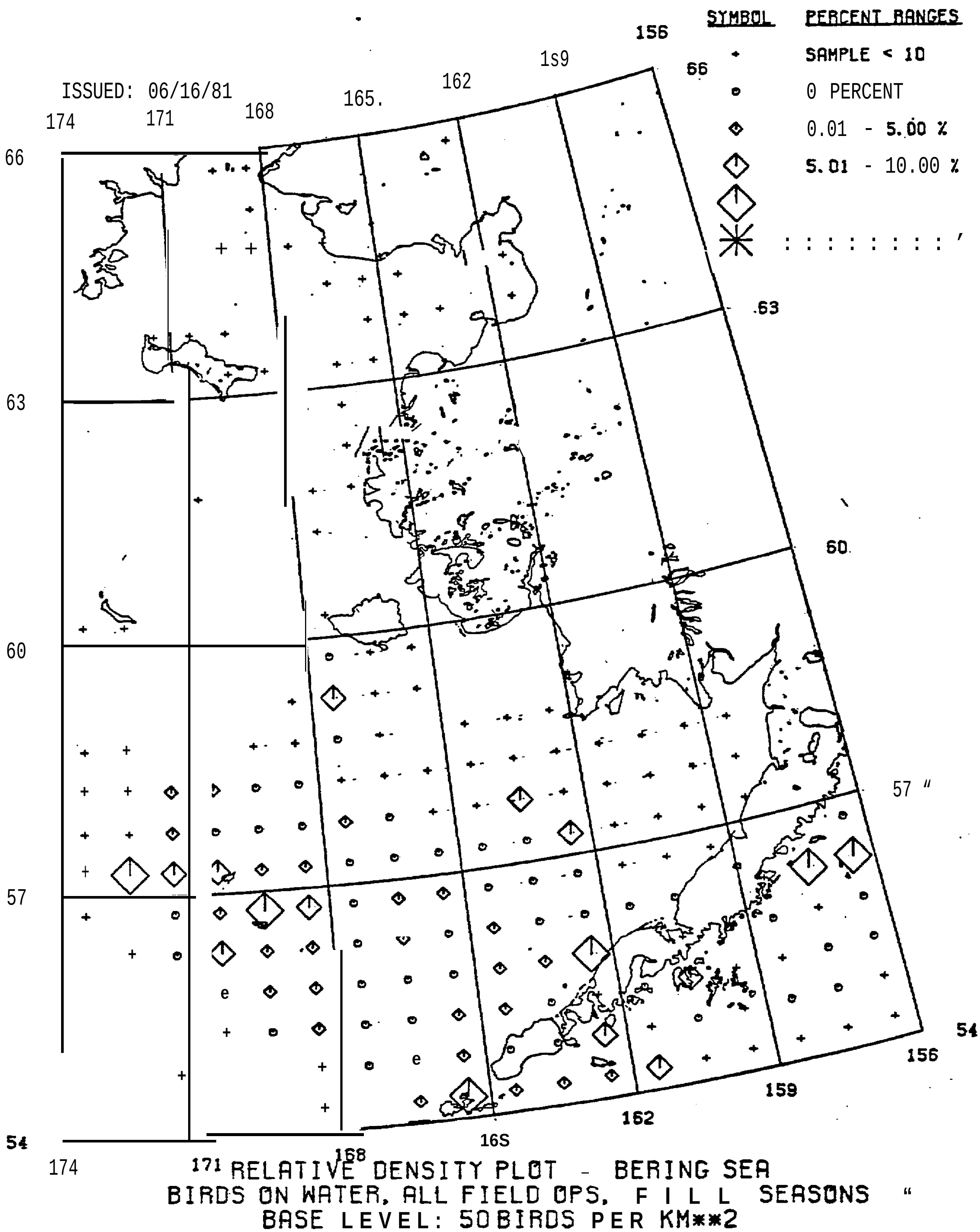
Figures 1-8 show the geographic distribution and frequency of transects with densities of birds greater than or equal to 50, 100, 500 and 1000 birds/km2. Areas where high densities were frequently encountered should be considered as areas of great avian sensitivity to oil spills. The Bering Strait, the vicinity of St. Lawrence Island, the area around the Pribilofs, the shelf-edge and Bristol Bay inside the 50 m curve are all sensitive areas. These highly sensitive areas are most readily seen in Figure 3. This assessment of sensitive areas is also born out by the analysis using means and coefficients of variation in Figures 13 to 22. Note, there are large areas which have yet to be surveyed which may contain very sensitive areas (e.g. the west end of St. Matthew Island).

Our zonal analysis of bird distribution showed that the areas close to the



RELATIVE DENSITY PLOT - BERING SEA
ALL BIRDS, ALL FIELD OPS, ALL SEASONS
BASE LEVEL: 50 BIRDS PER KM**2

Figure 1


SYMBOL
PERCENT RANGES
SAMPLE < 10
0 PERCENT
0.01 - 5.00 %
5.01 - 10.00 %
ISSUED: 06/16/81
174
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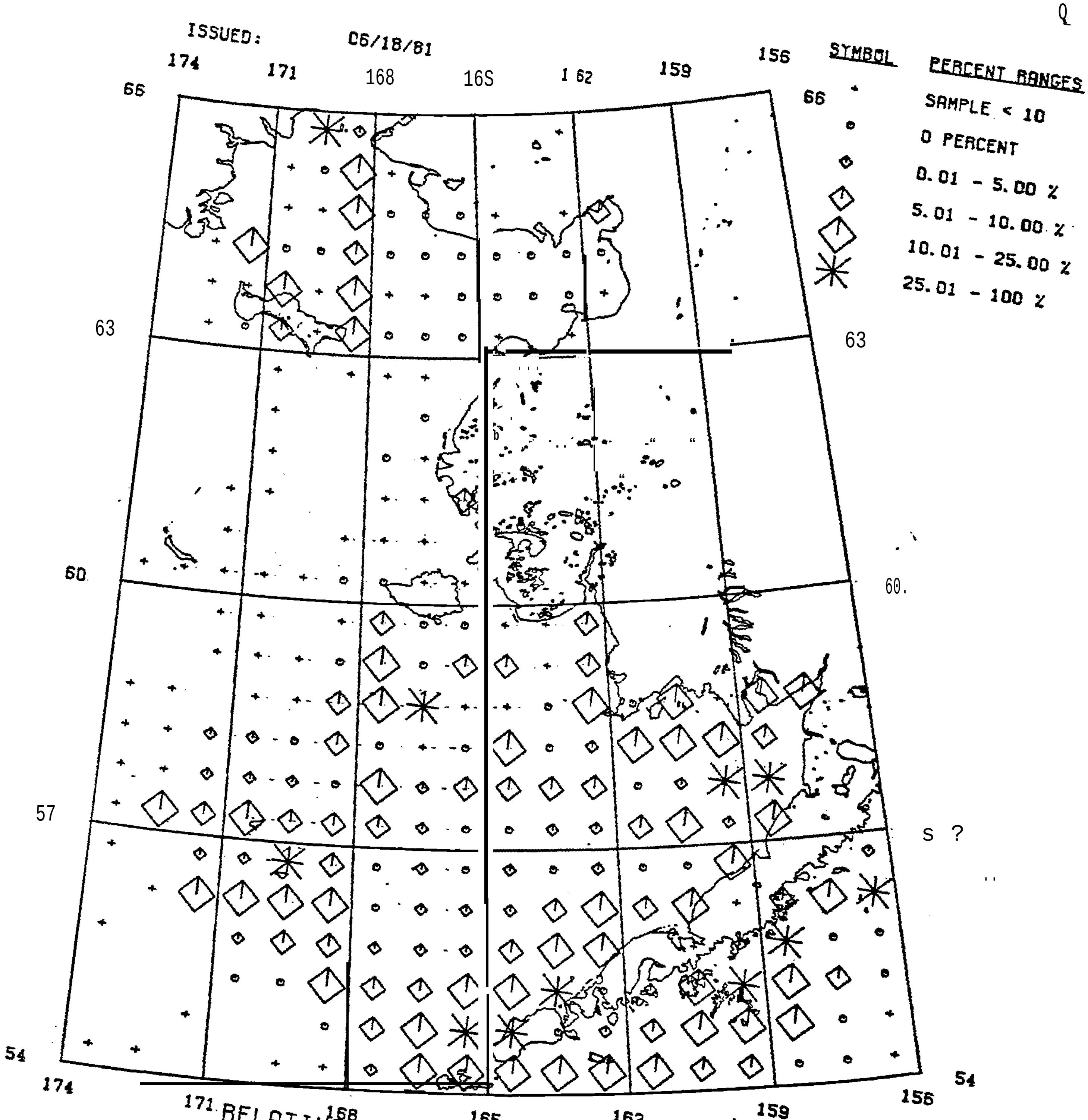
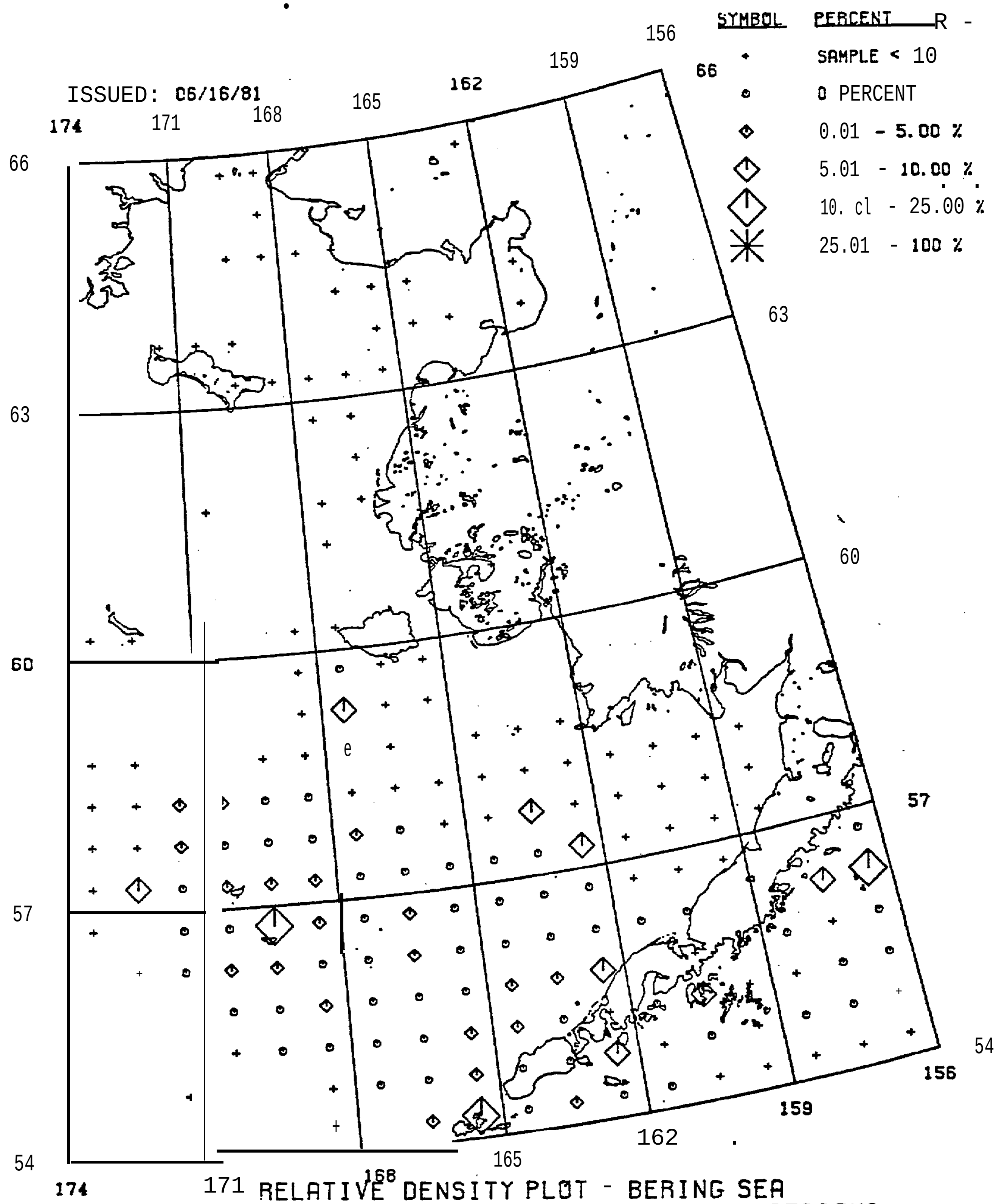
RELATIVE DENSITY PLOT - BERING SEA
BIRDS ON WATER, ALL FIELD OPS, F I L L SEASONS
BASE LEVEL: 50 BIRDS PER KM**2

Figure 2



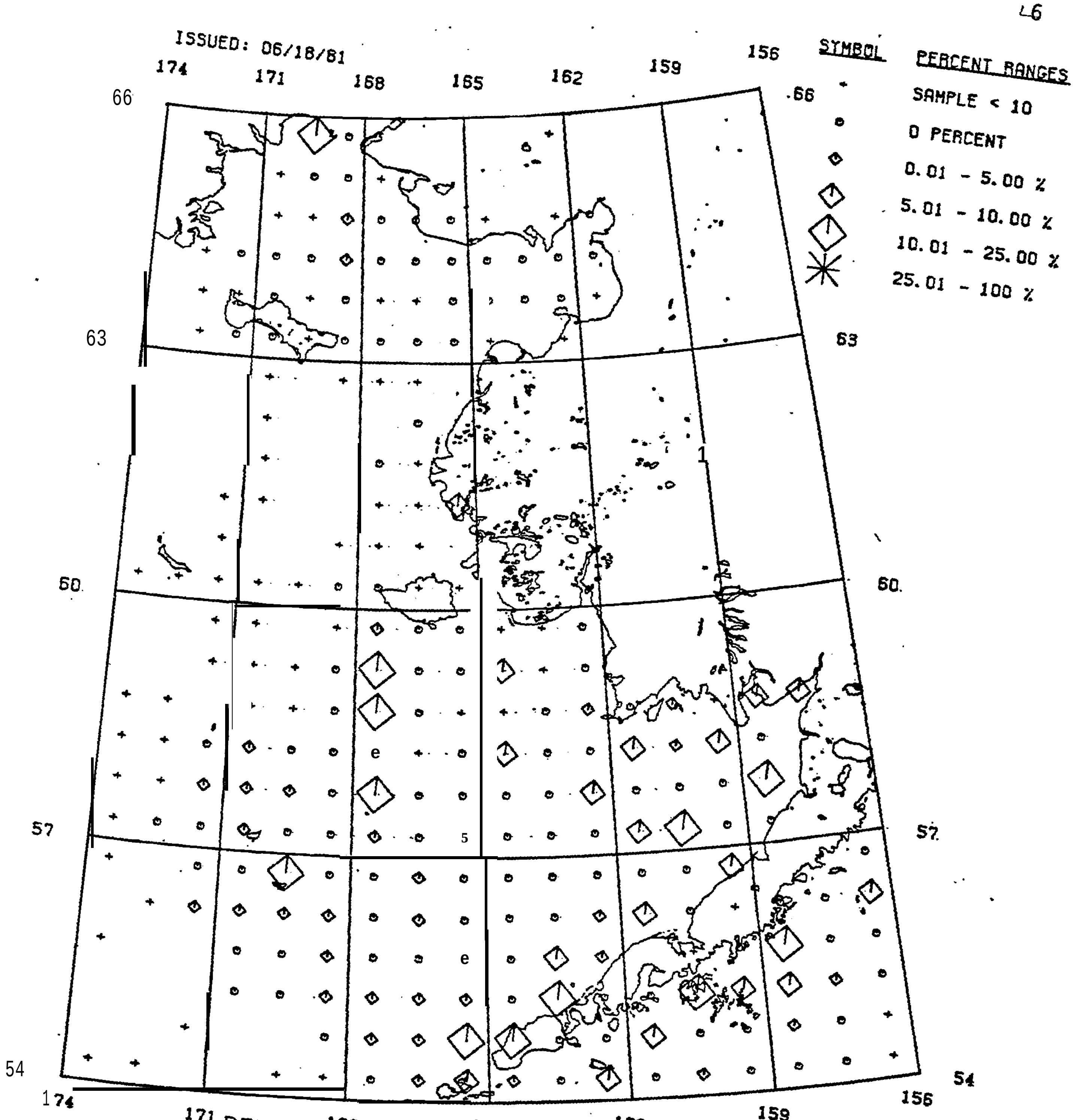
RELATIVE DENSITY PLOT - BERING SEA
ALL BIRDS, ALL FIELD OPS, ALL SEASONS
BASE LEVEL: 100 BIRDS PER KM**2

Figure 3



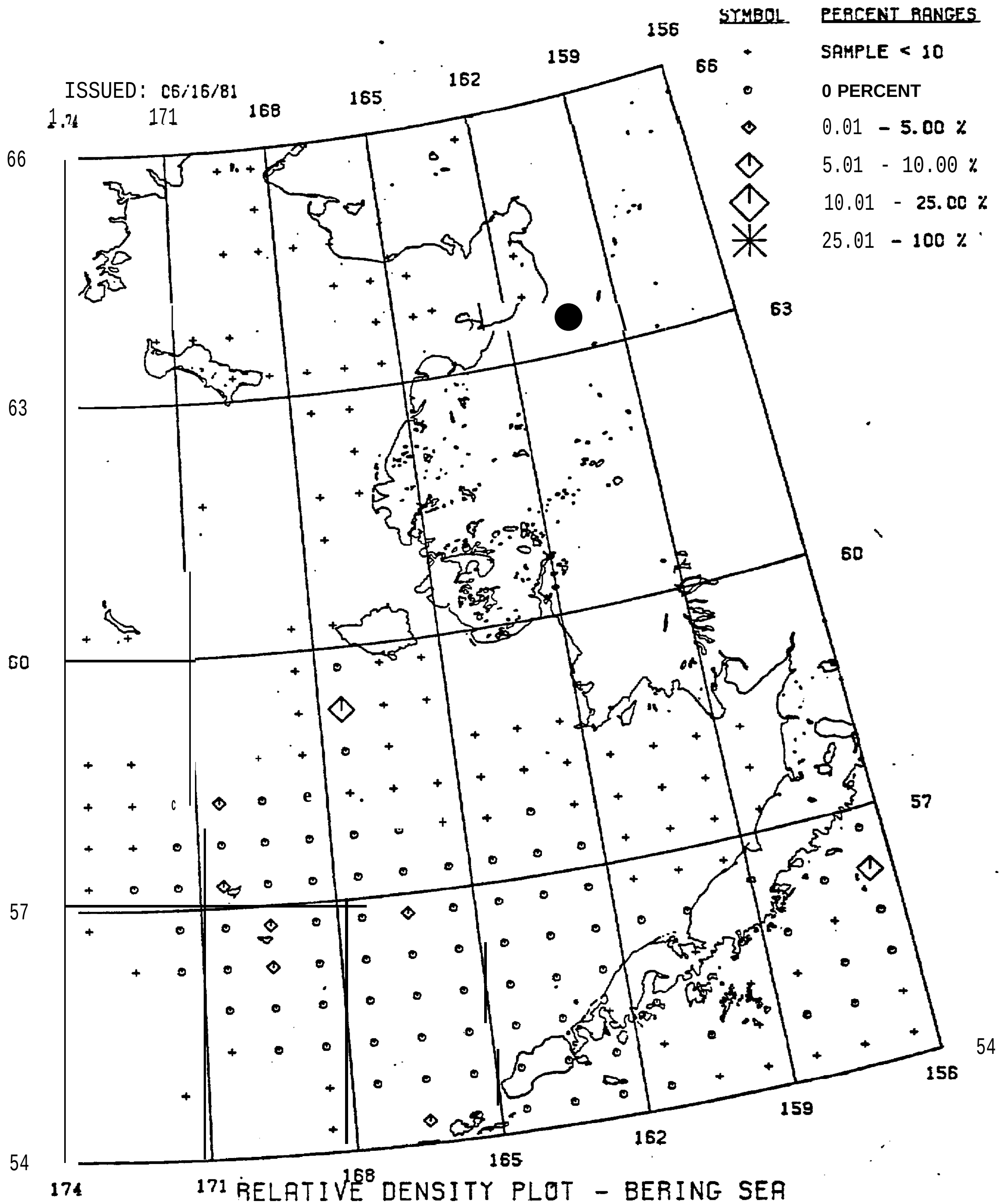
RELATIVE DENSITY PLOT - BERING SEA
BIRDS (3 N WATER, ALL FIELD OPS, ALL SEASONS .
BASE. LEVEL : 100 BIRDS PER KM**2

Figure 4



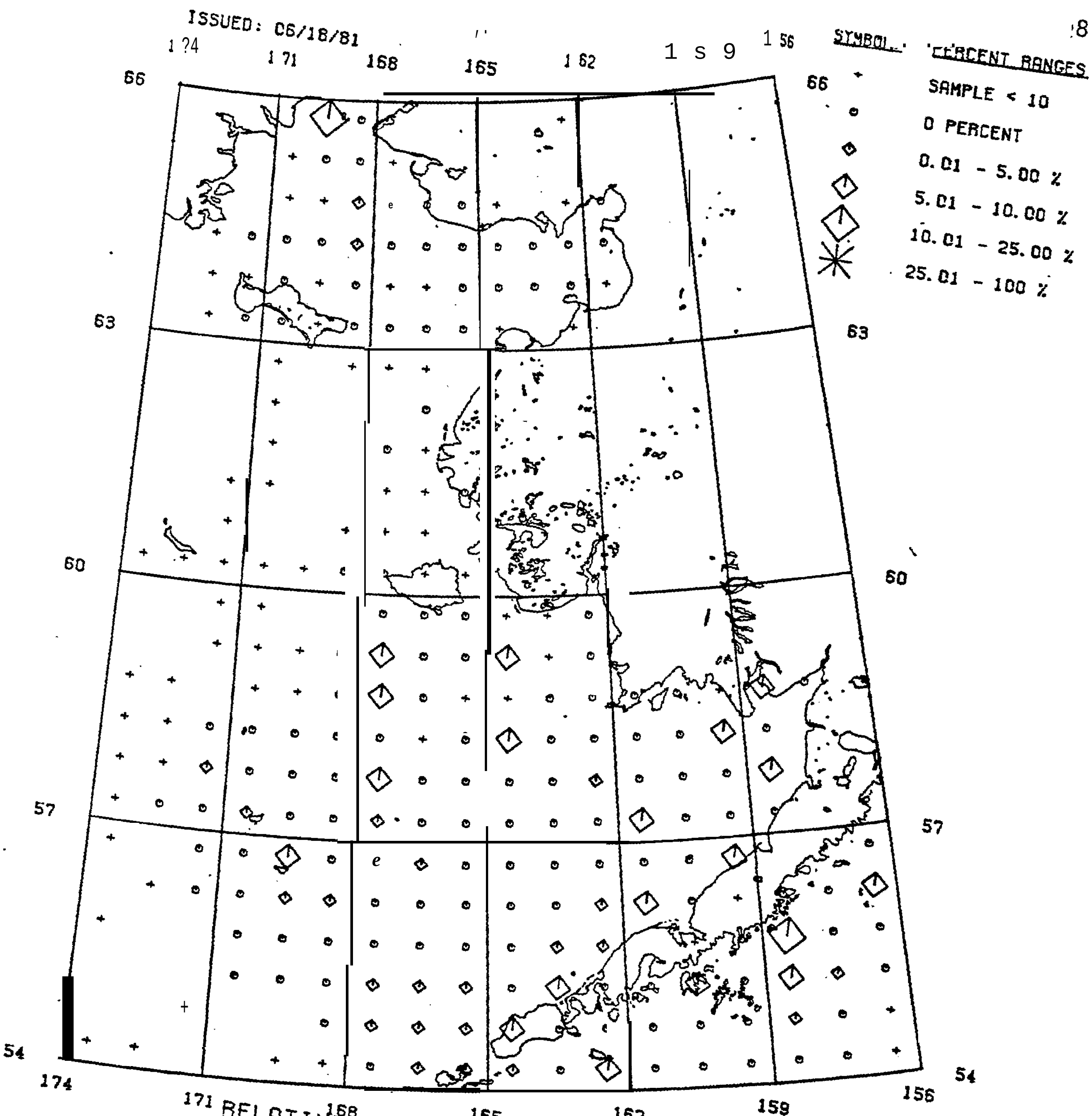
RELATIVE DENSITY PLOT - BERING SEA
ALL BIRDS, ALL FIELD OPS, ALL SEASONS
BASE LEVEL: 500 BIRDS PER KM**2

Figure 5



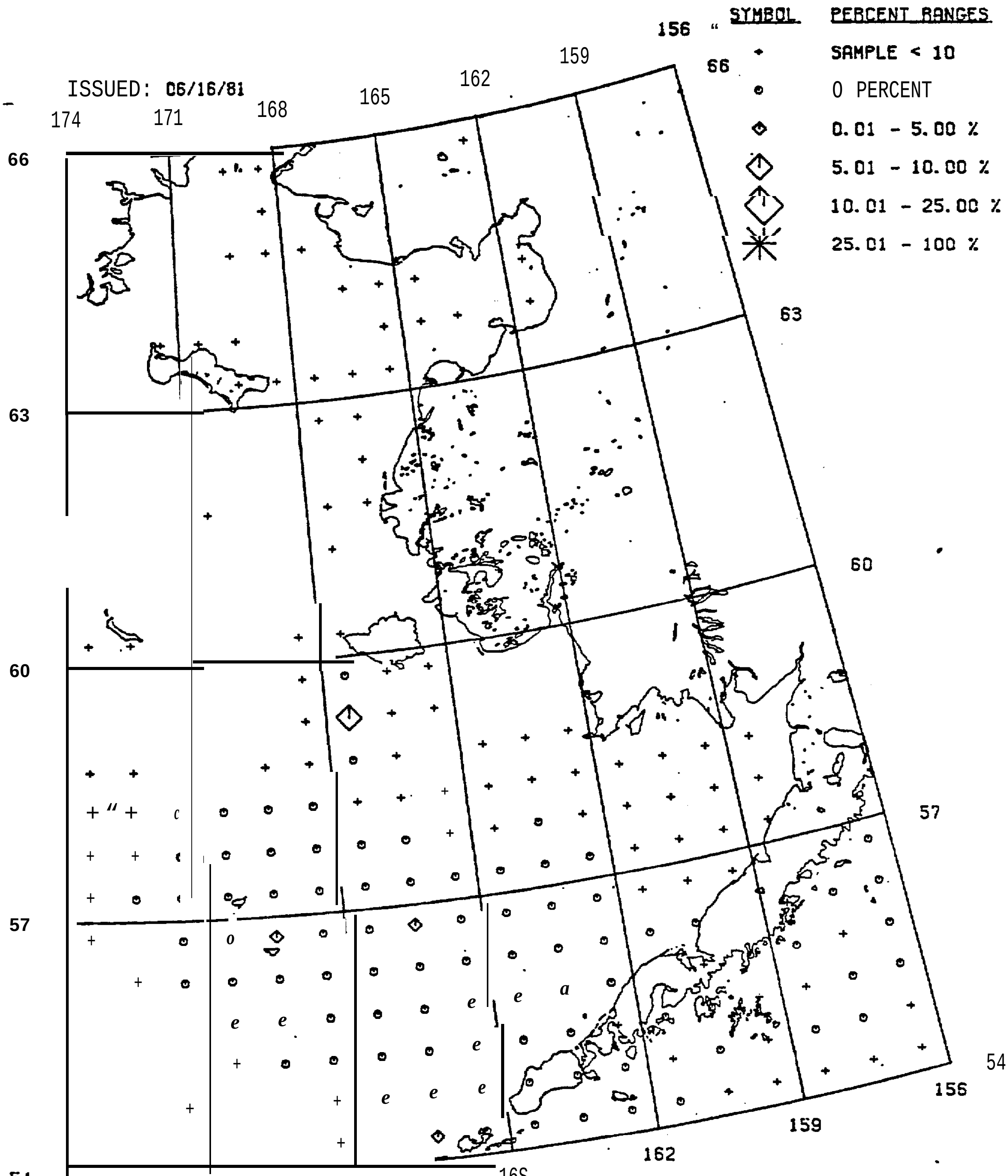
RELATIVE DENSITY PLOT - BERING SEA
BIRDS ON WATER, ALL FIELD OPS, ALL SEASONS
BASE LEVEL: 500 BIRDS PER KM**2

Figure 6



RELATIVE DENSITY PLOT - BERING SEA
ALL BIRDS, ALL FIELD OPS, ALL SEASONS
BASE LEVEL: 1000 BIRDS PER KM**2

Figure 7



RELATIVE DENSITY PLOT - BERING SEA
BIRDS ON WATER, ALL FIELD OPS, ALL SEASONS
BASE LEVEL : 1000 BIRDS PER KM**2

Figure 8

colonies, particularly on the side toward the shelf-edge have the greatest densities of birds and the most frequent occurrence of transects with high densities. Away from the colonies, areas near the shelf-edge have high densities, as do the areas along the 50 m curve in Bristol Bay.

A proposed sampling rationale suggests that regions to be surveyed be divided into zones by distance from colonies and by oceanographic domains away from colonies. A random sample of at least 100 transects within each zone, per season, will provide data on the frequency distribution of transects of different densities ± 10% at the 95% confidence level. This level of statistical certainty should be sufficient to provide reasonable confidence in the credibility of recommendations based on the survey effort. Because of seasonal variation, samples should he spread over three or four seasons.

INTRODUCTION

The purposes of this study were 1) to assess the relative likelihood of encountering birds in various areas of the eastern Bering Sea shelf waters surveyed, 2) to provide descriptions of those areas where birds have been found to congregate in order to predict where, in still-to-be explored waters, birds are likely to be common, and 3) to provide a statistically valid rationale for designing future bird survey efforts.

To assess the risk of bird loss in the event of an oil spill, several approaches can be taken. King and Sanger (1979) have concentrated upon developing an index of vulnerability that assesses the relative impact of oil on each of the species of marine birds frequenting Alaskan waters. Their approach, while directing attention to those species for which spilled oil poses the greatest threat, provides no information on the likelihood of encountering those species in any given area. The studies of Wiens et al. (1979) provide models for predicting the long term impact of a spill in the vicinity of a colony or other area for which a large data base on distribution, reproductive success and energetic relations of the birds is available.

The present effort focuses on where on the ocean spilled oil is likely to come into contact with large numbers of birds. There are two ways of assessing where large numbers of birds are likely to be encountered. First, we can focus on the locations of transects that have encountered high densities of birds, regardless of the variation in the density of birds at these locations. The percentage of transects encountering high densities gives an indication of the probability that a spill would impact large numbers of birds. Second, we can focus on the mean density of birds and the variation of the mean for a given area. Under this approach areas with high means and low variance would be considered high risk areas while those with low means and low variance would be considered low risk areas. Intermediate levels of risk would be assigned to areas having both a high mean and a high variance or a low mean and a high variance.

The second aspect of this report is an attempt to provide a description of the areas most preferred by birds so that reasonable predictions about where large numbers of birds are likely to be encountered can be made for unsurveyed areas. We first attempted to describe these areas of known high usage using linear regression models. However, due to the highly skewed distributions of seabirds, no clear association was found between oceanographic features and high bird densities using standard multivariate techniques. Our approach was therefore to first partition the available data base into biologically significant geographical zones and time (season) intervals. After imposing this structure on the data, we were able to categorize the sample densities into intervals which yielded probability estimates based on very few assumptions about the population distribution in general. The results of these two methods can be examined to identify, on the basis of our present knowledge, the most sensitive areas.

Finally, using the data in hand and our efforts at predicting where different densities of birds should be found, we have provided suggestions on the quantity and distribution of sampling effort required to give various types of information concerning bird densities. While one can always argue that the greater the sampling effort, the better the estimate of the population being studied, it is clear that there are neither adequate funds nor is there sufficient time to survey intensely all offshore oil lease-sale areas. We have therefore attempted to develop a rationale for distributing sampling effort in order to gain the maximum information possible per unit effort.

CURRENT STATE OF KNOWLEDGE

1) Pelagic Distribution

The pelagic distribution of seabirds is relevant to OCS oil production because bird density and location determines their potential vulnerability to oil spills. The relationship between the distribution of marine birds in the North Pacific/Bering Sea and the oceanographic features of these waters has been the subject of study in recent years. Kuroda (1960) attempted to correlate numbers of seabirds with food availability and sea surface temperature, while Shuntov (1972) stressed the importance of upwelling near the shelf break, as well as the higher productivity and the large bird concentrations associated with shelf waters. Swartz (1966) discussed bird distribution in the Chukchi Sea and Bering Strait regions.

Prior to OCSEAP cruises, knowledge of the pelagic distribution of seabirds over the eastern Bering Sea shelf was limited. Irving et al. (1970), Bartonek and Gibson (1972) and Wahl (1978) reported on birds seen in the course of single cruises, made for other purposes, which spent only brief periods in shelf waters. Wahl (1978) found a marked increase in the density of birds and species composition as he crossed from the deep oceanic waters to waters over the shelf. In particular, storm-petrels (*Oceanodroma* sp.) were less common over the shelf, while murres (*Uris* sp.) and shearwaters (*Puffinus* sp.) increased in density. Wahl estimated a density of 3.9 birds/km^2 for the oceanic waters compared to 14.9/km^2 for shelf waters. These values were similar to those obtained by Shuntov (1972) of 2.7/km^2 and 18/km^2, respectively. Sanger (1972) provided estimates of pelagic bird density over the Bering Sea shelf and oceanic basin based on extrapolations from other ocean regions. More recently, Iverson et al. (1979) have shown that seabird densities over the southeastern Bering Sea shelf are related to frontal systems. In a series of cruises, bird densities were highest from the Outer Front (Figure 10, p.22), at the 200 m isobath, shoreward to the Middle Front, at the 100 m isobath.

Hunt et al. (1980a) provide the most recent summary of new data from the eastern Bering Sea as a whole, while Hunt et al. (1980b) provide an update on seabird distributions near the Pribilof Islands. Schneider and Hunt (MS) and Hunt and Schneider (MS) discuss energy flow and pelagic distribution, respectively, for the region near the PROBES line. The present report will attempt to integrate and present the major portion of these recently accumulated data.

2) Oil Effects

A vast literature exists on the effects of oil pollution on seabirds. Vermeer and Vermeer (1974) provide an annotated bibliography. More recently Holmes and Cronshaw (1977) have reviewed the biological effects of petroleum on birds with particular emphasis on physiological effects. OCSEAP sponsored studies have investigated the effects of oil on seabird reproduction (Patten and Patten 1977, 1978), and OMPA has supported additional physiological work initiated by Graw et al. (1977).

There are conflicting reports as to the behavior of seabirds when encountering oil slicks; Curry-Lindahl (1960) reported that Oldsquaw (Clangula hyemalis) were attracted to slicks. In contrast, Herring Gulls (Larus argentatus), Black-legged Kittiwakes and Common Murres (U. aalge) are reported to leave slicks once they encounter one (Bourne 1968). Differences in the reaction of birds to oil slicks affects the vulnerability of a species and the potential for population loss when oil is spilled. The Bureau of Land Management is presently sponsoring studies of this problem in southern California (Gordon Reetz, Los Angeles BLM/OCS office, personal communication).

Other studies have concentrated on the effects of oil spills on populations.

Milon and Bougerol (1967, in Vermeer and Vermeer 1974) document changes in populations of seabirds on the Ile Rouzic in France subsequent to the Torrey Canyon disaster. Within a month the populations of Common Puffins (Fratercula arctica) and Razorbills (Alca Torda) were reduced by 88% while the population of Common Murres was reduced by 75%. Populations of fulmars and gulls were affected to only a minor degree. Studies by O'Connor (1967), Phillips (1967) and Monnat (1967) report on the effect of the Torrey Canyon spill on alcids and gannets (Sula bassana) at other locations. The lack of a baseline hindered the study of effects of the Torrey Canyon spill on seabird numbers and reproductive success.

These studies, although fragmentary, show that alcids and sea ducks are particularly vulnerable to oil. King and Sanger (1979) developed an oil vulnerability index for marine birds for the North Pacific and Bering Sea regions. The sensitivity of alcids to oil pollution is a critical problem in relation to Alaskan oil recovery, as the large colonies are predominately populated by alcids. In Fall and Spring, sea ducks may occur in vast numbers, also creating the potential for the devastation of populations. Wiens et al. (1979) have modeled the effects of oil spills under various conditions on the Pribilof seabird colonies, and made predictions about the time for population recovery.

Sublethal doses of oil may affect reproduction; Patten and Patten (1978) found that injested oil caused aberrent incubation behavior in Herring Gulls, which included a failure to replace lost eggs. Grau et al. (1977) reported that injested oil caused inhibition of egg-laying or altered yolk structure, while oil transferred from the plumage of adults onto eggs greatly reduced their viability (Macko and King 1980).

Sublethal doses of oil may also lower the viability of adults by ruining the insulation provided by the feathers (Hartung 1967, McEwan and Koelink 1973). Since oiled birds usually stop eating (Hartung 1967), starvation, accelerated by depletion of fat reserves for thermoregulation, rapidly follows oiling.

METHODS

1) Risk Assessment

An assessment of the environmental risk associated with oil spills and potential bird losses due to the impact of such events must be based, at least in part, on judgments as to the location and number of birds which might be encountered. In this report, the quantitative data available for such judgments are based on estimates of population densities obtained by ship-based and aircraft-based observers. The results described here are based on two methods of organizing these data. Both methods require a preliminary choice of areas used in the analysis. The first describes each area in terms of a mean and a coefficient of variation while the second categorizes density estimates within each area into predetermined intervals.

Bird densities were estimated using a line transect method (Burnham et al. 1980) modified for use at sea (Cline et al. 1969, Sanger 1976, Hunt et al. 1980). Counts were made from ships, using a 90° sector extending 300 m abeam and forward. Counts were made while the ship was underway at speeds ranging from 10 to 20 km/hr. Ship following birds were noted and excluded from counts. Ship's position to the nearest tenth of a degree was recorded at the start and end of each 10 minute count. Identifications were made to the lowest possible taxonomic level. Bird densities were computed for each count, about the time taken to scan a square kilometer at usual cruising speeds.

A. Means and Coefficient of Variation:

A preliminary identification of high risk areas in the Bering Sea was made by computing the average number of birds encountered in areas measuring 1 degree of longitude and 30 minutes of latitude. Average densities were computed for all birds in each of the four seasons, all birds on the water in each of the four seasons, and for each of the abundant species in each of the four seasons. As a convenient measure of the relationship between the mean and standard deviation for each block, a coefficient of variation (CV) was also calculated. This coefficient is the ratio of the standard deviation to the mean, chosen because it provides an obvious comparison of the relative shapes of the density distributions in each block. In keeping with the idea that high risk should be associated with large numbers of birds, those blocks having a high mean (high rate of encounter) and a low coefficient of variation (i.e. a reliably high rate of encounter) were identified as high risk areas. Variable risk areas were identified as those with a high coefficient (i.e. high and low counts of birds in the area), subdivided into two types: those with high means and those with low means. Low risk areas were deemed to be those in which both the average number of birds encountered and the variability of this figure (coefficient of variation) were low.

Four criteria were established to identify risk areas: I=high risk (# of birds $\geq$75.1 and CV<2); II=variable high risk (# of birds $\geq$75.1 and CV$\geq$2.1); III=variable low risk (# of birds<75 and CV$\geq$2.1); and IV=low risk (# of birds$\leq$75 and CV<2.1).

For this analysis, the Data Processing Group of Dr. Hal Peterson at the University of Rhode Island used all available bird data generated by OCSEAP investigators in the Bering Sea. These included contributions by the U.S. Fish and Wildlife team under the direction of Dr. Calvin Lensink, by the team under the direction of Mr. John Wiens and Juan Guzman working with M.T. Myers at the University of Calgary.

This method of assigning risk presents several difficulties. First, of course, is the obviously subjective nature of the cut-off values used to separate high and low coefficients of variation and also high and low means. These cut-off values were selected on the basis of arbitrary considerations and must therefore be evaluated on those terms. Other criteria might prove more useful. Another difficulty involves the actual sample statistics used to calculate the coefficients of variation. Having at this time no reliable method of mathematically describing the true overall distribution of the bird population, at best only moderate confidence can be placed on the stability of means for small areas and thus, also, on the resulting coefficients of variation. As future sampling provides further information, it may be possible to make stronger claims concerning the reliability of these estimates. Unfortunately, local instability seems to be an inherent property of seabird distributions and therefore the data used in this analysis are unlikely to be improved upon. Our second method of organizing the available data is designed to overcome, as much as possible, this very high local uncertainty.

B. Frequency Distributions of Density Categories

i. Statistical Rationale

Given the very serious complications involved with applying parametric statistical techniques directly to bird density data, we have summarized the available data by constructing eight mutually exclusive categories such that each transect in the data base is assigned to exactly one category according to the value of the observed density for that transect. This method greatly minimizes the number and strength of the assumptions required for analysis and allows the application of relatively simple discrete probability models to the problem of estimating the likelihood of encountering large numbers of birds.

For each sampling area, mean density estimates for several species were placed in the following eight mutually exclusive and exhaustive categories:

category	1	2	3	4	5	6	7	8
density/km	0	0.1-10	10.1-30	30.1-50	50.1-100	100.1-500	500.1-1000	over 1000

Confidence limits for the proportions observed in each category were computed using the formula (see Appendix 1),

(1) $$N > 1/4d^2 (1-\alpha)$$

where N = total number of transects (samples), d = the absolute value of the difference between the observed sample proportion and the population proportion, and α = the confidence level.

Using formula (1) we were able to calculate both a confidence level and confidence interval for any particular category or combination of categories, based on the existing sampling effort. We were also able to determine what future effort would be required to achieve various confidence levels and confidence intervals. For example, if α = 0.95 and d = 0.1 then from (1), $N \geq 1/4(0.1)^2 (1-0.95) = 500$. This means if we take a random sample of at least 500 observations, then the probability is at least 0.95 that the ohserved relative frequency of success for category i will differ from the true proportion by less than 0.1. Similarly, if N and a are fixed, we can also determine the value of d by

(2) $$d = 1/2 \sqrt{N(1-\alpha)}.$$

In addition to these estimates, we also calculated values for d and N when the proportion of successes (the observed relative frequencies) is assumed to be approximately normal. In this case, the formula is

(3) $$N > 1/4(k/d)^2$$

where k is the standard score from the cumulative normal distribution corresponding to a given u. Appendix 1 includes the derivation of formulae (1) through (3) and an explanation of the normal assumption. A discussion of the multinominal model which underlies this method, Chebyshev's Inequality and Khintchine's theory as they are used in Appendix 1 can be found in most intermediate statistical texts, for instance Chou (1963).

Data for this analysis were obtained entirely through the efforts of individuals working through RU83 or PROBES.

ii. Sampling Rationale

In order to provide useful sized areas within which: 1) sampling effort was sufficient to provide meaningful frequency distributions, 2) there would be a spatial, biological or oceanographic rationale for the boundaries, and 3) for which we could construct similar bounds for other regions as yet unsampled, we set up a series of zones around the Pribilof Islands and in the central southeastern Bering Sea along the PROBES line.

The houndaries of the zones around the Pribilof Islands are given in Figure 9 along with the number of transects completed in each zone. These zones divide the waters near the Pribilofs into shelf (east) and shelf-break (west) regions, and into regions at distances of 20 km, 40 km and 60 km from the nearest shore. These bounds let us compare both distance-from-colony effects and the oceanographic influence of distance from the shelf-break.

In the central southeastern Bering Sea region, all transects were classified in zones according to PROBES domains (Iverson et al. 1979). Boundaries for this classification were drawn by bathymetry, with each of the three areas (middle shelf, outer shelf, and slope) centering on the main PROBES transect and distant from the influence of the immediate vicinity of colonies (Figure 10). Seasonal variation in seabird abundance was controlled by making comparisons between domains for those seasons when a species was abundant in the southeastern

Zonal Analysis of the pelagic distribution of seabirds near the Pribilof Islands. Number of observations per zone

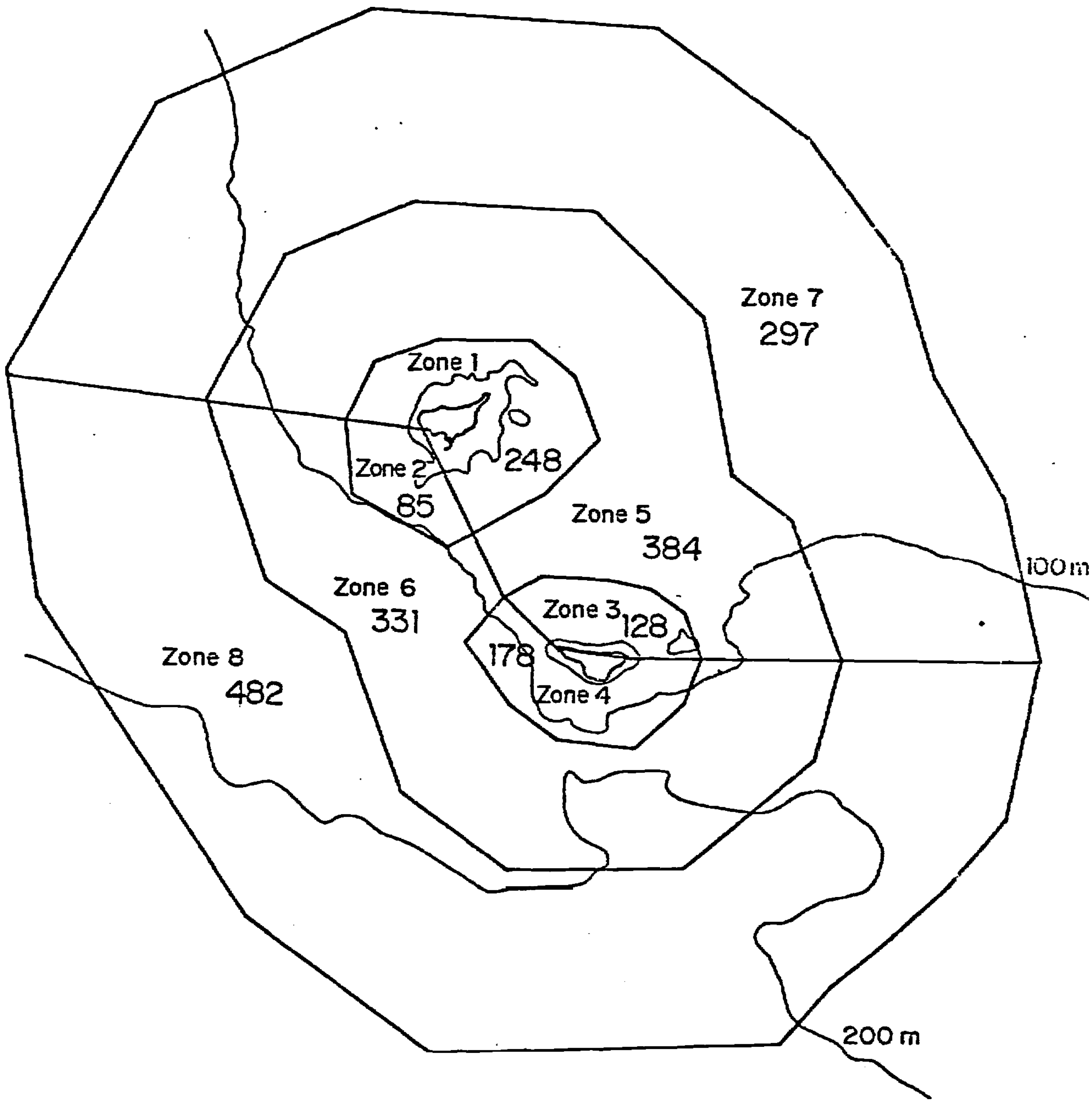


Figure 9

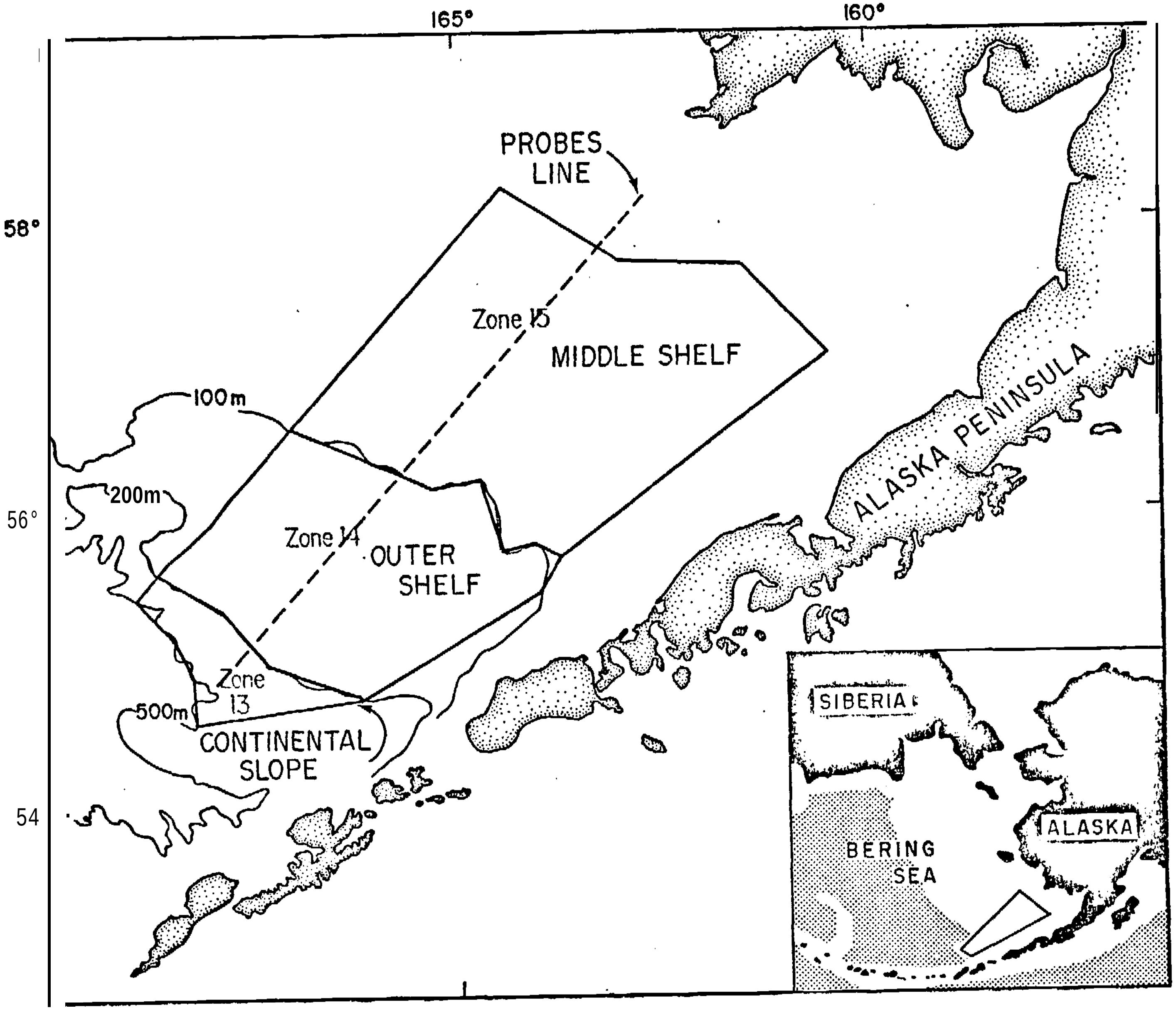


Figure 10. Zones near the PROBES line.

Bering Sea. A correction for ship attraction was not introduced in this analysis since there was no indication that this varied across the shelf. Division of this pelagic area into zones determined by the varying mixing regimes of the shelf domains permits us to relate the bird distribution to the underlying oceanography, and to develop predictions about bird numbers and species composition of as yet unsurveyed areas based upon that new area's oceanographic domains.

2) Description of Regions Used by Birds

If we are to be able to generalize from well studied areas to areas that have received little or no study, it is essential to be able to predict, based on present knowledge, where one would expect to find large numbers of birds. This requires relating bird distributions to features of their environment. We attempted to describe the habitats used by birds first with step-wise correlation analysis and then by analysis of variance (ANOVA) of transect data by zones.

A. Correlation Analysis

Preliminary analyses of single tracks or cruises suggested that step-wise multiple correlation analysis might be profitable. We therefore examined the combined 1975-1978 data set for the correlations between the density of individual bird species (and of all species combined) and environmental variables such as: distance to land, water depth, distance to shelf-edge, sea surface temperature and sea surface salinity. This effort was notably unsuccessful with r values generally less than 0.05. For this reason regression techniques were abandoned.

B. Zonal Analysis

Our second approach was to compare bird densities in the zones described above. These zones in the vicinity of the colonies were organized with respect to distance to colony and distance to shelf edge, while in the open ocean they were organized with respect to oceanographic domains.

Standard analysis of variance (ANOVA) techniques were used to test whether the observed differences between zones exceeded the expectations of chance. The hypothesis of relation of bird distribution to mixing regime in the zones along the PROBES line was tested by a two-step design. Outer shelf and slope averages were first compared. If this comparison was not significant, the average density over both outer shelf and slope waters was compared to average density over middle shelf waters. If slope and outer shelf averages differed, then just the outer shelf average was compared to the average in the adjacent middle shelf domain. Analyses were confined to common species or to species groupings if identification to the species level was unreliable.

Data used in this analysis were obtained entirely through the efforts of individuals associated with RU 83 or PROBES.

RESULTS

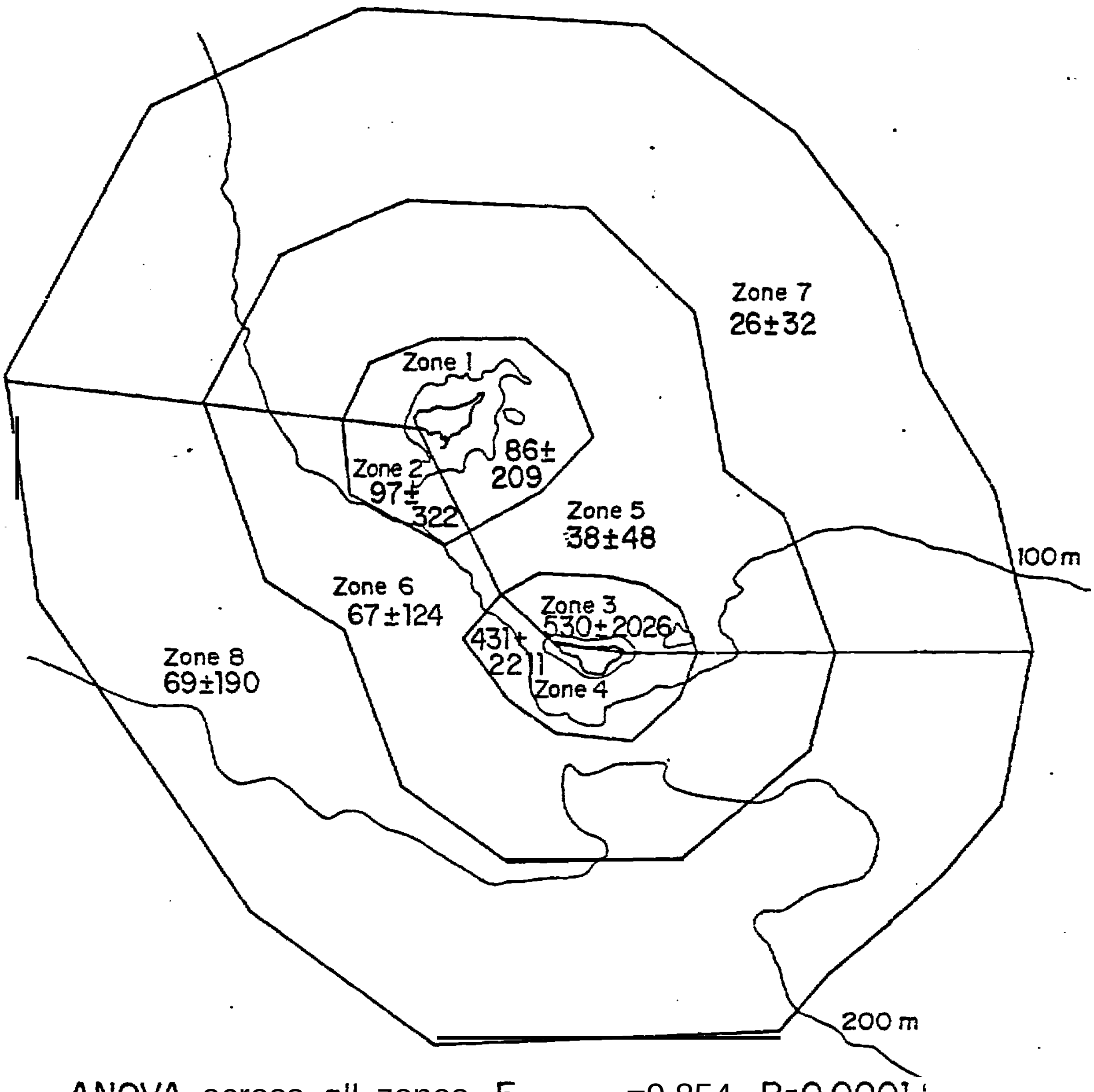
1) Pelagic Distribution

The distribution of birds in the vicinity of the Pribilof Islands in particular, and the southeastern Bering Sea in general, was covered thoroughly by Hunt et al. (1980a and b). Therefore, in this report we will briefly summarize their findings and concentrate on the area near the PROBES line for which detailed summaries have not been provided.

Figure 11 summarizes the use of zones around the Pribilof Islands by all species combined. The important generalities to take from this figure are that both toward and away from the shelf-break, bird densities drop off rapidly as one moves away from the colonies, but bird densities for any given distance from the island are higher on the side toward the shelf-break rather than northeastward over the shelf. The preference for shelf-edge waters rather than shelf waters is particularly pronounced for Northern Fulmars (Figure 12) and Red-legged Kittiwakes (Figure 13), while distance from colony and colony size, regardless of direction, appear to be the major determinants of murre (Figure 14) and small auklet (*Aethia* sp., *Cyclorrhynchus psittacula*, Figure 15) distributions. Other species show relatively weak patterns or virtually no pattern with respect to distance from colony or direction with respect to the shelf-break.

These results suggest that the only variables that need be considered near colonies are distance to colony and distance to shelf-break. However, Kinder et al. (in prep.) have demonstrated a front at about 50 m depth at which there is a shift between a well-mixed water column and a two layered water column. Murres appear to preferentially gather on the water near this front, and murre densities there are significantly greater than would be predicted by chance either inshore or offshore the front (Kinder et al., in prep.).

Distribution of seabirds by zones
near the Pribilof Islands, 1975-1979 $(\bar{x} \pm s)^*$



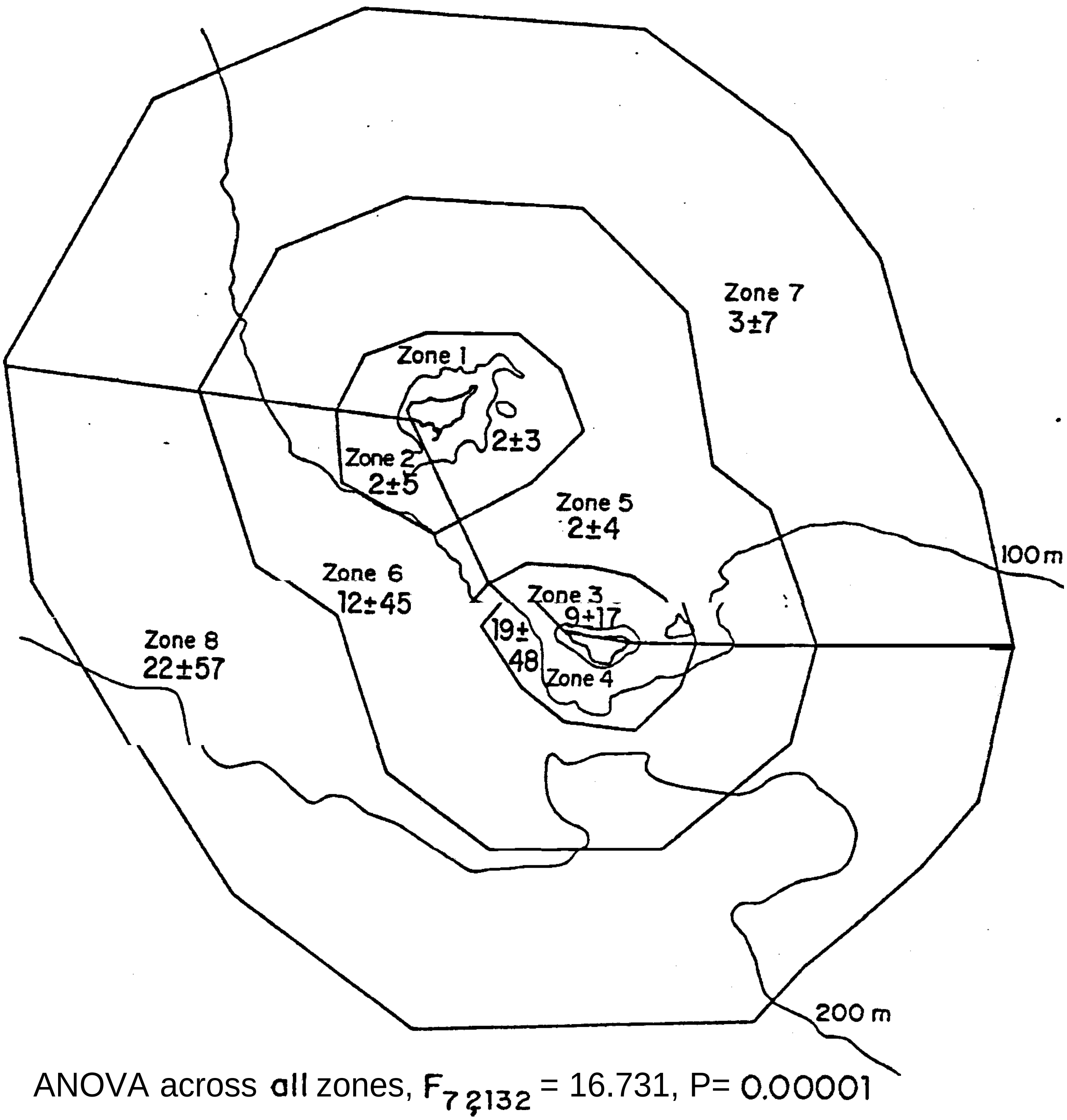
ANOVA across all zones, $F_{7,2125}$ =9.854, P=0.0001

Homogeneous subsets by m'edified LSD Procedure, α=0.05

Subset 1 Zones 7,5,6,8,1,2
Subset 2 Zones 2,4
Subset 3 Zones 4,3

*rounded to whole numbers

Distribution of Northern Fulmars by zones near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2132}$ = 16.731, P= 0.00001

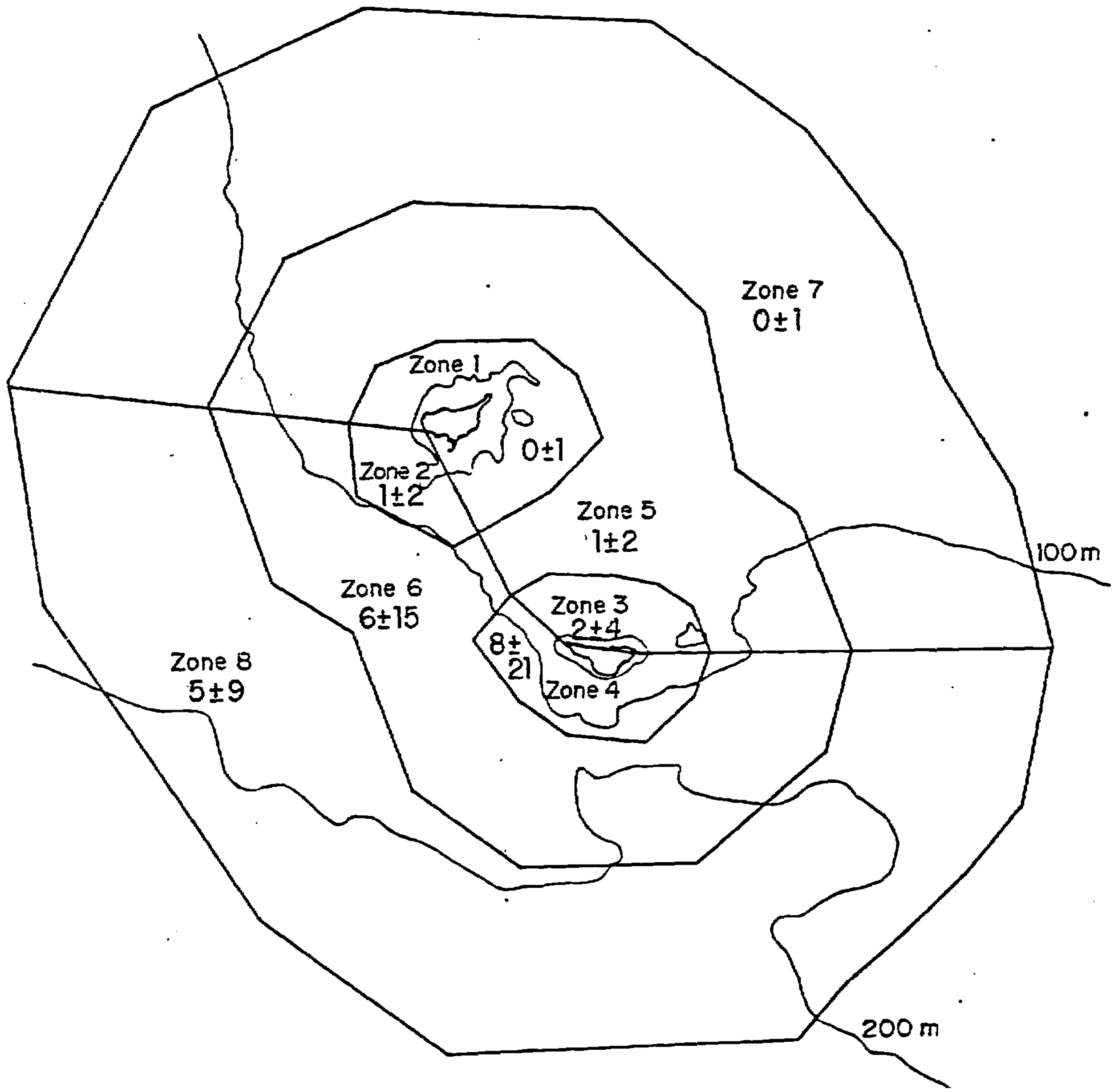
Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 1,5,2,7,3
Subset 2- Zones 2,7,3,6
Subset 3 Zones 3,6,4
Subset4 Zones 4,8

*rounded to whole numbers

Figure 12

Distribution of Red-legged Kittiwakes by zones
near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2154}$ =24.479, P= 0.00001

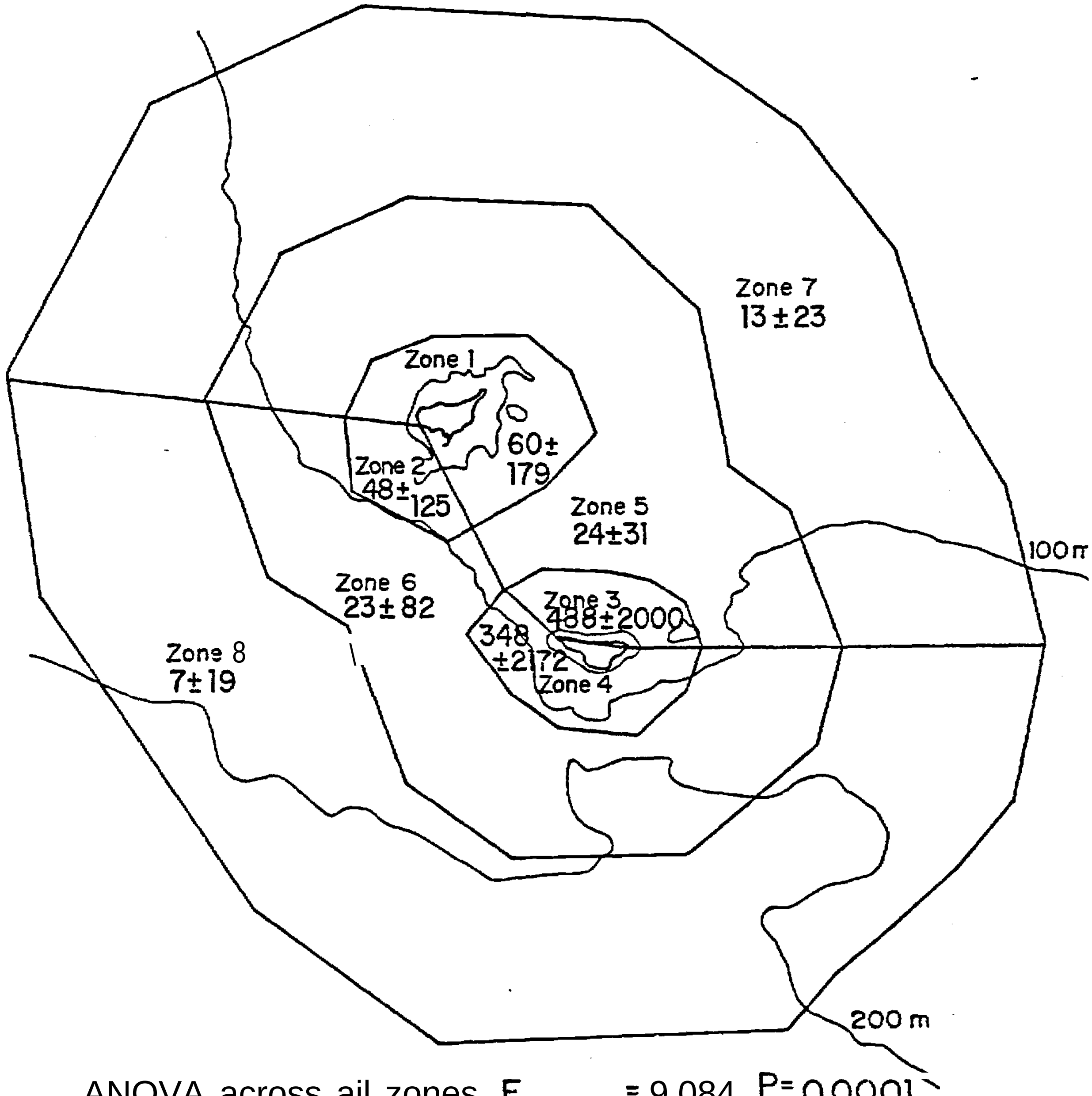
Homogeneous subsets by modified LSD Procedure, α =0.05

Subset 1 Zones 7,1,5,2,3
Subset 2 Zones 3,8
Subset 3 Zones 8,6
Subset 4 Zones 6,4

*rounded to whole numbers

Figure 13

Distribution of Murres by zones near the Pribilof islands, 1975-1979 ($\bar{x} \pm s$)*



ANOVA across ail zones, $F_{7,2128} = 9.084$, $P = 0.0001$

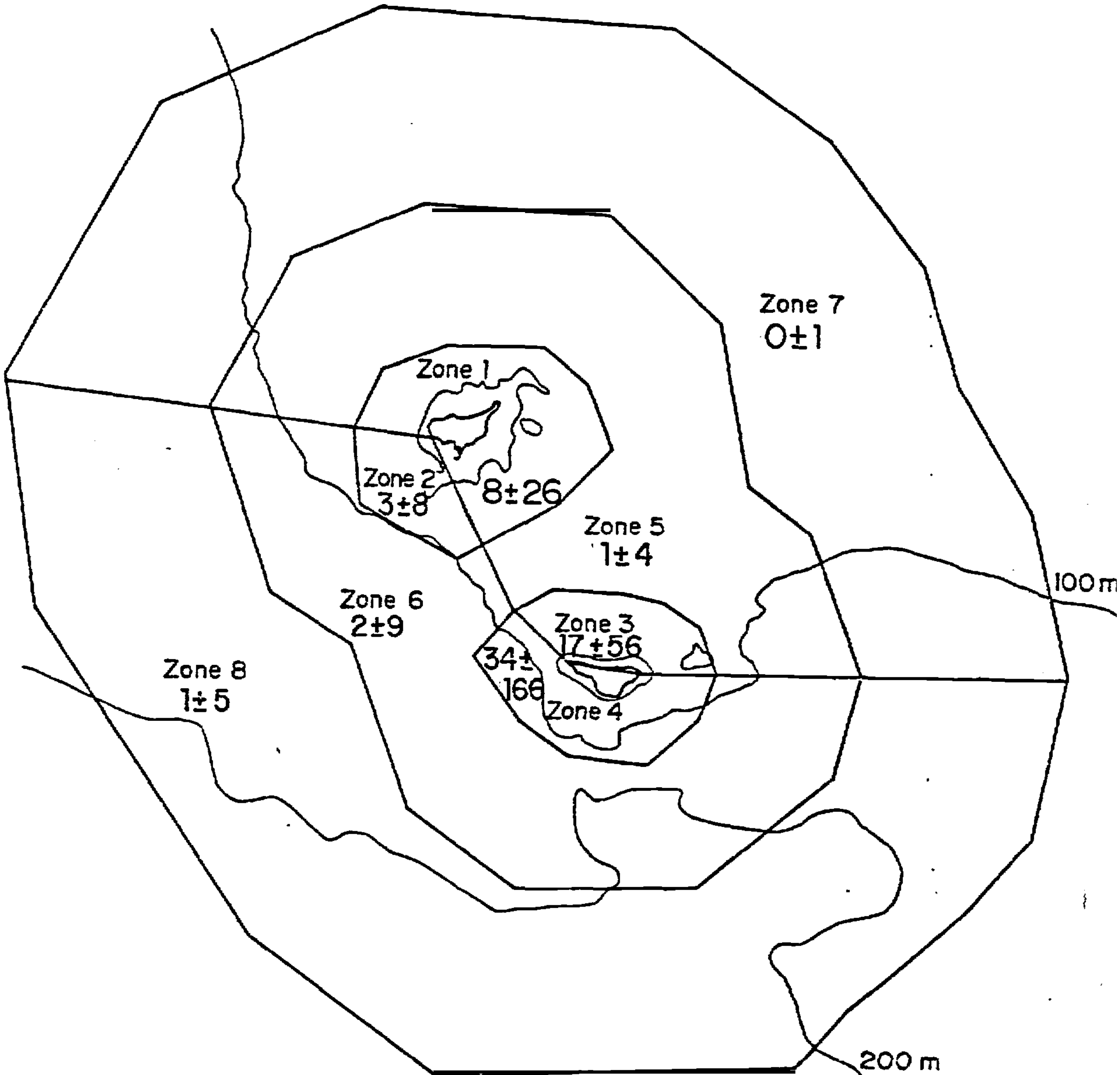
Homogeneous subsets by modified LSD Procedure, $\alpha = 0.05$

Subset 1 Zones 8,7,6,5,2,1
Subset .2 Zones 2,1,4
Subset 3 Zones 3,4

*rounded to whole numbers

Figure 14

Distribution of Small Auklets by zones
near the Pribilof Islands 1975-1979 ($\bar{x} \pm s$)*



ANOVA across all zones, $F_{7,2154}$ = 10.870, P= 0.00001
Homogeneous subsets by modified LSD Procedure, α = 0.05

Subset 1 Zones 7,8,5,6,2,1,3
Subset 2 Zones 3,4

*rounded to whole numbers

Figure 15

Therefore, one should take into account the potential influence of fronts at this position (50 m isobath) in detailing factors responsible for seabird distribution.

In the central southeastern Bering Sea region along the PROBES line, six of eight seabird groups analyzed showed significant differences in density between domains (Figure 16). Five groups showed the same pattern, that of high densities at the shelf-break, intermediate to high densities over the outer shelf, and low densities over the middle shelf. This pattern was most pronounced in Red-legged Kittiwakes, Fork-tailed Storm-Petrels (O. furcata), and Tufted Puffins (Lunda cirrhata). A similar pattern can be seen for Northern Fulmar (Fulmarus glacialis), but the role of chance could not be excluded in this case (Figure 16). Black-legged Kittiwakes showed a weak but significant pattern of reduced density over the middle shelf relative to the outer shelf and slope waters (Figure 16). Monthly variation was weak in Black-legged Kittiwakes, so all counts (April through August) were included in the analysis. Thus the sample sizes for this analysis (89, 497, and 395 counts over slope, outer shelf, and middle domains) were larger than for the four preceding species (33, 232, and 339 counts).

Dark-bellied shearwaters (P. tenuirostris and P. griseus) appear in the Bering Sea in early Summer (Hunt et al. 1980), so analysis was confined to June and July. During this period shearwaters showed a pattern of greater density of birds in the coastal domain as compared to the shelf-edge (Figure 16). The difference was not significant, perhaps because the coastal domain was not included in the analysis for lack of adequate sampling.

The analysis of murre and auklet densities was confined to April, before these species retreat to their breeding colonies. Auklet density was significantly higher in the middle domain than in the outer shelf or slope waters (Figure 16).

Density of seabirds in middle shelf (M), outer shelf (0), and slope (S) waters of the south-eastern Bering Sea, 1975-1979. Bars show two standard errors on either side of the mean.

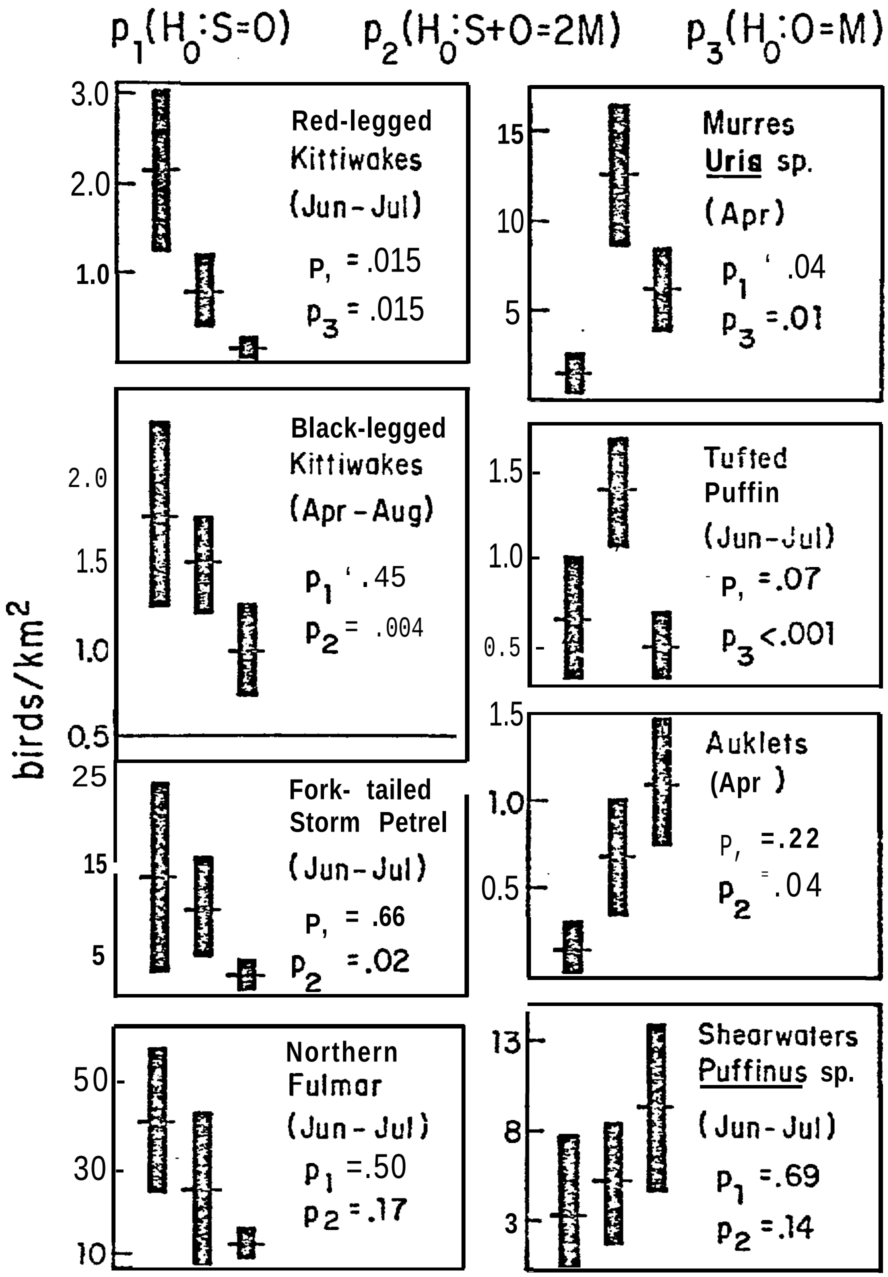


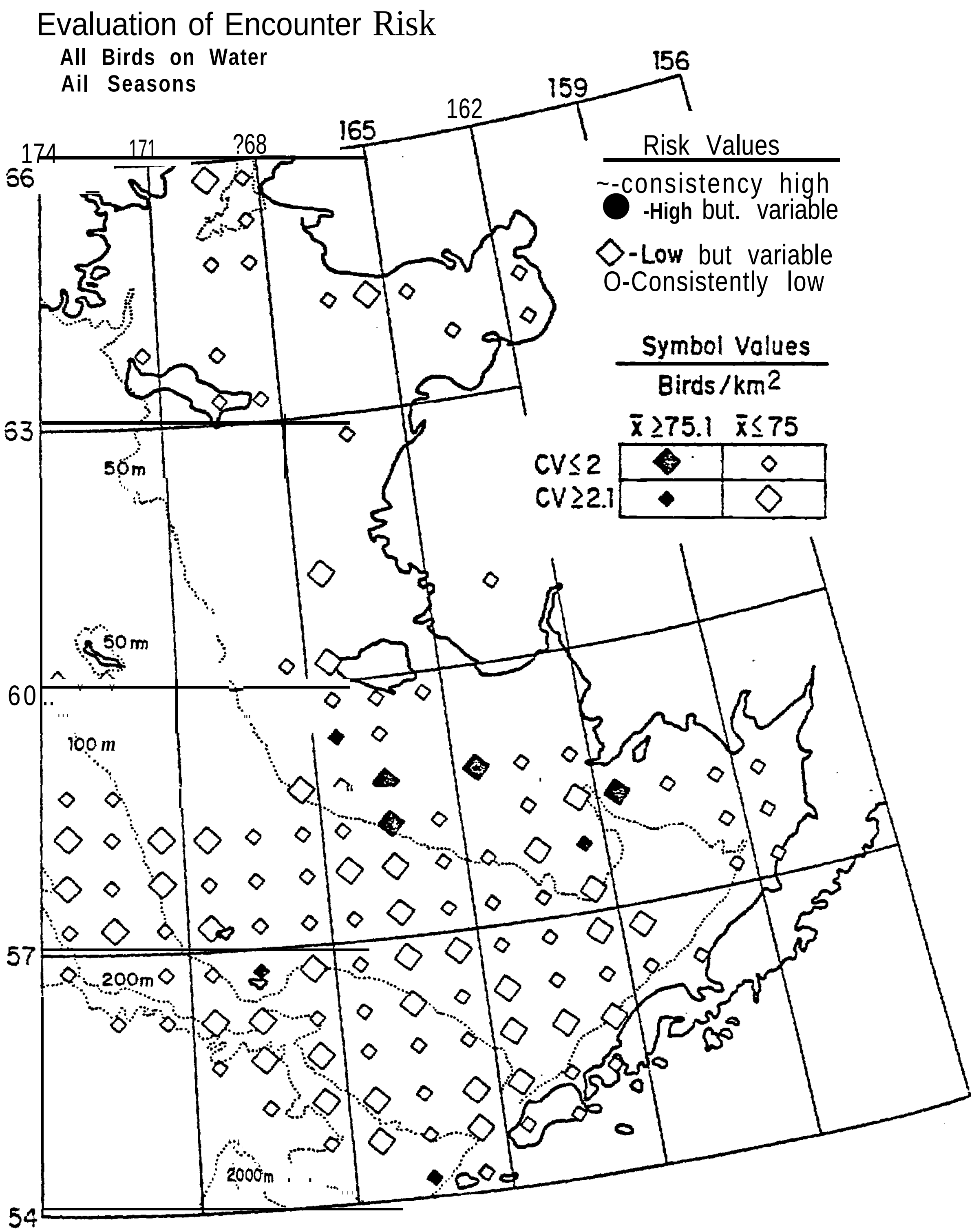
Figure 16

The three major species present were Least Auklets (*A. pusilla*), Crested Auklets (*A. cristatella*), and Parakeet Auklets (*Cyclorrhynchus psittacula*). No attempt was made to analyze individual species because of the small numbers involved. Murres showed a pattern of high density in the outer domain, intermediate density in the middle domain, and low density beyond the shelf-break (Figure 16).

The observed patterns of distribution relative to mixing regime were associated with the feeding capabilities of the seabird groups analyzed. Auklets and murres search for food while sitting on the water and are capable of diving to considerable depths. These were the only two groups that did not show a significantly reduced density in the middle shelf domain, with its poorly developed pelagic food web. Surface feeding groups (kittiwakes, Fork-tailed Storm Petrels, and Northern Fulmar) showed reduced densities over the middle shelf.

2) Risk assessment based on coefficients of variation

Figures 17 through 26 illustrate the distribution of encounter risks based on means and coefficients of variation derived from survey data obtained during the period 1975-1979. Figure 17 gives the coefficients for all birds encountered on the water throughout the entire survey effort. Consistently high risk areas (coefficient <2 and $\bar{X}>75.1$) are confined to the shelf area south of Nunivak Island. High but variable risk areas (coefficients >2.1 and $\bar{X}>75.1$) occur only next to St. George Island and just southwest of Unimak Pass. Consistently low (coefficients <2 and $\bar{X}<75$) and low but variable risk areas (coefficients >2.1 and $\bar{X}\leq75$) tend to be rather uniformly distributed throughout the southeastern Bering Sea and the region encompassed by St. Lawrence Island, Norton Sound,' and the Bering Straits. For much of the northern Bering Sea, data are insufficient to support this type of analysis.


Evaluation of Encounter Risk
All Birds on Water
Ail Seasons
156
159
162
165
174
171
?68
66
63
60
57
54
50m
50 m
100 m
200m
2000m
Risk Values
~-consistency high
-High but. variable
-Low but variable
O-Consistently low
Symbol Values
Birds/km2
X̄ ≥75.1
X̄ ≤75
CV≤2
CV≥2.1

Fiqure 17

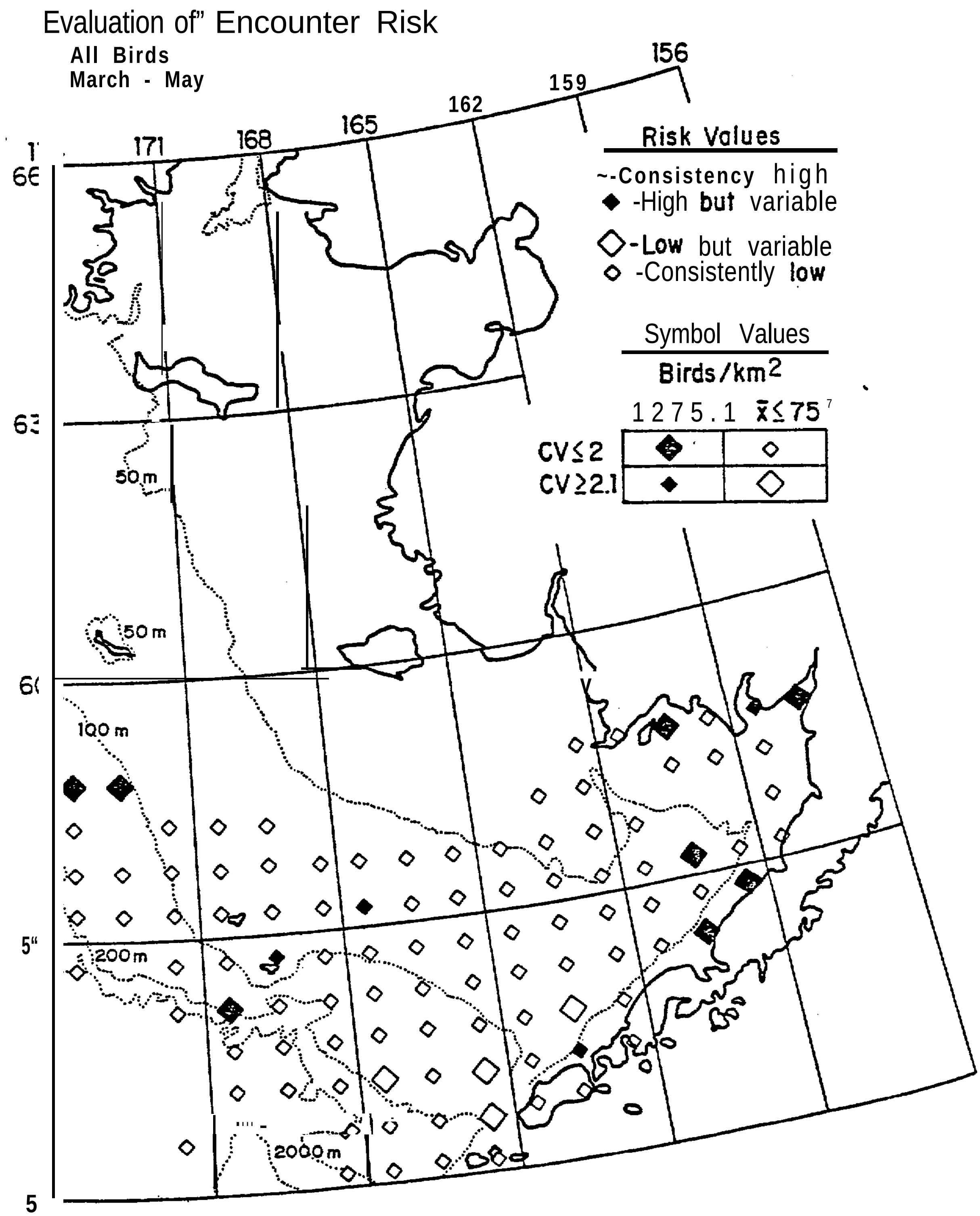

Evaluation of" Encounter Risk
All Birds
March - May
156
159
162
165
168
171
66
63
60
5"
5
Risk Values
~-Consistency high
◆ -High but variable
◇-Low but variable
◇ -Consistently low
Symbol Values
Birds/km2
1275.1 x̄≤75
CV≤2
CV≥2.1
50 m
50 m
100 m
200 m
2000 m

Figure 18

Evaluation of' Encounter Risk

All Birds

June - August

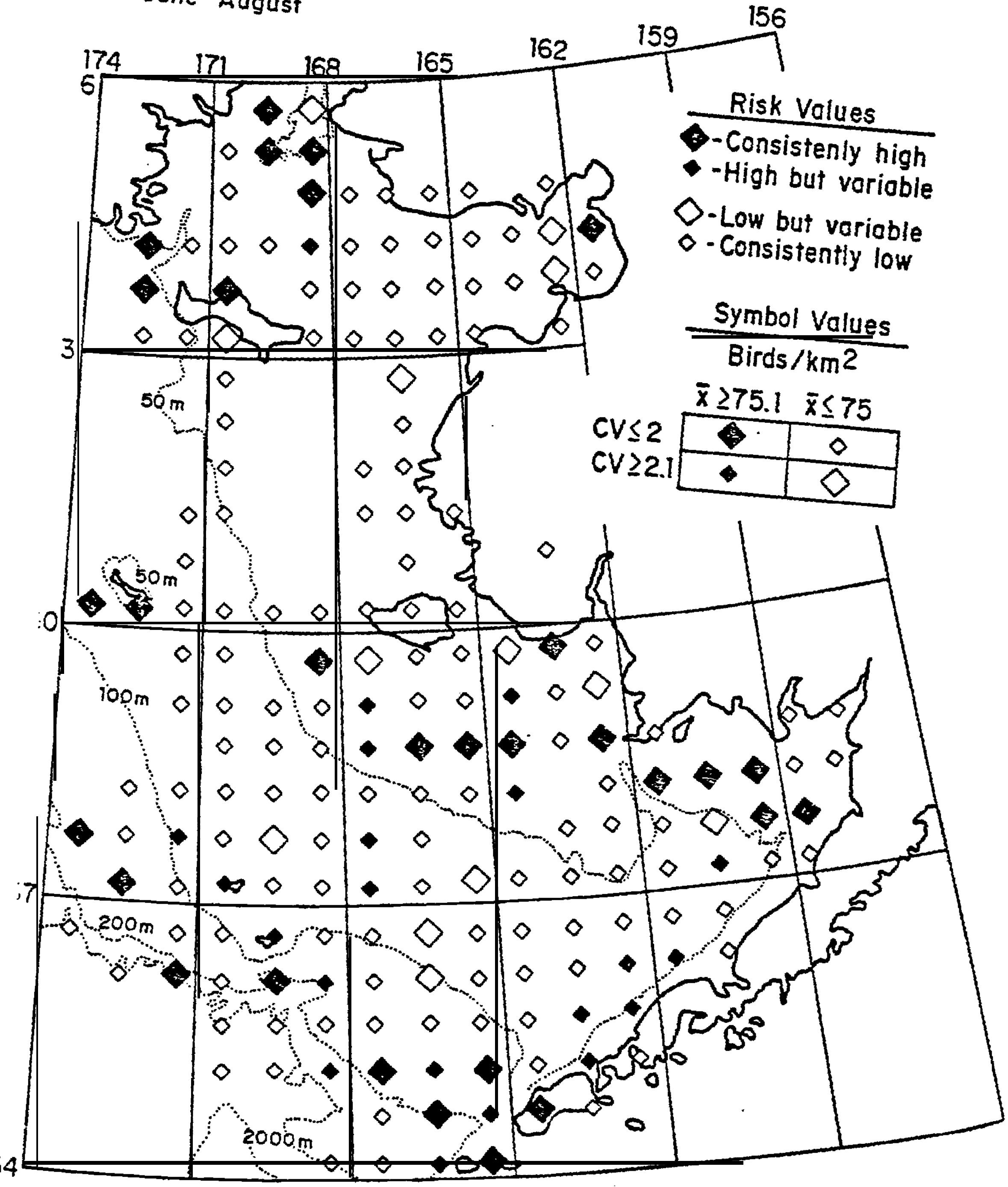


Figure 19

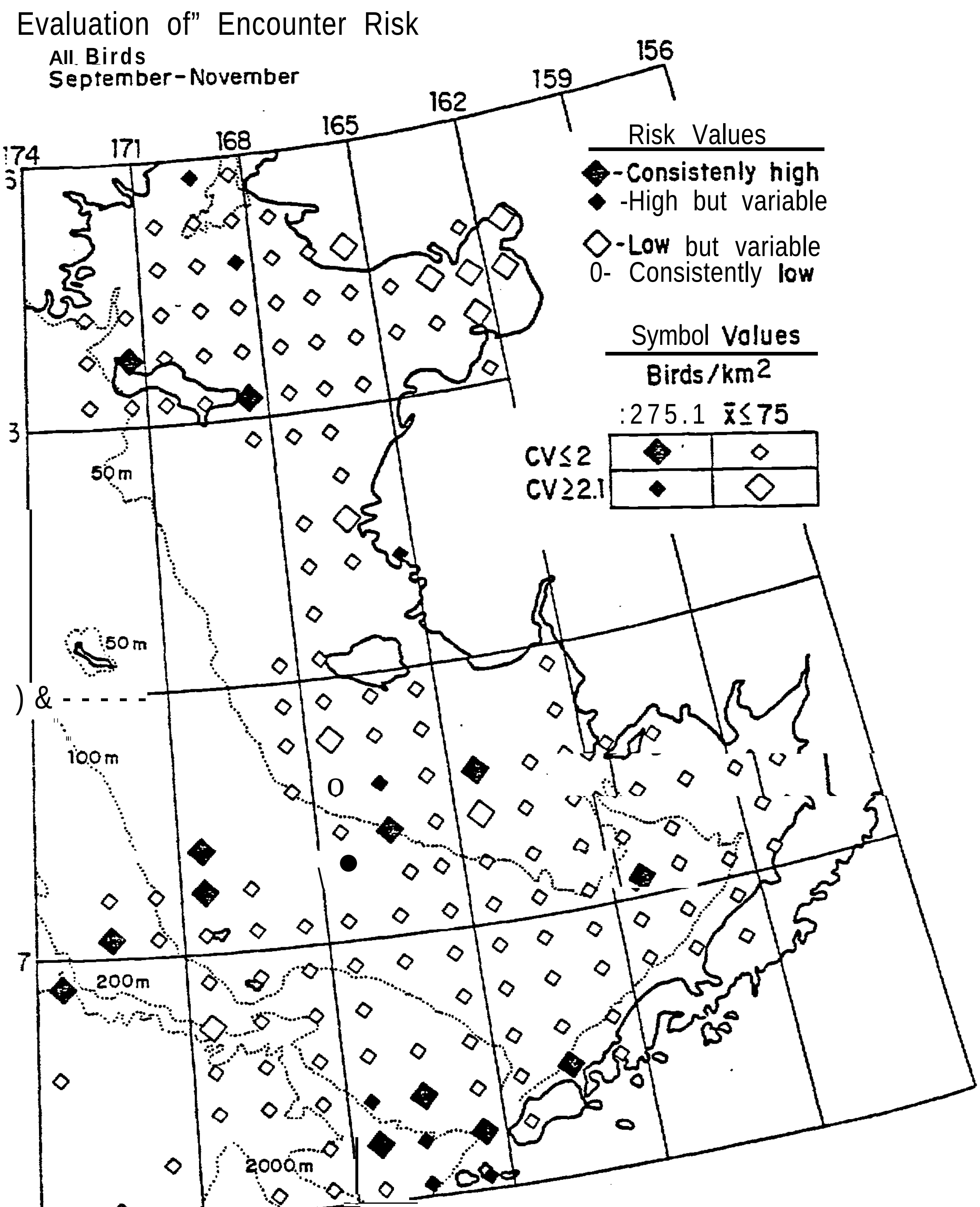

Evaluation of" Encounter Risk
All. Birds
September-November
174
171
168
165
162
159
156
Risk Values
-Consistenly high
-High but variable
-Low but variable
0- Consistently low
Symbol Values
Birds/km2
:275.1 x̄≤75
CV≤2
CV≥2.1
50m
50m
100m
200m
2000m

Figure 20

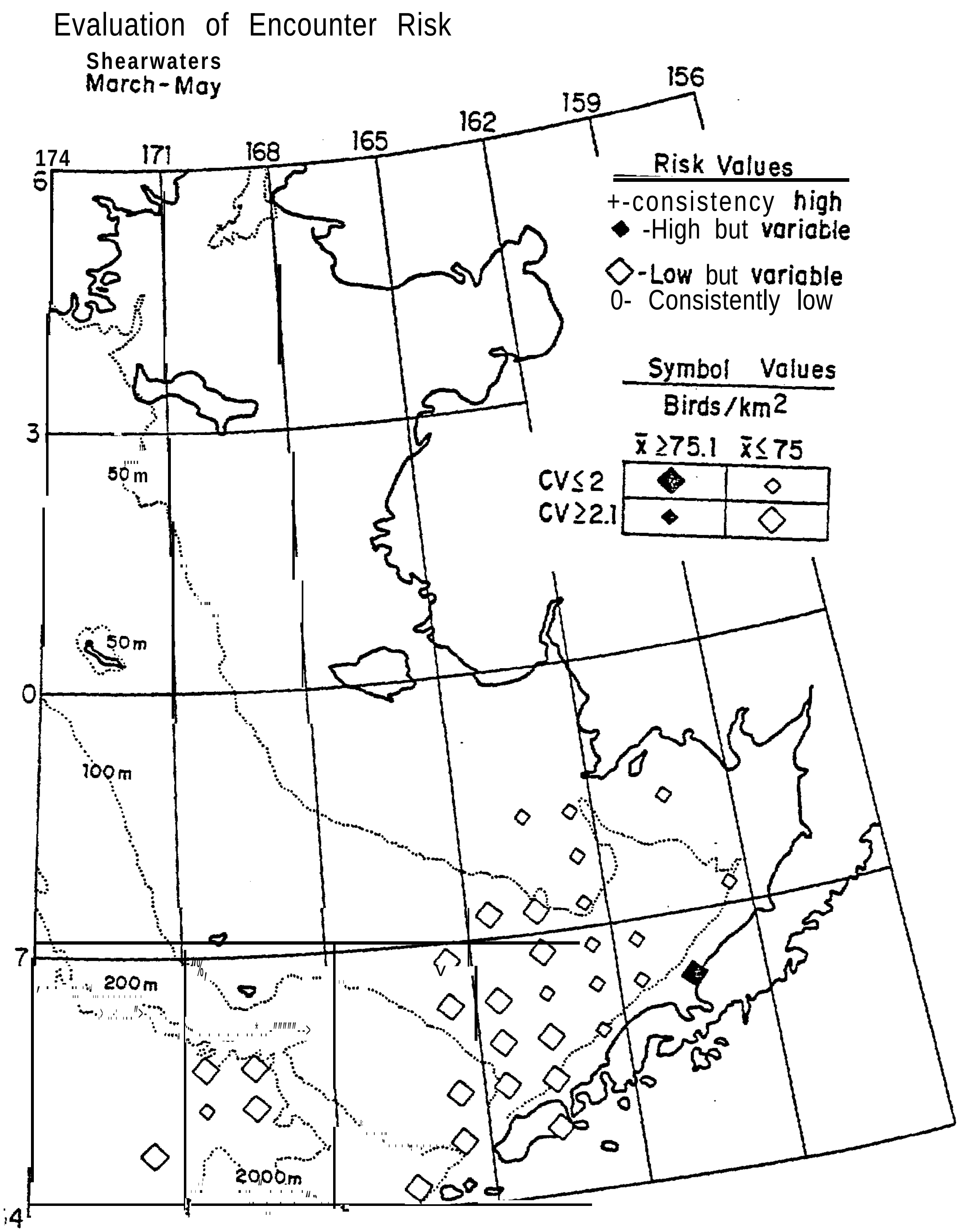

Evaluation of Encounter Risk
Shearwaters
March-May
174
171
168
165
162
159
156
6
3
0
7
4
50m
50m
100m
200m
2000m
Risk Values
+-consistency high
◆ -High but variable
◇-Low but variable
0- Consistently low
Symbol Values
Birds/km2
x̄ ≥75.1
x̄ ≤ 75
CV≤2
CV≥2.1

Figure 21

Evaluation of" Encounter **Risk**

Shearwaters
June-August

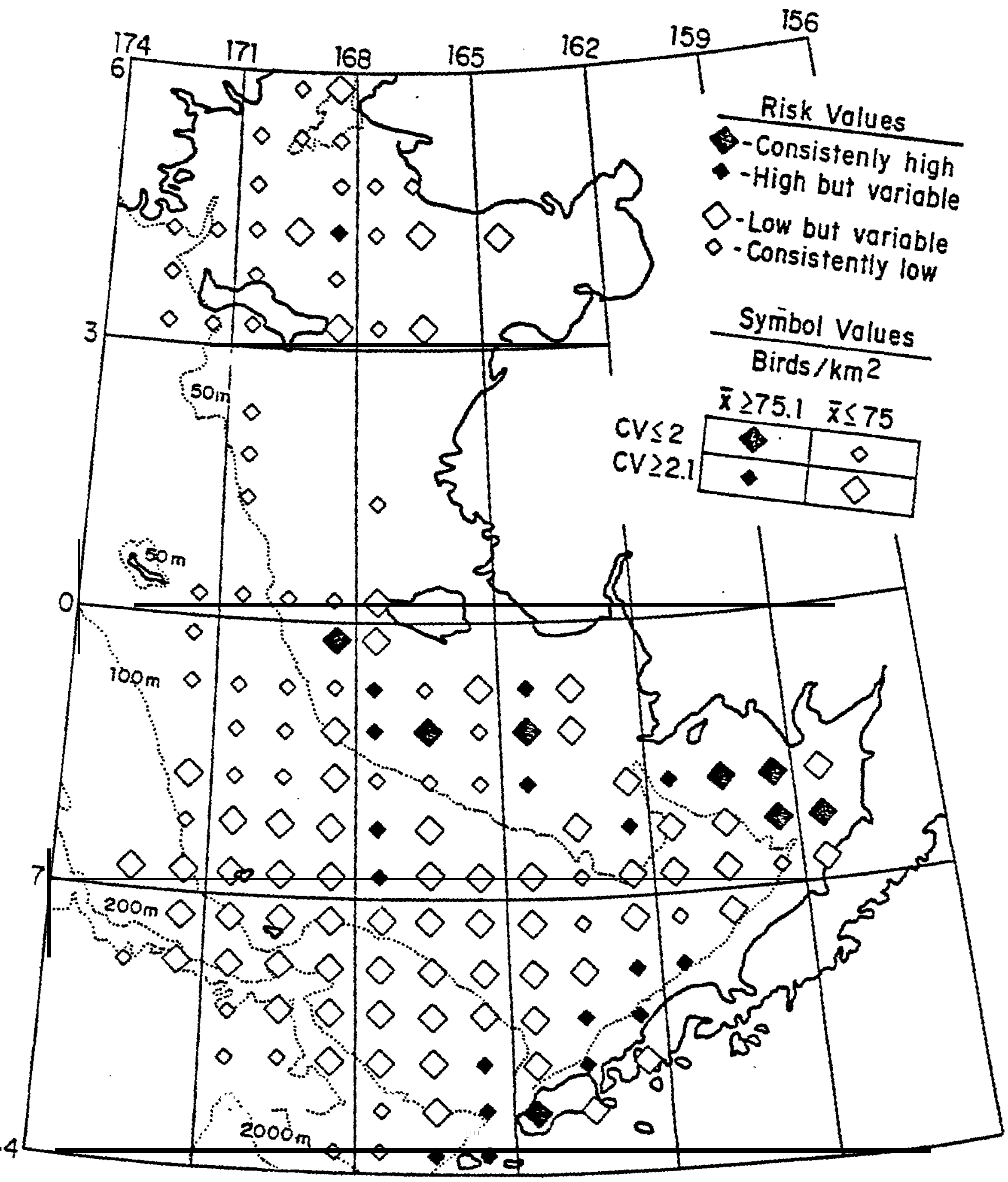


Figure 22

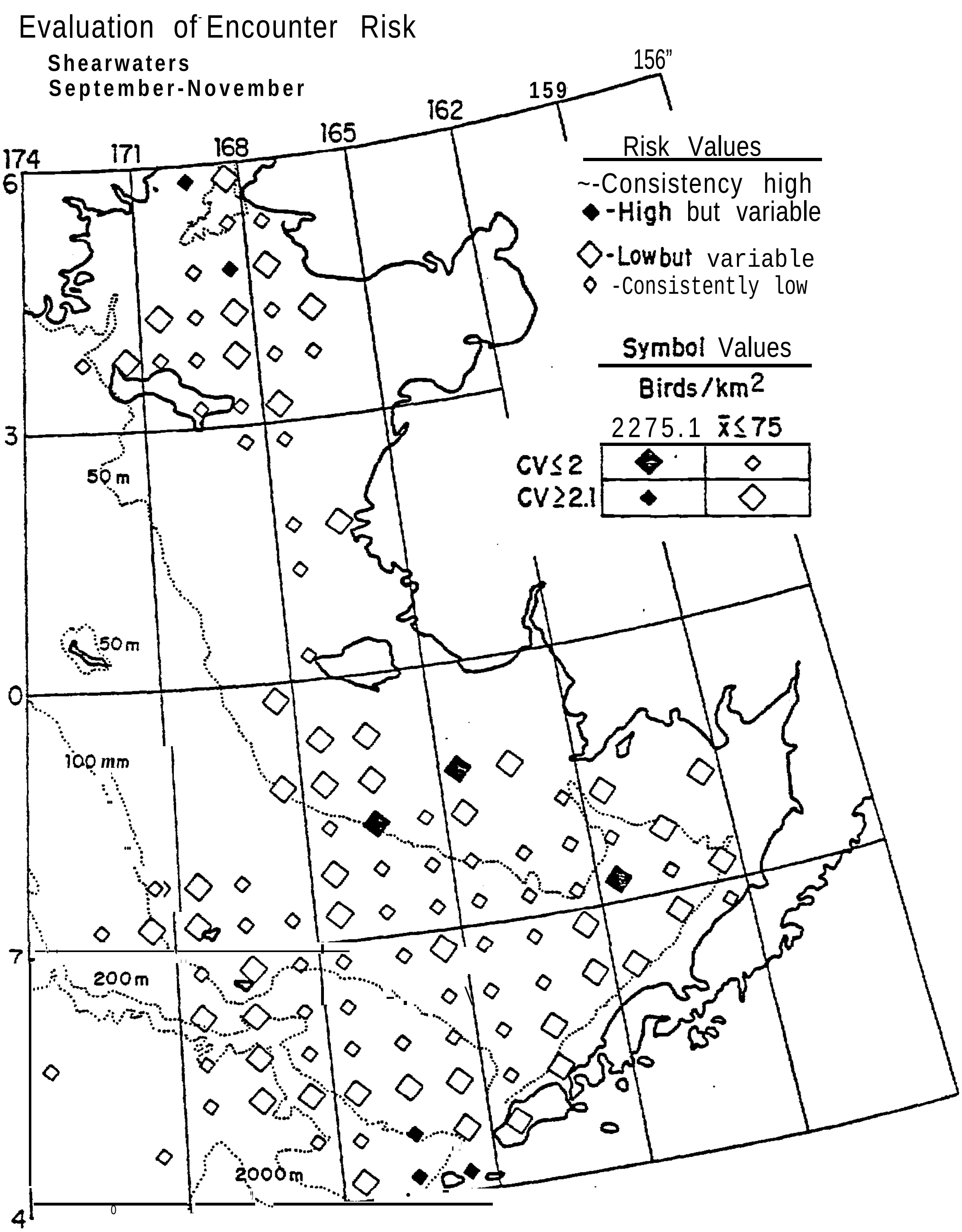

Evaluation of Encounter Risk
Shearwaters
September-November
156"
159
162
165
168
171
174
6
3
0
7
4
50 m
50m
100 mm
200m
2000m
0
Risk Values
~-Consistency high
◆-High but variable
◇-Low but variable
◇ -Consistently low
Symbol Values
Birds/km2
2275.1 x̄≤75
CV≤2
CV≥2.1

Figure 23

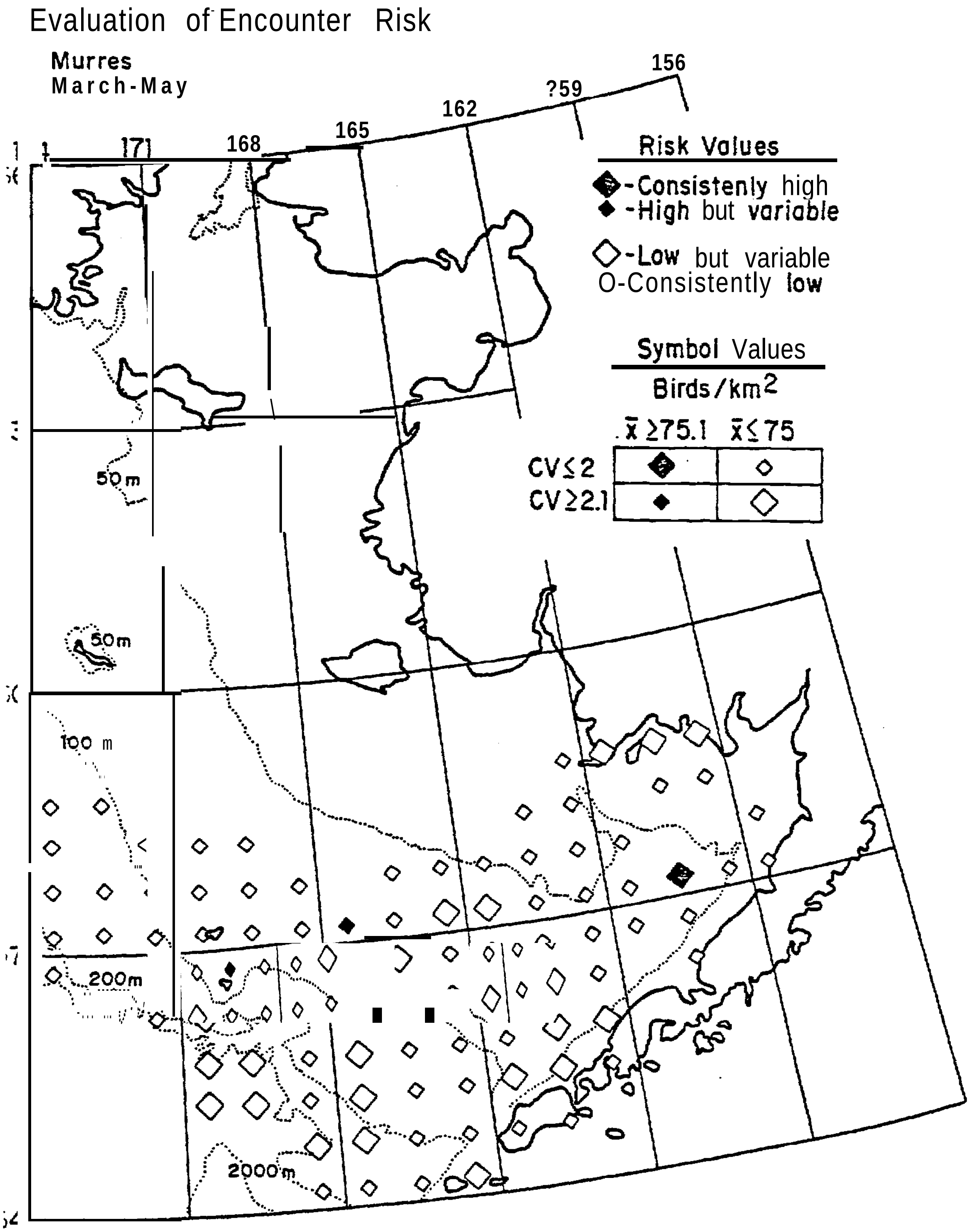
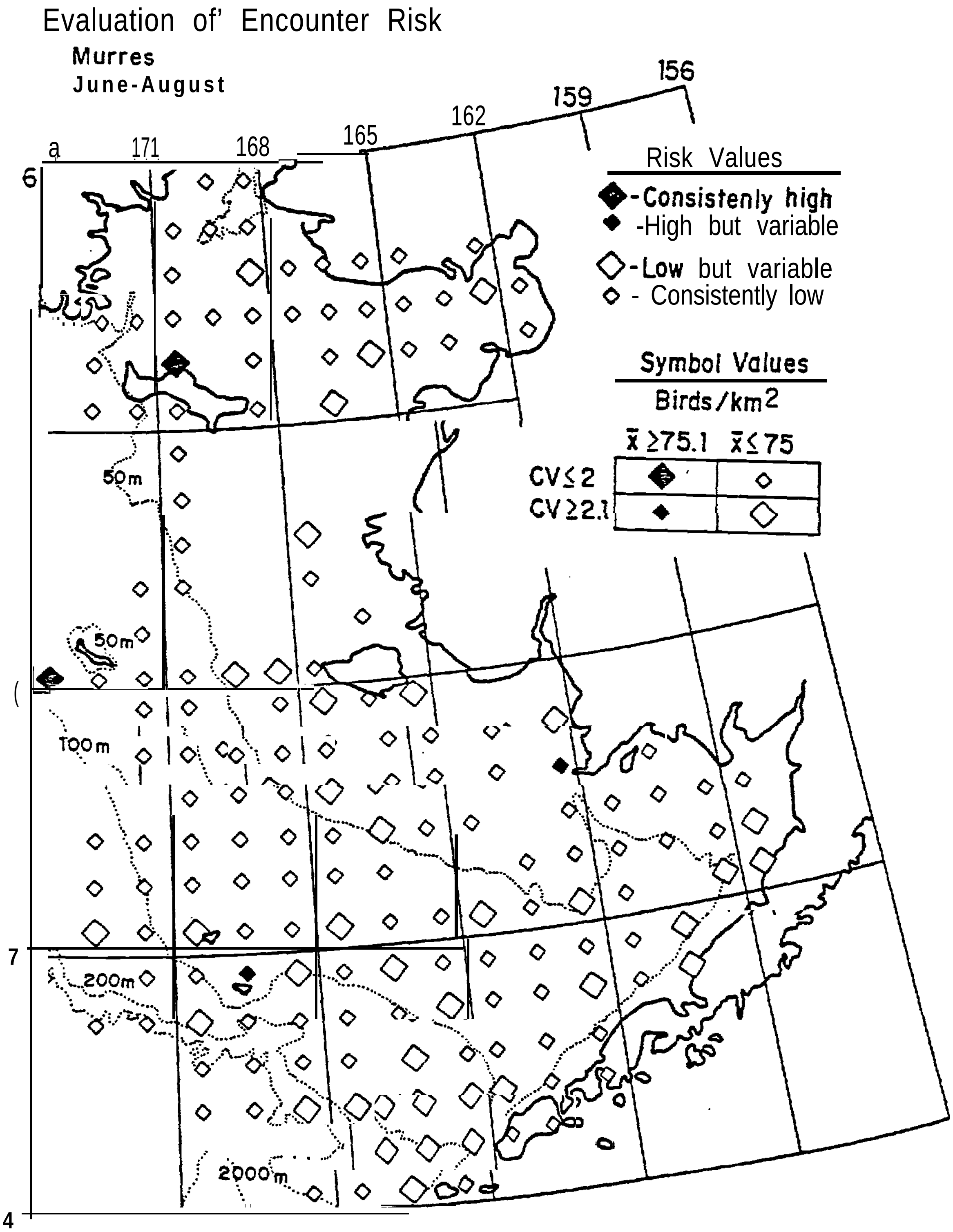

Evaluation of Encounter Risk
Murres
March-May
156
?59
162
165
168
171
Risk Values
-Consistenly high
-High but variable
-Low but variable
O-Consistently low
Symbol Values
Birds/km2
x̄ ≥75.1
x̄ ≤ 75
CV≤2
CV≥2.1
50m
50m
100 m
200m
2000m

Figure 24



Evaluation of' Encounter Risk
Murres
June-August
156
159
162
165
a
171
168
6
(
7
4
Risk Values
-Consistenly high
-High but variable
-Low but variable
- Consistently low
Symbol Values
Birds/km2
x̄ ≥75.1
x̄ ≤ 75
CV≤2
CV≥2.1
50m
50m
TOOm
200m
2000m

Fiqure 25

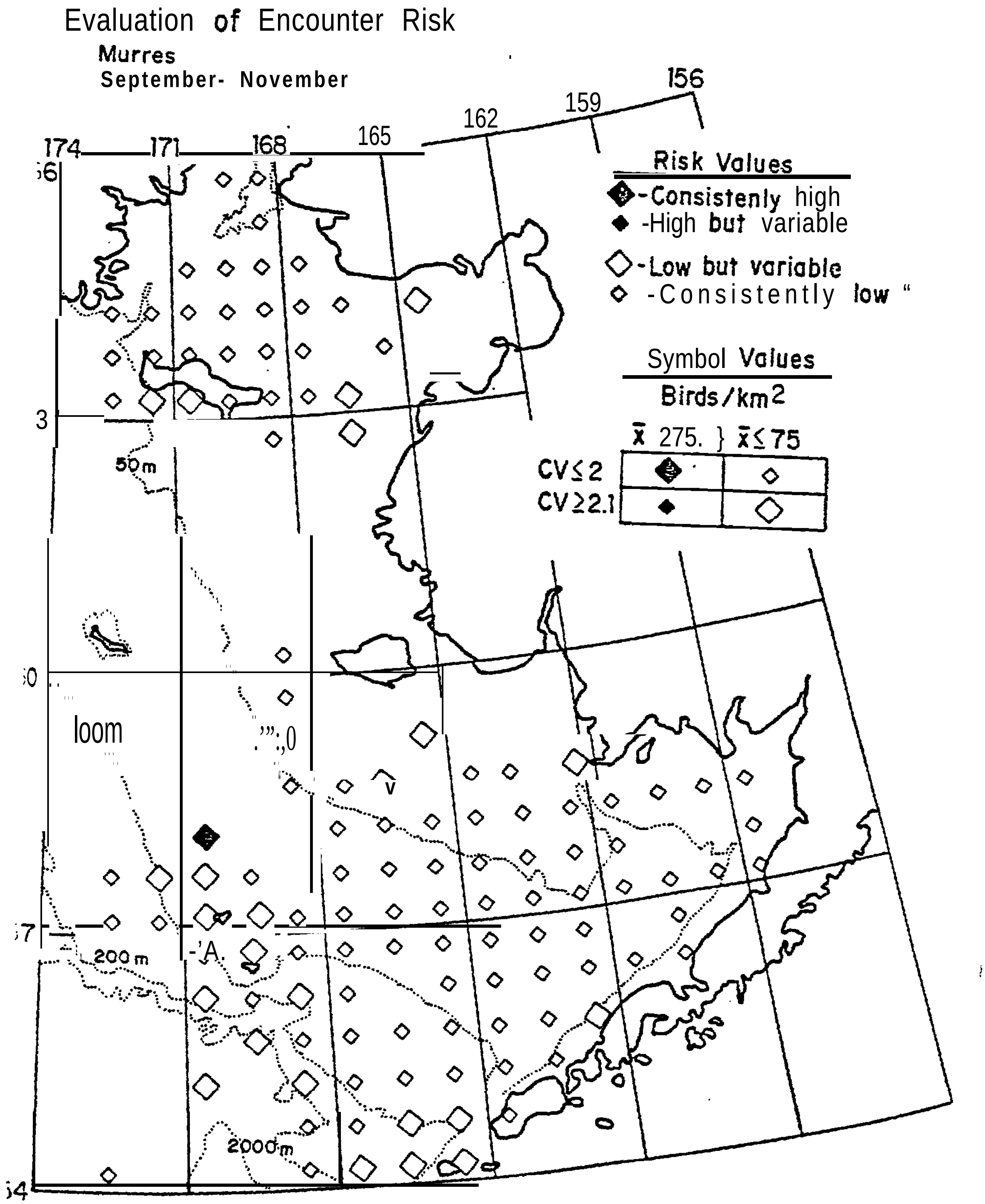

Evaluation of Encounter Risk
Murres
September- November
156
159
162
165
174
171
168
Risk Values
-Consistenly high
-High but variable
-Low but variable
-Consistently low
Symbol Values
Birds/km2
CV≤2
CV≥2.1
50m
200 m
2000m

Figure 26

Figures 18 through 20 show quite clearly the very strong seasonal variation in the distribution of the risk levels for all birds combined during the survey period. During Spring (Figure 18), high risk areas were found only within Bristol Bay, along the north coast of the Alaskan Peninsula, over the outer shelf near St. George Island and midway between the Pribilof Islands and St. Matthew Island. In the Summer, however, high risk areas - both consistently high and high but variable - were found more than twice as frequently as in the Spring (Figure 19). The entire shelf south of Nunivak Island possesses a large proportion of high risk areas, as does the shelf-break north and south of the Pribilof Islands, Unimak Pass, St. Matthew Island, St. Lawrence Island, and the Bering Strait.

In the Fall, the distribution of risk areas approaches that seen in the Spring with the middle shelf mostly devoid of consistently large numbers while high risk areas are found primarily in a relatively small region north of the Pribilof Islands, near Unimak Pass and south of Nunivak Island. Consistently large numbers of birds are still found around St. Lawrence Island but not nearly to the degree they are found in the Summer.

In addition to all birds surveyed, Figures 21-26 were prepared based on shearwater and murre densities. Shearwaters show a very marked change over Spring, Summer and Fall in the frequency and location of high risk areas. In Spring, a single consistently high risk area was found just north of the Alaskan Peninsula while in the Summer, high risk areas were encountered throughout the inner shelf region south of Nunivak Island and all along the Alaskan Peninsula from below Unimak Pass north. Summer and Fall distributions of risk areas seem to be quite similar in the Bering Strait. In the southeast Bering Sea, Summer and Fall season differ primarily in the decreased frequency of high risk areas in the Fall and the very high proportion of low but variable risk areas in the Summer. The most obvious feature of the seasonal patterns for murres is that high risk areas are few and very localized. Only the Pribilof Islands show a high risk area for all three seasons with other high risk areas encountered only near St. Matthew Island, St. Lawrence Island, and just off Cape Newenham during the Summer. In Spring, a consistently high risk area was found just north of the Alaska Peninsula in Bristol Bay.

3) Location of Large Densities

In order to reduce somewhat the uncertainty associated with the patchy population distribution of seabirds, the available survey data for the eight zones near the Pribilof Islands and the three PROBES area zones were organized into eight categories. The resulting categorical information for all birds, All birds on water, murres, and Red-legged Kittiwakes is displayed in Tables 1-4. In addition, Table 5 gives frequency data for small auklets, Horned Puffins, and Tufted Puffin, species which typically occur in rather low densities. The error, d (see Appendix 1), for each zone at the a = 0.95% level is given in Figures 27-28. As can be seen in the list of d values, even with the crude approximation required when ignoring the underlying distribution of densities, the sample sizes for the eight zones tend to be large enough so that the error is on the order of $\pm$ 13% (excepting zone 2). This means for instance, that we can estimate the proportion of all bird encounters within zone 1 (Table 1) in the range 0.1 birds/km to 30.0 $birds/km^2$ to be between 13% and 41%. This estimate can be improved upon if the sampling procedure is assumed to be reasonably random. In this case (see Appendix 1), the proportion of samples falling within any particular interval should be approximately normally distributed if the sample size is large (>50). Figures 27 and 29 give the error, d, for each zone calculated under these assumptions. Now, in zone 8 (Table 1) for

Table 1. Proportions of transects in various intervals: All Birds

Zone	N	0	o*l- 10	1o.1- 30	30.1- 50	50*l- 100	1oo.1- 500	5oo.1- 1000	1000
1	253	2.0	17.0	26.9	18.6	11.9	21.7	1.6	0.4
2	88	3.4	5.7	30.7	31.8	13.6	12.5	0.0	2.3
3	130	3.8	3.1	11*5	7.7	17.7	35.4	13.1	7.7
4	178	2.8	5.1	23.6	10.7	11.2	34.3	6.2	6.2
5	387	2.1	19*4	38.2	16.3	17.6	6.2	0.3	0.0
6	343	4.7	12.2	30.6	19.0	20.4	11.4	1.2	0.6
7	297	0.7	33.3	39*7	15.2	7*4	3.7	0.0	0.0
8	487	1.2	13.1	32.9	17.7	20.1	14.2	0.4	0.4
13	89	2.2	20.2	44.9	12.4	6.7	13.5	0.0	0.0
14	497	0.4	20.5	48.5	17.3	10.3	2.6	0.2	0.2
15	395	3.8	50.1	29.4	9.6	5.6	1.5	0.0	0.0

Zone	1	2	3	4	5	6	7	8	13	14	15
% transects											
50 /km	35.6	28.4	73.9	57.9	24.1	33.6	11.1	35.1	20.2	13.3	7.1

Table 2. Proportions of transects in various intervals: All Birds on Water

Zone	N	0	0.1-10	10.1-30	30.1-50	50.1-100	100.1-500	5oo.l-1000	1000
1	253	29.6	37.2	15.0	7.1	6.3	4.3	0.4	0.0
2	88	29.5	53*4	11.4	1*1	2.3	1.1	1.1	0.0
3	130	16.2	41.5	17.7	3.8	7.7	7.7	3.1	2.3
4	178	12.4	44*4	16.3	6.7	9.0	7.0	1.7	1.7
5	387	22.2	47.8	23.8	2.8	2.8	0.5	0.0	0.0
6	343	30.0	50.4	13.7	2.6	1.5	1.5	0.3	0.0
7	297	31.0	53.2	9.8	3.0	1.7	1.3	O*O	0.0
8	487	41.9	46.6	7.0	1.6	2.3	0.6	0.0	0.0
13	89	50.6	39.3	6.7	1.1	1.1	1.1	0.0	0.0
14	497	38.6	52.9	6.4	1.4	0.2	0.4	0.0	0.0
15	395	50.6	42.3	6.1	0*3	0.8	0.0	0.0	0.0

Zone 1 2 3 4 5 6 7 8 1 3 14 15

% transects

50/km 11 4.5 20.8 20.3 3.3 3.3 3.0 2.9 2.2 0.6 0.8

Table 3. Proportions of Transects in various intervals: Red-legged **Kittiwakes**

Zone	N	0	oel- 10	1o.1- 30	30.1- 50	50.1- 100	1oo.1- 500
1	253	84.2	15.4	0.4	0.0	0.0	0*O
2	88	71.6	27.3	1.1	0.0	0.0	0.0
3	130	64.6	30.8	4.6	0.0	0.0	0.0
4	178	37.1	45.5	11*2	3.4	1.7	1.1
5	387	78.0	20.9	1.0	0.0	0.0	0.0
6	343	40.5	43.4	12.5	2.0	0.9	0.6
7	297	90.6	9.4	0.0	0.0	0.0	0.0
8	487	37.8	51.3	8.4	1.4	1.0	0.0
13	89	58.4	38.2	2.2	0.0	1.1	0.0
14	497	82.7	16.3	0.8	0.2	0.0	0.0
15	395	95.9	4.1	0.0	0.0	0.0	0.0

Table 4. Proportions of transects in various intervals: Murres

one	N	0	0.1-10	10.1-30	30.1-50	50.1-100	100.1-500	500.1-1000	1000
1	253	14.6	21.7	25.3	12.3	11.5	13.4	0.8	0.4
2	88	10.2	18.2	44.3	11.4	10.2	3.4	2.3	0.0
3	130	18.5	6.9	6.9	6.2	16.2	28.5	10.0	6.9
4	178	15.7	21.9	11.2	6.7	14.6	20.8	5s1	3*9
5	387	14.2	32.3	24.8	13.2	12.9	2.6	0.0	0.0
6	343	23.3	36.4	27.4	6.4	2.9	2.9	0.3	0.3
7	297	12.1	53.9	22.2	7.4	3.0	1.3	0.0	0.0
8	487	42.3	44.6	8.4	1.4	2.7	0.6	0.0	0*0
3	89	58.4	37.1	4.5	0.0	0.0	0.0	0.0	0.0
4	497	39.0	45.5	12.9	1.8	0.6	0.2	0.0	0.0
5	395	46.6	46.6	5.8	0.5	0.3	0.3	0.0	0.0

one	1	2	3	4	5	6	7	8	13	14	15
transects											
50 /km	26.1	15.9	61.6	44.4	15.5	6.4	4.3	3.3	0.0	0.8	0.6

Table 5. Proportions of transects in various intervals for species with typically low densities

		Frequency of Transects								
		0			0.1-10.0			10.1		
Zone	N	SmAuk	HP	TP	SA	HP	TP	SA	HP	TP
1	253	59.3	74.7	73.1	26.5	24.1	26.9	4.2	1.2	0.0
2	88	61.4	68.2	59.1	29.5	30.7	40.9	9.1	1.1	0.0
3	130	53.8	57.7	72.3	26.2	36.9	26.2	9.9	5.4	1.6
4	178	55.1	66.9	67.4	25.3	32.0	31.5	9.7	1*1	1.2
5	387	77.3	82.4	73.4	19.4	17.6	26.4	3.1	0.0	0.3
6	343	86.3	88.6	71.4	9.6	11.4	28.3	4.1	0.0	0.3
7	297	87.9	90.2	81.1	12.1	9.8	18.9	0.0	0.0	0.0
8	487	89.7	97.9	78.4	7*4	2.1	21.4	2.9	0.0	0.2
13	89	93.3	89	74.2	6.7	11	25.8	0.0	0.0	0.0
14	497	90.5	95.6	75.3	9.1	4.4	24.3	0.4	0.0	0.4
15	395	82.3	98.2	89.9	17.2	1.8	10.1	0.5	0.0	0.0

Sm Auk = Small Auklet

HP = Horned Puffin

TP = Tufted Puffin

ZONE	1	2	3	4	5	6	7	8
N	253	88	130	178	387	343	297	487
d	.14	.24	.20	.17	.11	.12	.13	.10

$$d = \frac{1}{2}\sqrt{N(1-\alpha)}$$

Error rate (d) for zones around the Pribilof Islands, $\alpha = 0.95$

Figure 27

ZONE	1	2	3	4	5	6	7	8
N	253	88	130	178	387	343	297	487
d	.06	.14	.09	.07	.05	.05	.06	.04

$$d = \sqrt{\frac{k^2}{4N}}\ ,\quad k = 1.96$$

Error rate (d) for zones around the Pribilof Islands. $\alpha = 0.95$, normal approximation

Figure 28

example, we can estimate the proportion of all bird encounters in the range 10.1-30.0 birds/km^2 to be between 29% and 37% at the 95% confidence level. Further refinement is of course possible if the sample size is increased. Figures 29 and 30 give the error with and without the normal approximation for combinations of the at PROBES area. For instance, if the three at PROBES area zones are combined, the normal approximation (Figure 30) yields an error of only 1%.

In keeping with previous observations of seasonal redistribution of densities, seasonal information from four zones (Tables 6-13) has been included for all birds, all birds on water, shearwaters, storm-petrels, Black-legged and Red-legged Kittiwakes, murres, and auklets. Error estimates for these tables are given in Figures 31 and 32. An examination of these tables shows that the frequency data tends to be consistent with the distribution of coefficients of variation discussed above. Once again moderate to high densities ($\geq$50 birds/km^2) occur most often near the Pribilof Islands in the Summer and more so in the Spring than in the Fall.

4) Future Sampling Efforts

As pointed out earlier, if sample estimates of bird densities are organized into disjoint intervals, then rather straightforward formulas can be derived that relate confidence levels and errors of estimate to sample size. Two methods of calculating the error, d, were derived, one with and one without assumptions concerning the distribution of proportions. In summarizing the data available for this report, a confidence level of 95% was used throughout and estimates of the sampling errors were computed based on existing sample sizes. Of course, the same data could be described using different confidence levels and for comparison, Figures 33 and 34 have been provided giving the required sample size associated with four values of α and two values of error.

ZONE	13	14	15	13+14	13+14+15
N	89	497	395	586	981
d	.24	,10	.18	.09	,01

$$d = \frac{1}{2}\sqrt{N\,(1-\alpha)}$$

Error rate (d) for PROBES zones, CL = 0.95

Figure 29

ZONE	13	14	15	13+14	13+14+15
N	89	497	395	586	981
d	.10	.04	.05	.04	.01

$$d = \sqrt{\frac{k^2}{4N}}, \quad k = 1.96$$

Error rate (d) for PROBES zones, $\alpha = 0.95$, normal approximation

Figure 30

Table 6. Seasonal variation in Bird Density % occurrence

in frequency categories: All Birds

Zone	N	0	0.1-10	1o.1-30	30.1-50	50.1-100	00.1-500	5oo.l-1000	1000
5 Sp	59	3.4	44.1	42.4	8.5	1.7			
5 Su	256	2.3	9.0	33.2	21.4	25.0	8.6	0.4	
5 fa	72	0.0	36.1	52.8	4.2	5.6	1.4		
6 sp	62	1.6	12.9	40.3	22.6	12.9	8.1	1.6	
6 su	224	6.7	11.2	23.2	16.1	26.3	14*3	1*3	0.9
6 fa	57	0*0	15.5	49.1	26.3	5.3	3.5		
8 sp	134	0*0	20.9	43.3	12.7	14.9	8.2		
8 su	308	1.9	7.5	25.3	20.8	25.0	18.2	0.6	0.6
8 fa									
14 Sp	259	0*0	26.6	53.7	10.8	7.7	1.2		
14 su	238	0.8	13*9	42.9	24.4	13.0	4.2	0.4	0.4
14 fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 7. Seasonal Variation in Bird Density % occurrence in frequency categories: All Birds on Water

Zone	N	0	0.1- 10	10.1- 30	30.1- 50	5oo1- 100	100.1- 500	5oo.l- 1000	1000
5 Sp	59	39.0	45.8	15*3					
5 Su	256	18.4	44.5	28.9	3*5	3.9	0.8		
5 Fa	72	22.2	61.1	12.5	2.8	1.4			
6 Sp	62	35*5	35.5	14.5	6.5	3.2	4.8		
6 Su	224	32.6	51.3	11.6	2.2	0.9	0.9	0.4	
6 Fa	57	14.0	63.2	21.1	0.0	1.8			
8 Sp	134	47.0	41.8	6.0	3.0	1.5	0.7		
8 Su	308	40.6	46.8	7.8	1.3	2.9	0.6		
8 Fa									
14 Sp	259	39.4	51.4	7.3	1.9				
14 Su	238	37.8	54.6	5.5	0.8	0.4	0.8		
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 8. Seasonal Variation in Bird Density **%** Occurrence

in frequency categories: Red-legged **Kittiwakes**

Zone	**N**	0	0.1- 10	1o.1- 30	30.1- 50	50.1- 100	loo.l- 500	500.1- 1000	1000
5 Sp	59	94*9	5.1						
5 **Su**	256	84.8	14.5	0.8					
5 Fa	72	40.3	56.9	2.8					
6 **Sp**	62	38.7	45.2	12.9	1.6	1.6			
6 **Su**	224	46.9	36.6	12.1	2.7	0.9	0.9		
6 Fa	57	17.9	68.4	14.0					
8 **Sp**	134	44.0	47.8	7.5	0.7				
8 **Su**	308	38.6	50.0	8.1	1.6	1.6			
8 Fa									
14 Sp	259	88.0	**12.0**						
14 **Su**	238	76.9	21.0	1.7	0.4				
14 Fa									

Sp = **Spring** (March, April, May)

Su = **Summer** (June, July, August)

Fa = **Fall** (September, October, November)

Table 9. Seasonal Variation in Bird Density, % Occurrence

in frequency Categories: **Murre**

Zone	N	0	0.1-10	10.1-30	30.1-50	50.1-100	100.1-500	5oo.l-1000	1000
5 Sp	59	8.5	57.6	28.8	3.4	0.0	1.7	-	-
5 Su	256	4.3	25.0	29.3	18.8	19.1	3*5		
5Fa	72	54.2	37*5	5.6	1.4	1.4			
6 Sp	62	17.7	35.5	30.6	6.5	1.6	6.5	1.6	
6 Su	224	14*3	37.1	33.5	8.0	4.0	2.7	0.0	0.8
6 Fa	57	64.9	35.1						
8 Sp	134	38.8	35.1	12.7	3*7	8.2	1.5		
8 Su	308	36.4	54.2	7.8	0.6	0.6	0.3		
8 Fa									
14 Sp	259	21.6	52.1	21.2	3.5	1*2	0.4		
14 Su	238	58.0	38.2	3.8					
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 10. Seasonal Variation in Bird Density, % Occurrence
in Frequency Categories: Shearwaters

Zone	N	0	0.1-10	1o.1-30	30.1-50	50.1-100	100.1-500	5oo.l-1000	1000
5 Sp	59								
5 Su	256	66.8	25.0	5*9	0.4	102	0.4	0.4	-
5 Fa	72	63.9	33.3	1.4	O*O	1.4			
6 sp	62								
6 Su	224	63.4	26.8	6.3	1.8	1.3	0.4		
6 Fa	57	61.4	35.1	3.5					
8 sp	134	99.3	0.7						
8 Su	308	49.0	35.4	7.1	2.6	2.6	3.2		
8 Fa									
14 Sp	259	96.5	2.3	0.4	0.4	0.0	0.4		
14 Su	238	73.9	20.2	2.0	0.4	1.3	1.3		
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 11. Seasonal Variation in Bird Density, % Occurrence in Frequency Categories: Storm Petrel

Zone	N	0	0.1- 10	lo*l- 30	30.1- 50	50.1- 100	100.1- 500	5oo.l- 1000	1000
5 Sp	59								
5 Su	256	93.0	5.9	0.8	0.4				
5 Fa	72								
6 sp	62	98.4	1.6						
6 Su	224	67.0	20.1	8.5	1.3	0.4	2.2	O*4	
6 Fa	57	80.7	19.3						
8 Sp	134	90.3	8.2	1.5					
8 Su	308	34.1	42.5	10.1	2.6	6.2	3.2	1.0	0.3
8 Fa									
14 Sp	259	79.2	20..1	0.8					
14 Su	238	29.0	49.6	16.8	2.5	1.7	0.4		
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 12. Seasonal Variation in Bird Density, % Occurrence in Frequency Categories Black-legged Kittiwakes

Zone	N	0	0.1- 10	lo*l- 30	30.1- 50	50.1- 100	100.1- 500	5oo.l- 1000	1000
5 Sp	59	28.8	69.5	1.7					
5 Su	256	40.2	59.0	0.8					
5 Fa	72	8.3	81.9	8.3	1.4				
6 sp	62	30.6	61.3	8.1					
6 Su	224	42.9	45.5	9.4	1.8	0.4			
6 Fa	57	35.1	63.2	1.8					
8 Sp	134	42.5	51.5	5.2	0.7				
8 Su	308	37.3	52.3	9*4	1.0				
8 Fa									
14 Sp	259	56.0	41.7	2.3					
14 Su	238	60.9	36.1	2.9					
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Table 13. Seasonal Variation in Bird Density, % Occurrence in Frequency Categories: All Auklets

Zone	N	0	0.1-10	1o.1-30	30.1-50	50.1-100	100.1-500	5oo.l-1000	1000
5 Sp	59	62.7	32.2	5.1					
5 Su	256	75.0	21.2	3.5	0.0	0.4			
5 Fa	72	97.2	2.8						
6 sp	62	59.7	24.2	11.3	. 1.6	1.6	1.6		
6 su	224	91.1	7.1	1.3	0.4				
6 Fa	57	96.5	3.5						
8 sp	134	70.9	18.7	7.5	2.2	0.7			
8 Su	308	97.4	2.6						
8 Fa									
14 Sp	259	84.6	14.7	0.8					
14 Su	238	97*1	2.9						
14 Fa									

Sp = Spring (March, April, May)

Su = Summer (June, July, August)

Fa = Fall (September, October, November)

Sp = spring (March, April, May), Su = summer (June, July, August), Fa = fall (September, October, November)

ZONE	5 Sp	5 Su	5 Fa	6 Sp	6 Su	6 Fa	8 Sp	8 Su	14 Sp	14 Su
N	59	256	72	62	244	57	134	308	259	238
d	.29	.14	.26	.28	.18	.30	.19	.13	.14	.15

$$d = \frac{1}{2}\sqrt{N(1-\alpha)}$$

Error estimates (d) for Tables 1 - 6, $\alpha = 0.95$

Figure 31

Sp = spring (March, April, May), Su = summer (June, July, August), Fa = fall (September, October, "November)

ZONE	5 Sp	5 Su	5 Fa	6 Sp	6 Su	6 Fa	6 Sp	8 Su	14 Sp	14 Su
N	59	256	72	62	224	57	134	308	259	238
d	.13	.06	.11	.12	.07	.13	.09	.06	.06	.06

$$d = \sqrt{\frac{k^2}{4N}}, \quad k = 1.96$$

Error estimates (d) for Tables 6 - 13, $\alpha = 0.95$, normal approximation

Figure 32

α	d = .1	d = .25	k
.99	2500	400	2.58
.95	500	80	1.96
.90	250	40	1.65
.75	100	16	1.16

$$N = \frac{1}{4} d^2 (1-\alpha)$$

Sample size (N) required for a given confidence level (α) and error rate (d)

Figure 33

α \ d	.1	.25	k
.99	665	166	2.58
.95	384	96	1.96
.90	272	68	1.65
.75	135	34	1.16

$$N = \frac{1}{4}(k/d)^2$$

Sample size (N) required for a given confidence level (α) and error rate (d), with the normal approximation

Figure 34

Future survey efforts are likely to have as objectives both the refinement of current estimates and the acquisition of information about previously unsurveyed regions. The formulas used in Figures 33 and 34 can be used to give planners clear criteria for consistent decisions in this regard.

To illustrate, zone 3 (Table 1) shows a higher proportion of density estimates of >50 birds/km^2 than any other zone, but with a sample size of only 130 the error is approximately 20%. Zone 5 on the other hand, which is adjacent to zone 3, has only about one-third the proportion of density estimates >50 birds/km^2 but almost three times the number of transects. Clearly, if other considerations are judged equal, an allocation of new survey resources to zone 3 rather than zone 5 would be preferred since reducing the error of estimates for the former is likely to be of more value. Similarly, if seasonal data are examined, density estimates for Red-legged Kittiwakes (Table 11) tend to be found in more restricted ranges during the Fall but the sample sizes for this season are relatively small.

Turning now to the question of which of the two available formulas should be used in planning survey efforts, the choice will depend primarily on just how closely a proposed survey will approximate a random sample. A comparison of Figures 33 and 34 show that a survey including 100 transects would yield an error of 10% at the .95% confidence level if the normal approximation is assumed while the same precision would require 500 transects if the normal approximation does not hold. This considerable increase in efficiency suggests that, even though in the majority of surveys random observations might be costly in terms of resources, a fewer number of random observations would be more cost-effective than a larger number of more convenient efforts.

In developing a sampling rationale for any new area, zones in the vicinity of colonies should be organized to sample different distances from the colony

(10, 20, 40km bands) and toward and away from the shelf-edge, assuming that no currents or fronts are nearby. If fronts or currents are within 100-150km of the colony (as near the Bering Strait colonies), then sampling should include these areas.

In pelagic surveys removed from colonies, our experience suggests that it is valuable to organize sampling on the basis of oceanographic domains. So doing provides a biologically rational basis for partitioning sampling effort.

For all zones, seasonal variation needs to be considered, although annual variation is not significant. Thus sampling should be spread over Spring, Summer and Fall and if possible Winter with sufficient transects in each zone in each season to provide the desired level of confidence and error.

DISCUSSION

1) Mixing Regimes and Seabird Distribution

Our analysis showed that both surface feeding and diving seabirds exhibited significant differences in density between shelf domains that differ in mixing regime and food webs. Our results establish, at a relatively fine scale, a connection between seabird numbers and mixing regimes that differ in the timing of algal productivity and the type of marine food web. Large scale correlations between seabird abundance and physical parameters have been presented by Pocklington (1974) for the Indian Ocean, and by Shuntov (1974) and Sanger (1972), who described latitudinal variation in seabird abundance associated with temperature gradients in the North Pacific. A mesoscale analysis of seabird abundance has been presented by Joiris (1978) for a single cruise in the North Sea in July. Joiris found a reduced number of Northern Fulmar, storm-petrels, and alcids in "North Sea water" (middle shelf) as compared to the numbers of these species in "Atlantic water" (outer shelf). Our analysis of seabird abundance relative to domains in the Bering Sea closely parallels some of the results of Joiris. We found a reduced density of fulmars, storm-petrels, and one alcid (Tufted Puffins) in the middle domain. Black-1egged Kittiwakes differed little in density between domains. For murres we found a lower density in the middle shelf than in outer shelf waters.

Our results do not indicate that usage of the middle shelf is uniformly reduced in all seabird species. Auklet densities were higher in the middle shelf than on the outer shelf, and there was some indication that shearwater density increases as one moves from the shelf-break toward the coastal domain* Murre densities on the middle shelf were lower than on the outer shelf, but still far above those recorded beyond the shelf-break.

An association between bird densities and surface water temperatures has been noted in other studies at high latitudes (Brown 1968). Our results for the southeastern Bering Sea offer an explanation for this, since surface waters are warmer for the middle shelf regime (two-layer system) than for the outer shelf (three-layer system). This suggests that the relation that we have established between bird densities and mixing regimes in the southeastern Bering Sea may be generally true of those seabirds that inhabit the wide continental shelves found at high latitudes.

2) Comparison of Density Estimates

Significant differences in bird density among domains can affect estimates of density for an entire shelf, especially if effort is not proportional to the area of each domain. A similar consideration applies to seasonal fluctuations, if sampling effort and seabird numbers fluctuate from month to month. If sampling effort and bird numbers do vary greatly from region to region and month to month, then these differences need to be taken into account when developing density estimates. Using seasonal data presented by Schneider and Hunt (in prep), we computed integrated averages for the entire area covered by the three shelf regions shown in Figure 10. The slope, outer, and middle regions accounted for 6%, 34%, and 60% respectively of the total area of 89,780 km^2. An integrated estimate was obtained by computing the number of birds in each of these three regions, taking the sum, then dividing by the total area. The integrated average was 12 birds/km^2 in April, 14 birds/km^2 in May, 29 birds/km^2 in June, and 56 birds/km^2 in July.

These values are roughly the same as a colony based estimate (Hunt et al. 1980a), while differing from previous pelagic estimates (Hunt et al. 1980a, Shuntov 1974, Wahl 1978). Hunt et al. (1980a) took a value of 60%

of the birds in all colonies in the eastern Bering Sea as an estimate of the number of birds at sea at any one time, added the total estimated shearwater population, and divided this figure by shelf area (807,000 km^2). This method yielded an estimate of 32 birds/km^2 during the breeding season. Using counts made at sea, Wahl (1978) reported a value of 15 birds/km^2 for the southeastern Bering Sea. Shuntov (1974) reported 20 birds/km^2 on the eastern Bering Sea shelf in May-June, 18 birds/km^2 in July-August. Hunt et al. (1980a), using both ship and air counts, report values of 56, 41, and 12 birds/km^2 for the continental shelf, shelf-break, and oceanic waters of the eastern Bering Sea in March through May. For June through August they report 109, 58, and 11 birds/km^2 for shelf, shelf-break, and oceanic waters respectively. Their higher values in summer were due primarily to the inclusion of nearshore counts, including counts near Unimak Pass. Shearwaters are concentrated in these areas, and accounted for 80% of the largest zonal average, 109 birds/km^2.

The discrepancies between pelagic estimates can be attributed to differing sampling efforts and designs, in conjunction with a highly aggregated bird distributions. If sampling is controlled by an equalization of effort or by a stratified design, then at-sea counts are likely to underestimate total birds unless effort is great enough to detect large feeding flocks, which can account for the major proportion of the birds at sea at any one time. For highly aggregated species, increased sampling effort will increase the probability of encounter with large flocks, thereby increasing the observed average. The estimates that we present are based on 163.5 hours of observation (981 counts). The lower estimate of Wahl was based on 20.3 hours. Shuntov's estimates were based on 170 (Spring) and 280 (Sumner) counts of unknown duration and location.

3) Areas of Great Sensitivity to Oil Spills

Considerable between and within season variability notwithstanding, Figures 3 and 18-20 delineate areas in which spilled oil would be likely to encounter high concentrations of birds. Whether one concentrates on regions in which a high percentage of transects encountered high densities of birds (Figure 3), or regions where high means and low coefficients of variation coincide (Figures 18-20), the conclusions are the same. The areas near Unimak Pass, along and inshore of the 50m isobath in Bristol Bay, along the shelf-edge, and near major colonies (Pribilof Islands, Cape Newenham, St. Matthew, St. Lawrence, King Island, and the Diomedes) all support" large numbers of birds. While the impact would vary with season (Figures 18-20), at virtually any time a spill would have serious consequences. The blank areas on the figures represent regions with inadequate survey coverage and some of these areas may also contain high densities of birds.

It is also clear that the species of birds at risk differ with location and season. For instance, shearwaters predominate in inner Bristol Bay, particularly in Summer (Figures 21-23), while murres are most concentrated near their major colonies (Figures 24-26). Most of the birds seen near St. Lawrence Island and northward into the Bering Strait were small auklets. All of these species are found in large, dense aggregations on the water and hence are exceedingly vulnerable to floating oil.

4) Statistical Considerations

The most dominant characteristic of sea-bird density estimates is the extreme local instability found throughout the entire Bering Sea. This is illustrated both by the wide range of coefficients of variation calculated for small blocks of ocean area and the inability of simple linear regressions based on oceanographic variables to significantly reduce the observed variability.

The prediction of bird populations in particular locations must take this fact into account and this report offers the suggestion that a useful step in this direction is to categorize bird density estimates into intervals.

The Binominal model and certain associated equations described in this report seem to have considerable merit in terms of their applicability to seabird data if the statistic of interest is the proportion of density estimates that fall within specified ranges. With very few underlying assumptions, quantitative relationships can be derived that yield useful confidence levels and estimates of error for past sampling efforts and also provide reasonably precise criteria for planning decisions concerning future sampling efforts. The requirement that sampling be done randomly and that the observations be as independent as possible can of course be only approximated and not achieved exactly. However, the sensitivity of this approach to violations of randomness and independence is likely to be less than that of any other practical quantitative program.

Finally, if one of the purposes of obtaining quantitative estimates of seabird populations is to provide input to evaluations of the biological risk associated with oil spills in specific regions, then the analysis described in this report bears directly on this task. For example, if two or more areas or locations are to be compared in terms of their relative "riskiness", then an important component of this decision is the potential value of additional information and what it would cost to obtain it. The relationships between the acquisition of new or better information and the methods used in this report were discussed in the preceding section on future sampling efforts.

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APPENDIX 1

Density estimates derived from transect samples can be categorized into c disjoint intervals with the following assumptions:

(1) Each sample is considered to be an independent Bernoulli trial.

(2) For each i, i = 1,...,C, π_i is the probability that the sample statistic (in this case the mean) will fall within interval i and therefore belong to category i. For categories 1,...,C;

$$\pi_1 + \pi_2 + \ldots + \pi_c = 1 \quad .$$

(3) The number of transects (samples) belonging to category i is the number of successes S associated with the category;

$$N = S_1 + S_2 + \ldots + S_c \quad .$$

(4) The probability of obtaining a particular set of successes is given by the multinomial model as follows:

$$m(S_1, S_2, \ldots, S_c; \pi_1, \pi_2, \ldots, \pi_c) = \binom{N}{S_1, S_2, \ldots, S_c} \pi_1 \pi_2 \ldots \pi_c^{S_c}$$

where $$\binom{N}{S_1, S_2, \ldots, S_c} = \frac{N!}{S_1! S_2! \cdot \cdot \cdot S_c!} .$$

(5) If the number of categories is reduced by combining two or more of the original set then, for example,

$$m(S_1, S_2, S_3'; \pi_1, \pi_2, \pi_3') = \binom{N}{S_1, S_2, S_3'} \pi_1^{S_1} \pi_2^{S_2} \pi_3'^{S_3'}$$

where $S_3' = N - (S_1 + S_2)$

and $\pi_3' = \pi_3 + \pi_4 + \ldots + \pi_c$.

(6) If only one category is of interest then the multinominal model given in (4) reduces to the Binomial model so that:

$$b(S_i; N, \pi_i) = \binom{N}{S_i} \pi_i^{S_i} (1 - \pi_i)^{N - S_i} \quad .$$

The practical application of statements (1) through (6) requires estimations of the probabilities $\pi_1, \ldots, \pi_c$. This entails the derivation of a formula which provides, for any given confidence level and interval, a lower bound on the required sample size. This formula, for any given sample size and confidence level, also yields an upper bound on the associated confidence interval. The derivation is straight-forward and requires only Chebyshev's Inequality and the weak law of large numbers. The version of the former used here can be stated as follows: at least $1 - 1/h^2$ of the probability associated with any random variable will lie within h standard deviations of the mean. In particular,

(A) $$Pr(|x - \mu| < h\sigma) \geq 1 - \frac{1}{h^2}$$

which is read as: the probability that the absolute value of the difference between a random variable and its mean is less than $h\sigma$ is equal to or greater than $1 - 1/h^2$. The Chebyshev Inequality holds for any distribution so long as it has a mean and variance and therefore can be used to validate Khintchine's Theorem for the weak law of large numbers, described next.

Given a random sample of n observations taken from a population with mean μ and variance σ^2, the expectation of the sample mean $\bar{x}$ is σ^2/N. This last statement implies that as n gets large the variance of the sample mean approaches zero which is the significant implication of the law of large numbers. That is, for any $d > 0$,

(B) $$\Pr(|\bar{x} - \mu| < d) \to 1 \quad \text{as} \quad N \to \infty \quad .$$

To show this analytically, Chebyshev's Inequality can be written as

(c) $$\Pr(|x - \mu| < d) \geq 1 = \frac{1}{h^2}$$

where $$d = h\sigma \quad \text{and} \quad h = \frac{d}{\sigma} \quad .$$

Consequently, if we substitute $\bar{x}$ for x' and σ^2/N for σ^2, the result is Khintchine's theorem:

$$\Pr(|\bar{X} - \mu| < d) \geq 1 - \frac{1}{\left(\frac{d}{\sqrt{\sigma^2/N}}\right)^2} = 1 - \frac{\sigma^2}{Nd^2}$$

Since σ^2 and d^2 are fixed, as $N \to \infty$, $\sigma^2/Nd^2 \to 0$ giving (B).

The equation relating sample size to confidence level and confidence interval can nowbe derived using the Bernoulli model and statements (A) through (C). In this model, each transect is considered to be one of N independent Bernoulli trials with population probability π_i associated with category i. If S is the number of transects in category i (i.e., the number of successes) then the sample mean is S/N and

$$Pr\left(|\frac{S}{N} - \pi_i| < d \right) \to 1 \quad \text{as} \quad N \to \infty \quad .$$

This is the Bernoulli law of large numbers, first published in 1713. In words, as N gets large the proportion of successes in the sample will get arbitrarily close to the population proportion π_i. The question is, how large must N be for S/N to be a "good" estimate of π_i? To answer this we wish to estimate the size of N such that the observed frequency of success in the sample will be within a specific distance d of π_i at a given high level of probability α. Formally, we wish to find an integer N such that

$$Pr\left(|\frac{S}{N} - \pi_i| \leq d \right) \geq \alpha \quad \text{for all} \quad \pi_i \quad \text{in} \quad 0 \leq \pi_i \leq 1 \quad .$$

To find a lower bound on N, note that from (C)

$$\alpha = 1 - \frac{\sigma^2}{Nd^2} ,$$

and from the Bernoulli model the variance of S/N is $\pi_i(1 - \pi_i) / N$.

Furthermore,

$$\pi_i(1 - \pi_i) = \pi_i - \pi_i^2$$

$$= \frac{1}{4} - \left(\frac{1}{4} - \pi_i + \pi_i^2\right)$$

$$= \frac{1}{4} - \left(\frac{1}{2} - \pi_i\right)^2$$

so $\pi_i(1 - \pi_i)$ is maximum at $\pi_i = 1/2$. Therefore,

(D) $$\Pr\left(\left| \frac{S}{N} - \pi_i\right| \leq d\right) \geq 1 - \frac{1}{4Nd^2}$$

since $$\frac{\sigma^2}{N} = \pi_i(1 - \pi_i)/N \leq \frac{1}{4N} .$$

The relation in (D) is satisfied if

$$N \geq \frac{1}{4d^2(1 - \alpha)} .$$

The estimates given above for sample sizes required for particular values of α and d can be improved if S is the sum of a large number of independent trials (usually greater than 30). If this is true then the Central Limit Theorem holds approximately and S/N can be assumed to be nearly normal. In this case, the error

$$d = k\sigma_{S/N}$$

$$= k\sqrt{\frac{\pi_i(1 - \pi_i)}{N}}$$

and

$$N \geq \pi(1 - \pi)\left(\frac{k}{d}\right)^2 .$$

Once again $\pi(1 - \pi)$ is a maximum at $\pi = 1/2$. Therefore

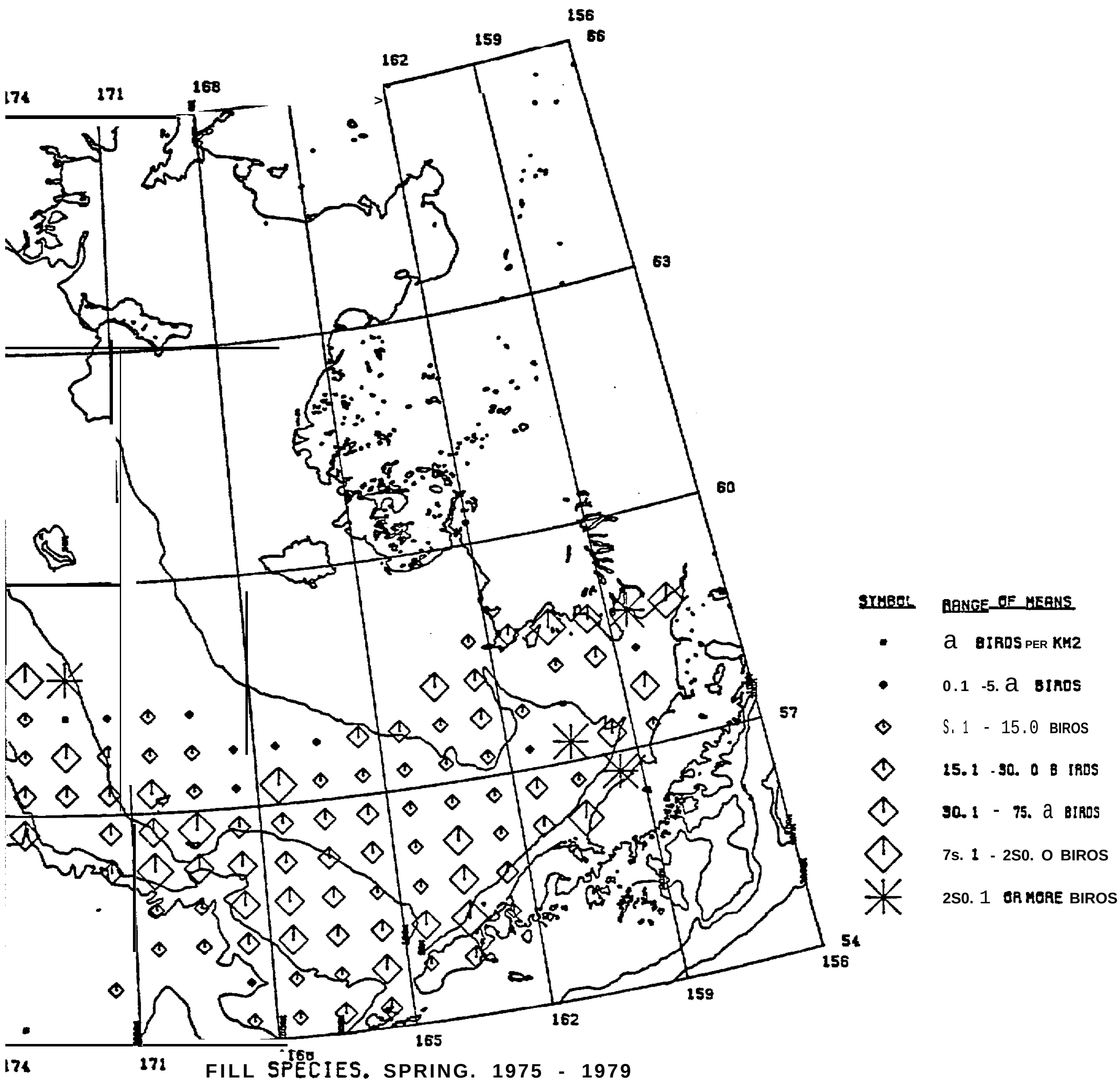
$$N \geq \frac{1}{4}\left(\frac{k}{d}\right)^2$$

and also,

$$d = \sqrt{\frac{k^2}{4N}} .$$

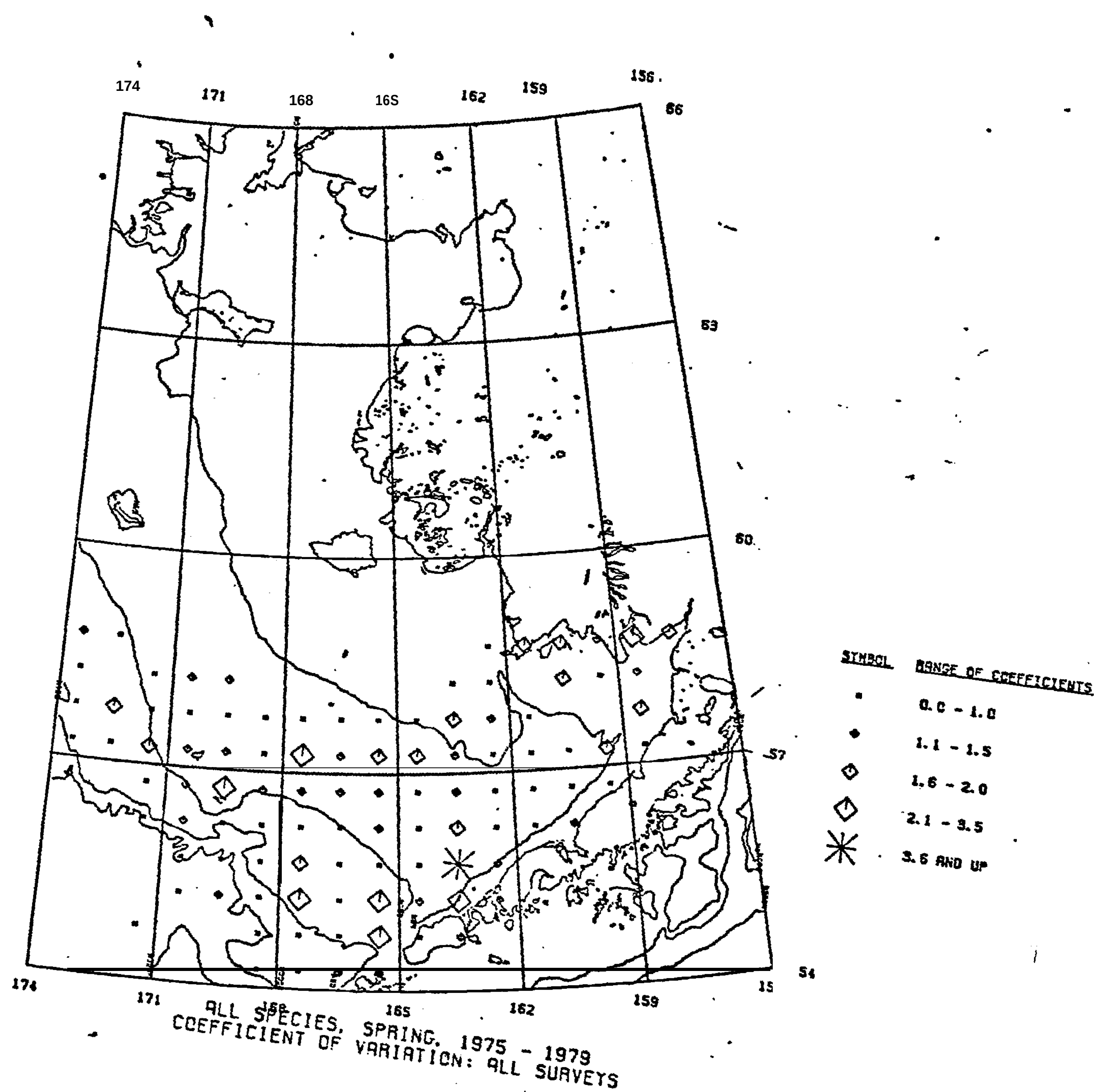
APPENDIX 2

Maps of Mean Densities and Associated Coefficients of Variation



FILL SPECIES. SPRING. 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 35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SYMBOL
RANGE OF COEFFICIENTS
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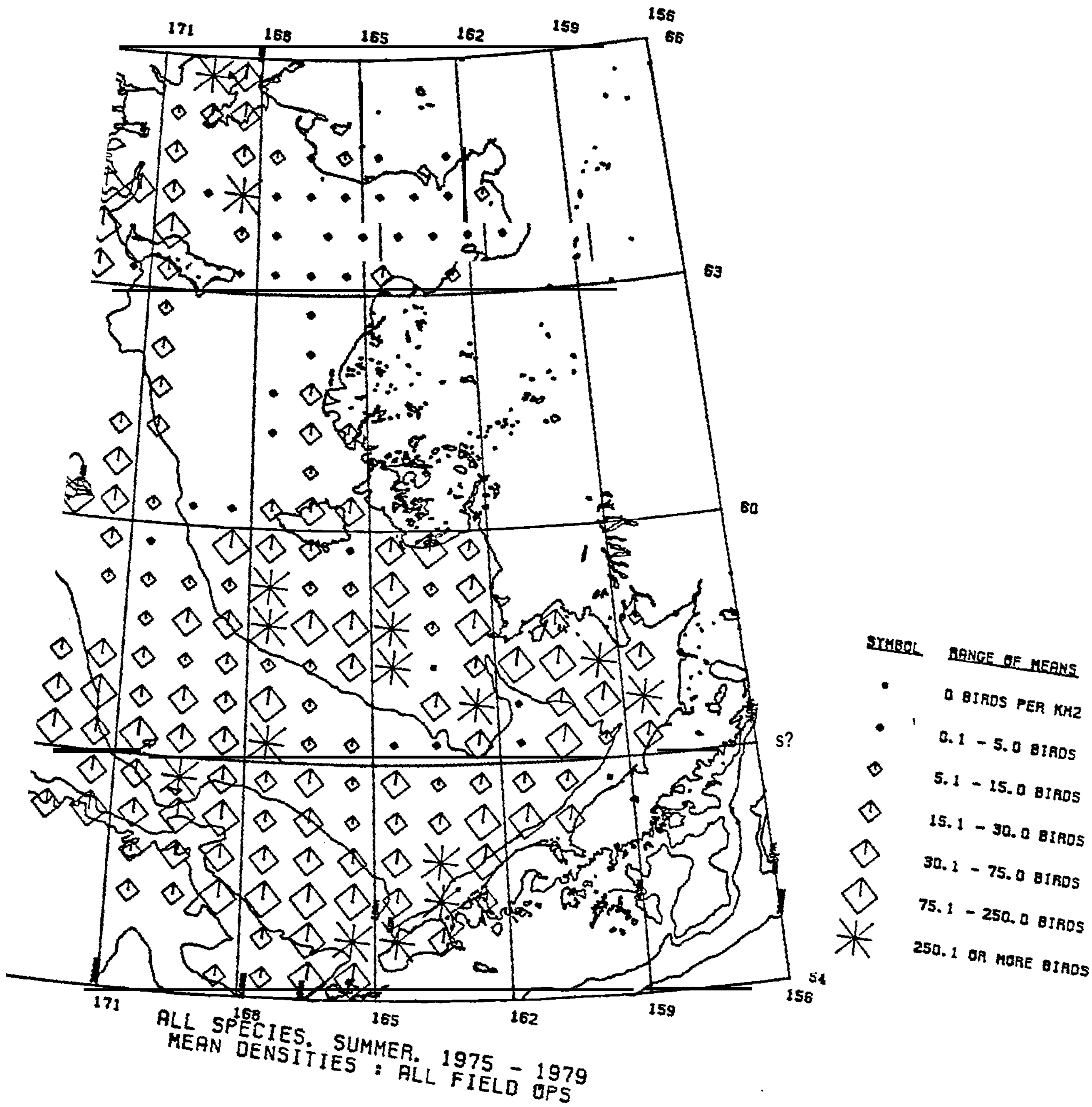
1.1 - 1.5
1.6 - 2.0
2.1 - 3.5
3.6 AND UP
ALL SPECIES, SPRING, 1975 - 1979
COEFFICIENT OF VARIATION: ALL SURVEYS

Figure 36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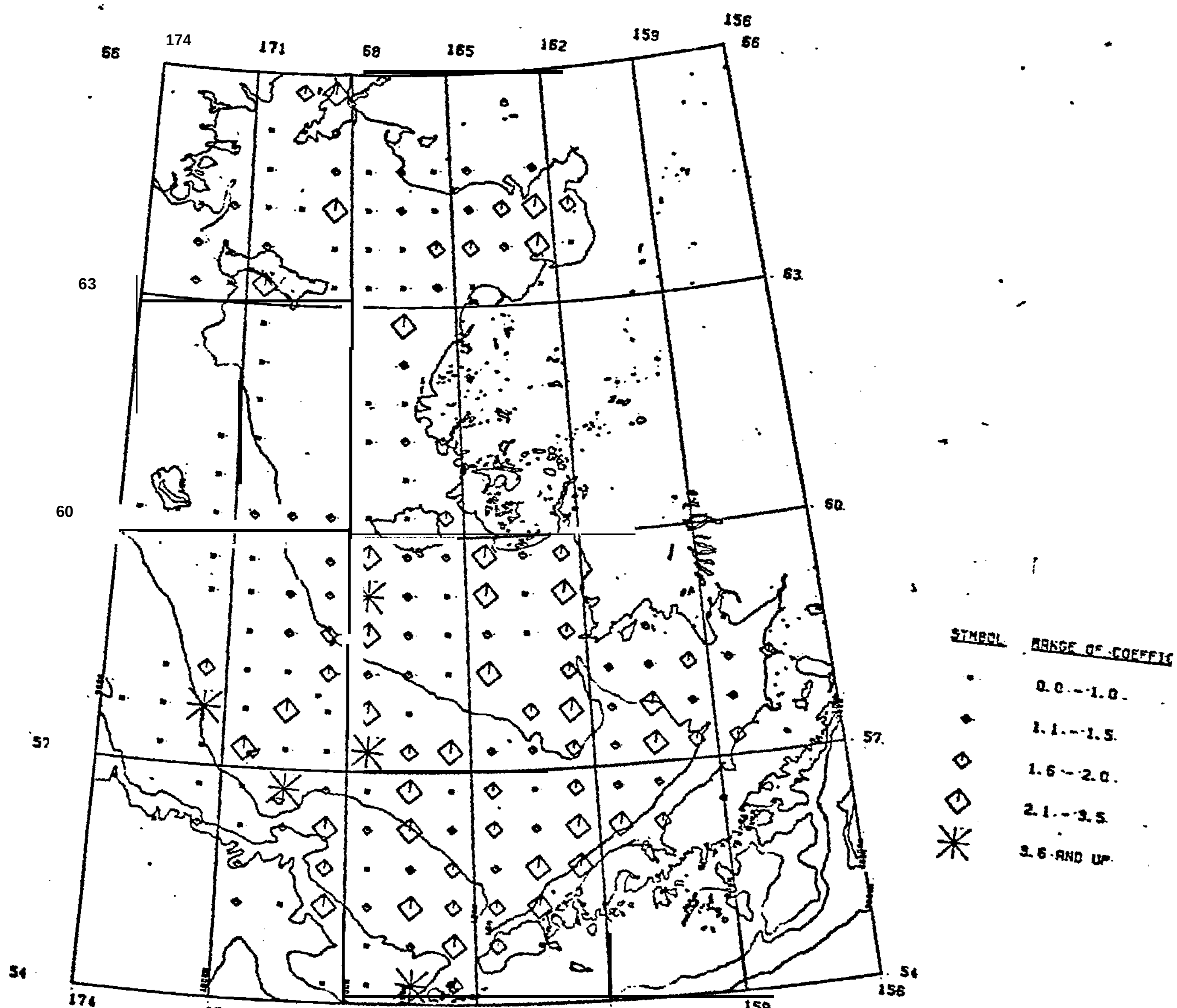
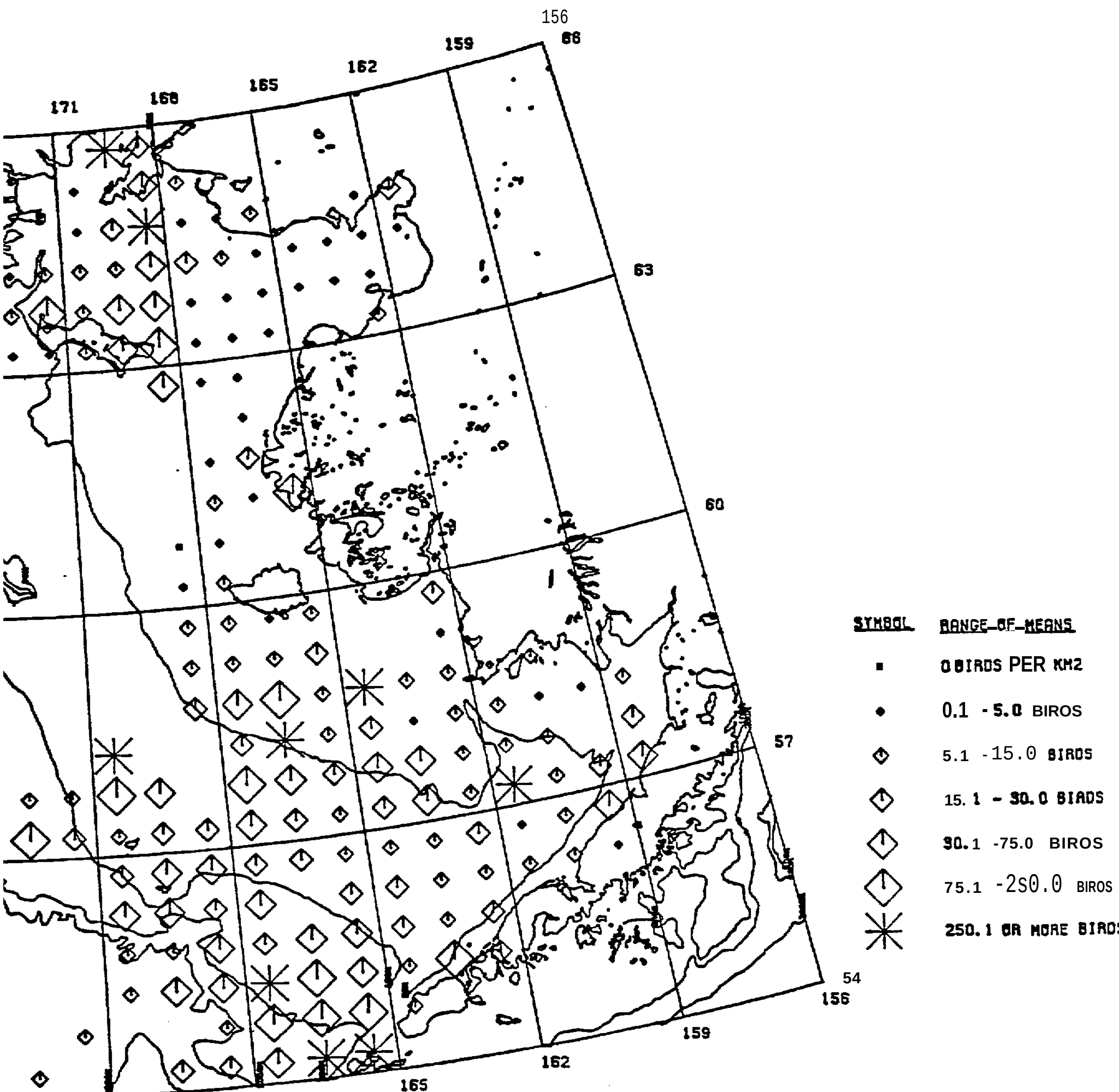
SYMBOL
RANGE OF MEANS
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
ALL SPECIES. SUMMER. 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 37



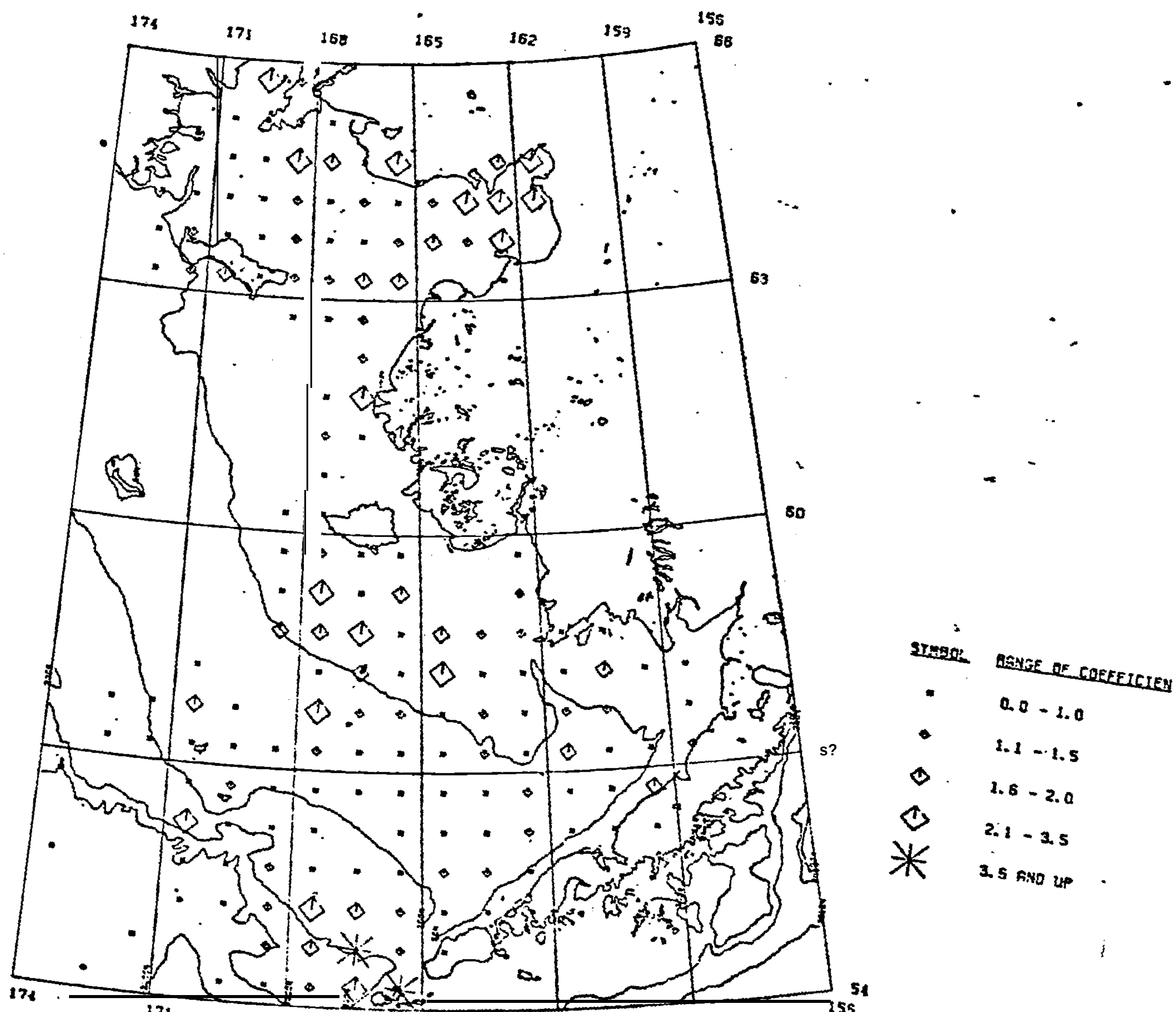
ALL SPECIES, SUMMER, 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 38



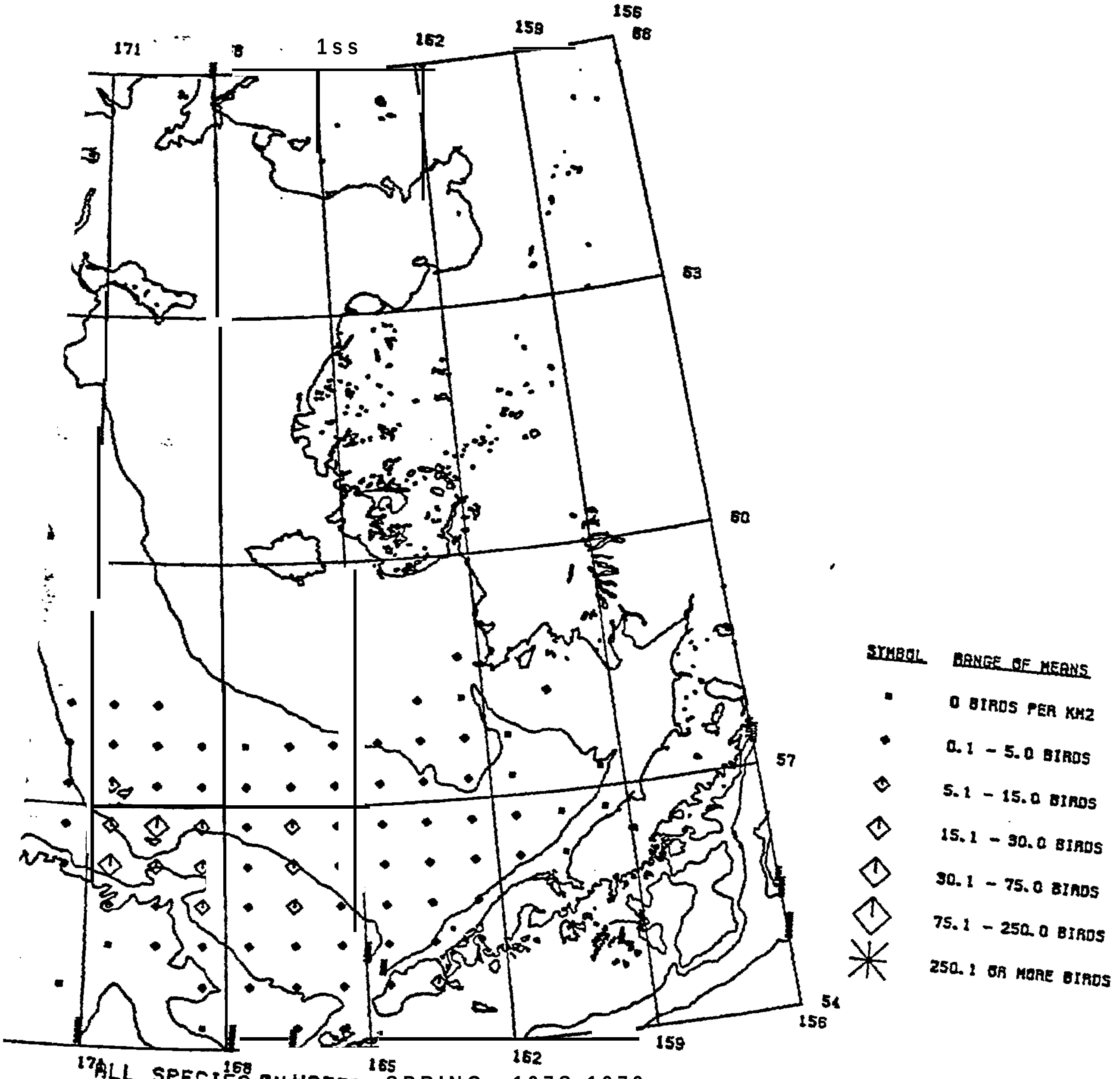
ALL SPECIES, AUTUMN, 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 39



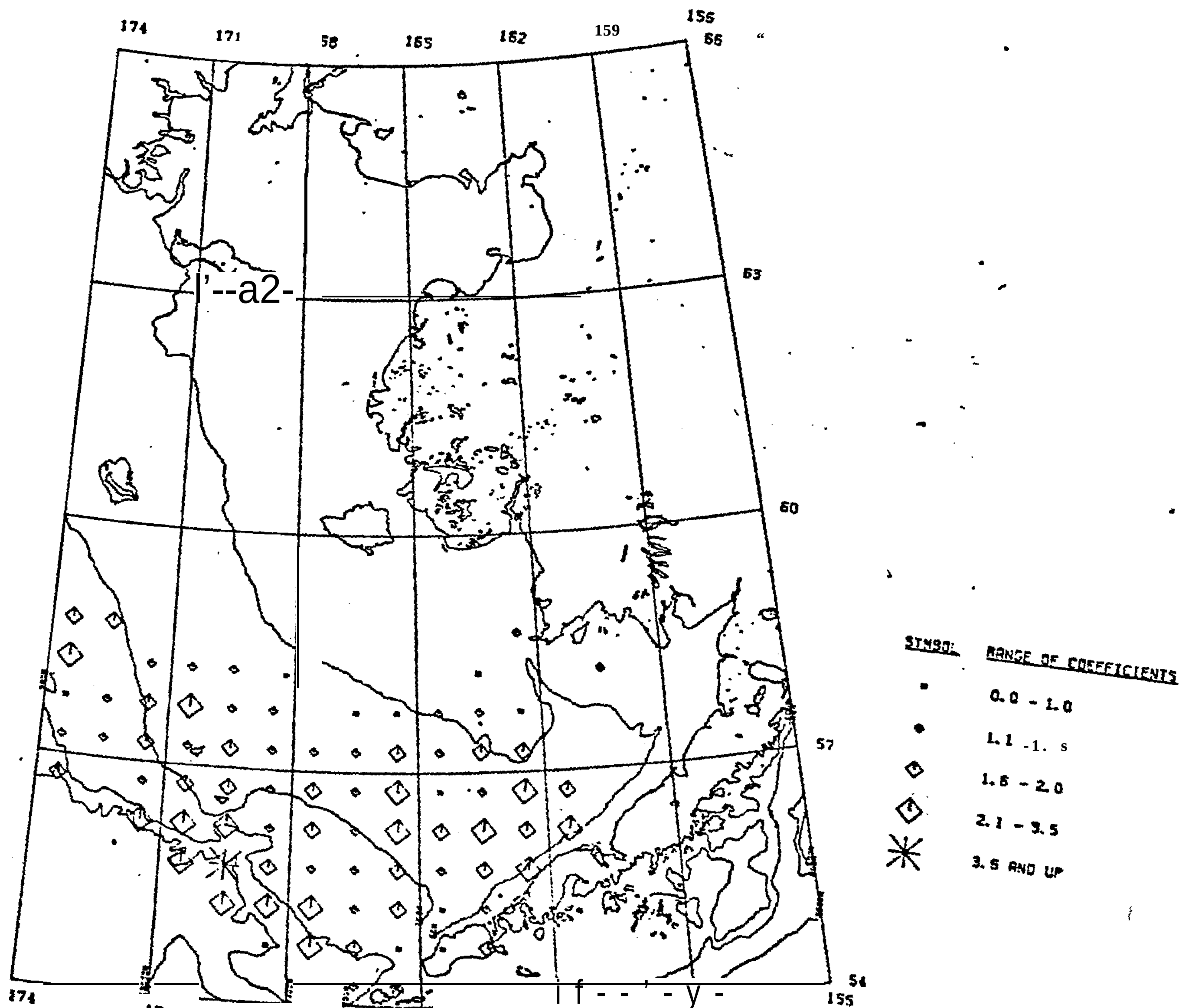
ALL SPECIES, AUTUMN, 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 40



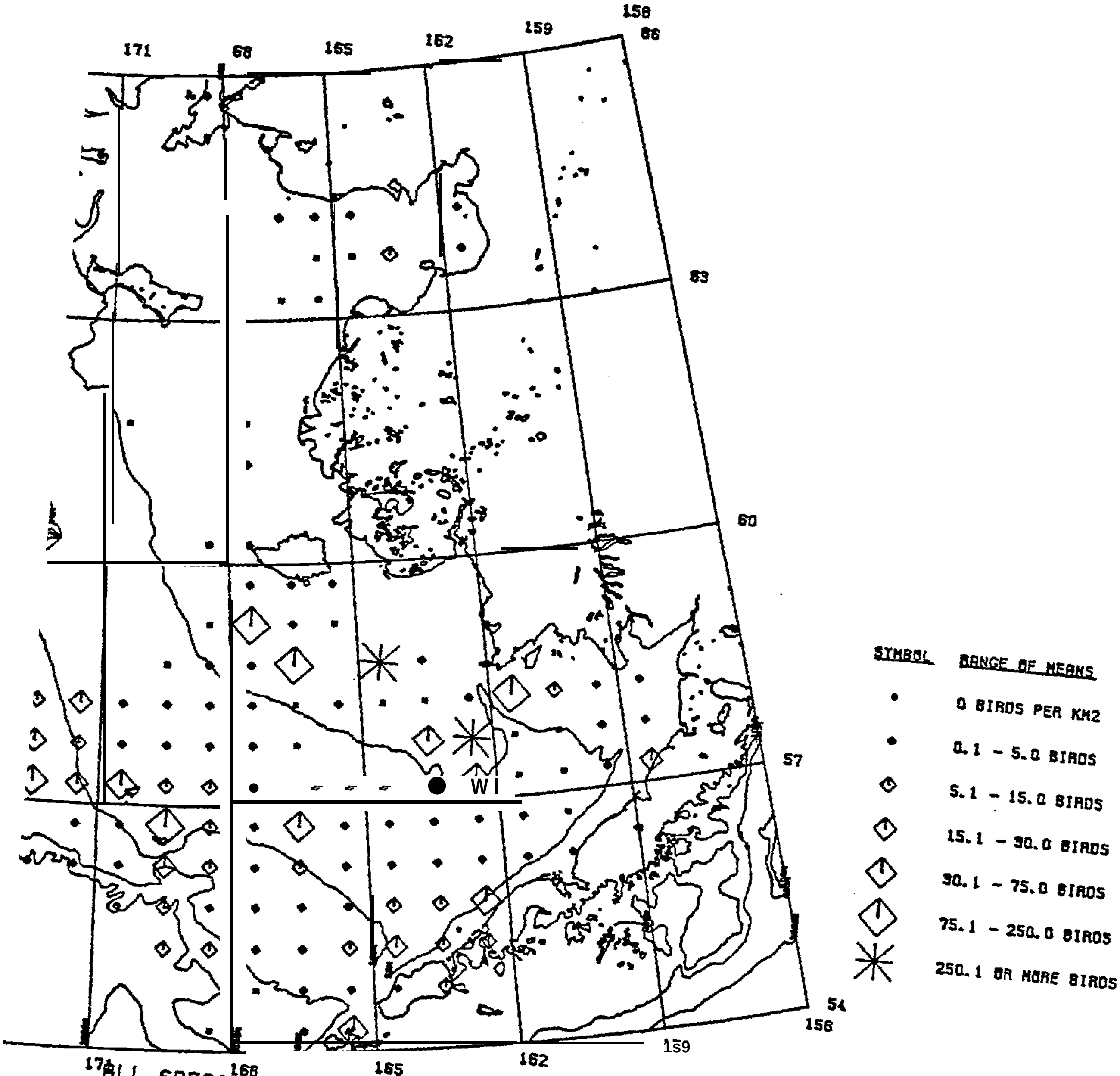
ALL SPECIES ON WATER, SPRING. 1975-1979
MEAN DENSITIES : ALL FIELD OPS

Figure 41



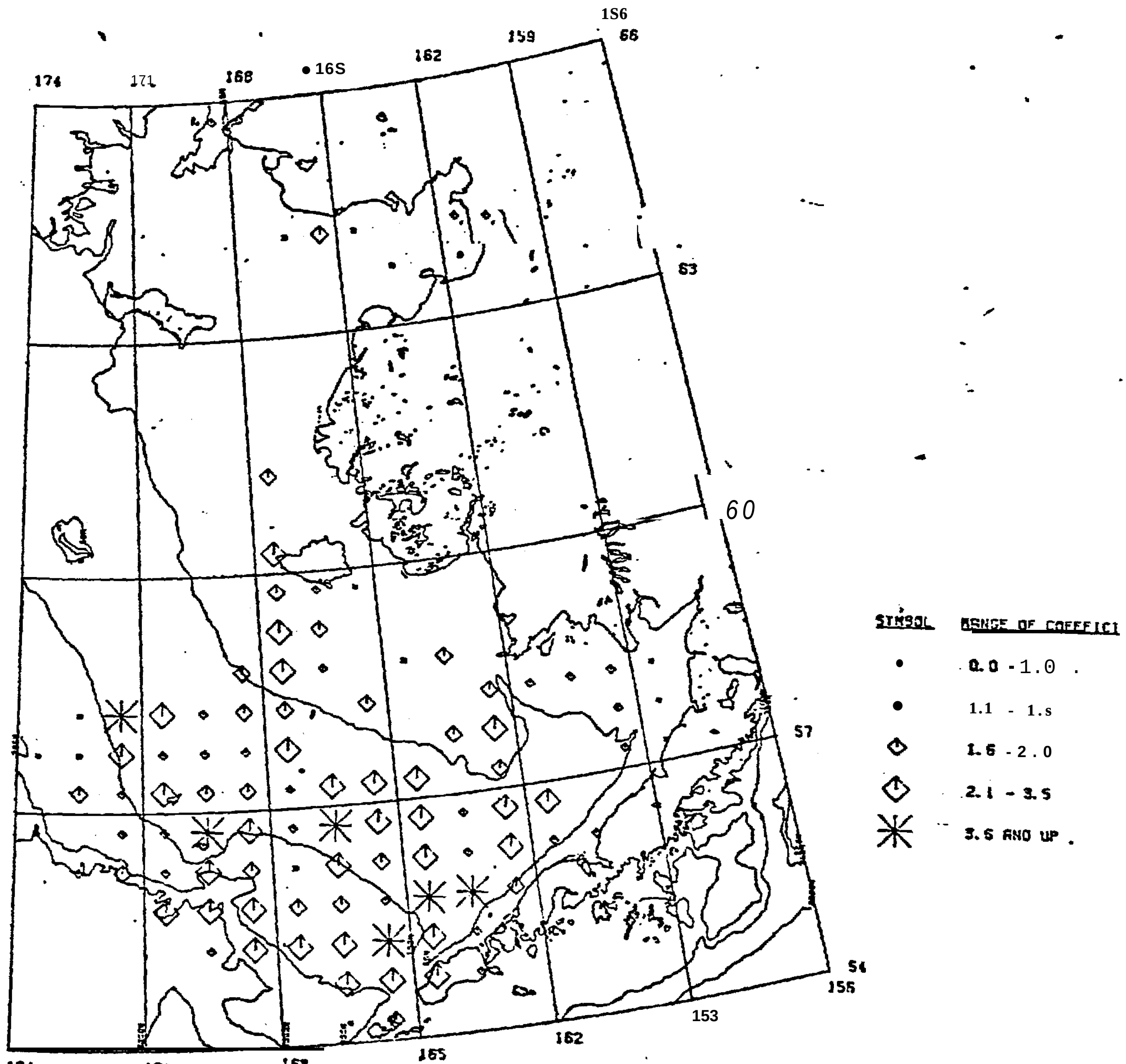
ALL SPECIES ON WATER, SPRING, 1975-79
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 42



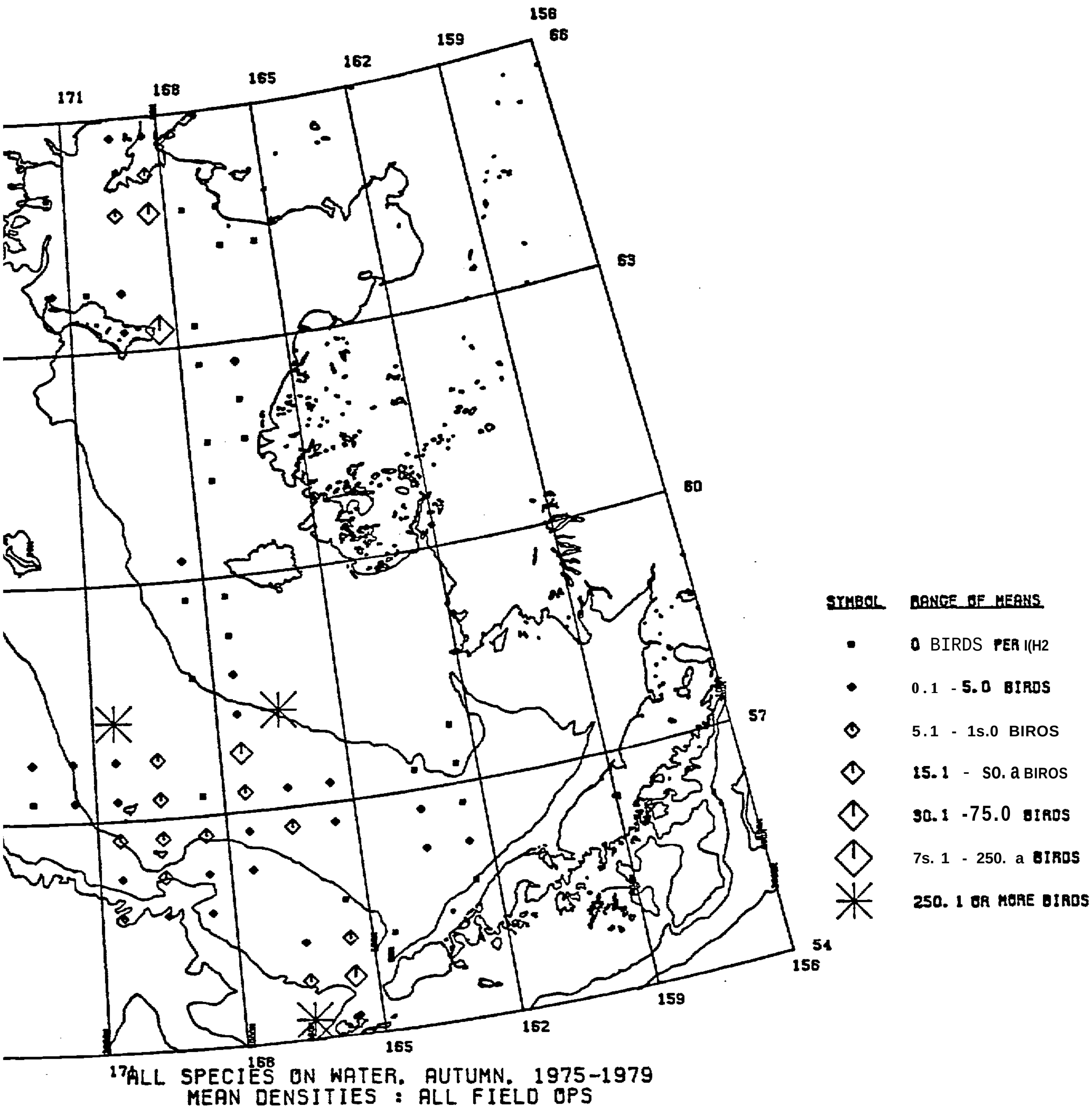
ALL SPECIES ON WATER. SUMMER. 19?5-19?9
MEAN DENSITIES : ALL FIELD OPS

Figure 43



ALL SPECIES ON WATER, SUMMER, 1975-79
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 44



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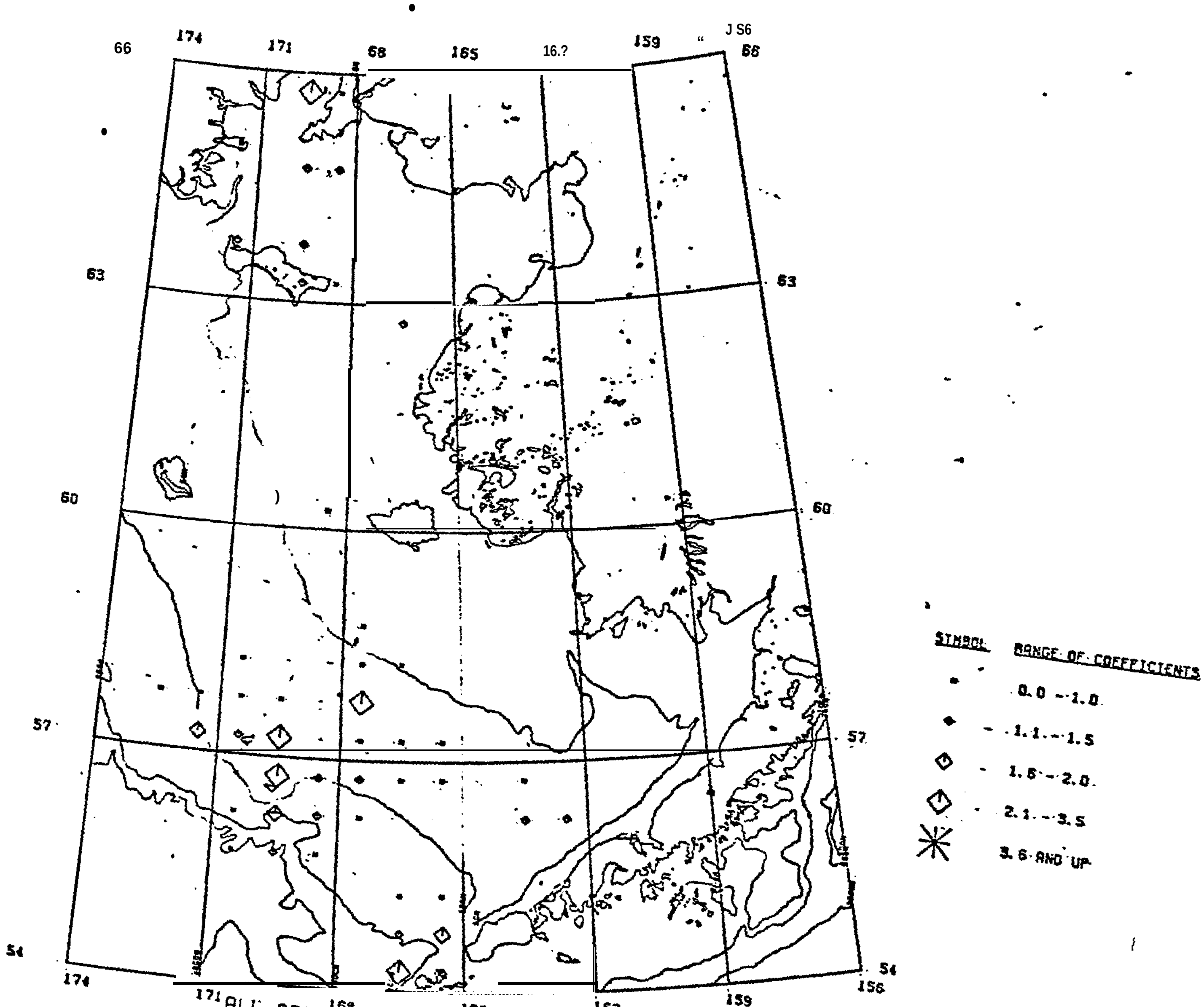
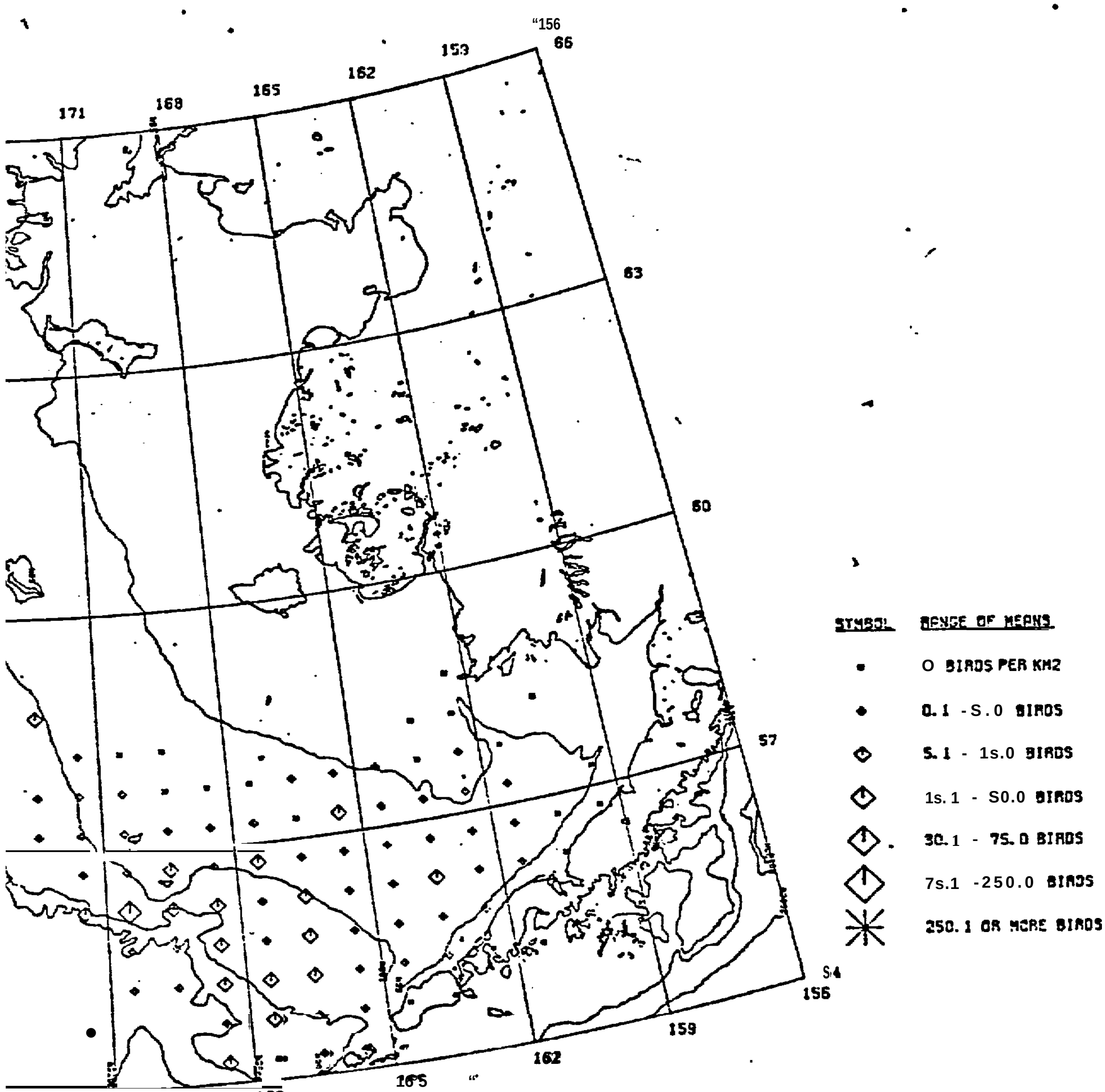
SYMBOL
RANGE OF MEANS
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
ALL SPECIES ON WATER, AUTUMN, 1975-1979
MEAN DENSITIES : ALL FIELD OPS

Figure 45



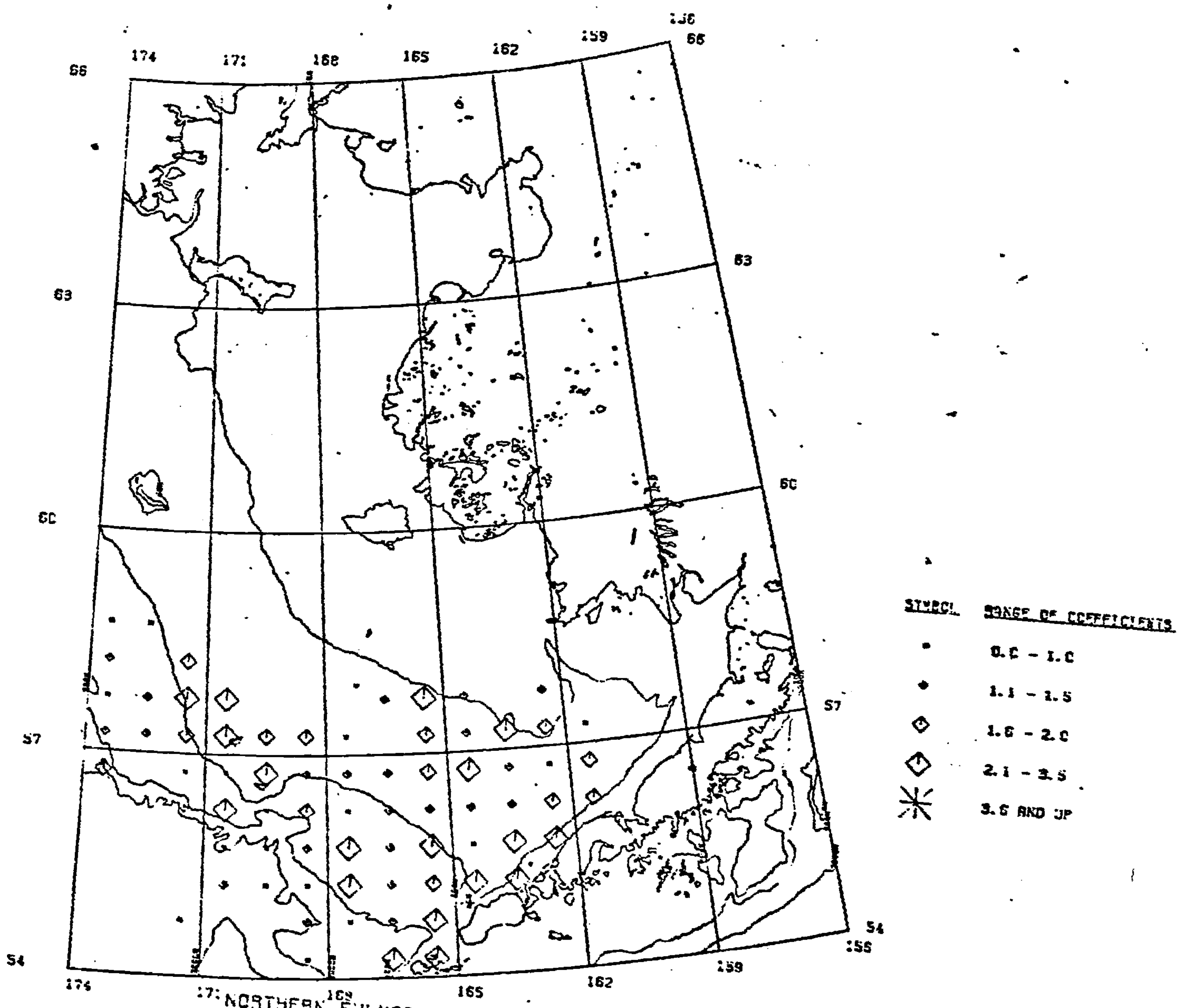
ALL SPECIES ON WATER, AUTUMN, 1975-79
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 46



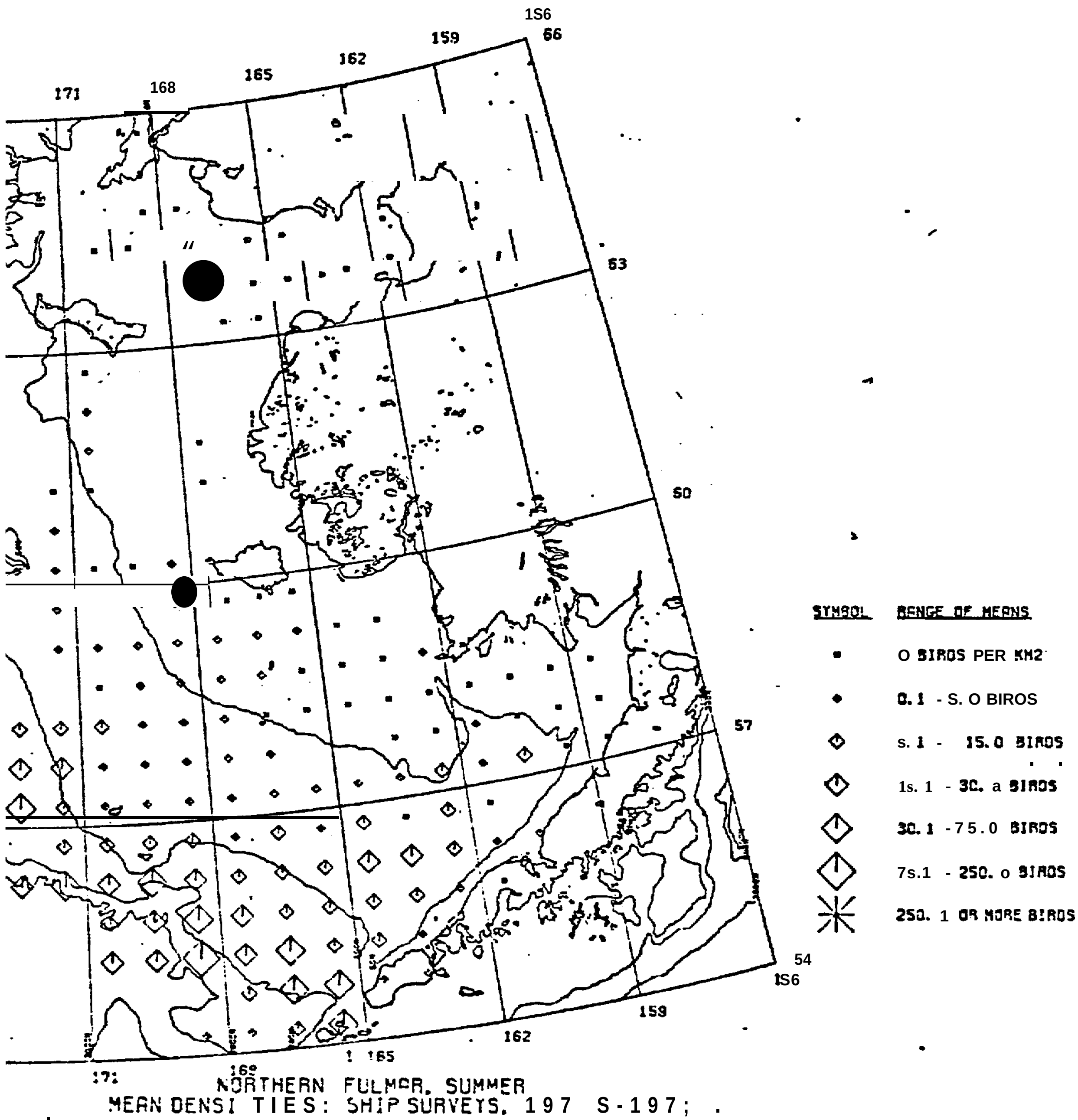
NORTHERN FULMAR, SPRING
MEAN DENSITIES: SHIP SURVEYS. 1975-1979

Figure 47



NORTHERN FULMARS (ALL), SPRING, 75-79
COEFFICIENT OF VARIATION : SHIP SURVEYS

Figure 48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SYMBOL
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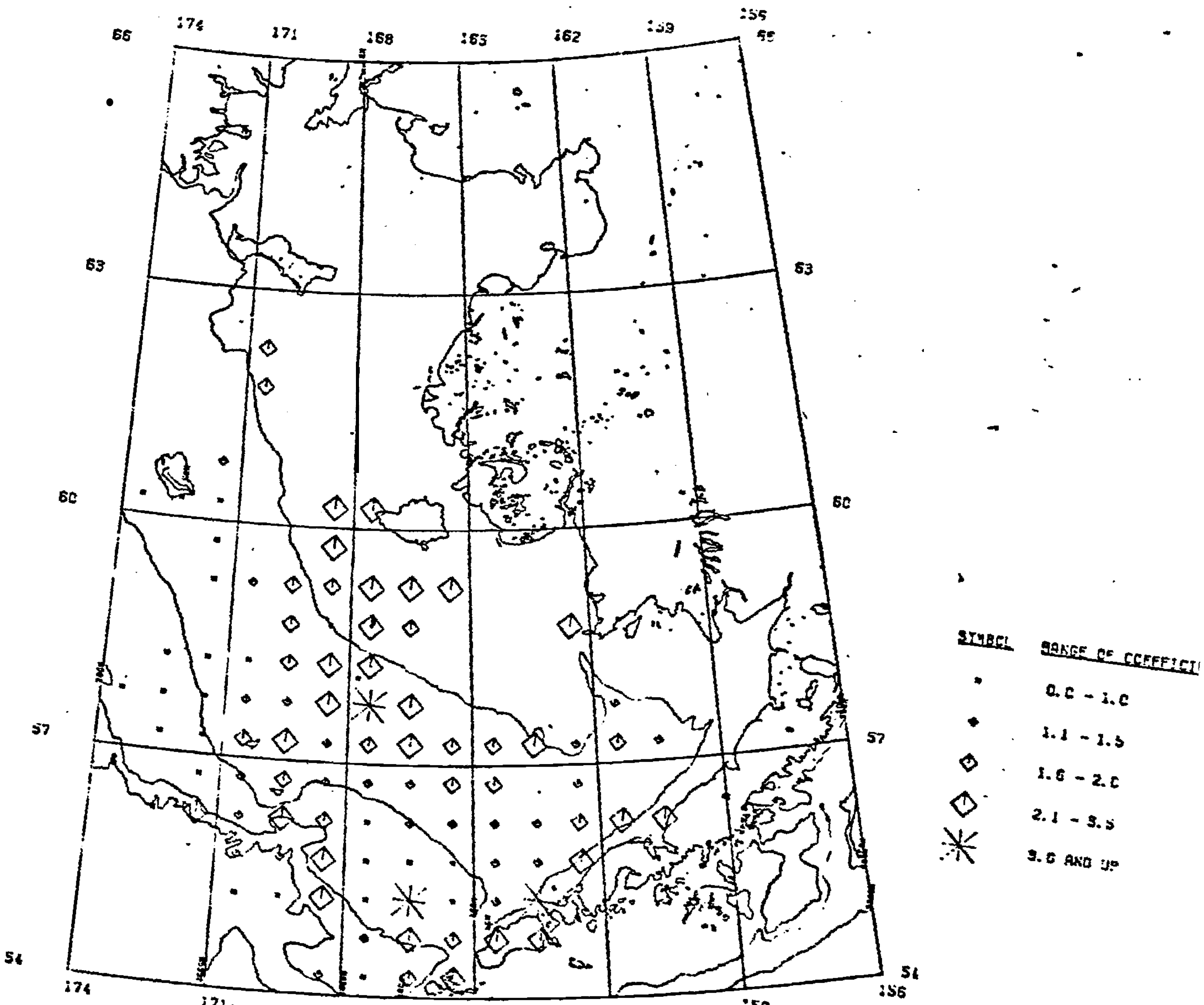
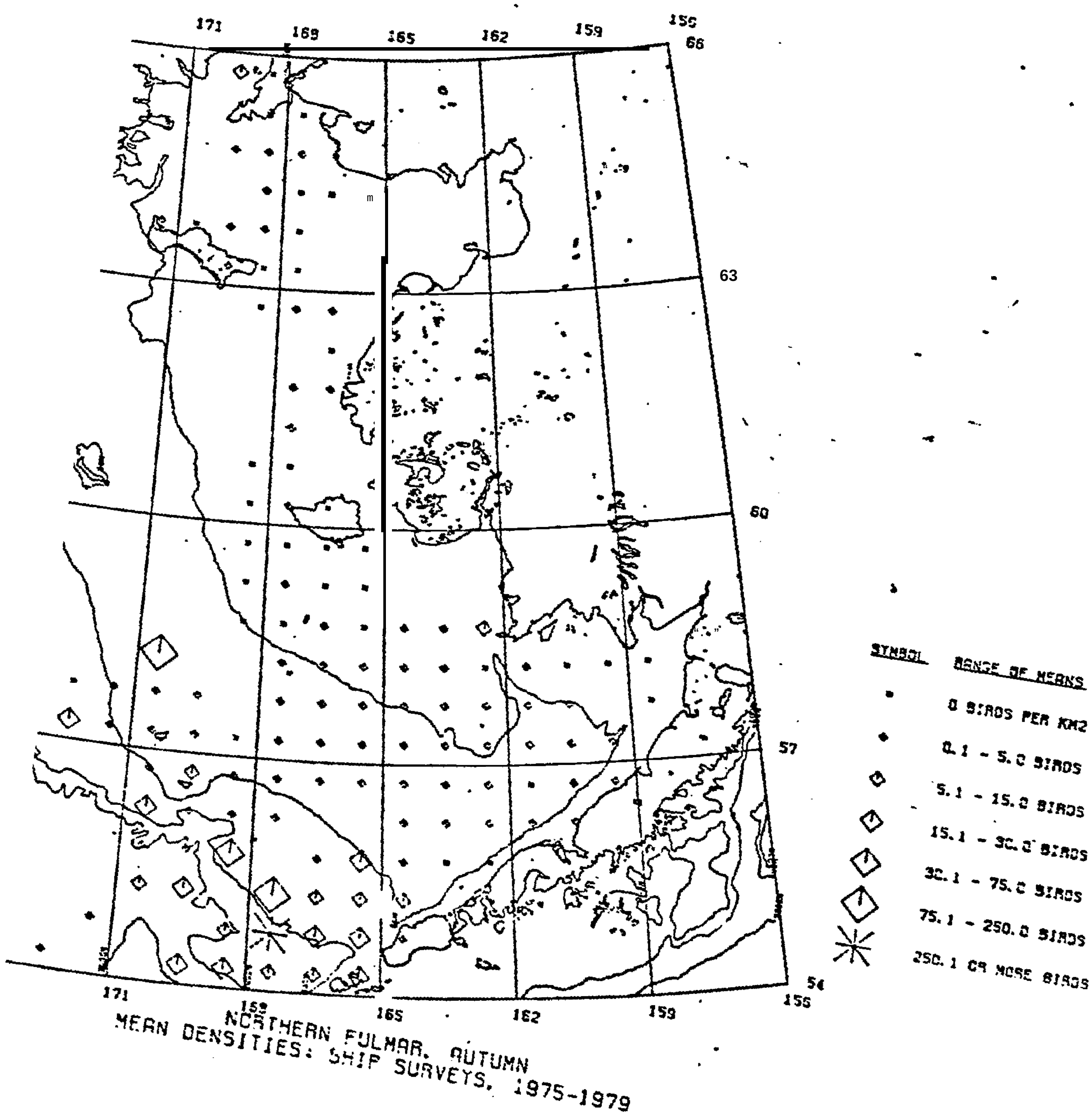
30.1 - 75.0 BIRDS
7s.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
NORTHERN FULMAR, SUMMER
MEAN DENSITIES: SHIP SURVEYS, 197 S-197;

Figure 49”



NORTHERN FULMARS (ALL), SUMMER, 75-79
COEFFICIENT OF VARIATION : SHIP SURVEYS

Figure 50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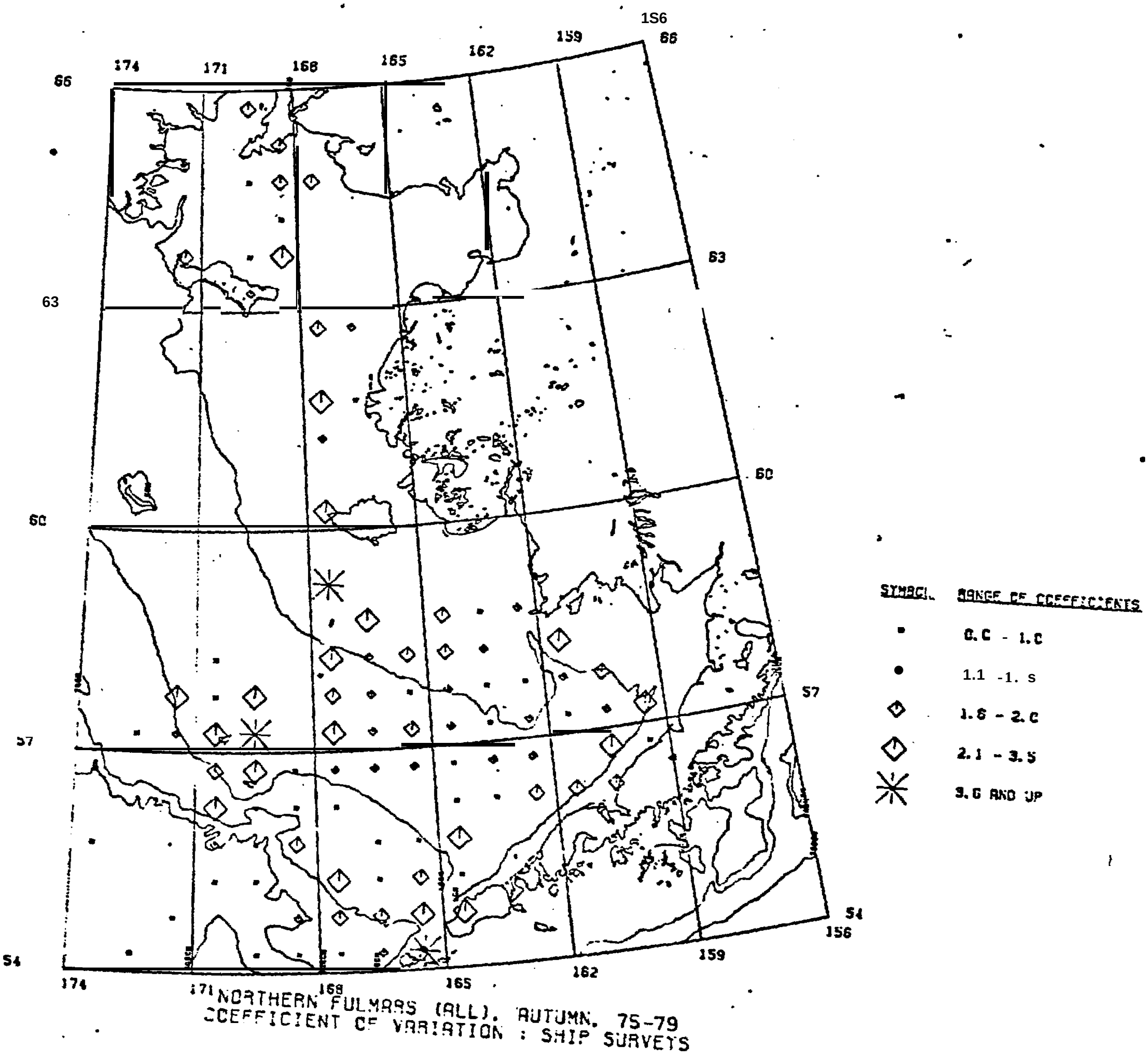
SYMBOL
RANGE OF MEANS
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
NORTHERN FULMAR, AUTUMN
MEAN DENSITIES: SHIP SURVEYS, 1975-1979

Figure 51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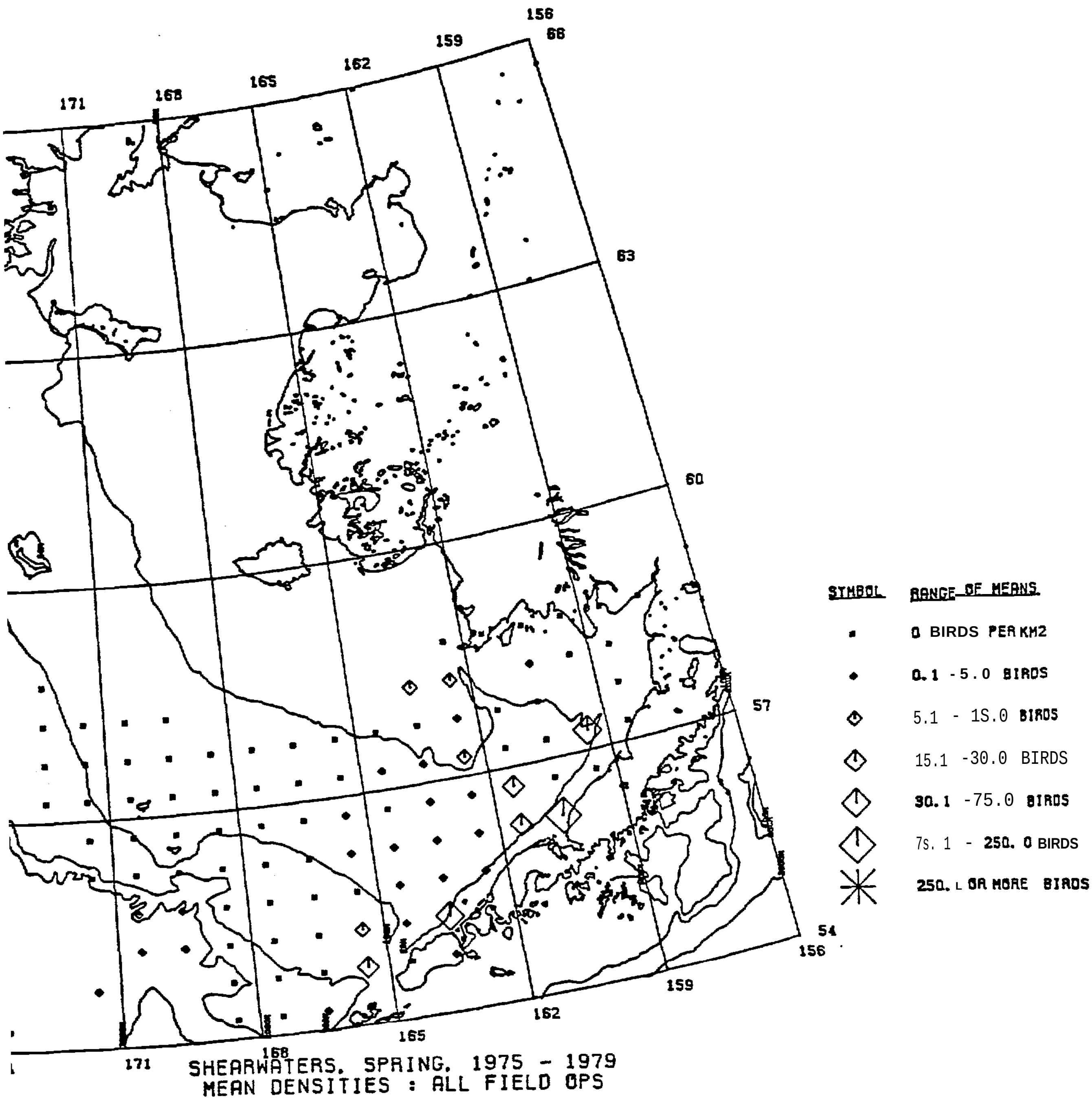
SYMBOL
RANGE OF COEFFICIENTS
0.0 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 3.5
3.6 AND UP
NORTHERN FULMARS (ALL), AUTUMN, 75-79
COEFFICIENT OF VARIATION : SHIP SURVEYS

Figure 52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SYMBOL
RANGE OF MEANS
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
SHEARWATERS, SPRING, 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 53

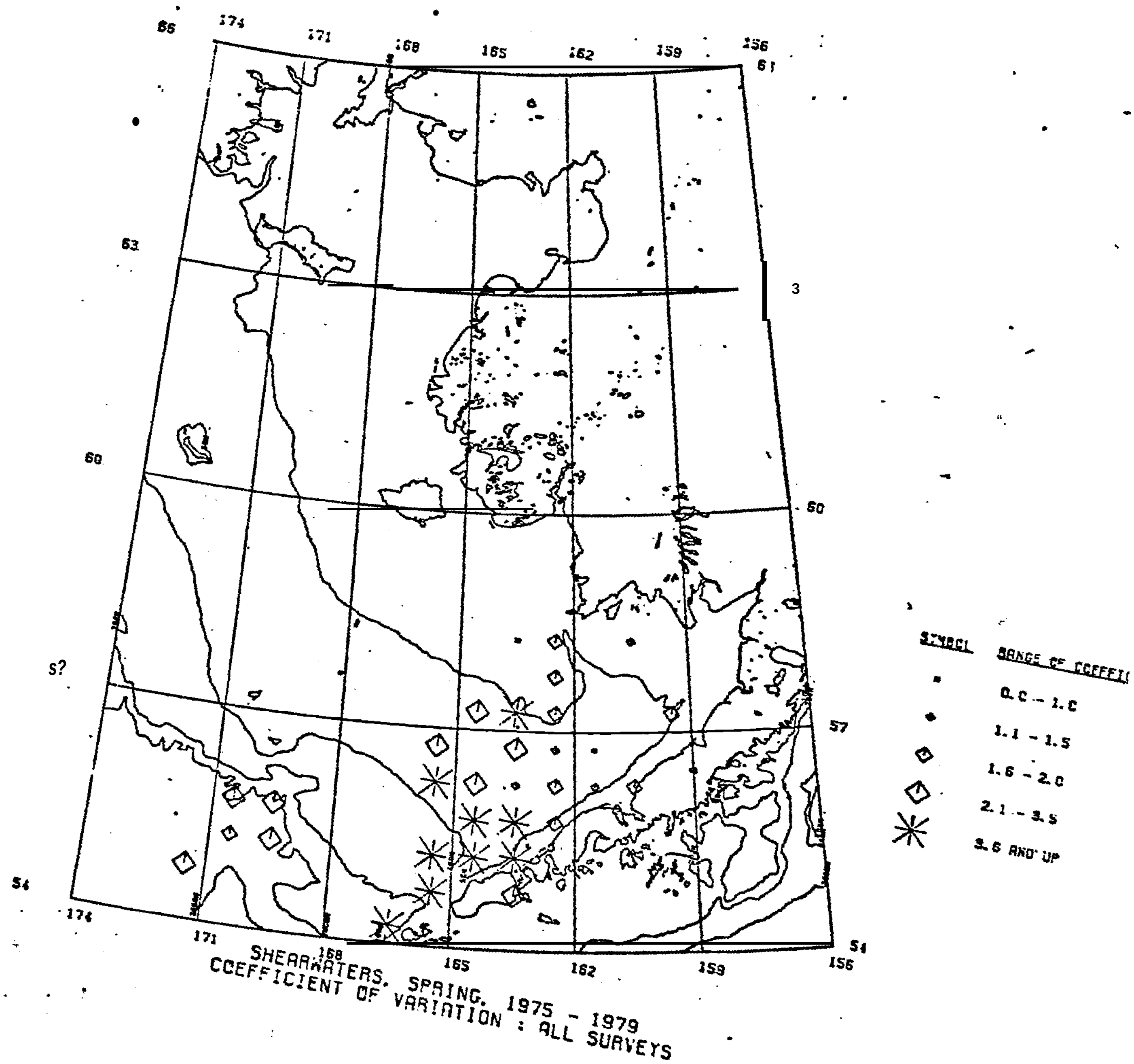
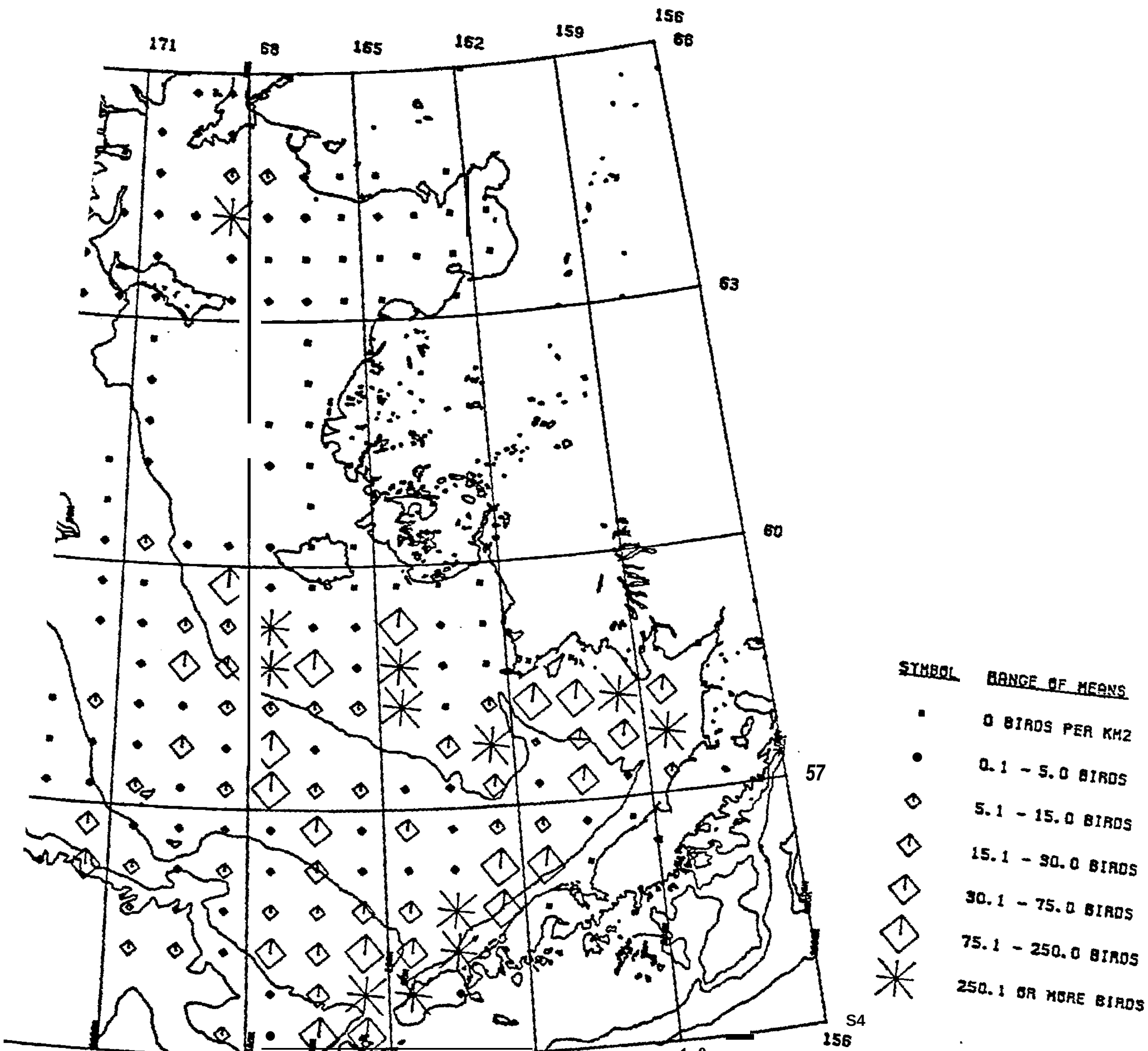
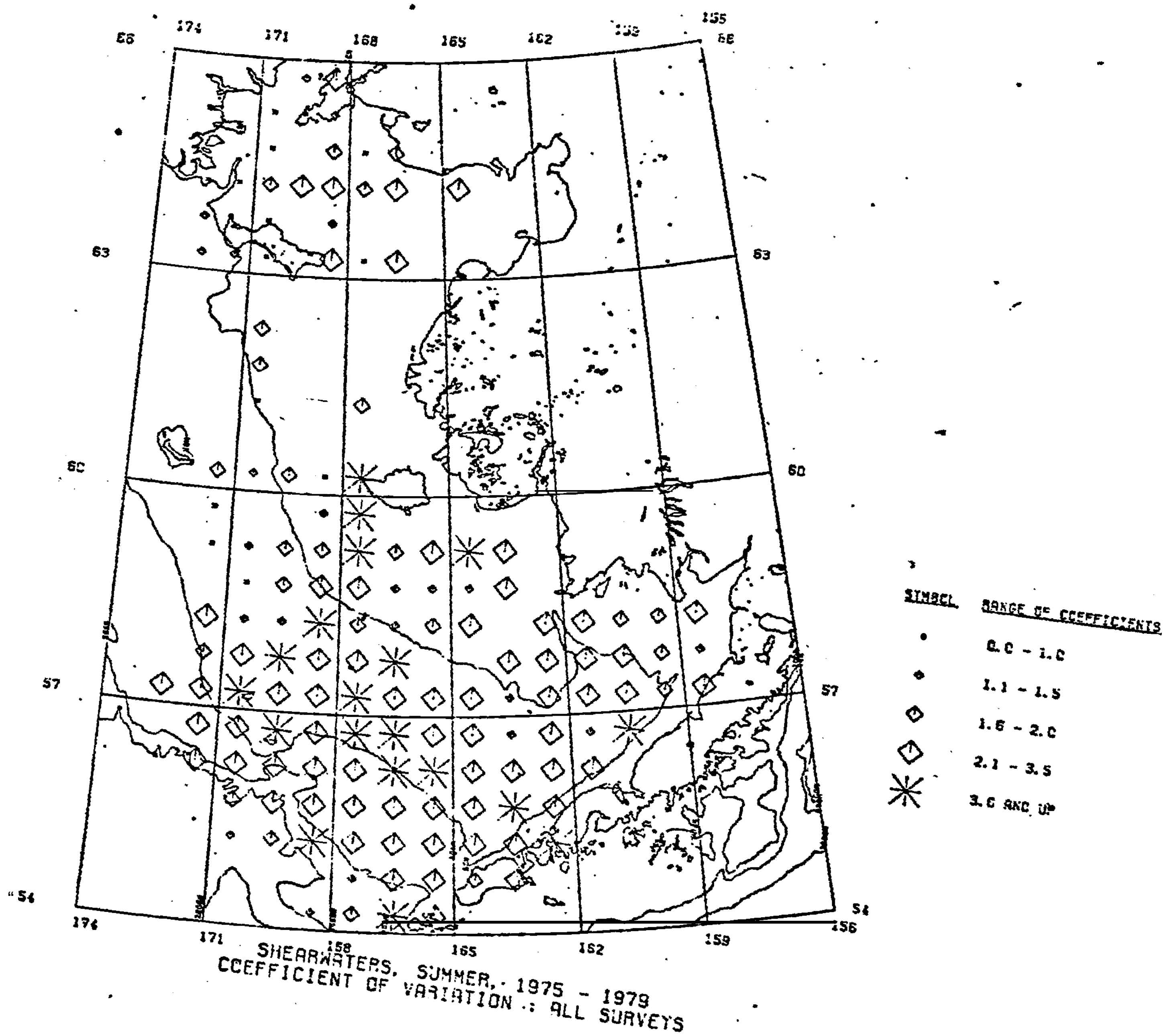

SHEARWATERS, SPRING, 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS
0.0 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 3.5
3.6 AND UP

Figure 54



SHEARWATERS, SUMMER, 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 55



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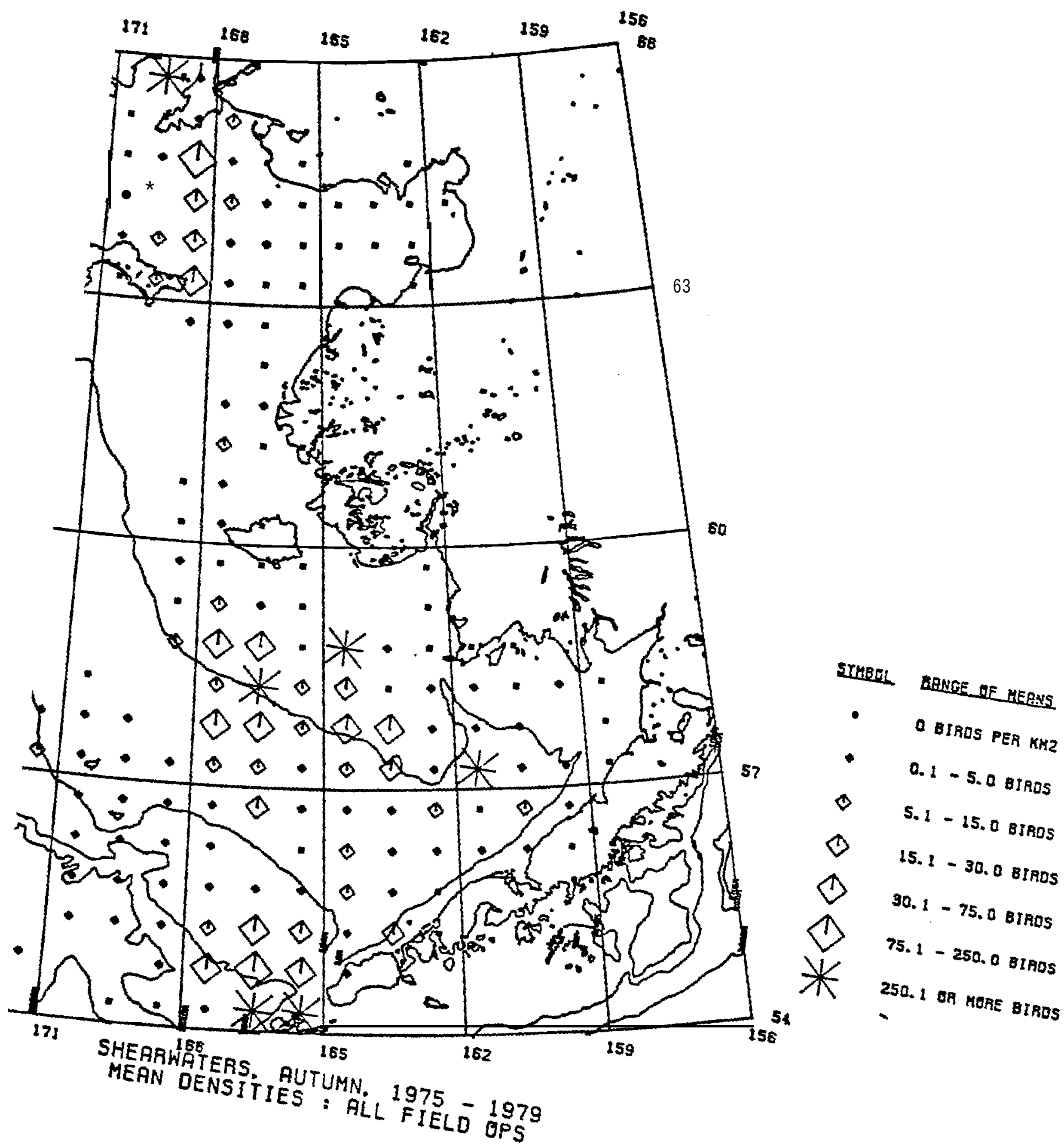
SYMBOL
RANGE OF COEFFICIENTS
0.0 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 3.5
3.6 AND UP
SHEARWATERS, SUMMER, 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 56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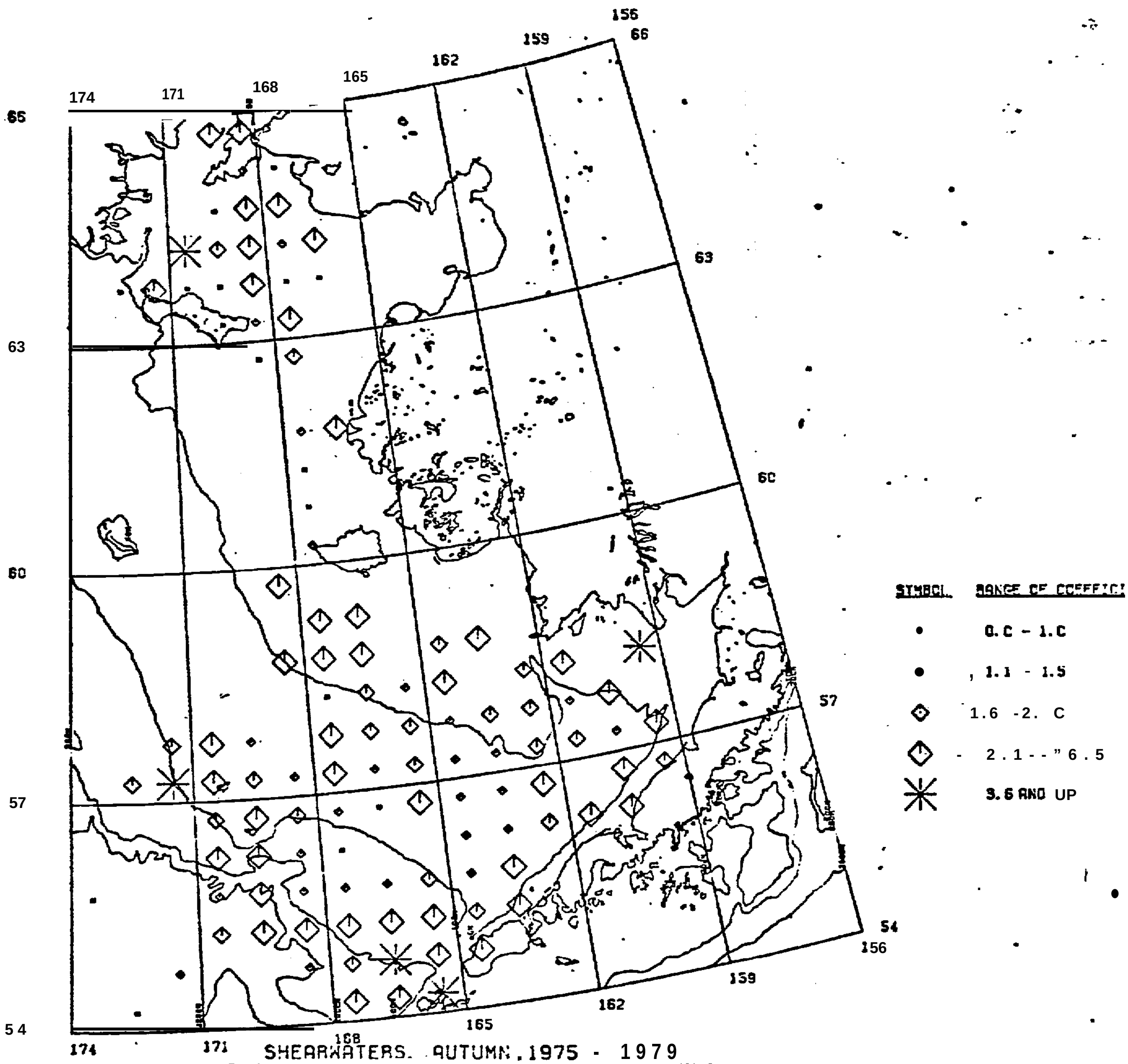
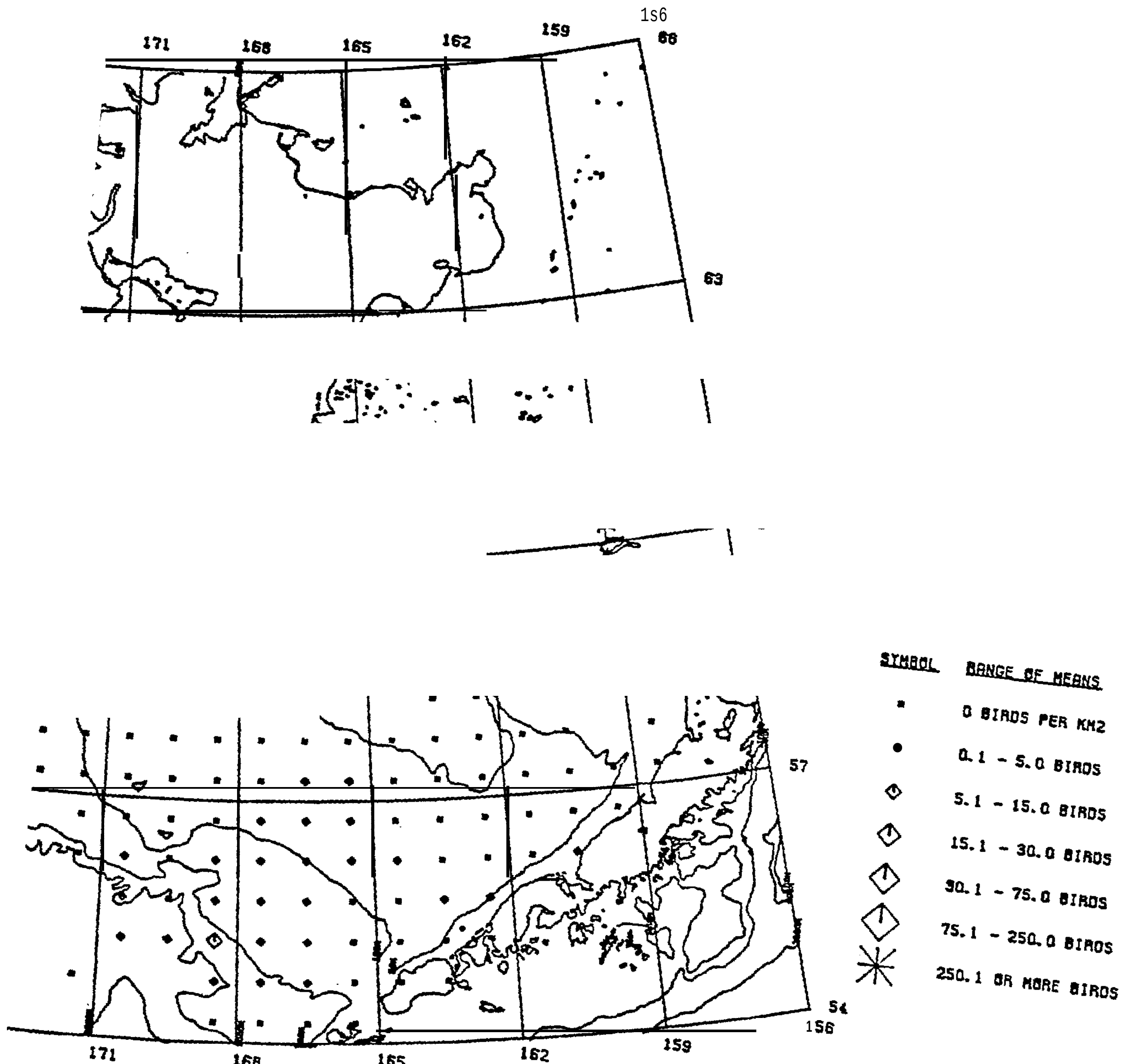
SYMBOL RANGE OF MEANS
0 BIRDS PER KM2
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
SHEARWATERS, AUTUMN, 1975 - 1979
MEAN DENSITIES : ALL FIELD OPS

Figure 57



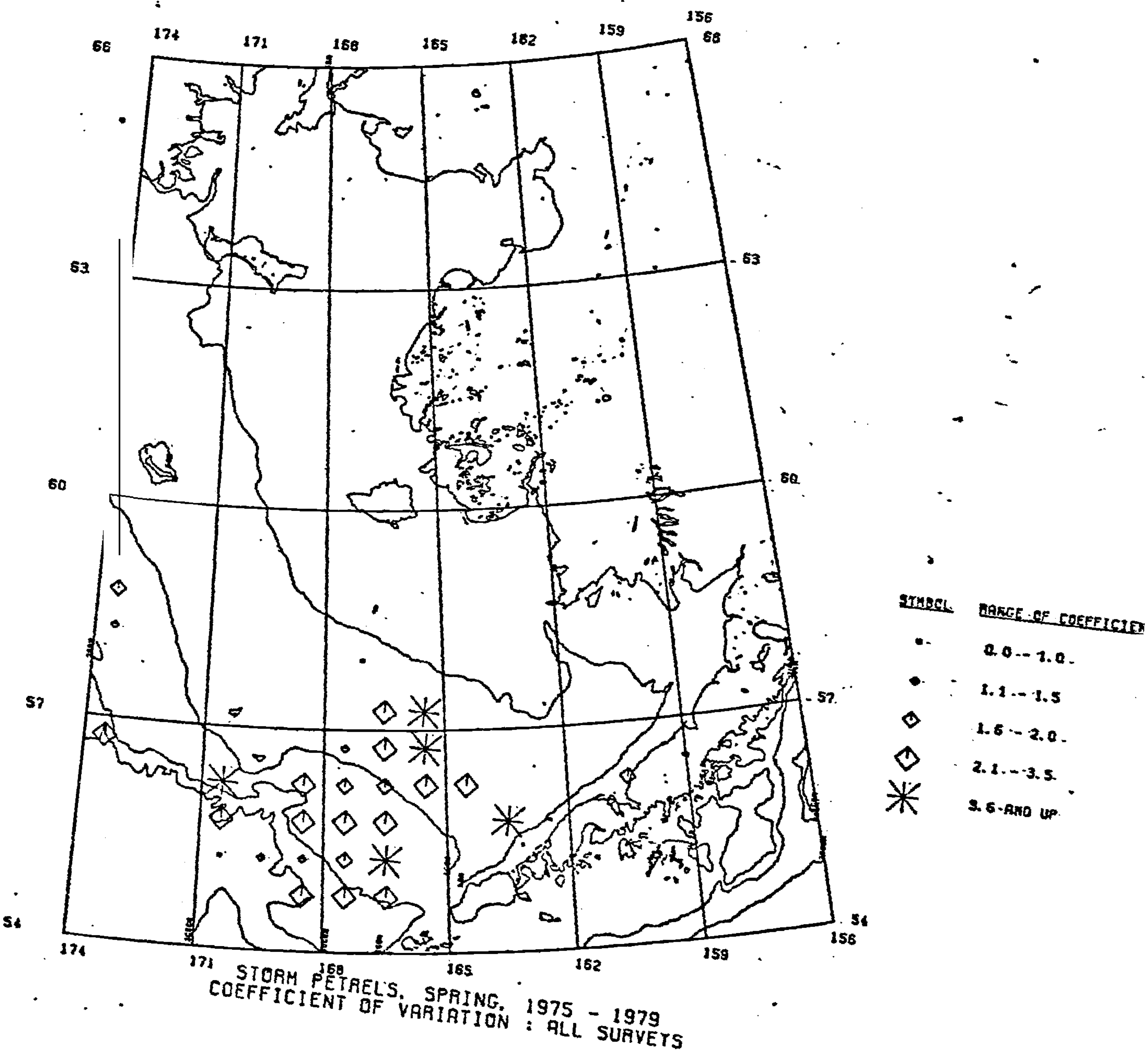
SHEARWATERS. AUTUMN, 1975 - 1979
COEFFICIENT OF VARIATION. : ALL SURVEYS

Figure 58



STORM PETREL - SPRING
MEAN DENSITIES: ALL FIELD OPS. 1975 -19?9

Figure 59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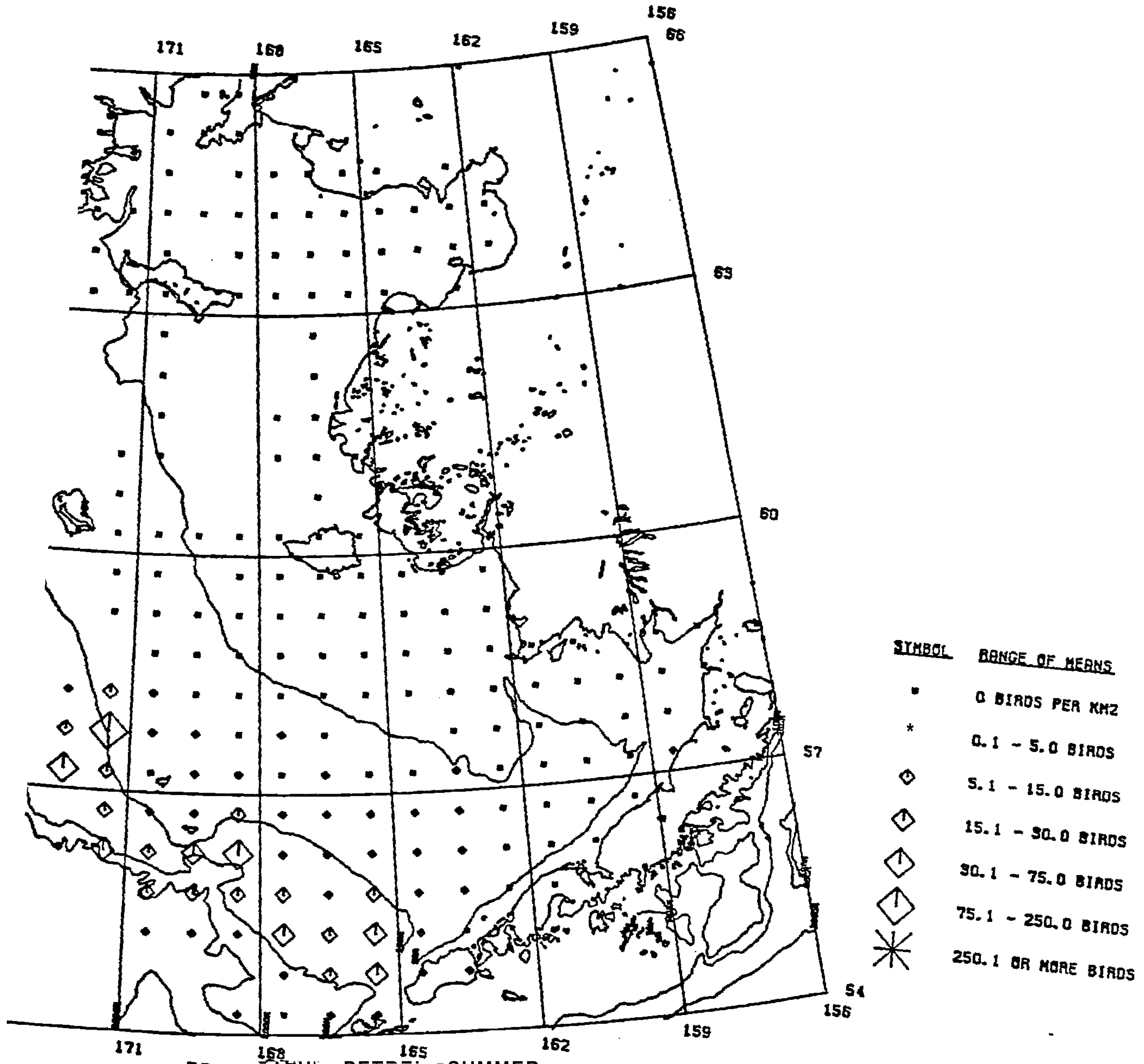
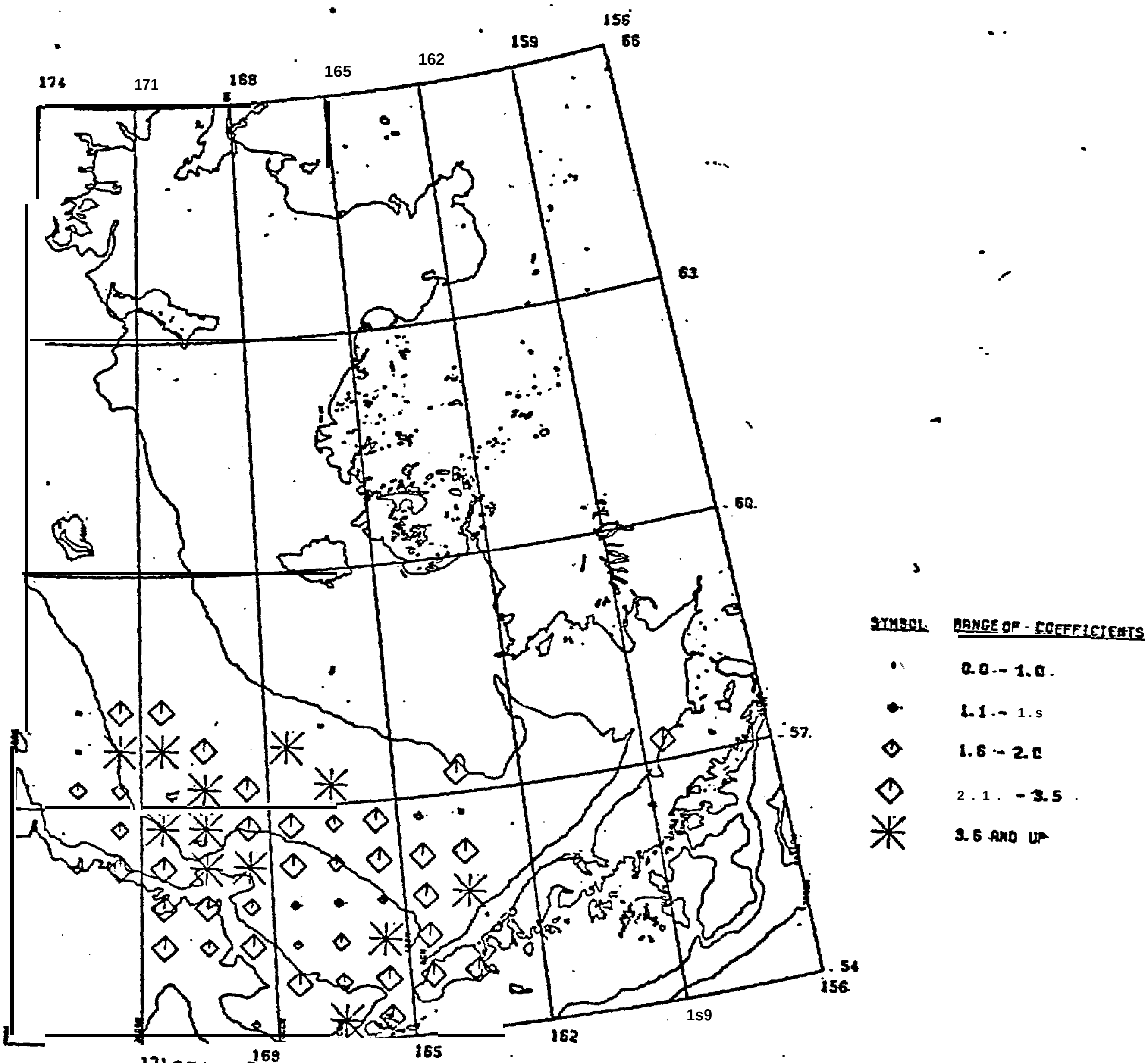
STORM PETRELS, SPRING, 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS
SYMBOL
RANGE OF COEFFICIEN
0.0 -- 1.0
1.1 -- 1.5
1.6 -- 2.0
2.1 -- 3.5
3.6 AND UP

Figure 60



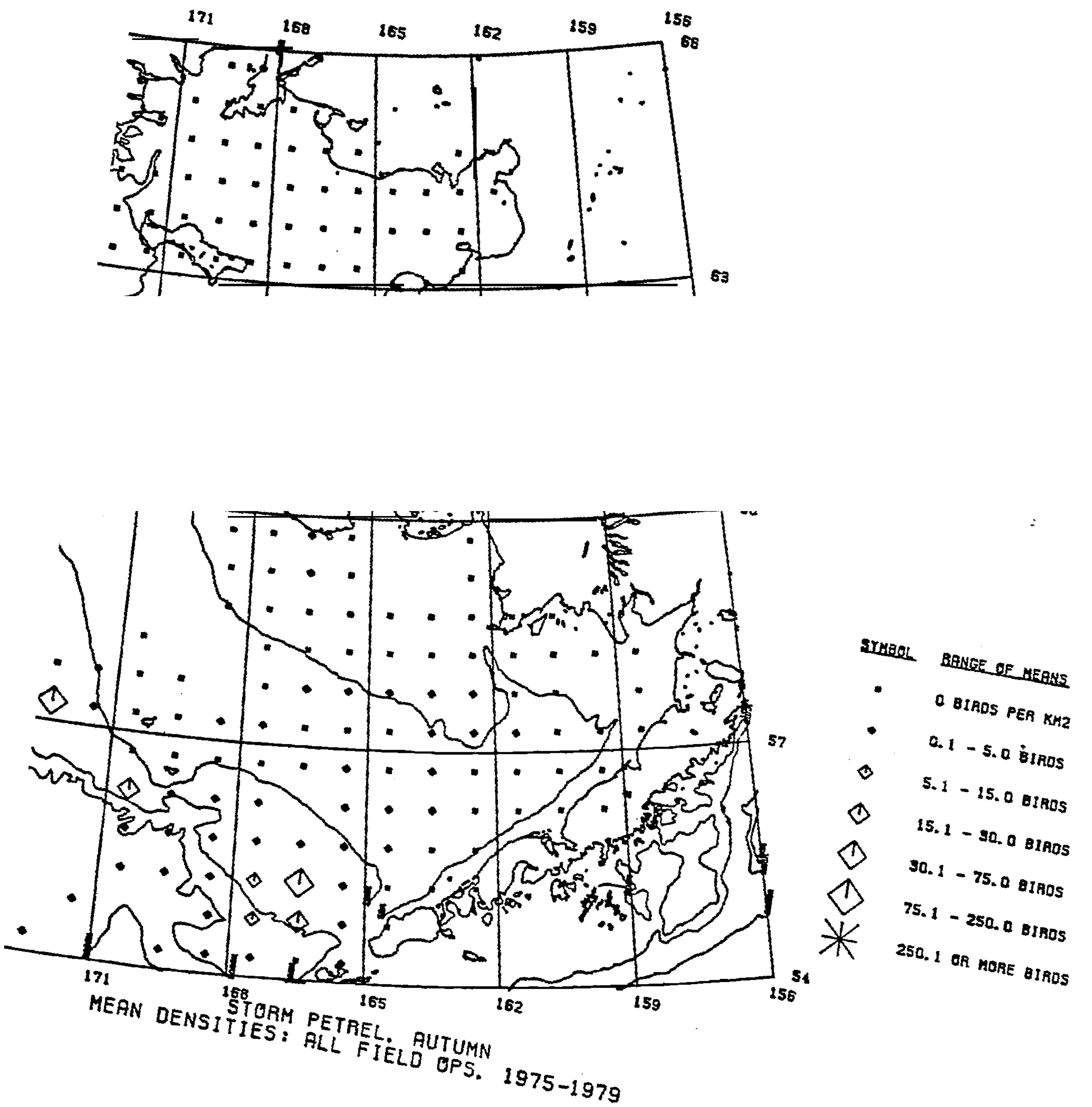
MEAN DENSITIES: ALL FIELD OPS, 1975-1979

Figure 61



STORM PETRELS, SUMMER, 197S - 1979
COEFFICIENT OF VARIATION: ALL SURVEYS

Figure 62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SYMBOL
RANGE OF MEANS
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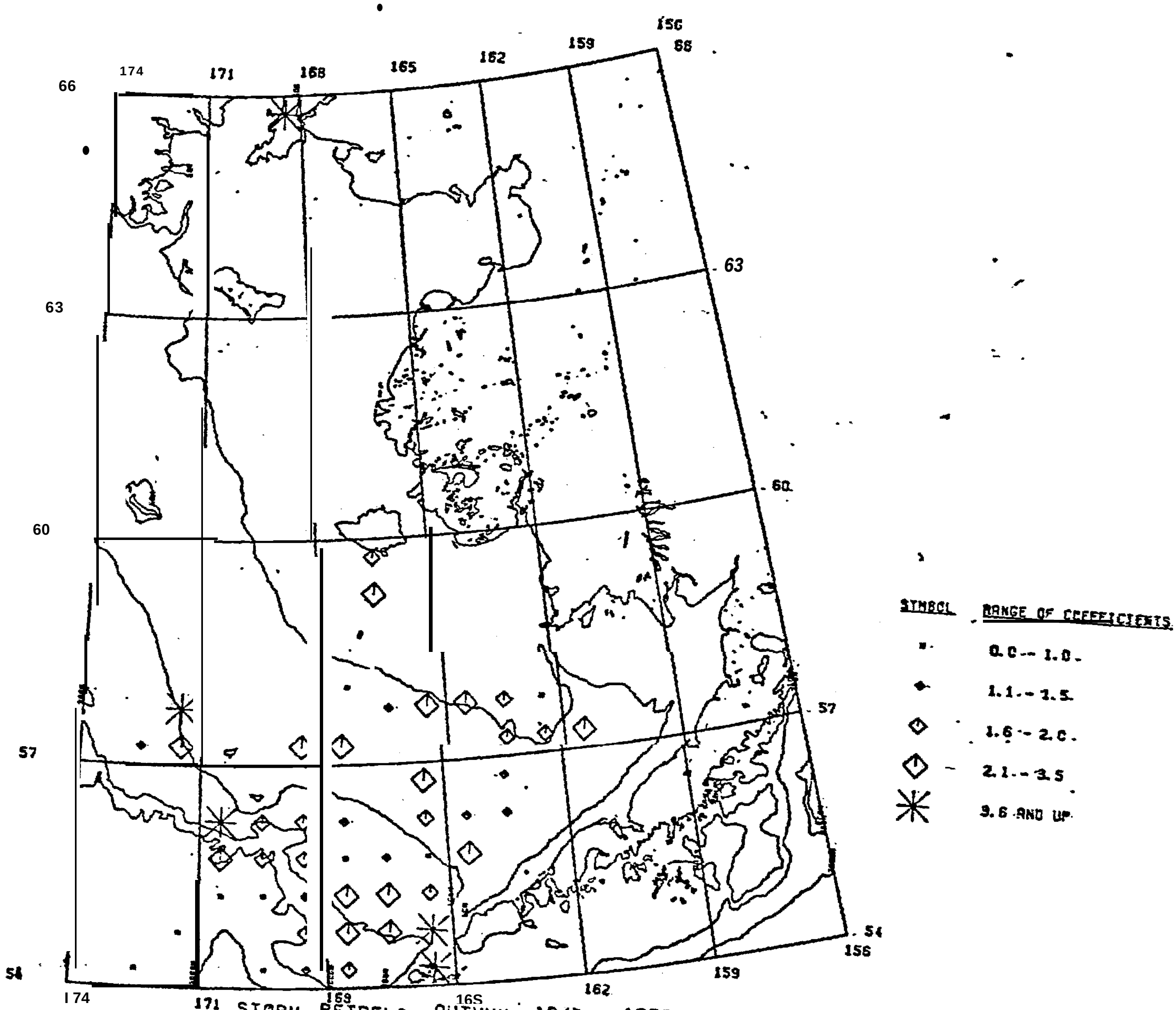
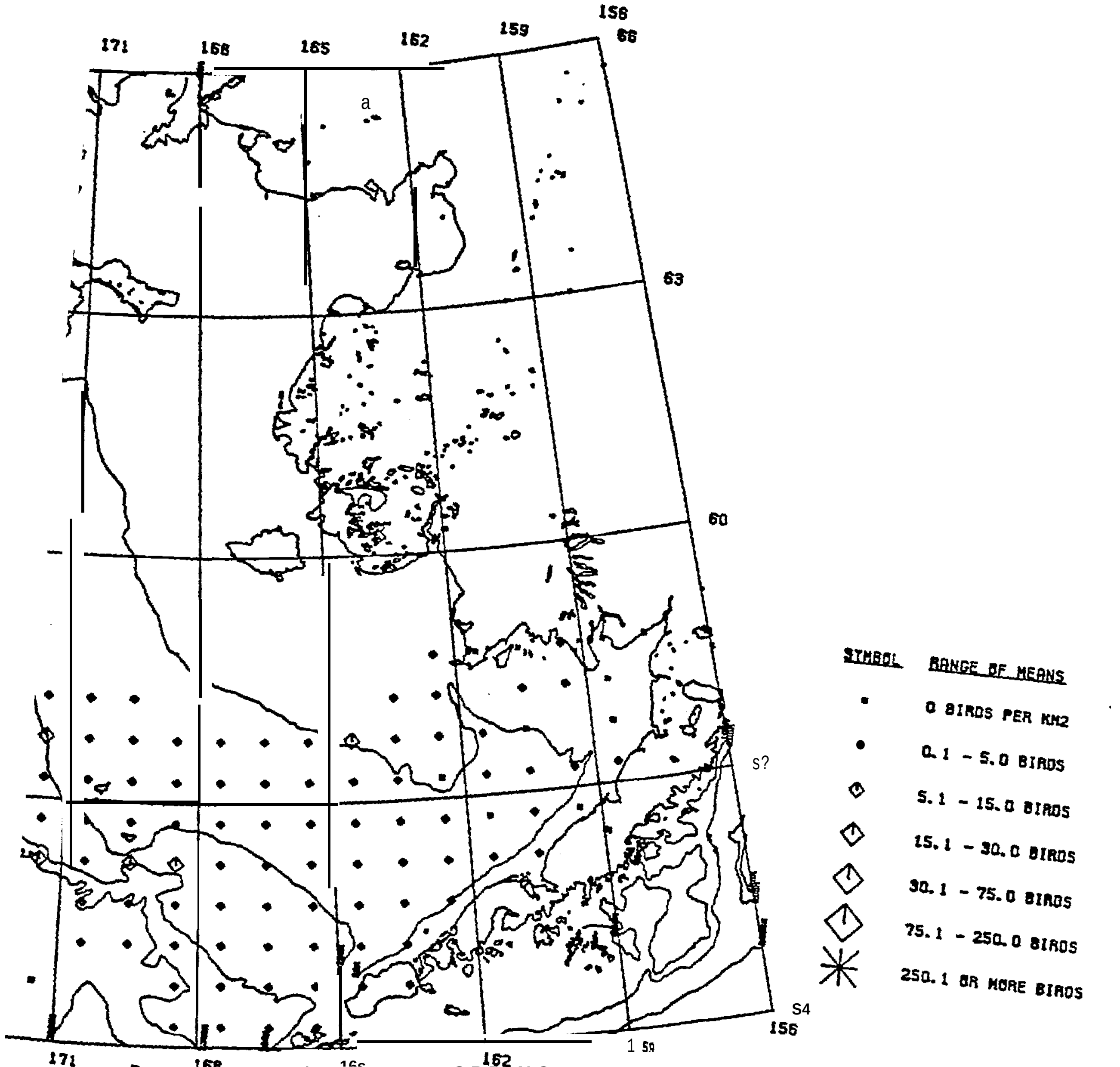
0.1 - 5.0 BIRDS
5.1 - 15.0 BIRDS
15.1 - 30.0 BIRDS
30.1 - 75.0 BIRDS
75.1 - 250.0 BIRDS
250.1 OR MORE BIRDS
STORM PETREL, AUTUMN
MEAN DENSITIES: ALL FIELD OPS. 1975-1979

Figure 63



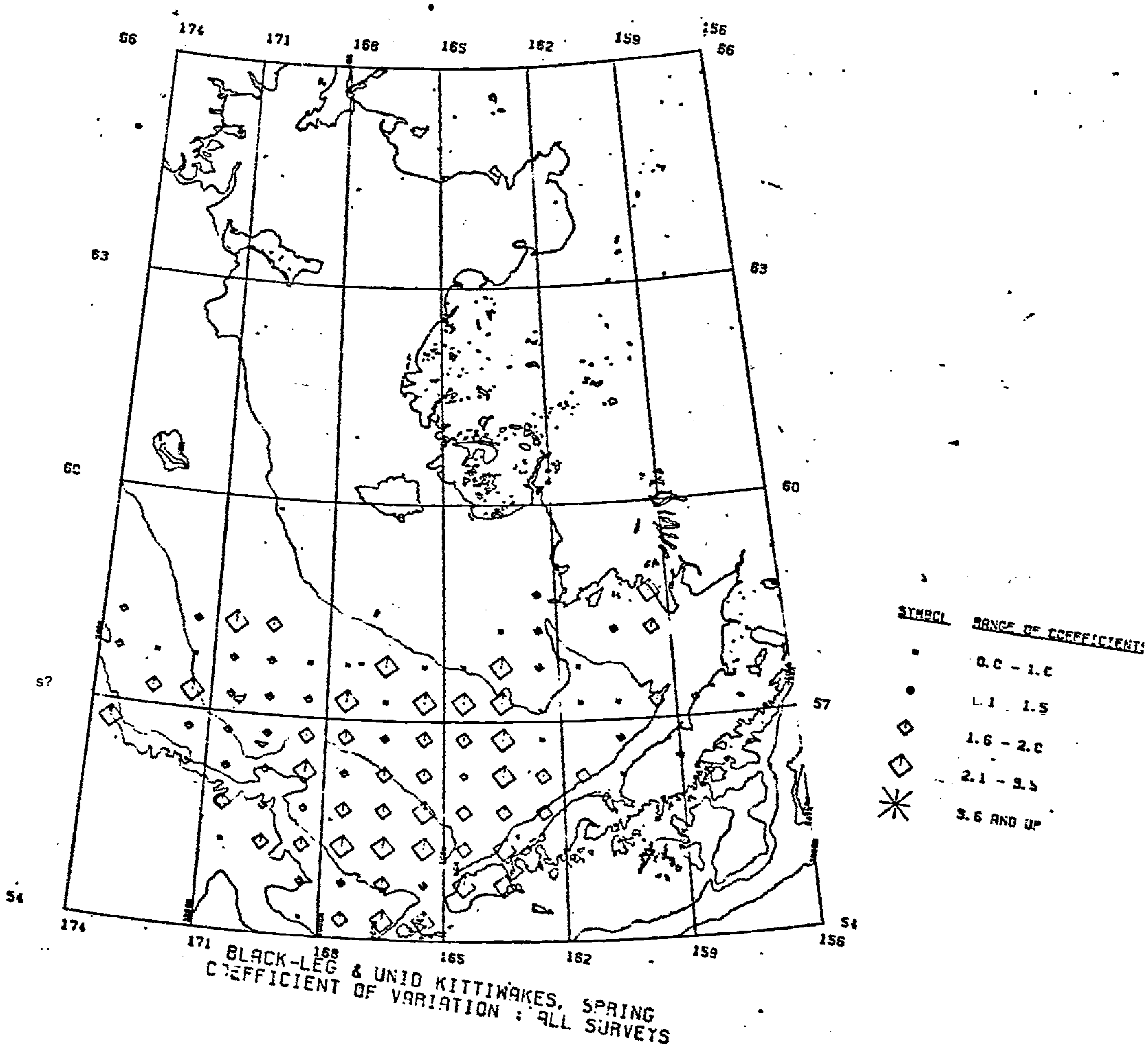
STORM PETRELS AUTUMN 1975 - 1979
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 64



BLACK-LEGGED KITTIWAKE SPRING
MEAN DENSITIES: ALL FIELD OPS. 1975-1979

Figure 65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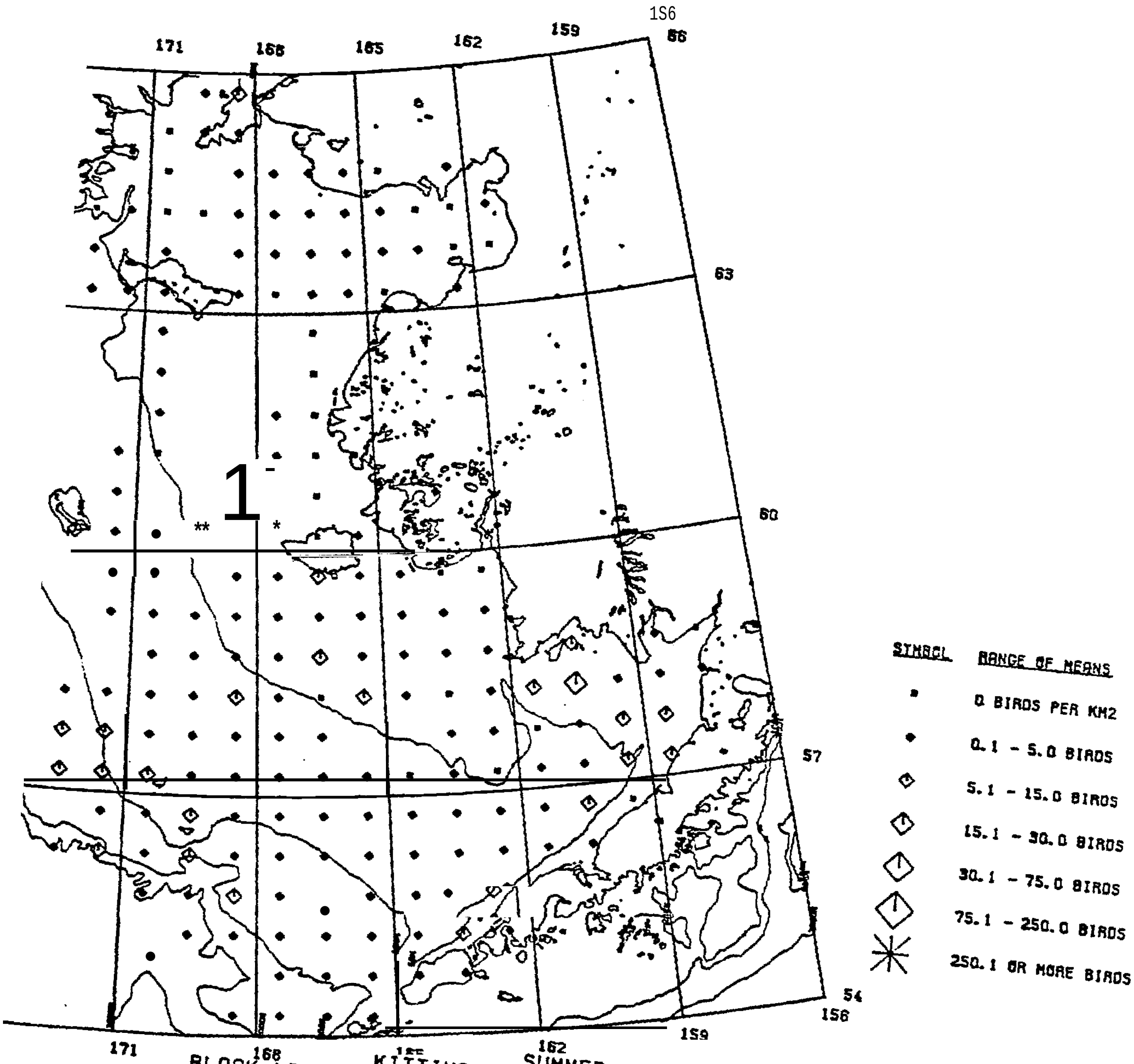
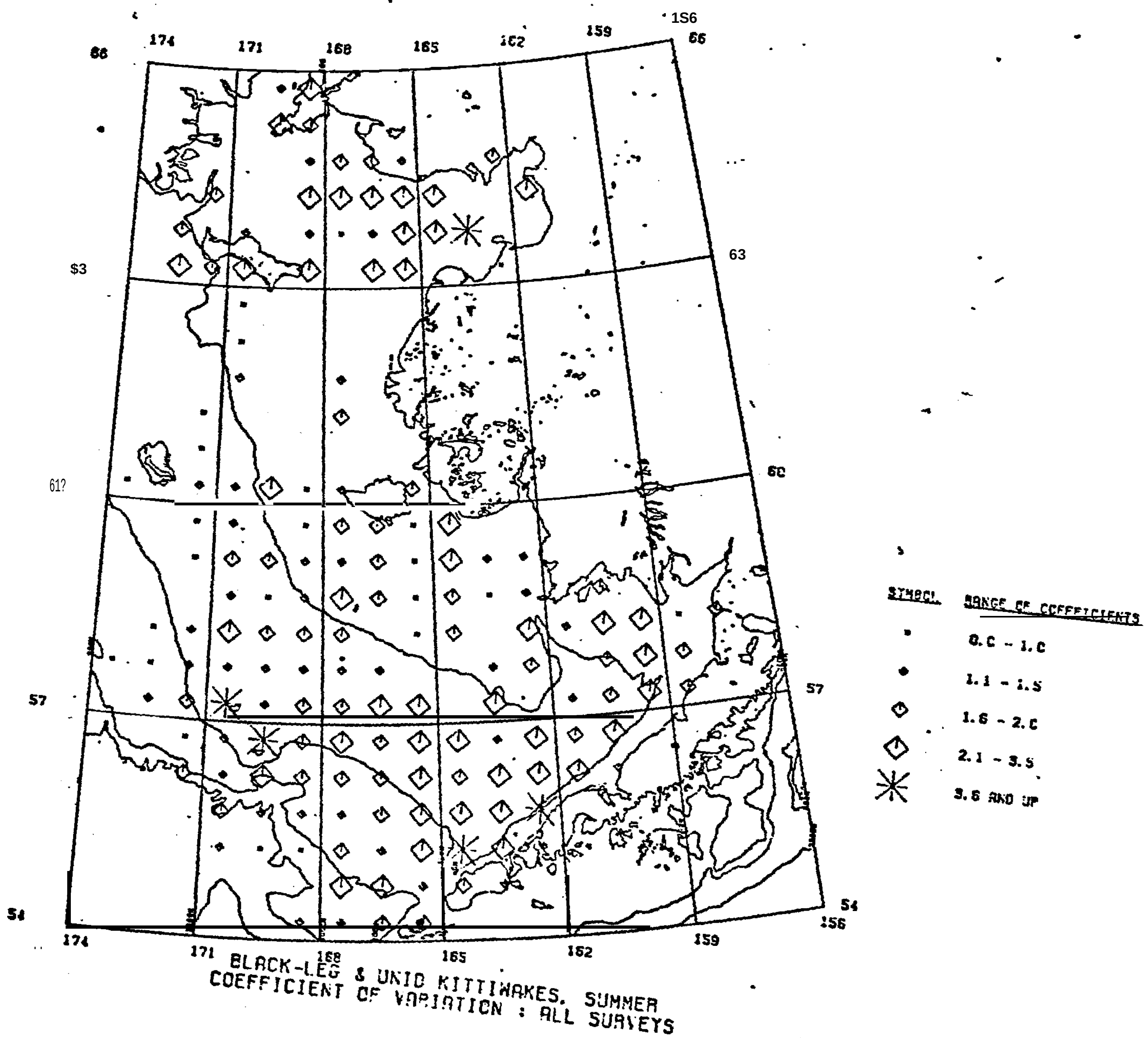
SYMBOL
RANGE OF COEFFICIENTS
0.0 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 3.5
3.6 AND UP
BLACK-LEG & UNID KITTIWAKES, SPRING
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 66



KITTIWAKE SUMMER
MEAN DENSITIES: ALL FIELD OPS., 197 S 1979

Figure 67


SYMBOL RANGE OF COEFFICIENTS
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1.6 - 2.0
2.1 - 3.5
3.6 AND UP
BLACK-LEG & UNID KITTIWAKES, SUMMER
COEFFICIENT OF VARIATION : ALL SURVEYS

Figure 68